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|  | **Analysis Ready Data**  ***For Land*** | **Product Family**  **Specification**  **Aquatic Reflectance (CARD4L-AR)** |

# Document Status

**Product Family Specification, Aquatic Reflectance**

This Specification should next be reviewed on: March 2021, or no later than 2 weeks before LSI-VC-11 meeting.

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

# Document History

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| **Version** | **Date** | **Description of Change** | **Author** |
| 1.0 | 30.10.2020 | Initial draft | Barnes |
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# Description

**Product Family Title:** **Aquatic Reflectance (CARD4L-AR)**

**Applies to:**Data collected with multispectral sensors operating in the VIS/NIR wavelengths over water bodies. These typically operate with ground sample distance and resolution in the order 10-100m however the Specification is not inherently limited to this resolution.

# Definitions

|  |  |
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| AR | Aquatic Reflectance |
| Ancillary Data | Data other than instrument measurements, originating in the instrument itself or from the satellite, required to perform processing of the data. They include orbit data, attitude data, time information, spacecraft engineering data, calibration data, data quality information, and data from other instruments. |
| Auxiliary Data | The data required for instrument processing, which does not originate in the instrument itself or from the satellite. Some auxiliary data will be generated in the ground segment, whilst other data will be provided from external sources. |
| Metadata | Structured information that describes other information or information services. With well-defined metadata, users should be able to get basic information about data, without the need to have knowledge about its entire content. |
| MTF | Modulation Transfer Function |
| Spectral Resolution | Defines the narrowest spectral feature that can be resolved by a spectrometer. |
| Spatial Resolution | The highest magnification of the sensor at the ground surface. |
| Spectral Sampling Distance | Spectral sampling is the interval, in wavelength units, between discrete data points in the measured spectrum. |
| Spatial Sampling Distance | Spatial sampling distance is the barycentre-to-barycentre distance between adjacent spatial samples on the Earth's surface. |

# 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 following requirements:*

| **#** | **Item** | **Threshold (Minimum)**  **Requirements** | **Target (Desired) Requirements** | **Threshold Self-Assessment** | **Target Self-Assessment** | **Self-Assessment Explanation/ Justification** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **1.1** | **Traceability** | Not required. | 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** | 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 | As threshold, but metadata is formatted should be provided in accordance with a community endorsed standard that facilitates machine-readability, such as ISO 19115-2. |  |  |  |  |
| **1.3** | **Data Collection Time** | The data collection time is identified in the metadata, expressed in date/time, to the second, with the time offset from UTC unambiguously identified. | Acquisition time for each pixel is identified (or can be reliably determined) in the metadata, expressed in date/time at UTC, to the second. |  |  |  |  |
| **1.4** | **Geographical Area** | The surface location to which the data relates is identified, typically as a series of four corner points, expressed in an accepted coordinate reference system (e.g., WGS84). | The geographic area covered by the observations is identified specifically, such as through a set of coordinates of a closely bounding polygon. The location to which each pixel refers is identified (or can be reliably determined) with the projection system (if any) and reference datum provided. |  |  |  |  |
| **1.5** | **Coordinate Reference System** | The metadata lists the coordinate reference system that has been used. | As threshold. |  |  |  |  |
| **1.6** | **Map Projection** | 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. | As threshold. |  |  |  |  |
| **1.7** | **Geometric Correction Methods** | Not required.  The user is not explicitly advised of the geometric correction source and methods. | 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** | Not required.  The user is not provided with results of geometric accuracy assessments pertaining to the dataset. | 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** | The instrument used to collect the data is identified in the metadata. | 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** | The central wavelength for each band for which data is included is identified in the metadata, expressed in SI units. | As threshold, with instrument spectral response details (e.g., full spectral response function) also included or directly accessible using details in the metadata.  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** | Not required.  The general metadata does not include sensor calibration details. | Sensor calibration parameters are identified in the metadata, or can be accessed using details included in the metadata. Ideally this would support machine-to-machine access.  *Note 1: Information on sensor calibration should be available in the metadata as a single DOI landing page.* |  |  |  |  |
| **1.12** | **Radiometric Accuracy** | Not required. The general metadata does not include information on the radiometric accuracy of the data. | The metadata includes metrics describing the assessed absolute radiometric uncertainty of the version of the data or product, expressed as absolute radiometric uncertainty relative to appropriate, known reference sites and standards (for example, pseudo-invariant calibration sites, rigorously collected field spectra, PICS, Rayleigh, DCC, etc.)  *Note 1: Information on radiometric accuracy should be available in the metadata as a single DOI landing page.* |  |  |  |  |
| **1.13** | **Algorithms** | All algorithms, and the sequence in which they were applied in the generation process, are identified in the metadata. For example, these may be available through Algorithm Theoretical Basis documents.  *Note 1: Information on algorithms should be available in the metadata as a single DOI landing page.* | 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** | The metadata identifies the sources of auxiliary data used in the generation process, ideally expressed as a single DOI landing page.  *Note 1: Ancillary data includes DEMs, aerosols, land mask, bathymetry, NO2, etc. data sources.* | 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** | Not required. | Information on processing chain provenance should be available in the metadata as a single DOI landing page containing detailed description of the processing steps used to generate the product, including the versions of software used, giving full transparency to the users. |  |  |  |  |
| **1.16** | **Data Access** | Information on data access should be available in the metadata as a single DOI landing page.  *Note 1: Manual and offline interaction action (e.g., login) may be required.* | As threshold. |  |  |  |  |
| **1.17** | **Overall Data Quality** | Not applicable. | 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 on the basis of their individual suitability for application.*

