Committee on Earth Observation Satellites	**Analysis Ready Data *For Land***	**Product Family Specification Surface Reflectance (CARD4L-SR)**

Document Status

Product Family Specification, Surface 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

Document History

Version	Date	Description of Change	Author
0.0.2	01.03.2017	Zero Draft translating previous materials to this format. With many thanks to all CEOS contributors.	Ross
1.0.0	16.04.2017	Included document history; added numbering and pagination to improve navigability and internal referencing of sections; Added Guidance Section: - various minor edits - revised 1.4 'target' - 1.7, 1.8, 1.9 may need revisiting - Added 3.1, measurement - Added 3.2, uncertainty - Added 2.10, terrain occlusion	Lewis
2.0.0	30.08.2017	Feedback incorporated, circulated to LSI-VC	Lewis
2.1.0	06.09.2017	Feedback from ESA incorporated and comments noted on 1.11, 1.12, 1.8; 1.15; 1.17; 3.6-3.8; 4.1.	Lewis
2.1.1	06.09.2017	Tracked changes rolled in.	Lewis
2.1.2	11.11.2017	Edits.	Lewis
3.0	22.01.2018	Feedback during and after (emails) the teleconference (06/12/2018) included.	Siqueira
3.1	31.01.2019	Proposed final SR PFS draft shared with USGS, ESA, and GA self-assessment leads seeking further comments. The draft addressed the feedback provided by the agencies' ARD data self-assessment process.	Siqueira
3.1.1	06.02.2019	Final draft shared with LSI-VC list and LSI-VC-7 meeting participants seeking support for document endorsement at the LSI-VC-7.	Siqueira
3.1.1	22.02.2019	Comments and suggestions from LSI-VC-7 meeting (minutes) and feedback from USGS incorporated.	Siqueira

3.1.2	28.02.2019	Formatting and verbiage updated for consistency.	Metzger
4.0	02.03.2019	Version endorsed at LSI-VC7 meeting (14Feb 2019)	LSI-VC
4.1	26.06.2019	Added self-assessment columns	Bontje
4.2	08.05.2020	This review cycle considers feedback received from USGS and ESA after the formal self-assessment for Surface Reflectance products (Landsat and Sentinel-2). Minor editorial changes were done throughout the document. Requirements *1.2, 1.3, 1.7, 1.12, 1.13, 1.14, 1.16, 2.1, 2.11, 2.12, 2.13 and 3.3* have been updated.	Siqueira
4.3	25.05.2020	Feedback from USGS added (email: 21/05/2020).	Siqueira
5.0	08.06.2020	Tech edit.	Bontje, Labahn

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Darcie Bontje, USGS, USA
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Description

Product Family Title: **Surface Reflectance (CARD4L-SR)**
Applies to: Data collected with multispectral sensors operating in the VIS/NIR/SWIR 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.

Definitions

SR	Surface 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	Recommended Requirement Modification
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.*	Yes	//	Not Required.	
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 should be provided in a community endorsed standard that facilitates machine-readability, such as ISO 19115-2.	Yes	//	The metadata within a Sentinel-2 Level-2A product is contained in the root XML (eXtensible Markup Language) file within the product, which enables its use through computer algorithm. The Copernicus Open Access Hub [https://scihub.copernicus.eu/] enables any client to search for Sentinel-2 data, also by specifying the requested values/characteristics in the product metadata.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
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.	Yes	//	The acquisition date and time, to the second, at the center of the scene are provided in Sentinel-2 Level-2A tile metadata. Start and stop time of data collection can be easily determined by using the information provided in the product metadata. Example: <SENSING_TIME metadataLevel="Standard">2017-08-28T08:54:34.369Z</SENSING_TIME>	
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.	Yes	//	The latitude and longitude of the corner points are provided in the Sentinel-2 Level-2A product metadata, in the projection system UTM. This information can be used to easily retrieve the surface location related to the remaining pixels. Example: <n1:Geometric_Info> <Product_Footprint> <Product_Footprint> <Global_Footprint> <EXT_POS_LIST>37.925590547672954 29.27507346075699 37.89483865903757	

