CEOS-ARD - Optical - Aquatic 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, Aquatic Reflectance

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

Document History

2026-04-13 (PATCH)

- 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 definitions are included in the document instead of referring to the CEOS Terms and Defintions Wiki
- The references are not grouped by requirements and threshold/goal any longer. Instead, they are listed in the requirements as a note.
- The requirement “Radiometric corrections must lead to a valid measurement […]” has been moved from the category description to the measurement requirement.
- The requirement references (i.e. “3.1-3.3” and “3.4 onwards”) were removed from the category description of “Products and Algorithms”.
- If no threshold requirement applies, the wording has been made consistent (e.g. former req. 1.7 and 1.8).

Justification: Migration to building blocks.

Editor: Matthias Mohr

Contributing Authors

Technical Leads

- Arnold Dekker (CSIRO)
- Daniela Gurlin (Independent Consultant)

Organisational Leads

- Matt Steventon (CEOS-ARD Oversight Group Secretariat)
- Harvey Jones (CEOS-ARD Oversight Group Secretariat)

Contributors

- Carsten Brockmann (Brockmann Consult)
- Vittorio Brando (CNR)
- Claudia Giardino (CNR)
- Nicole Pinnel (DLR)
- Peter Gege (DLR)
- Barbara Bulgarelli (EC)
- Peter Strobl (EC)
- Frédéric Mélin (EC)
- Ewa Kwiatkowska (EUMETSAT)
- Hayley Evers-King (EUMETSAT)
- Andreia Siqueira (GA)
- Medhavy Thankappan (GA)
- Peter Harrison (GA)
- Igor Ogashawara (IGB Berlin)
- Raisha Lovindeer (IOCCG)
- Hiroshi Murakami (JAXA)
- Joseph D. Ortiz (Kent State)
- Sean Bailey (NASA)
- Nima Pahlevan (NASA)
- Anthony Vodacek (RIT)
- Heidi Dierssen (University of Connecticut)
- Maycira Costa (University of Victoria)
- Ben Page (USGS)
- Chris Barnes (USGS)
- Liesbeth de Keukelare (VITO)

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, Aquatic Reflectance (AR)

Version: 2.0.1-draft

Applies to: Data collected with multispectral and hyperspectral imaging sensors operating in the VIS/NIR/SWIR wavelengths over water bodies (including oceans, seas, coastal zones, and inland waters). These typically operate with ground sample distance and resolution in the order of 1-4000 metres however the specification is not inherently limited to these resolutions.

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.

AOD
: Aerosol Optical Depth

AR
: Aquatic Reflectance

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.

BIPM
: Bureau International des Poids et Mesures (International Bureau of Weights and Measures)

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)

DOI
: Digital Object Identifier

GIS
: Geographic Information System

GSD
: Ground Sample Distance

GUM
: Guide to the Expression of Uncertainty in Measurement

NIR
: Near Infrared

rRMSE
: Radial Root Mean Square Error

SI

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

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.

Information should be available in the metadata as a single DOI landing page, which may include links to further detailed documents and references to citable peer-reviewed algorithms or technical documentation.

1.1. CEOS-ARD PFS Compliance Version

Identifier: `meta-ardver`

Threshold requirements:

Version of the CEOS-ARD PFS with which the product is complying is identified.

Goal requirements:

As threshold.

1.2. Traceability

Identifier: `meta-trace-ar`

Threshold requirements:

Aquatic Reflectance (dimensionless) or the Remote Sensing Reflectance (sr^{-1}) of the water bodies ($AR = \pi \cdot R_{rs}$) is given.

Goal requirements:

Data must be traceable to SI reference standard.

Note:

1. Relationship to Products and Algorithms: Measurement Uncertainty. Traceability requires an estimate of measurement uncertainty.

1.3. 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.

1.4. Data Collection Time

Identifier: `meta-time-ar`

Threshold requirements:

The beginning and end of the data collection time is expressed in date/time and identified in the metadata consistent with ISO 8601. The time is expressed with the time offset from UTC unambiguously identified.

Goal requirements:

As threshold, but information required to determine, within a stated uncertainty, when the individual observations were taken is available.

1.5. 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.

1.6. Coordinate Reference System

Identifier: `meta-crs-ar`

Threshold requirements:

The coordinate reference system that has been used is detailed.

Goal requirements:

As threshold.

1.7. Map Projection

Identifier: `meta-mapproj-ar`

Threshold requirements:

The map projection that has been used and any relevant parameters required in relation to use of data in that map projection is detailed.

Goal requirements:

As threshold.

1.8. Geometric Correction Methods

Identifier: `meta-geocorm-ar`

Threshold requirements:

Not required.

Goal requirements:

Information on geometric correction source and methods are provided, including reference database and auxiliary data such as elevation model(s) and reference chipsets.

1.9. Geometric Uncertainty of the Data

Identifier: `meta-geounc`

Threshold requirements:

Not required.

Goal requirements:

Inclusion of metrics describing the assessed geodetic uncertainty of the data, expressed in units of the coordinate system of the data. Uncertainty is assessed by independent verification (as well as internal model-fit where applicable). Uncertainties are expressed quantitatively.

1.10. Instrument

Identifier: `meta-instru-ar`

Threshold requirements:

The instrument used to collect the data is identified.

Goal requirements:

As threshold, with references to the relevant “CEOS Missions, Instruments, and Measurements Database” record (database.eohandbook.com).

1.11. Spectral Bands

Identifier: `meta-specband-ar`

Threshold requirements:

Full spectral response function is provided.

Goal requirements:

As threshold.

1.12. Sensor Calibration

Identifier: `meta-sencal-ar`

Threshold requirements:

Binary description of calibrated/not calibrated only.

Goal requirements:

Specification of sensor calibration parameters including history of onboard calibrations where available.

