



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: <ul style="list-style-type: none"> - 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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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. <i>Note 1: Relationship to 3.2. Traceability requires an estimate of measurement uncertainty.</i> <i>Note 2: Information on traceability should be available in the metadata as a single DOI landing page.</i>	Not required.	No	Currently, no measurement of uncertainty is provided, but it is under consideration for a future Collection. However, the Principal Investigator (PI) does provide reference to a dataset that can be used to determine the accuracy, precision, and uncertainty (APU) of the Landsat surface reflectance product. The link to the PI's publication is available through the Level-2 U.S. Albers Equal Area DOI landing page. Example: <DIGITAL_OBJECT_IDENTIFIER> https://doi.org/10.5066/P9HDSXAC	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						</DIGITAL_OBJECT_ID ENTIFIER>	
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	No	The XML metadata file is machine readable. For instance, the lxml package in Python can be used to parse the XML metadata file. In addition to the XML metadata file, STAC catalog enables any client to search/crawl Landsat data.	
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	Yes	The acquisition date and the scene center time for all contributing scenes are provided. The per-pixel acquisition time is not provided but can be reliably determined from the information provided. Example: <DATE_ACQUIRED>2013-05-03</DATE_ACQUIRED> <SCENE_CENTER_TIME>04:43:58.0429310Z	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
						<p></SCENE_CENTER_TIME></p> <p><i>Note: Collection time for each pixel can be calculated from <SCENE_CENTER_TIME></i></p> <p><i>Note: Collection time for pixels in overlapping area should be attained from the northern scene.</i></p>	
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	Yes	<p>The latitude and longitude of the corner points are provided. Also, the coordinates of the corner points in the projection system (e.g., Albers Equal Area) are provided, which can be used to determine the location of pixels.</p> <p>Example:</p> <p><CORNER_UL_LAT_PRODUCT>34.65555</CORNER_UL_LAT_PRODUCT></p>	