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						30.52255091504655 36.90697181308603 30.47655434426329 36.93665039764339 29.245323289646365 37.925590547672954 29.27507346075699 </EXT_POS_LIST> </Global_Footprint> </Product_Footprint>	
1.5	**Coordinate Reference System**	The metadata lists the coordinate reference system that has been used.	As threshold.	Yes	//	The coordinate reference system is specified under the projection attributes section, both in the Sentinel-2 Level-2A product and tile metadata. Example: <Coordinate_Reference_System> <GEO_TABLES version="1">**EPSG**</GEO_TABLES> <HORIZONTAL_CS_TYPE>GEOGRAPHIC</HORIZONTAL_CS_TYPE> </Coordinate_Reference_System> <Tile_Geocoding metadataLevel="Brief"> <HORIZONTAL_CS_NAME>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						WGS84 / UTM zone 35N</HORIZONTAL_CS_NAME>	
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.	Yes	//	The map projection parameters are provided in the Sentinel-2 Level-2A tile metadata. Example: <Tile_Geocoding metadataLevel="Brief"> <HORIZONTAL_CS_NAME>WGS84 / **UTM zone 35N**</HORIZONTAL_CS_NAME>	
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.	Yes	//	The single DOI landing page, provided in the Level-2A metadata, can be used to determine the geometric correction methods applied. This information is present in the Level-2A Dataset Specification section of the landing page.	
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,	Yes	//	The single DOI landing page in the Sentinel-2 Level-2A metadata provides information on the geometric accuracy assessment by pointing at the Sentinel-2 Data Quality Report webpage.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			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.	Yes	//	The instrument used to collect Sentinel-2 data (i.e. MSI) is specified in the Sentinel-2 Level-2A product metadata. Example: <SPACECRAFT_NAME>Sentinel-2A</SPACECRAFT_NAME> <PRODUCT_TYPE>S2**MSI**2A</PRODUCT_TYPE> There is reference to the to the CEOS MIM on the single DOI landing page.	
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	Yes	//	The central wavelength for each band, for which data is included, is identified in the Sentinel-2 product metadata, expressed in SI units. The full spectral response (i.e. minimum, maximum and intermediate wavelength	

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			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.*			values within the band) is also reported in the metadata. Moreover, it is scheduled to add a single DOI landing page in the Sentinel-2 Level-2A metadata so that the Sentinel-2 Spectral Response Function can be easily retrieved. Example: <Spectral_Information_ List> <Spectral_Information bandId="0" physicalBand="B1"> <RESOLUTION>60</R ESOLUTION> <Wavelength> <MIN unit="nm">430</MIN> <MAX unit="nm">457</MAX> <CENTRAL unit="nm">443.9</CEN TRAL> </Wavelength> <Spectral_Response> <STEP unit="nm">1</STEP> <VALUES>0.01522444 0.06669758 0.19425897 0.35395736 0.45648857	

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						0.50759455 0.54750739 0.58419244 0.61012868 0.64603585 0.69458246 0.74037505 0.78703023 0.85862712 0.94458791 0.9928916 1 0.99055275 0.97282606 0.95596914 0.95429069 0.91888272 0.72055356 0.38639386 0.14531035 0.05161255 0.01738704 0.00029585</VALUES> </Spectral_Response> The single DOI landing page in the Sentinel-2 Level-2A metadata provides information on the Sentinel-2 Spectral Response Function (S2-SRF).	
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.*	Yes	//	Not Required.	
1.12	**Radiometric Accuracy**	Not required. The general metadata does not include information on the	The metadata includes metrics describing the assessed absolute	Yes	//	The single DOI landing page in the Sentinel-2 Level-2A metadata provides information on	