| **#** | **Item** | **Threshold (Minimum)**  **Requirements** | **Target (Desired) Requirements** | **Threshold Self-Assessment** | **Target Self-Assessment** | **Self-Assessment Explanation/ Justification** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **2.1** | **Metadata Machine Readability** | Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use. | As threshold. |  |  |  |  |
| **2.2** | **No Data** | Pixels that do not correspond to an observation (‘empty pixels’) are flagged. | As threshold. |  |  |  |  |
| **2.3** | **Incomplete Testing** | The metadata identifies pixels for which the per-pixel tests (below) have not all been successfully completed.  *Note 1: This may be the result of missing ancillary data for a subset of the pixels.* | The metadata identifies which tests have, and have not, been successfully completed for each pixel. |  |  |  |  |
| **2.4** | **Saturation** | Metadata indicates where one or more spectral bands are saturated. | Metadata indicates which pixels are saturated for each spectral band. |  |  |  |  |
| **2.5** | **Cloud** | Metadata indicates whether a pixel is assessed as being cloud. | As threshold, information on cloud detection should be available in the metadata as a single DOI landing page.  <*Perhaps introduce cloud type here?*> |  |  |  |  |
| **2.6** | **Cloud Shadow** | Metadata indicates whether a pixel is assessed as being cloud shadow. | As threshold, but information on cloud shadow detection should be available in the metadata as a single DOI landing page. |  |  |  |  |
| **2.7** | **Land/Water Mask** | 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. | As threshold. |  |  |  |  |
| **2.8** | **Sea Ice Mask** | The metadata indicates whether a pixel is assessed as being sea ice or not. Information on snow/ice mask should be available in the metadata as a single DOI landing page. | As threshold. |  |  |  |  |
| **2.9** | **Sun Glint Mask** | The amount of Sun glint is provided for each pixel. | As threshold, but includes information on per-pixel percent uncertainty. |  |  |  |  |
| **2.10** | **Sky Glint Mask** | The amount of sky glint is provided for each pixel. | As threshold. |  |  |  |  |
| **2.11** | **Whitecap/ Foam Mask** | Provide presence of whitecaps or foam on the surface only if the wind speed is high (i.e., >9m/s). | As threshold. |  |  |  |  |
| **2.12** | **Solar and Viewing Geometry** | Provide average solar and sensor viewing azimuth and zenith angles. | Provide per-pixel solar and sensor viewing azimuth and zenith angles. |  |  |  |  |
| **2.13** | **Atmospheric Adjacency Spectral Correction** | The amount of atmospheric adjacency spectral correction is provided for each pixel. | As threshold. |  |  |  |  |
| **2.14** | **Surface Reflected Vegetation Spectral**  **Correction** | Not required. | The amount of surface reflected vegetation spectral correction is provided for each pixel. |  |  |  |  |
| **2.15** | **Aerosol Optical Depth Parameters** | Not required. | To be determined. |  |  |  |  |

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| **2.16** | **Sun and Observation Geometry** | To be determined. | To be determined. |  |  |  |  |
| **2.17** | **Coastline Mask** | To be determined. | To be determined. |  |  |  |  |
| **2.18** | **Floating Vegetation/Surface Scum** | To be determined. | To be determined. |  |  |  |  |
| **2.19** | **Suspended Sediment** | To be determined. | To be determined. |  |  |  |  |
| **2.20** | **Bidirectional Reflectance Distribution Function** | Not required. | Metadata indicates which pixels are corrected for BRDF effects. |  |  |  |  |
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Additional per-pixel meta data:

* Sun and observation geometry. It may be even necessary to have multiple grids with the observation geometry if there are significant changes due to sensor design (multiple focal planes).
* A coastline is often useful, in addition to the land/water mask

## Radiometric and Atmospheric Corrections

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

| **#** | **Item** | **Threshold (Minimum)**  **Requirements** | **Target (Desired) Requirements** | **Threshold Self-Assessment** | **Target Self-Assessment** | **Self-Assessment Explanation/ Justification** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **3.1** | **Measurement** | Pixel values that are expressed as a measurement of the Aquatic Reflectance of the water bodies. This is a dimensionless value. | Aquatic Reflectance measurements are SI traceable (see also 1.1). |  |  |  |  |
| **3.2** | **Measurement Uncertainty** | 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.* | An estimate of the uncertainty 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** | Not required. | Measurements are normalised for solar and viewing conditions (i.e., nadir view angle and average solar angles). This may include terrain illumination and/or Bi-Directional Reflectance Function (BRDF) correction.  *Note 1: Information on measurement normalisation should be available in the metadata as single DOI landing page.* |  |  |  |  |
| **3.4** | **Directional Atmospheric Scattering** | Corrections are applied for aerosols and molecular (Rayleigh) scattering.  Metadata contains a single DOI landing page with references to:   * a citable peer-reviewed algorithm, * technical documentation regarding the implementation of that algorithm * the sources of ancillary data used to make corrections.   *Note 1: Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.* | As threshold. |  |  |  |  |
| **3.5** | **Water Vapour Corrections** | Corrections are applied for water vapour.  Metadata contains a single DOI landing page with references to:   * a citable peer-reviewed algorithm, * technical documentation regarding the implementation of that algorithm   *Note 1: Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.* | As threshold. |  |  |  |  |
| **3.6** | **Ozone Corrections** | Required | 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** | To be determined. | To be determined. |  |  |  |  |
| **3.8** | **Sun Glint Correction** | Surface contributions from Sun glint is removed from the data. | As threshold. |  |  |  |  |
| **3.9** | **Sky Glint**  **Correction** | Surface contributions from sky glint is removed from the data. | As threshold. |  |  |  |  |
| **3.10** | **Whitecap and Foam Correction** | The water leaving radiance is corrected for the contribution from surface whitecaps and foam. | As threshold. |  |  |  |  |
| **3.11** | **Atmospheric Adjacency Spectral Correction** | Data is corrected for atmospheric adjacency spectral effects | As threshold. |  |  |  |  |
| **3.12** | **Surface Reflected Vegetation Spectral**  **Correction** | Not required. | Data is corrected for surface reflected vegetation spectral effects |  |  |  |  |
| **3.13** | **Floating Vegetation/ Surface Scum**  **Correction** | To be determined. | To be determined. |  |  |  |  |
| **3.14** | **Suspended Sediment**  **Correction** | To be determined. | To be determined. |  |  |  |  |
| **3.15** | **Bidirectional Reflectance Distribution Function Correction** | Not required. | Data is corrected for BRDF effects. |  |  |  |  |
|  |  |  |  |  |  |  |  |

## Geometric Corrections

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

| **#** | **Item** | **Threshold (Minimum)**  **Requirements** | **Target (Desired) Requirements** | **Threshold Self-Assessment** | **Target Self-Assessment** | **Self-Assessment Explanation/ Justification** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **4.1** | **Geometric Correction** | Sub-pixel accuracy is achieved in relative geolocation, that is, the pixels from the same instrument and platform are consistently located, and in 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.* | 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