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						<CORNER_UL_LON_PRODUCT>- 119.40918</CORNER_UL_LON_PRODUCT> <CORNER_LR_LAT_PRODUCT>33.03652</CORNER_LR_LAT_PRODUCT> <CORNER_LR_LON_PRODUCT>- 117.44010</CORNER_LR_LON_PRODUCT>	
1.5	Coordinate Reference System	The metadata lists the coordinate reference system that has been used.	As threshold.	Yes	Yes	The coordinate reference system is defined under the projection attributes section of the U.S. ARD tile metadata. Example: <MAP_PROJECTION>AEA</MAP_PROJECTION> <DATUM>WGS84</DATUM>	
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	Yes	The map projection parameters are provided. Example:	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
						<pre> <MAP_PROJECTION>A EA</MAP_PROJECTIO N> <DATUM>WGS84</D ATUM> <ORIGIN_LAT>23.000 000</ORIGIN_LAT> <CENTRAL_MERIDIAN _LON>- 96.000000</CENTRAL _MERIDIAN_LON> <STANDARD_PARALLE L_1_LAT>29.500000</ STANDARD_PARALLEL _1_LAT> <STANDARD_PARALLE L_2_LAT>45.500000</ STANDARD_PARALLEL _2_LAT> <FALSE_EASTING>0.00 0000</FALSE_EASTIN G> <FALSE_NORTHING>0. 000000</FALSE_NORT HING> <GRID_CELL_SIZE_REF LECTIVE>30.00</GRID _CELL_SIZE_REFLECTI VE> <GRID_CELL_SIZE_THE RMAL>30.00</GRID_C ELL_SIZE_THERMAL> <GRID_CELL_SIZE_UNI TS>METERS</GRID_CE LL_SIZE_UNITS> </pre>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
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.	Not required.	Yes	<p>The version, model, and number of GCPs used for processing of all input scenes along with the source of elevation data are provided in the metadata.</p> <p>Example:</p> <pre><GROUND_CONTROL_POINTS_VERSION>5</GROUND_CONTROL_POINTS_VERSION> <GROUND_CONTROL_POINTS_MODEL>860</GROUND_CONTROL_POINTS_MODEL></pre> <p>A single Level-1 U.S. Albers Equal Area product DOI landing page is provided in the Level-2 metadata, which can be used to determine the geometric correction methods applied.</p> <p>Example:</p> <pre><DIGITAL_OBJECT_IDENTIFIER>https://doi.org/10.5066/P99C5E7F<</pre>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						/DIGITAL_OBJECT_IDE NTIFIER>	
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. <i>Note 1: Information on geometric accuracy of the data should be available in the metadata as a single DOI landing page.</i>	Not required.	No	The metadata provides the RMSE of the geometric correction for all input scenes. The RMSE_VERIFY parameter provides an independent assessment of the geometric accuracy. Examples: <GEOMETRIC_RMSE_MODEL>4.503</GEOMETRIC_RMSE_MODEL> <GEOMETRIC_RMSE_MODEL_Y>3.397</GEOMETRIC_RMSE_MODEL_Y> <GEOMETRIC_RMSE_MODEL_X>2.956</GEOMETRIC_RMSE_MODEL_X> <i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
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	Yes	<p>There is reference to the instrument used to collect the data in the metadata and to the CEOS MIM on the DOI landing page.</p> <p>Example:</p> <pre><SPACECRAFT_ID>LANDSAT_8</SPACECRAFT_ID> <SENSOR_ID>OLI_TIRS</SENSOR_ID></pre> <p><i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i></p>	
1.10	Spectral Bands	The central wavelength for each band for which data is included is identified in the metadata, expressed in SI units.	<p>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.</p> <p><i>Note 1: Information on spectral bands should be available in the metadata as a single DOI landing page.</i></p>	Yes	Yes	<p>The central wavelength information is not provided in the metadata but is accessible using the DOI landing page.</p> <p>The Landsat Spectral Characteristics Viewer link is provided on the DOI landing pages.</p> <p><i>Note: See Item 1.1 for complete Landsat</i></p>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
						<i>instrument DOI listings.</i>	
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. <i>Note 1: Information on sensor calibration should be available in the metadata as a single DOI landing page.</i>	Not required.	Yes	CPFs are provided. Example: <FILE_NAME_CPF>LC08CPF_20211101_20211231_02.02</FILE_NAME_CPF>	
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.) <i>Note 1: Information on radiometric accuracy should be available in the metadata as a single DOI landing page.</i>	Not required.	Yes	Information about the radiometric accuracy can be found using the DOI landing page link. <i>Note: See Item 1.7 for complete Landsat instrument DOI listings.</i>	
1.13	Algorithms	All algorithms, and the sequence in which they were applied in the	As threshold, but only algorithms that have been	Yes	Yes	Level 2 scene-based Albers product DOI landing pages provide	

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		<p>generation process, are identified in the metadata. For example, these may be available through Algorithm Theoretical Basis documents.</p> <p><i>Note 1: Information on algorithms should be available in the metadata as a single DOI landing page.</i></p>	<p>published in a peer-reviewed journal.</p> <p><i>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.</i></p> <p><i>Note 2: Information on algorithms should be available in the metadata as a single DOI landing page.</i></p>			<p>direct access to the atmospheric correction algorithms and citable papers.</p> <p>Example:</p> <pre><ALGORITHM_SOURCE_SURFACE_REFLECTANCE>LaSRC_1.5.0</ALGORITHM_SOURCE_SURFACE_REFLECTANCE></pre> <p><i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i></p>	
1.14	Auxiliary Data	<p>The metadata identifies the sources of auxiliary data used in the generation process, ideally expressed as a single DOI landing page.</p> <p><i>Note 1: Auxiliary data includes DEMs, aerosols, etc. data sources.</i></p>	<p>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.</p>	Yes	Yes	<p>The information about the elevation model, reanalysis grid, etc. are provided in the metadata, can be found using the DOI link, and can be downloaded from the provider's webpage.</p> <p>Examples:</p> <pre><DATA_SOURCE_OZONE>MODIS</DATA_SOURCE_OZONE></pre>	