1.13. Measurand Radiometric Uncertainty

Identifier: `meta-radunc`

Threshold requirements:

Metrics describing the assessed radiometric uncertainty of the version of the data or product are provided. Method of determination of radiometric uncertainty is specified.

Goal requirements:

As threshold, but the absolute radiometric uncertainty of the data is provided.

1.14. Radiometric Encoding

Identifier: `meta-radenc`

Threshold requirements:

Range and bit depth are provided.

Goal requirements:

As threshold.

1.15. Algorithms

Identifier: `meta-malgos-ar`

Threshold requirements:

All algorithms and the sequence in which they were applied in the generation process are identified.

Algorithms must be published and validated, and a description of the validation process is included.

Note:

1. It is possible that corrections are applied through non-disclosed processes. CEOS-ARD does not require full and open data and methods.

Goal requirements:

As threshold.

1.16. Auxiliary Data

Identifier: `meta-auxdat-ar`

Threshold requirements:

Lists the sources of auxiliary data used in the generation process.

Goal requirements:

As threshold, but information on auxiliary data should be available for free online download, contemporaneously with the product or through a link to the source.

1.17. Processing Chain Provenance

Identifier: `meta-proprov-ar`

Threshold requirements:

Not required.

Goal requirements:

Information on processing chain provenance should be available with a detailed description of the processing steps used to generate the product, including the versions of software used, giving full transparency to the users.

1.18. 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.

1.19. Valid Pixels

Identifier: `meta-valpix`

Threshold requirements:

Percentage of valid pixels in a specified area based on the applied flags from Per-Pixel Metadata.

Goal requirements:

As threshold.

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.

Information should be available in the metadata as a single DOI landing page, which may include links to further detailed documents and references to citable peer-reviewed algorithms or technical documentation.

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-ar`

Threshold requirements:

Pixels that do not correspond to an observation (e.g., empty pixels / invalid observations / below noise floor) are masked.

Goal requirements:

As threshold.

2.3. Per-pixel Assessment

Identifier: `pxl-pixass`

Threshold requirements:

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:

Identifies which tests have and have not been successfully completed for each pixel.

2.4. Saturation

Identifier: `pxl-pisatur-ar`

Threshold requirements:

Specification of whether there is pixel radiometric saturation at Level 1 in one or more spectral bands.

Goal requirements:

As threshold, with specification of which pixels are radiometrically saturated for each spectral band.

2.5. Cloud

Identifier: `pxl-picloud-ar`

Threshold requirements:

Specification of whether a pixel is cloud or cloud-affected.

Goal requirements:

As threshold, but clouds and cirrus clouds are differentiated.

Note:

1. See Foga et al. (2017), Skakun et al. (2022), Zhu and Woodcock (2012), and Zhu et al. (2015).

2.6. Cloud Shadow

Identifier: `pxl-picloudsh-ar`

Threshold requirements:

Specification of whether a pixel is cloud shadow or cloud shadow-affected.

Goal requirements:

As threshold.

2.7. Land

Identifier: `pxl-lawama-ar`

Threshold requirements:

Specification of whether a pixel is less than 100% water covered due to land.

Note:

1. See Jones (2019), Mikelsons et al. (2021), and Pekel et al. (2016).

Goal requirements:

As threshold.

2.8. Ice

Identifier: `pxl-pice`

Threshold requirements:

Specification of whether a pixel is ice or ice-affected.

Note:

1. See Dworak et al. (2021), Liu and Key (2015), Liu et al. (2016), Robinson et al. (2003), Bourg (2014), and Heinilä, Kirsikka and Metsämäki, Sari and Mattila, Olli-Pekka (2018).

Goal requirements:

As threshold.

2.9. Sun Glint

Identifier: `pxl-pisungli`

Threshold requirements:

Specification of whether sun glint in a pixel is negligible, correctable (moderate), or uncorrectable (severe).

Notes:

1. Sun glint is deemed uncorrectable if the upper limit of the dynamic range of a sensor's spectral band is reached (i.e., radiometric saturation occurs).
2. See Botha et al. (2016), Kay et al. (2013), and Bourg (2014).

Goal requirements:

Specification of the amount of sun glint for each pixel and spectral band.

Notes:

1. An additional product must be provided to specify the amount.
2. See Products and Algorithms: Sun Glint Correction and Fink (2014).

2.10. Sky Glint

Identifier: `pxl-piskygli`

Threshold requirements:

Not required.

Goal requirements:

Specification of the amount of sky glint for each pixel and spectral band.

Notes:

1. An additional product must be provided to specify the amount.
2. Sky glint is the at-water-surface reflected component of the diffuse downwelling irradiance.
3. See Products and Algorithms: Sky Glint Correction, Reusen et al. (2023), and Fink (2014).

2.11. Solar and Viewing Geometry

Identifier: `pxl-vigeso-ar`

Threshold requirements:

Specification of the solar and sensor viewing azimuth and zenith angles.

Goal requirements:

As threshold.

2.12. Whitecap / Foam

Identifier: `pxl-piwhifo`

Threshold requirements:

Not required.

Goal requirements:

Specification of whether a pixel is affected by whitecaps or foam. If affected, detail the method applied.

Note:

1. See Products and Algorithms: Whitecap / Foam Correction, Dierssen (2019), Dierssen (2021), Frouin et al. (2019), Koepke (1984), Moore et al. (2000), Wang et al. (2017), and EUMETSAT (2021).

2.13. Aerosol Optical Depth Parameters

Identifier: `pxl-paodpara`

Threshold requirements:

Not required.

Goal requirements:

Either per-pixel spectral AOD or per-pixel AOD (550 nm) and Angstrom exponent are provided.

Note:

1. This might be an input or an output parameter.

2.14. Adjacency Effects

Identifier: `pxl-pajdeff`

Threshold requirements:

Not required.

Goal requirements:

Depending on the adjacency effects correction method (embedded in the atmospheric correction or separate from the atmospheric correction) the metadata specifies the amount of per-pixel adjacency effect contamination.