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		radiometric accuracy of the data.	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.*			the radiometric accuracy assessment by pointing at the Sentinel-2 Data Quality Report webpage.	
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.*	Yes	//	The single DOI landing page in the Sentinel-2 Level-2A metadata provide direct access to the all algorithms and citable papers. This information is present in the Level-2A Dataset Specification section of the landing page.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
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: Auxiliary data includes DEMs, aerosols, 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.	Yes	//	Sentinel-2 Level-2A tile metadata embeds information on all auxiliary files including the ESA CCI and Global Snow Map used, etc. Example: <ESACCI_WaterBodies_Map>ESACCI-LC-L4-WB-Map-150m-P13Y-2000-v4.0.tif</ESACCI_WaterBodies_Map> <ESACCI_LandCover_Map>ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.0.7.tif</ESACCI_LandCover_Map> <ESACCI_SnowCondition_Map_Dir>ESACCI-LC-L4-Snow-Cond-500m-P13Y7D-2000-2012-v2.0</ESACCI_SnowCondition_Map_Dir> The information about the digital elevation model, auxiliary files, etc. are provided in the metadata and can be found using the DOI link.	

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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.	Yes	//	The single DOI landing page in the Sentinel-2 Level-2A metadata provide direct access to the all algorithms and citable papers. This information is present in the Level-2A Dataset Specification section of the landing page.	
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.	Yes	//	Sentinel-2 Level-2A User Product metadata embeds the single DOI landing Page Example: <PRODUCT_DOI>https://doi.org/10.5270/S2_-znk9xsj</PRODUCT_DOI> The Copernicus Open Access Hub URLs is provided on the DOI landing page and within "How to access this data" section.	
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	Yes	//	Overall data quality of Sentinel-2 Level-2A products is provided in the metadata. The information on data quality and percentage of scene covered by clouds is included and is machine readable through XML parsing.	

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			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	Recommended Requirement Modification
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.	Yes	//	The metadata within a Sentinel-2 Level-2A product is contained in the root XML (eXtensible Markup Language) file within the product, which enables its use through computer algorithm. The Copernicus Open Access Hub [https://scihub.copernicus.eu/] enables any client to search for Sentinel-2 data, also by specifying the requested values/characteristics in the product metadata.	
2.2	**No Data**	Pixels that do not correspond to an observation ('empty pixels') are flagged.	As threshold.	Yes	//	Quality information about pixels is provided at Tile level through dedicated quality masks embedded into the Sentinel-2 Level-2A products. A "NoData pixels" mask is included, indicating the position of pixels with no data.	
2.3	**Incomplete Testing**	The metadata identifies pixels for which the per-pixel tests (below) have not all been successfully completed.	The metadata identifies which tests have, and have not, been successfully completed for each pixel.	Yes	//	Not applicable to Sentinel-2 data. The test algorithm always provides a value and assign pixels to one of the following classes:	

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		Note 1: This may be the result of missing ancillary data for a subset of the pixels.				dark feature, cloud shadow, vegetation, water, cloud low/medium/high probability, thin cirrus, snow, cast shadows, desert, no data, saturated or defective, unclassified.	
2.4	**Saturation**	Metadata indicates where one or more spectral bands are saturated.	Metadata indicates which pixels are saturated for each spectral band.	Yes	//	Quality information about pixels is provided at Tile level through dedicated quality masks embedded into the Sentinel-2 Level-2A products. A "Saturated pixels" mask is included, indicating the position of saturated pixels.	
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.	Yes	//	Quality information about pixels is provided at Tile level through dedicated quality masks embedded into the Sentinel-2 Level-2A products. A "Cloud Low Probability" mask, a "Cloud Medium Probability" mask, and a "Cloud High Probability" mask are included, indicating the position of cloudy pixels with low, medium and high probability, respectively. These masks are also displayed as a jp2000 image.	