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						<p><DATA_SOURCE_WATER_VAPOR>MODIS</DATA_SOURCE_WATER_VAPOR></p> <p><DATA_SOURCE_PRESSURE>Calculated</DATA_SOURCE_PRESSURE></p> <p><DATA_SOURCE_AIR_TEMPERATURE>MODIS</DATA_SOURCE_AIR_TEMPERATURE></p> <p><DATA_SOURCE_ELEVATION>GLS2000</DATA_SOURCE_ELEVATION></p> <p><i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i></p>	
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,	Not required.	Yes	<p>The processing software version is provided in the metadata.</p> <p>Level 2 product DOI landing pages provide direct access to documentation and citable papers.</p>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
			giving full transparency to the users.			<p>Example:</p> <p><PROCESSING_SOFTWARE_VERSION>ARD TILING CODE VERSION 2.0.1</PROCESSING_SOFTWARE_VERSION></p> <p><PROCESSING_SOFTWARE_VERSION>LPGS_15.5.0</PROCESSING_SOFTWARE_VERSION></p> <p><i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i></p>	
1.16	Data Access	<p>Information on data access should be available in the metadata as a single DOI landing page.</p> <p><i>Note 1: Manual and offline interaction action (e.g., login) may be required.</i></p>	As threshold.	Yes	Yes	<p>The metadata includes a single U.S. ARD DOI landing page.</p> <p>https://doi.org/10.5066/P960F8OC</p>	
1.17	Overall Data Quality	Not applicable.	<p>Machine-readable metrics describing the overall quality of the data are included in the metadata, at minimum the cloud cover extent, i.e.:</p> <ul style="list-style-type: none"> Proportion of observations over land (c.f. ocean) affected by non-target 	Not required.	Yes	<p>The information on the composite image quality of the sensor, percentage of scene cloud cover, land cloud cover, etc. are provided, which are machine readable through XML parsing.</p>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
			phenomena, e.g., cloud and cloud shadows			Example: <CLOUD_COVER>13.82</CLOUD_COVER> <CLOUD_COVER_LAND>13.82</CLOUD_COVER_LAND> <IMAGE_QUALITY_OLI>9</IMAGE_QUALITY_OLI>	

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	Yes	Metadata is machine readable through the per-pixel QA bands associated with the data.	
2.2	No Data	Pixels that do not correspond to an observation ('empty pixels') are flagged.	As threshold.	Yes	Yes	NoData pixels have a value of 1 in the QA_PIXEL band.	
2.3	Incomplete Testing	The metadata identifies pixels for which the per-pixel tests (below) have not all been successfully completed. <i>Note 1: This may be the result of missing ancillary data for a subset of the pixels.</i>	The metadata identifies which tests have, and have not, been successfully completed for each pixel.	Yes	Yes	Not applicable to Landsat data products. Algorithm will always provide a value. In addition, cloud, cloud shadow, snow/ice and cirrus confidence information are provided.	
2.4	Saturation	Metadata indicates where one or more spectral bands are saturated.	Metadata indicates which pixels are saturated for each spectral band.	Yes	Yes	QA_RADSAT band provide per pixel information about saturation of each band.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						<i>Note: TIRS bands 10 and 11 are not tested for saturation because they do not saturate.</i>	
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	Yes	QA_PIXEL band bit 3 indicates whether a pixel is assessed as cloud. Cloud confidence are provided in QA_PIXEL band bits 8 and 9. The product guides within the DOI landing page provide information on the cloud detection algorithm. <i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i>	
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	Yes	QA_PIXEL band bit 4 indicates cloud shadow. Cloud shadow confidence are provided in QA_PIXEL band bits 10 and 11. The product guides within the DOI landing pages provide information on the cloud shadow detection algorithm.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
						<i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i>	
2.7	Land/Water Mask	Not required.	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.	Not required.	Yes	QA_PIXEL band bit 7 indicates whether a pixel is water or non-water. The non-water pixel can be land, cloud, cirrus, snow, etc. <i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i>	
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 the metadata as a single DOI landing page.	Not required.	Yes	QA_PIXEL band bit 5 indicates snow. Snow/Ice confidence are provided in QA_PIXEL band bits 12 and 13. <i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i>	
2.9	Terrain Shadow Mask	Not required.	The metadata indicates pixels that are not directly illuminated due to terrain shadowing.	Not required.	No	Terrain shadow is not provided.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
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.	Not required.	Yes	QA_RADSAT band bit 11 indicates the terrain occlusion.	
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	No	<p>The average solar azimuth and zenith (elevation) angle values for all input scenes are provided in metadata.</p> <p>Example:</p> <pre><SUN_AZIMUTH>159.86953091</SUN_AZIMUTH> <SUN_ELEVATION>35.27372484</SUN_ELEVATION></pre> <p>The per-pixel solar and sensor viewing azimuth and zenith angles are included in Collection 2 U.S. ARD product package.</p>	
2.12	Terrain Illumination Correction	Not required.	Coefficients used for terrain illumination correction are provided for each pixel.	Not required.	No		
2.13	Aerosol Optical Depth Parameters	Not required.	To be determined.	Not required.	Yes		