Notes:

1. An additional product must be provided to specify the amount.
2. See Botha et al. (2016), Bulgarelli et al. (2014), Bulgarelli and Zibordi (2018), Sei (2015), and Wu et al. (2023).

2.15. Floating Vegetation / Surface Scum

Identifier: `pxl-floatveg`

Threshold requirements:

Specification of whether a pixel is affected by floating vegetation/surface scum.

Note:

1. See Bell (2023), Bresciani et al. (2014), Gendall et al. (2023), Hu (2009), Matthews et al. (2012), and Matthews and Odermatt (2015).

Goal requirements:

As threshold.

2.16. Bathymetry

Identifier: `pxl-pibathy`

Threshold requirements:

Not required.

Goal requirements:

Water surface to bottom substratum depth (i.e., water column depth) at the specific pixel location is specified.

Notes:

1. Specify whether a recalculation to a mean sea level has taken place for oceanic waters.
2. Specify whether a recalculation to a mean water surface level has taken place for any non-oceanic waters.

3. See Hartmann et al. (2022), Khazaei et al. (2022), Kim et al. (2024), Weatherall et al. (2015), GEBCO Bathymetric Compilation Group 2024 (2024), and IHO (2024).

2.17. Optically Deep or Optically Shallow Assessment

Identifier: `pxl-podosas`

Threshold requirements:

Information regarding whether pixels are optically deep or shallow is provided if there is an assumption during the processing that a pixel is optically deep or optically shallow.

Note:

1. See Kutser et al. (2020).

Goal requirements:

A flag that indicates optically deep and shallow waters is provided.

Note:

1. See Brando et al. (2009), Dekker et al. (2011), and Richardson et al. (2024).

2.18. Optical Water Type

Identifier: `pxl-powaty`

Threshold requirements:

Specification of optical water type, when applicable (for optically deep waters).

Note:

1. See Bi and Hieronymi (2024).

Goal requirements:

As threshold.

2.19. Turbid Water

Identifier: `pxl-pituwa`

Threshold requirements:

Specification of whether a pixel is assessed as being turbid.

Notes:

1. See Morel and Bélanger (2006), Morel and Gentili (2008), and Hooker et al. (2003).
2. References for the corresponding flag algorithms are Hudson et al. (2016) and Shi and Wang (2007), respectively.

Goal requirements:

As threshold.

2.20. Elevation

Identifier: `pxl-piwaele`

Threshold requirements:

Specification of approximate elevation (above mean sea level) of the surface of the water body pixels is required for atmospheric correction (range = -430 m to approx. 6500 m)

Note:

1. See Guth et al. (2021).

Goal requirements:

As threshold.

3. Products and Algorithms

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

Metadata must contain a single DOI landing page with relevant information to support each requirement. For corrections, references to a citable peer-reviewed algorithm or technical documentation regarding the implementation of that algorithm and the sources of ancillary data used to make corrections/provision of parameterisation data are required. Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.

3.1. Measurement

Identifier: `pral-measur-ar`

Threshold requirements:

Pixel values that are expressed as a measurement of the Aquatic Reflectance (dimensionless) or the Remote Sensing Reflectance (sr^{-1}) of the water bodies ($AR = \pi \cdot R_{rs}$).

Note:

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

Goal requirements:

As threshold.

Note:

1. See also General Metadata: Traceability and Products and Algorithms: Measurement Normalisation

3.2. Measurement Uncertainty

Identifier: `pral-muncer-ar`

Threshold requirements:

An estimate of the uncertainty of the values is provided in measurement units, following the BIPM Guide to the Expression of Uncertainty in Measurement (GUM).

Notes:

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.
2. See JCGM Working Group 1 (2020) and Vabson et al. (2024).

Goal requirements:

As threshold.

3.3. Measurement Normalisation

Identifier: `pral-mnormal-ar`

Threshold requirements:

Not required.

Goal requirements:

Measurements are normalised (to nadir) to remove the effect of bidirectional dependence of the upwelling radiance on observation and solar-illumination geometries.

3.4. Directional Atmospheric Scattering

Identifier: `pral-dirats-ar`

Threshold requirements:

Specification of corrections applied for molecular (Rayleigh) scattering and for aerosol scattering and absorption..

Note:

1. See Mobley et al. (2016).

Goal requirements:

As threshold.

3.5. Water Vapour Corrections

Identifier: `pral-wavap-ar`

Threshold requirements:

Corrections are applied for water vapour if spectral bands are affected.

Goal requirements:

As threshold.

3.6. Ozone Corrections

Identifier: `pral-cozone`

Threshold requirements:

Data is corrected for ozone if spectral bands are affected.

Notes:

1. Relevant metadata must be provided in General Metadata: Geometric Uncertainty of the Data and General Metadata: Instrument.
2. See Keukelaere et al. (2018), Harmel et al. (2018), Mobley et al. (2016), Pahlevan et al. (2017), Pahlevan et al. (2021), and Vanhellemont (2019).

Goal requirements:

As threshold.

3.7. Other Gaseous Absorption Corrections

Identifier: `pral-ogasab`

Threshold requirements:

Not required.

Goal requirements:

Data is corrected for other trace gaseous absorption for affected spectral bands.

Notes:

1. Relevant metadata must be provided in General Metadata: Geometric Uncertainty of the Data and General Metadata: Instrument.
2. See Keukelaere et al. (2018), Harmel et al. (2018), Mobley et al. (2016), Pahlevan et al. (2017), and Pahlevan et al. (2021).

3.8. Sun Glint Correction

Identifier: `pral-cosungli`

Threshold requirements:

Not required.

Goal requirements:

Sun glint is removed from the data if a pixel is of correctable (i.e., not radiometrically saturating) sun glint.

Notes:

1. Sun glint removal methods can only partially remove sun glint from a pixel. Over or under correction may occur.
2. See Per-Pixel Metadata: Sun Glint, Botha et al. (2016), Groetsch et al. (2020), Harmel et al. (2018), Kay et al. (2009), Kutser et al. (2009), and Lavender and Kay (2010).