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						The Products and Algorithms guides quoted in the Level-2A Dataset Specification section within the DOI landing page provide information on quality Indicators, including the cloud probabilities.	
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.	Yes	//	Quality information about pixels is provided at Tile level through dedicated quality masks embedded into the Sentinel-2 Level-2A products. A "Cloud shadow pixels" mask is included, indicating the position of cloud shadow pixels. The mask is also displayed as a jp2000 image. The Products and Algorithms guides quoted in the Level-2A Dataset Specification section within the DOI landing page provide information on the cloud shadow detection algorithm.	
2.7	**Land/Water Mask**	Not required.	The metadata indicates whether a pixel is assessed as being land or water.	Yes	//	Even if not required for "CARD4L Threshold compliancy", information on whether a	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			Information on land/water mask should be available in the metadata as a single DOI landing page.			pixel is assessed as being land or water is provided in Sentinel-2 Level-2A products. Quality information about pixels is provided at Tile level through dedicated quality masks embedded into the Sentinel-2 Level-2A products. A "Land pixels" mask and a "Water pixels" mask are included, indicating the position of pixels assessed as being land and water, respectively. The mask is also displayed as a jp2000 image. The Products and Algorithms guides quoted in the Level-2A Dataset Specification section within the DOI landing page provide information on the quality indicators, including Land/Water percentages.	
2.8	**Snow/Ice Mask**	Not required.	The metadata indicates whether a pixel is assessed as being snow/ice or not. Information on snow/ice mask should be available in	Yes	//	Even if not required for "CARD4L Threshold compliancy", information on whether a pixel is assessed as being snow is provided in	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			the metadata as a single DOI landing page.			Sentinel-2 Level-2A products. Quality information about pixels is provided at Tile level through dedicated quality masks embedded into the Sentinel-2 Level-2A products. A "Snow pixels" mask is included, indicating the position of pixels assessed as being snow. The mask is also displayed as a jp2000 image. The Products and Algorithms guides quoted in the Level-2A Dataset Specification section within the DOI landing page provide information on quality Indicators, including snow probabilities.	
2.9	**Terrain Shadow Mask**	Not required.	The metadata indicates pixels that are not directly illuminated due to terrain shadowing.	Yes	//	Even if not required for "CARD4L Threshold compliancy", information on whether a pixel is assessed as being "terrain shadow" is provided in Sentinel-2 Level-2A products. Quality information about pixels is provided at Tile level through	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						dedicated quality masks embedded into the Sentinel-2 Level-2A products. A "Terrain Shadow" mask is included, indicating the position of pixels assessed as not directly illuminated due to terrain shadowing. The mask is also displayed as a jp2000 image. The Products and Algorithms guides quoted in the Level-2A Dataset Specification section within the DOI landing page provide information on the Terrain Shadow detection algorithm.	
2.10	**Terrain Occlusion**	Not required.	The metadata indicates pixels that are not visible to the sensor due to terrain occlusion during off-nadir viewing.	Yes	//	Not Required.	
2.11	**Solar and Viewing Geometry**	Provide average solar and sensor viewing azimuth and zenith angles.	Provide per-pixel solar and sensor viewing azimuth and zenith angles.	Yes	//	The average illumination/viewing geometry is provided through dedicated masks embedded into the Sentinel-2 Level-2A products.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
2.12	**Terrain Illumination Correction**	Not required.	Coefficients used for terrain illumination correction are provided for each pixel.	Yes	//	The Sentinel-2 L2A products contain the surface reflectance adjusted from incident solar illumination and adjacency	
2.13	**Aerosol Optical Depth Parameters**	Not required.	To be determined.	Yes	//	Even if not required for "CARD4L Threshold compliancy", information on the computed aerosol optical depth is provided in Sentinel-2 Level-2A products	