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	No	Because traceability requires an estimate of uncertainty, Landsat Surface Reflectance is not currently traceable.	
3.2	Measurement Uncertainty	Not required. <i>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.</i>	An estimate of the certainty of the values is provided in measurement units. <i>Note 1: This is a requirement for SI traceability. See also 1.1.</i> <i>Note 2: Information on measurement uncertainty should be available in the metadata as a single DOI landing page.</i>	Not required.	No	Currently, no measurement of uncertainty is provided, but it is under consideration for a future Collection.	
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. <i>Note 1: Information on measurement normalisation should be available in the</i>	Not required.	Yes	Solar and sensor viewing angles are used in Level 2 correction. Example: <FILE_NAME_ANGLE_SENSOR_AZIMUTH_BAND_4>LC08_L1TP_140041_20130503_20190828_02_T1_VAA.TIF	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
			<i>metadata as single DOI landing page.</i>			<pre> </FILE_NAME_ANGLE_SENSOR_AZIMUTH_BAND_4><FILE_NAME_ANGLE_SENSOR_ZENITH_BAND_4>LC08_L1TP_140041_20130503_20190828_02_T1_VZA.TIF</FILE_NAME_ANGLE_SENSOR_ZENITH_BAND_4><FILE_NAME_ANGLE_SOLAR_AZIMUTH_BAND_4>LC08_L1TP_140041_20130503_20190828_02_T1_SAA.TIF</FILE_NAME_ANGLE_SOLAR_AZIMUTH_BAND_4><FILE_NAME_ANGLE_SOLAR_ZENITH_BAND_4>LC08_L1TP_140041_20130503_20190828_02_T1_SZA.TIF</FILE_NAME_ANGLE_SOLAR_ZENITH_BAND_4> </pre>	
3.4	Directional Atmospheric Scattering	<p>Corrections are applied for aerosols and molecular (Rayleigh) scattering.</p> <p>Metadata contains a single DOI landing page with references to:</p> <ul style="list-style-type: none"> a citable peer-reviewed algorithm 	As threshold.	Yes	Yes	<p>Corrections are applied in Level 2 processing.</p> <p>Level 2 DOI landing page provides direct access to the atmospheric correction algorithms and citable papers.</p>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
		<ul style="list-style-type: none"> technical documentation regarding the implementation of that algorithm the sources of ancillary data used to make corrections <p><i>Note 1: Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.</i></p>				<i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i>	
3.5	Water Vapour Corrections	<p>Corrections are applied for water vapour. Metadata contains a single DOI landing page with references to:</p> <ul style="list-style-type: none"> a citable peer-reviewed algorithm technical documentation regarding the implementation of that algorithm <p><i>Note 1: Examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.</i></p>	As threshold.	Yes	Yes	<p>Level 2 DOI landing pages link to information about atmospheric correction of water vapour.</p> <p><i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i></p>	
3.6	Ozone Corrections	Not required.	<p>Data is corrected for ozone.</p> <p>Relevant metadata must be provided under 1.8 and 1.9.</p>	Not required.	Yes	Level 2 DOI landing page provides direct access to the atmospheric correction algorithms	