3.9. Sky Glint Correction

Identifier: `pral-coskygli`

Threshold requirements:

Specification of whether or not sky glint is implicitly corrected for in the atmospheric correction procedure

Notes:

1. Sky glint is often modelled in forward models explicitly. It is also often measured with above surface spectroradiometers. However, sky glint is seldom corrected for separately in atmospheric and air-water interface correction methods.
2. See Per-Pixel Metadata: Sky Glint, Gege and Groetsch (2016), Groetsch et al. (2020), and Zhang et al. (2017).

Goal requirements:

Sky glint is separately assessed and corrected for in the data processing. The metadata indicates the surface contributions from sky glint removed from the data.

3.10. Whitecap / Foam Correction

Identifier: `pral-cowhifo`

Threshold requirements:

Specification of whether the water leaving reflectance or radiance is corrected for the contribution from surface whitecaps and foam.

Note:

1. See Dierssen (2019), Dierssen (2021), Frouin et al. (2019), Koepke (1984), Moore et al. (2000), Wang et al. (2017), EUMETSAT (2021), and Lavender (2010).

Goal requirements:

The data are corrected for the contribution from surface whitecaps and foam and reported on a per-pixel basis.

Note:

1. See Per-Pixel Metadata: Whitecap / Foam.

3.11. Adjacency Effects Correction

Identifier: `pral-cajdeff`

Threshold requirements:

Not required.

Goal requirements:

The data are corrected for adjacency effects.

Note:

1. See Castagna and Vanhellemont (2025), Kiselev et al. (2015), Pan and Bélanger (2025), Sterckx et al. (2015), and Wu et al. (2024).

3.12. Turbid Water Reflectance Correction

Identifier: `pral-cotuwa`

Threshold requirements:

Specification of whether the atmospheric correction accounted for a pixel being turbid or not.

Note:

1. See Gossn et al. (2019), Moore et al. (1999), and Stumpf et al. (2003).

Goal requirements:

As threshold.

4. Geometric Corrections Metadata (Co-Registration and Ortho-Rectification)

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. Ocean and coastal imagery do not have an independent terrestrial referencing system and therefore Geometric Corrections Metadata (Co-Registration and Ortho-Rectification): Co-Registration and Ortho-Rectification applies to that imagery.

4.1. Geometric Correction

Identifier: `gcom-geocorr-ar`

Applies for:

1. land
2. inland waters where an independent terrestrial referencing system is available

Threshold requirements:

Sub-pixel uncertainty 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 uncertainty 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 Uncertainty of the Data and General Metadata: Instrument.

Notes:

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.
2. It is useful to note if the sensor is used at its native resolution before geometric correction or that some resampling must be done.

Goal requirements:

Sub-pixel uncertainty is achieved relative to an identified absolute independent terrestrial referencing system (such as a national map grid).

Relevant metadata must be provided under General Metadata: Geometric Uncertainty 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.

4.2. Co-Registration and Ortho-Rectification

Identifier: `gcom-corore`

Threshold requirements:

Co-registration is performed to ensure consistency of pixel location in each spectral band of one image at 0.5 GSD.

Ortho rectification specifies the pointing accuracy related to a geographic reference grid. The associated uncertainty is pixel size dependent and therefore cannot be given an a priori measure of uncertainty.

The specifications of the co-registration and ortho-rectification processing (including parameterisation data) must be provided, including the estimated uncertainty of each processing, in publicly available documentation.

Note:

1. Including but not limited to ocean-to-sea to coastal, estuarine, deltaic, lagoonal waters and inland water bodies such as canals, rivers, lakes and reservoirs.

Goal requirements:

Co-registration is performed to ensure consistency of pixel location in each spectral band of one image at 0.2 GSD.

Ortho rectification specifies the pointing accuracy related to a geographic reference grid. The associated uncertainty is pixel size dependent and therefore cannot be given an a priori measure of uncertainty.

The specifications of the co-registration and ortho-rectification processing (including parameterisation data) must be provided, including the estimated uncertainty of each processing, in publicly available documentation.

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

Bell, Kyle C. AND Saccomanno, Tom W. AND Cavanaugh. 2023. “Kelpwatch: A New Visualization and Analysis Tool to Explore Kelp Canopy Dynamics Reveals Variable Response to and Recovery from Marine Heatwaves.” *PLOS ONE* 18 (3): 1–21. https://doi.org/10.1371/journal.pone.0271477.

Bi, Shun, and Martin Hieronymi. 2024. “Holistic Optical Water Type Classification for Ocean, Coastal, and Inland Waters.” *Limnology and Oceanography* 69 (7): 1547–61. https://doi.org/https://doi.org/10.1002/lno.12606.

Botha, Elizabeth J., Vittorio E. Brando, and Arnold G. Dekker. 2016. “Effects of Per-Pixel Variability on Uncertainties in Bathymetric Retrievals from High-Resolution Satellite Images.” *Remote Sensing* 8 (6). https://doi.org/10.3390/rs8060459.

Bourg, L. 2014. *Sentinel-3 OLCI Level 0 and Level 1B, Algorithm Theoretical Basis Document (ATBD), Issue 5.0*. Algorithm Theoretical Basis Document S3-ACR-TN-007. https://sentiwiki.copernicus.eu/__attachments/1672112/S3-ACR-TN-007%20-%20Sentinel%203%20OLCI%20Level%200%20and%201B%20ATBD%202014%20-%205.0.pdf.

Brando, Vittorio E., Janet M. Anstee, Magnus Wettle, Arnold G. Dekker, Stuart R. Phinn, and Chris Roelfsema. 2009. “A Physics Based Retrieval and Quality Assessment of Bathymetry from Suboptimal Hyperspectral Data.” *Remote Sensing of Environment* 113 (4): 755–70. https://doi.org/https://doi.org/10.1016/j.rse.2008.12.003.