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| --- | --- | --- |
|  | **Threshold** | **Target** |
| **1. General Metadata** |  |  |
| 1.1 Traceability |  |  |
| 1.2 Metadata Machine Readability |  |  |
| 1.3 Data Collection Time |  |  |
| 1.4 Geographical Area |  |  |
| 1.5 Coordinate Reference System |  |  |
| 1.6 Map Projection |  |  |
| 1.7 Geometric Correction Methods |  |  |
| 1.8 Geometric Accuracy of the Data |  |  |
| 1.9 Instrument |  |  |
| 1.10 Spectral Bands |  |  |
| 1.11 Sensor Calibration |  |  |
| 1.12 Radiometric Accuracy |  |  |
| 1.13 Algorithms |  |  |
| 1.14 Auxiliary Data |  |  |
| 1.15 Processing Chain Provenance |  |  |
| 1.16 Data Access |  |  |
| 1.17 Overall Data Quality |  |  |
|  |  |  |
| **2. Per-Pixel Metadata** |  |  |
| 2.1 Metadata Machine Readability |  |  |
| 2.2 No Data |  |  |
| 2.3 Incomplete Testing |  |  |
| 2.4 Saturation |  |  |
| 2.5 Cloud |  |  |
| 2.6 Cloud Shadow |  |  |
| 2.7 Land/Water Mask |  |  |
| 2.8 Sea Ice Mask |  |  |
| 2.9 Sun Glint Mask |  |  |
| 2.10 Sky Glint Mask |  |  |
| 2.11 Whitecap/Foam Mask |  |  |
| 2.12 Solar and Viewing Geometry |  |  |
| 2.13 Atmospheric Adjacency Spectral Correction |  |  |
| 2.14 Surface Reflected Vegetation Spectral Correction |  |  |
| 2.15 Aerosol Optical Depth Parameters |  |  |
| 2.16 Sun and Observation Geometry |  |  |
| 2.17 Coastline Mask |  |  |
| 2.18 Floating Vegetation/Surface Scum |  |  |
| 2.19 Suspended Sediment |  |  |
| 2.20 Bidirectional Reflectance Distribution Function |  |  |
|  |  |  |
| **3. Radiometric and Atmospheric Corrections** |  |  |
| 3.1 Measurement |  |  |
| 3.2 Measurement Uncertainty |  |  |
| 3.3 Measurement Normalisation |  |  |
| 3.4 Directional Atmospheric Scattering |  |  |
| 3.5 Water Vapour Corrections |  |  |
| 3.6 Ozone Corrections |  |  |
| 3.7 Other Trace Gaseous Absorption Corrections |  |  |
| 3.8 Sun Glint Correction |  |  |
| 3.9 Sky Glint Correction |  |  |
| 3.10 Whitecap and Foam Correction |  |  |
| 3.11 Atmospheric Adjacency Spectral Correction |  |  |
| 3.12 Surface Reflected Vegetation Spectral Correction |  |  |
| 3.12 Floating Vegetation/ Surface Scum |  |  |
| 3.13 Suspended Sediment |  |  |
| 3.14 Bidirectional Reflectance Distribution Function |  |  |
|  |  |  |
| **4. Geometric Corrections** |  |  |
| 4.1 Geometric Correction |  |  |

# Guidance

This section aims to provide background and specific information on the processing steps that can be used to achieve analysis ready data. This Guidance material does not replace or over-ride the specifications.

# Introduction to CARD4L

**What is CEOS Analysis Ready Data for Land (CARD4L) products?**

CARD4L products 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. 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.

CARD4L 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 CARD4L?**

The CARD4L branding is applied to a particular product once:

* that product has been assessed as meeting CARD4L requirements by the agency responsible for production and distribution of the product, and
* that assessment has been peer reviewed by the CEOS Land Surface Imaging Virtual Constellation in consultation with other CEOS working groups as appropriate, including the CEOS Working Group on Calibration and Validation.

Agencies or other entities considering undertaking an assessment process should contact the [Land Surface Imaging Virtual Constellation](http://ceos.org/ourwork/virtual-constellations/lsi/).

A product can continue to use CARD4L branding as long as its generation and distribution remain consistent with the peer-reviewed assessment.

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

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

Products that meet target 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.

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

# Procedural Examples

**Processes to produce Threshold Aquatic Reflectance CARD4L:**

The following correction processes would typically be applied to produce CARD4L-AR Threshold:

* *No example processes are provided at this time.*

The following additional processes could be applied to produce CARD4L-AR Target:

* *No example processes are provided at this time.*

# Specific Examples

**Processes to produce Threshold Aquatic Reflectance CARD4L.**

* *No example processes are provided at this time.*

# Reference Papers

The following papers provide scientific and technical guidance:

Feldman, G. “Level 2 Ocean Color Flags.” NASA Ocean Color Web, Ocean Biology Processing Group, Accessed <https://oceancolor.gsfc.nasa.gov/atbd/ocl2flags/>

Gao, Bo-Cai & Montes, Marcos & Davis, Curtiss & Goetz, Alexander. (2009). Atmospheric correction algorithms for hyperspectral remote sensing data of land and ocean. Remote Sensing of Environment. 113. 10.1016/j.rse.2007.12.015.

Hochberg, E.J., Bruce, C.F., Green, R.O., Oaida, B.V., Muller-Karger, F.E., Mobley, C.D., Park, Y., Goodman, J., Knox, R.G., Middleton, E.M., Turpie, K.R., Ungar, S.G., Minnett, P.J., Gentemann, C., Zimmerman, R.C., Turner, W., and Gao, B.-C., 2011, HyspIRI sun glint report: National Aeronautics and Space Administration JPL Publication 11–4, 73 p., at https://hyspiri.jpl.nasa.gov/document