#	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: <ul style="list-style-type: none"> • a citable peer-reviewed algorithm • technical documentation regarding the implementation of that algorithm 			details and citable papers <i>Note: See Item 1.1 for complete Landsat instrument DOI listings.</i>	

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	<p>Sub-pixel accuracy is achieved in <u>relative</u> geolocation, that is, the pixels from the same instrument and platform are consistently located, and in thus comparable, through time.</p> <p>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.</p> <p>A consistent gridding/sampling frame is used, including common cell size, origin, and nominal sample point location within the cell (centre, ll, ur).</p> <p>Relevant metadata must be provided under 1.8 and 1.9. <i>Note 1: The threshold level will not necessarily enable interoperability between data from <u>different</u> sources as the</i></p>	<p>Sub-pixel accuracy is achieved relative to an identified absolute independent terrestrial referencing system (such as a national map grid).</p> <p>A consistent gridding/sampling frame is necessary to meet this requirement.</p> <p>Relevant metadata must be provided under 1.8 and 1.9. <i>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.</i></p>	Yes	Yes	<p>0.5-pixel radial RMSE is met through use of only Tier 1 data and some Tier 2 data.</p> <p>Landsat C2 U.S. ARD is generated using a consistent gridding schema for each U.S. region. The Landsat Collection 2 U.S. ARD DOI landing page provides access to the gridding schema.</p> <p><DIGITAL_OBJECT_IDENTIFIER>https://doi.org/10.5066/P9HDSXAC</DIGITAL_OBJECT_IDENTIFIER></p>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/Justification	Recommended Requirement Modification
		<i>geometric corrections for each of the sources may differ.</i>					

Summary Self-Assessment Table

	Threshold	Target
1. General Metadata		
1.1 Traceability	Not required.	No
1.2 Metadata Machine Readability	Yes	No
1.3 Data Collection Time	Yes	Yes
1.4 Geographical Area	Yes	Yes
1.5 Coordinate Reference System	Yes	Yes
1.6 Map Projection	Yes	Yes
1.7 Geometric Correction Methods	Not required.	Yes
1.8 Geometric Accuracy of the Data	Not required.	No
1.9 Instrument	Yes	Yes
1.10 Spectral Bands	Yes	Yes
1.11 Sensor Calibration	Not required.	Yes
1.12 Radiometric Accuracy	Not required.	Yes
1.13 Algorithms	Yes	Yes
1.14 Auxiliary Data	Yes	Yes
1.15 Processing Chain Provenance	Not required.	Yes
1.16 Data Access	Yes	Yes
1.17 Overall Data Quality	Not required.	Yes
2. Per-Pixel Metadata		
2.1 Metadata Machine Readability	Yes	Yes
2.2 No Data	Yes	Yes
2.3 Incomplete Testing	Yes	Yes
2.4 Saturation	Yes	Yes
2.5 Cloud	Yes	Yes
2.6 Cloud Shadow	Yes	Yes
2.7 Land/Water Mask	Not required.	Yes
2.8 Snow/Ice Mask	Not required.	Yes
2.9 Terrain Shadow Mask	Not required.	No
2.10 Terrain Occlusion	Not required.	Yes
2.11 Solar and Viewing Geometry	Yes	No
2.12 Terrain Illumination Correction	Not required.	No
2.13 Aerosol Optical Depth Parameters	Not required.	Yes
3. Radiometric and Atmospheric Corrections		
3.1 Measurement	Yes	No
3.2 Measurement Uncertainty	Not required.	No
3.3 Measurement Normalisation	Not required.	Yes
3.4 Directional Atmospheric Scattering	Yes	Yes
3.5 Water Vapour Corrections	Yes	Yes
3.6 Ozone Corrections	Not required.	Yes
4. Geometric Corrections		
4.1 Geometric Correction	Yes	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., Lyburner, 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>.