Bresciani, Mariano, Maria Adamo, Giacomo De Carolis, et al. 2014. “Monitoring Blooms and Surface Accumulation of Cyanobacteria in the Curonian Lagoon by Combining MERIS and ASAR Data.” *Remote Sensing of Environment* 146: 124–35. https://doi.org/https://doi.org/10.1016/j.rse.2013.07.040.

Bulgarelli, Barbara, Viatcheslav Kiselev, and Giuseppe Zibordi. 2014. “Simulation and Analysis of Adjacency Effects in Coastal Waters: A Case Study.” *Appl. Opt.* 53 (8): 1523–45. https://doi.org/10.1364/AO.53.001523.

Bulgarelli, Barbara, and Giuseppe Zibordi. 2018. “On the Detectability of Adjacency Effects in Ocean Color Remote Sensing of Mid-Latitude Coastal Environments by SeaWiFS, MODIS-a, MERIS, OLCI, OLI and MSI.” *Remote Sensing of Environment* 209: 423–38. https://doi.org/https://doi.org/10.1016/j.rse.2017.12.021.

Castagna, Alexandre, and Quinten Vanhellemont. 2025. “A Generalized Physics-Based Correction for Adjacency Effects.” *Appl. Opt.* 64 (10): 2719–43. https://doi.org/10.1364/AO.546766.

Dekker, Arnold G., Stuart R. Phinn, Janet Anstee, et al. 2011. “Intercomparison of Shallow Water Bathymetry, Hydro-Optics, and Benthos Mapping Techniques in Australian and Caribbean Coastal Environments.” *Limnology and Oceanography: Methods* 9 (9): 396–425. https://doi.org/https://doi.org/10.4319/lom.2011.9.396.

Dierssen, Heidi M. 2019. “Hyperspectral Measurements, Parameterizations, and Atmospheric Correction of Whitecaps and Foam from Visible to Shortwave Infrared for Ocean Color Remote Sensing.” *Frontiers in Earth Science* Volume 7 - 2019. https://doi.org/10.3389/feart.2019.00014.

Dierssen, Heidi M. 2021. “Corrigendum: Hyperspectral Measurements, Parameterizations, and Atmospheric Correction of Whitecaps and Foam from Visible to Shortwave Infrared for Ocean Color Remote Sensing.” *Frontiers in Earth Science* Volume 9 - 2021. https://doi.org/10.3389/feart.2021.683136.

Dworak, Richard, Yinghui Liu, Jeffrey Key, and Walter N. Meier. 2021. “A Blended Sea Ice Concentration Product from AMSR2 and VIIRS.” *Remote Sensing* 13 (15). https://doi.org/10.3390/rs13152982.

EUMETSAT. 2021. *Sentinel-3 OLCI L2 Report for Baseline Collection OL_L2M_003*. EUM/RSP/REP/21/1211386. EUMETSAT. https://user.eumetsat.int/s3/eup-strapi-media/Sentinel_3_OLCI_L2_report_for_baseline_collection_OL_L2_M_003_2_B_c8bbc6d986.pdf.

Fan, Yongzhen, Wei Li, Kenneth J. Voss, Charles K. Gatebe, and Knut Stamnes. 2016. “Neural Network Method to Correct Bidirectional Effects in Water-Leaving Radiance.” *Appl. Opt.* 55 (1): 10–21. https://doi.org/10.1364/AO.55.000010.

Fink, Colin M. 2014. “Glint Avoidance and Removal in the Maritime Environment.” Master's Thesis, Rochester Institute of Technology. https://repository.rit.edu/theses/8301.

Foga, Steve, Pat L. Scaramuzza, Song Guo, et al. 2017. “Cloud Detection Algorithm Comparison and Validation for Operational Landsat Data Products.” *Remote Sensing of Environment* 194: 379–90. https://doi.org/https://doi.org/10.1016/j.rse.2017.03.026.

Frouin, Robert J., Bryan A. Franz, Amir Ibrahim, et al. 2019. “Atmospheric Correction of Satellite Ocean-Color Imagery During the PACE Era.” *Frontiers in Earth Science* Volume 7 - 2019. https://doi.org/10.3389/feart.2019.00145.

GEBCO Bathymetric Compilation Group 2024. 2024. *The GEBCO_2024 Grid - a Continuous Terrain Model of the Global Oceans and Land*. GEBCO Compilation Group. https://doi.org/10.5285/1c44ce99-0a0d-5f4f-e063-7086abc0ea0f.

Gege, Peter, and Philipp Groetsch. 2016. “A Spectral Model for Correcting Sunglint and Skyglint.” October.

Gendall, Lianna, Sarah B. Schroeder, Peter Wills, Margot Hessing-Lewis, and Maycira Costa. 2023. “A Multi-Satellite Mapping Framework for Floating Kelp Forests.” *Remote Sensing* 15 (5). https://doi.org/10.3390/rs15051276.

Gossn, Juan Ignacio, Kevin George Ruddick, and Ana Inés Dogliotti. 2019. “Atmospheric Correction of OLCI Imagery over Extremely Turbid Waters Based on the Red, NIR and 1016 Nm Bands and a New Baseline Residual Technique.” *Remote Sensing* 11 (3). https://doi.org/10.3390/rs11030220.

Groetsch, Philipp M. M., Robert Foster, and Alexander Gilerson. 2020. “Exploring the Limits for Sky and Sun Glint Correction of Hyperspectral Above-Surface Reflectance Observations.” *Appl. Opt.* 59 (9): 2942–54. https://doi.org/10.1364/AO.385853.

Guth, Peter L., Adriaan Van Niekerk, Carlos H. Grohmann, et al. 2021. “Digital Elevation Models: Terminology and Definitions.” *Remote Sensing* 13 (18). https://doi.org/10.3390/rs13183581.