Radiometric and Atmospheric Corrections

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

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
3.1	**Measurement**	Pixel values that are expressed as a measurement of the Surface Reflectance of the land. This is a dimensionless value.	Surface Reflectance measurements are SI traceable (see also 1.1).	Yes	//	Sentinel-2 Level-2A pixel values are expressed as a measurement of the Surface Reflectance and this is a dimensionless value.	
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 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.*	Yes	//	Not Required.	
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.	Yes	//	Not Required.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			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.	Yes	//	Corrections for aerosols and molecular (Rayleigh) scattering are applied to Sentinel-2 Level-2A data. The Level-2A processing includes an atmospheric correction applied to Top-Of-Atmosphere (TOA) Level-1C orthoimage products. One of the Level-2 output is an Aerosol Optical Thickness (AOT) map, The single DOI landing page provides direct access to the atmospheric correction algorithms and citable papers. This information is present in the Level-2A Dataset Specification section of the landing page.	
3.5	**Water Vapour Corrections**	Corrections are applied for water vapour.	As threshold.	Yes	//	Corrections for water vapour are applied to Sentinel-2 Level-2A data.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
		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.*				The single DOI landing page provides information about atmospheric correction of water vapour. This information is present in the Level-2A Dataset Specification section of the landing page.	
3.6	**Ozone Corrections**	Not 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	Yes	//	The single DOI landing page provides direct access to the atmospheric correction algorithms details and citable papers The ozone source and the ozone value are provided in the Sentinel-2 Level-2A product metadata Examples: <OZONE_SOURCE>AUX_ECMWFT</OZONE_SOURCE> <OZONE_VALUE>261.249328</OZONE_VALUE>	

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	Recommended Requirement Modification
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.	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.*	Yes	//	The Geometric Correction requirements is fully met by the Sentinel-2 Level-2A data with the introduction of the Global Reference Image (GRI). This GRI is made of Sentinel-2 mono-spectral images whose geometrical model has been refined and it ensures a multi-temporal registration performance within 0.5 pixel. A consistent gridding/sampling frame is already used in the Sentinel-2 Level-2A products.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
		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.*					

Summary Self-Assessment Table

	Threshold	Target
1. General Metadata		
1.1 Traceability	Yes	
1.2 Metadata Machine Readability	Yes	
1.3 Data Collection Time	Yes	
1.4 Geographical Area	Yes	
1.5 Coordinate Reference System	Yes	
1.6 Map Projection	Yes	
1.7 Geometric Correction Methods	Yes	
1.8 Geometric Accuracy of the Data	Yes	
1.9 Instrument	Yes	
1.10 Spectral Bands	Yes	
1.11 Sensor Calibration	Yes	
1.12 Radiometric Accuracy	Yes	
1.13 Algorithms	Yes	
1.14 Auxiliary Data	Yes	
1.15 Processing Chain Provenance	Yes	
1.16 Data Access	Yes	
1.17 Overall Data Quality	Yes	
2. Per-Pixel Metadata		
2.1 Metadata Machine Readability	Yes	
2.2 No Data	Yes	
2.3 Incomplete Testing	Yes	
2.4 Saturation	Yes	
2.5 Cloud	Yes	
2.6 Cloud Shadow	Yes	
2.7 Land/Water Mask	Yes	
2.8 Snow/Ice Mask	Yes	
2.9 Terrain Shadow Mask	Yes	
2.10 Terrain Occlusion	Yes	
2.11 Solar and Viewing Geometry	Yes	
2.12 Terrain Illumination Correction	Yes	
2.13 Aerosol Optical Depth Parameters	Yes	
3. Radiometric and Atmospheric Corrections		
3.1 Measurement	Yes	
3.2 Measurement Uncertainty	Yes	
3.3 Measurement Normalisation	Yes	
3.4 Directional Atmospheric Scattering	Yes	
3.5 Water Vapour Corrections	Yes	
3.6 Ozone Corrections	Yes	

4. Geometric Corrections		
4.1 Geometric Correction	Yes	

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.
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 Surface Reflectance CARD4L:
The following correction processes would typically be applied to produce CARD4L-SR Threshold:

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

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

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

Specific Examples

Processes to produce Threshold Optical Surface Reflectance CARD4L:

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

Reference Papers

The following paper provides scientific and technical guidance:

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.