Harmel, Tristan, Malik Chami, Thierry Tormos, Nathalie Reynaud, and Pierre-Alain Danis. 2018. “Sunglint Correction of the Multi-Spectral Instrument (MSI)-SENTINEL-2 Imagery over Inland and Sea Waters from SWIR Bands.” *Remote Sensing of Environment* 204: 308–21. https://doi.org/https://doi.org/10.1016/j.rse.2017.10.022.

Hartmann, Knut, Mona Reithmeier, Kim Knauer, Julian Wenzel, Christoph Kleih, and Thomas Heege. 2022. “SATELLITE-DERIVED BATHYMETRY ONLINE.” *The International Hydrographic Review* 28: 53–75. https://doi.org/https://doi.org/10.58440/ihr-28-a14 .

Heinilä, Kirsikka and Metsämäki, Sari and Mattila, Olli-Pekka. 2018. *Lake Ice Extent (LIE), Collection 250m Baltic Sea Region, Version 1.0.1*. Copernicus Global Land Service. https://land.copernicus.eu/en/technical-library/quality-

assessment-report-for-lake-ice-extent-baltic-sea-region-250-m-raster/@@download/file.

Hooker, Stanford, Elaine Firestone, et al. 2003. *Algorithm Updates for the Fourth SeaWiFS Data Reprocessing*. June.

Hu, Chuanmin. 2009. “A Novel Ocean Color Index to Detect Floating Algae in the Global Oceans.” *Remote Sensing of Environment* 113 (10): 2118–29. https://doi.org/https://doi.org/10.1016/j.rse.2009.05.012.

Hudson, Benjamin D., Irina Overeem, and James P. M. Syvitski. 2016. “A Novel Technique to Detect Turbid Water and Mask Clouds in Greenland Fjords.” *International Journal of Remote Sensing* 37 (7): 1730–46. https://doi.org/10.1080/01431161.2016.1157641.

IHO. 2024. *Guidance to Satellite-Derived Bathymetry*. B-13 Edition 1.0.0. International Hydrographic Organization (IHO). https://iho.int/uploads/user/pubs/bathy/B_13_Ed100_032024.pdf.

Ilori, Christopher O., Nima Pahlevan, and Anders Knudby. 2019. “Analyzing Performances of Different Atmospheric Correction Techniques for Landsat 8: Application for Coastal Remote Sensing.” *Remote Sensing* 11 (4). https://doi.org/10.3390/rs11040469.

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

International Organization for Standardization. 2019. *Date and time — Representations for information interchange — Part 1: Basic rules*. Standard. International Organization for Standardization.

JCGM Working Group 1. 2020. *Guide to the Expression of Uncertainty in Measurement — Part 6: Developing and Using Measurement Models*. Norm. Joint Committee for Guides in Metrology; Joint Committee for Guides in Metrology, JCGM GUM-6:2020. https://www.bipm.org/documents/20126/2071204/JCGM_GUM_6_2020.pdf.

Jones, John W. 2019. “Improved Automated Detection of Subpixel-Scale Inundation—Revised Dynamic Surface Water Extent (DSWE) Partial Surface Water Tests.” *Remote Sensing* 11 (4). https://doi.org/10.3390/rs11040374.

Kay, Susan, John D. Hedley, and Samantha Lavender. 2009. “Sun Glint Correction of High and Low Spatial Resolution Images of Aquatic Scenes: A Review of Methods for Visible and Near-Infrared Wavelengths.” *Remote Sensing* 1 (4): 697–730. https://doi.org/10.3390/rs1040697.

Kay, Susan, John Hedley, and Samantha Lavender. 2013. “Sun Glint Estimation in Marine Satellite Images: A Comparison of Results from Calculation and Radiative Transfer Modeling.” *Appl. Opt.* 52 (23): 5631–39. https://doi.org/10.1364/AO.52.005631.

Keukelaere, L. De, S. Sterckx, S. Adriaensen, et al. 2018. “Atmospheric Correction of Landsat-8/OLI and Sentinel-2/MSI Data Using iCOR Algorithm: Validation for Coastal and Inland Waters.” *European Journal of Remote Sensing* 51 (1): 525–42. https://doi.org/10.1080/22797254.2018.1457937.

Khazaei, Bahram, Laura Read, Matthew Casali, Kevin Sampson, and David Yates. 2022. “GLOBathy, the Global Lakes Bathymetry Dataset.” *Scientific Data* 9 (February). https://doi.org/10.1038/s41597-022-01132-9.

Kim, Minsu, Jeff Danielson, Curt Storlazzi, and Seonkyung Park. 2024. “Physics-Based Satellite-Derived Bathymetry (SDB) Using Landsat OLI Images.” *Remote Sensing* 16 (5). https://doi.org/10.3390/rs16050843.

Kiselev, Viacheslav, Barbara Bulgarelli, and Thomas Heege. 2015. “Sensor Independent Adjacency Correction Algorithm for Coastal and Inland Water Systems.” *Remote Sensing of Environment* 157: 85–95. https://doi.org/https://doi.org/10.1016/j.rse.2014.07.025.

Koepke, Peter. 1984. “Effective Reflectance of Oceanic Whitecaps.” *Appl. Opt.* 23 (11): 1816–24. https://doi.org/10.1364/AO.23.001816.

Kutser, Tiit, John Hedley, Claudia Giardino, Chris Roelfsema, and Vittorio E. Brando. 2020. “Remote Sensing of Shallow Waters – a 50 Year Retrospective and Future Directions.” *Remote Sensing of Environment* 240: 111619. https://doi.org/https://doi.org/10.1016/j.rse.2019.111619.

Kutser, Tiit, Ele Vahtmäe, and Jaan Praks. 2009. “A Sun Glint Correction Method for Hyperspectral Imagery Containing Areas with Non-Negligible Water Leaving NIR Signal.” *Remote Sensing of Environment* 113 (10): 2267–74. https://doi.org/https://doi.org/10.1016/j.rse.2009.06.016.

Lavender, S. 2010. *SENTINEL-3 Optical Products and Algorithm Definition – OLCI Level 2 ATBD: White Caps Correction*. Algorithm Theoretical Basis Document S3-L2-SD-03-C06-ARG-ATBD. ARGANS. https://user.eumetsat.int/s3/eup-strapi-media/pdf_s3_l2_atbd_white_caps_corr_ac4301c8fe.pdf.

Lavender, S., and S. Kay. 2010. *SENTINEL-3 OPTICAL PRODUCTS AND ALGORITHM DEFINITION – OLCI Level 2 ATBD – Glint Correction*. Algorithm Theoretical Basis Document S3-L2-SD-03-C09-ARG-ATBD. ARGANS. https://user.eumetsat.int/s3/eup-strapi-media/pdf_s3_l2_atbd_glint_corr_6d7b828eec.pdf.

Lee, Zhong Ping, Keping Du, Kenneth J. Voss, et al. 2011. “An Inherent-Optical-Property-Centered Approach to Correct the Angular Effects in Water-Leaving Radiance.” *Appl. Opt.* 50 (19): 3155–67. https://doi.org/10.1364/AO.50.003155.

Liu, Yinghui, and Jeffrey Key. 2015. *Ice Surface Temperature, Ice Concentration, and Ice Cover Algorithm Theoretical Basic Document*.

Liu, Yinghui, Jeffrey Key, and Robert Mahoney. 2016. “Sea and Freshwater Ice Concentration from VIIRS on Suomi NPP and the Future JPSS Satellites.” *Remote Sensing* 8 (6). https://doi.org/10.3390/rs8060523.

Matthews, Mark William, Stewart Bernard, and Lisl Robertson. 2012. “An Algorithm for Detecting Trophic Status (Chlorophyll-a), Cyanobacterial-Dominance, Surface Scums and Floating Vegetation in Inland and Coastal Waters.” *Remote Sensing of Environment* 124: 637–52. https://doi.org/https://doi.org/10.1016/j.rse.2012.05.032.

Matthews, Mark William, and Daniel Odermatt. 2015. “Improved Algorithm for Routine Monitoring of Cyanobacteria and Eutrophication in Inland and Near-Coastal Waters.” *Remote Sensing of Environment* 156: 374–82. https://doi.org/https://doi.org/10.1016/j.rse.2014.10.010.

Mikelsons, Karlis, Menghua Wang, Xiao-Long Wang, and Lide Jiang. 2021. “Global Land Mask for Satellite Ocean Color Remote Sensing.” *Remote Sensing of Environment* 257: 112356. https://doi.org/https://doi.org/10.1016/j.rse.2021.112356.

Mobley, Curtis, Jeremy Werdell, Bryan Franz, Ziauddin Ahmad, and Sean Bailey. 2016. *Atmospheric Correction for Satellite Ocean Color Radiometry*. https://doi.org/10.13140/RG.2.2.23016.78081.

Moore, G. F., J. Aiken, and S. J. Lavender. 1999. “The Atmospheric Correction of Water Colour and the Quantitative Retrieval of Suspended Particulate Matter in Case II Waters: Application to MERIS.” *International Journal of Remote Sensing* 20 (9): 1713–33. https://doi.org/10.1080/014311699212434.

Moore, Karl D., Kenneth J. Voss, and Howard R. Gordon. 2000. “Spectral Reflectance of Whitecaps: Their Contribution to Water-Leaving Radiance.” *Journal of Geophysical Research: Oceans* 105 (C3): 6493–99. https://doi.org/https://doi.org/10.1029/1999JC900334.

Morel, André, David Antoine, and Bernard Gentili. 2002. “Bidirectional Reflectance of Oceanic Waters: Accounting for Raman Emission and Varying Particle Scattering Phase Function.” *Appl. Opt.* 41 (30): 6289–306. https://doi.org/10.1364/AO.41.006289.

Morel, Andre, and Simon Bélanger. 2006. “Improved Detection of Turbid Waters from Ocean Color Sensors Information.” *Remote Sensing of Environment* 102 (3): 237–49. https://doi.org/https://doi.org/10.1016/j.rse.2006.01.022.

Morel, André, and Bernard Gentili. 2008. “Practical Application of the ‘Turbid Water’ Flag in Ocean Color Imagery: Interference with Sun-Glint Contaminated Pixels in Open Ocean.” *Remote Sensing of Environment* 112 (3): 934–38. https://doi.org/https://doi.org/10.1016/j.rse.2007.07.009.

Pahlevan, Nima, Antoine Mangin, Sundarabalan V. Balasubramanian, et al. 2021. “ACIX-Aqua: A Global Assessment of Atmospheric Correction Methods for Landsat-8 and Sentinel-2 over Lakes, Rivers, and Coastal Waters.” *Remote Sensing of Environment* 258: 112366. https://doi.org/https://doi.org/10.1016/j.rse.2021.112366.

Pahlevan, Nima, John R. Schott, Bryan A. Franz, et al. 2017. “Landsat 8 Remote Sensing Reflectance (Rrs) Products: Evaluations, Intercomparisons, and Enhancements.” *Remote Sensing of Environment* 190: 289–301. https://doi.org/https://doi.org/10.1016/j.rse.2016.12.030.

Pan, Yanqun, and Simon Bélanger. 2025. “Genetic Algorithm for Atmospheric Correction (GAAC) of Water Bodies Impacted by Adjacency Effects.” *Remote Sensing of Environment* 317: 114508. https://doi.org/https://doi.org/10.1016/j.rse.2024.114508.

Park, Young-Je, and Kevin Ruddick. 2005. “Model of Remote-Sensing Reflectance Including Bidirectional Effects for Case 1 and Case 2 Waters.” *Appl. Opt.* 44 (7): 1236–49. https://doi.org/10.1364/AO.44.001236.

Pekel, J.-F, Andrew Cottam, Noel Gorelick, and Alan Belward. 2016. “High-Resolution Mapping of Global Surface Water and Its Long-Term Changes.” *Nature* 540 (December). https://doi.org/10.1038/nature20584.

Reusen, Ils, Liesbeth De Keukelaere, Sindy Sterckx, et al. 2023. *Atmospheric Corrections*. Zenodo. https://doi.org/10.5281/zenodo.10357236.

Richardson, Galen, Neve Foreman, Anders Knudby, Yulun Wu, and Yiwen Lin. 2024. “Global Deep Learning Model for Delineation of Optically Shallow and Optically Deep Water in Sentinel-2 Imagery.” *Remote Sensing of Environment* 311: 114302. https://doi.org/https://doi.org/10.1016/j.rse.2024.114302.

Robinson, Wayne, Bryan Franz, Frederick Patt, Sean Bailey, and Jeremy Werdell. 2003. “Masks and Flags Updates.” *NASA Technical Memorandum - SeaWIFS Postlaunch Technical Report Series*, May, 34–40.

Sei, Alain. 2015. “Efficient Correction of Adjacency Effects for High-Resolution Imagery: Integral Equations, Analytic Continuation, and Padé Approximants.” *Appl. Opt.* 54 (12): 3748–58. https://doi.org/10.1364/AO.54.003748.

Shi, Wei, and Menghua Wang. 2007. “Detection of Turbid Waters and Absorbing Aerosols for the MODIS Ocean Color Data Processing.” *Remote Sensing of Environment* 110 (2): 149–61. https://doi.org/https://doi.org/10.1016/j.rse.2007.02.013.

Skakun, Sergii, Jan Wevers, Carsten Brockmann, et al. 2022. “Cloud Mask Intercomparison eXercise (CMIX): An Evaluation of Cloud Masking Algorithms for Landsat 8 and Sentinel-2.” *Remote Sensing of Environment* 274: 112990. https://doi.org/https://doi.org/10.1016/j.rse.2022.112990.

Soppa, Mariana A., Brenner Silva, François Steinmetz, et al. 2021. “Assessment of Polymer Atmospheric Correction Algorithm for Hyperspectral Remote

Sensing Imagery over Coastal Waters." *Sensors* 21 (12). https://doi.org/10.3390/s21124125.

Sterckx, S., S. Knaeps, S. Kratzer, and K. Ruddick. 2015. "SIMilarity Environment Correction (SIMEC) Applied to MERIS Data over Inland and Coastal Waters." *Remote Sensing of Environment* 157: 96–110. https://doi.org/https://doi.org/10.1016/j.rse.2014.06.017.

Stumpf, Richard, Robert Arnone, R. Gould, P. Martinolich, and Varis Ransibrahmanakul. 2003. "A Partially Coupled Ocean-Atmosphere Model for Retrieval of Water-Leaving Radiance from SeaWiFS in Coastal Waters." *NASA Tech. Memo* 206892 (May): 51–59.

Vabson, Viktor, Ilmar Ansko, Kim Duong, et al. 2024. "Complete Characterization of Ocean Color Radiometers." *Frontiers in Remote Sensing* Volume 5 - 2024. https://doi.org/10.3389/frsen.2024.1320454.

Vanhellemont, Quinten. 2019. "Adaptation of the Dark Spectrum Fitting Atmospheric Correction for Aquatic Applications of the Landsat and Sentinel-2 Archives." *Remote Sensing of Environment* 225: 175–92. https://doi.org/https://doi.org/10.1016/j.rse.2019.03.010.

Wang, Menghua, Xiaoming Liu, Lide Jiang, and SeungHyun Son. 2017. *VIIRS Ocean Color Products: Algorithm Theoretical Basis Document (ATBD), Version 1.0*. Algorithm Theoretical Basis Document. NOAA NESDIS Center for Satellite Applications; Research (STAR). https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_OceanColor_v1.0.pdf.

Weatherall, Pauline, K. M. Marks, Martin Jakobsson, et al. 2015. "A New Digital Bathymetric Model of the World's Oceans." *Earth and Space Science* 2 (8): 331–45. https://doi.org/https://doi.org/10.1002/2015EA000107.

Wu, Yulun, Anders Knudby, and David Lapen. 2023. "Topography-Adjusted Monte Carlo Simulation of the Adjacency Effect in Remote Sensing of Coastal and Inland Waters." *Journal of Quantitative Spectroscopy and Radiative Transfer* 303: 108589. https://doi.org/https://doi.org/10.1016/j.jqsrt.2023.108589.

Wu, Yulun, Anders Knudby, Nima Pahlevan, David Lapen, and Chuiqing Zeng. 2024. "Sensor-Generic Adjacency-Effect Correction for Remote Sensing of Coastal and Inland Waters." *Remote Sensing of Environment* 315: 114433. https://doi.org/https://doi.org/10.1016/j.rse.2024.114433.

Zhang, Xiaodong, Shuangyan He, Afshin Shabani, Peng-Wang Zhai, and Keping Du. 2017. "Spectral Sea Surface Reflectance of Skylight." *Opt. Express* 25 (4): A1–13. https://doi.org/10.1364/OE.25.0000A1.

Zhu, Zhe, Shixiong Wang, and Curtis E. Woodcock. 2015. "Improvement and Expansion of the Fmask Algorithm: Cloud, Cloud Shadow, and Snow Detection for Landsats 4–7, 8, and Sentinel 2 Images." *Remote Sensing of Environment* 159: 269–77. https://doi.org/https://doi.org/10.1016/j.rse.2014.12.014.

Zhu, Zhe, and Curtis E. Woodcock. 2012. "Object-Based Cloud and Cloud Shadow Detection in Landsat Imagery." *Remote Sensing of Environment* 118: 83–94. https://doi.org/https://doi.org/10.1016/j.rse.2011.10.028.