Committee on Earth Observation Satellites	**Analysis Ready Data** ***For Land***	**Product Family Specification** **Surface Temperature**

Document Status

Product Family Specification, Surface Temperature

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	23.03.2017	Zero Draft based on materials provided by Geoscience Australia and the USGS in particular.	Ross
	16.04.2017	Included document history;	
1.0.0	18.04.2017	Revised to: - Formatting and structure - Included guidance section	Lewis
1.0.1	18.04.2017	Merged 'geometric source' and 'geometric method' elements.	Lewis
2.0	25.08.2017	Incorporated first round of revisions following feedback from the UK and others.	Lewis
2.1	06.09.2017	Feedback from ESA; removed reference to bands (1.10) as these are not relevant to ST; Feedback on 1.13 included to the effect that ST algorithm may not be supplied at Threshold level. Added qualifying notes to 2.7,2.8.	Lewis
3.0	05.12.2017	Feedback during the teleconference.	Lewis
3.1	22.12.2017	Feedback during and after (emails) the teleconference (05/12/2017) included.	Siqueira
3.2	01.08.2018	Outcome from LSI-VC-6 meeting addressed: *Surface Brightness Temperature (SBT) is not needed as a CARD4L product – there is no clear user base. The Surface Temperature (ST) PFS will be retained, with references to SBT removed in the next update cycle."* Therefore, ST became the minimum requirement (threshold) for CARD4L ST PFS.	Siqueira
3.3	21.01.2019	Feedback from ESA and USGS self-assessment included. Added Annex 1 containing examples (provided by USGS and ESA) on selected requirements.	Siqueira
3.3.1	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 meeting.	Siqueira

3.3.1	20.02.2019	Comments and suggestions from LSI-VC-7 meeting (minutes) and feedback from USGS incorporated.	Siqueira
3.3.2	28.02.2019	Formatting and verbiage updates 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	04.09.2019	Requirement 3.2 (Corrections for Atmosphere and Emissivity) rewording - agreed at LSI-VC8 meeting.	Siqueira
4.3	08.05.2020	This review cycle considers feedback received from USGS and ESA after the formal self-assessment for Surface Temperature products (Landsat and Sentinel-2). Minor editorial changes were done throughout the document. Requirements 1.2, 1.14, 1.16 and 2.1 have been updated.	Siqueira
4.4	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 Temperature (CARD4L-ST)**

Applies to: Data collected with multispectral sensors operating in the thermal infrared (TIR) wavelengths. These typically operate with ground sample distance and resolution in the order of 10-100m; however, the Specification is not inherently limited to this resolution.

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

Definitions

LST	Land Surface Temperature
ST	Surface Temperature
SBT	Surface Brightness Temperature
Ancillary Data	Ancillary data is 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	Auxiliary data is 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	Metadata is 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	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. Information on traceability should be available in the metadata as a single DOI landing page. Policy on measurement traceability: https://anab.qualtraxcloud.com/ShowDocument.aspx?ID=6536 Guidance on measurement traceability: https://anab.qualtraxcloud.com/ShowDocument.aspx?ID=6532 *Note 1: SI Traceability requires an estimate of measurement uncertainty.*	Not required.	Yes	Both Surface Temperature and Surface Temperature Uncertainty are provided in the SI base unit of thermodynamic temperature (Kelvin), with resolutions of 0.00341802 and 0.01 Kelvin respectively. The Surface Temperature is SI traceable because the uncertainty is provided with the product and described in the following peer-reviewed publication, Laraby, K. G., Schott, J. R.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						(2018). Uncertainty estimation method and Landsat 7 global validation for the Landsat surface temperature product. Remote Sensing of Environment, 216, 472-481. https://doi.org/10.1016/j.rse.2018.06.026. The Level 2 DOI landing page provides additional information. Example: <DIGITAL_OBJECT_IDENTIFIER> L4-5: https://doi.org/10.5066/P9IAXOVV L7: https://doi.org/10.5066/P9C7I13B	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						L8: https://doi.org/10.5066/P9OGBGM6	
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 XML package in Python can be used to parse the XML metadata file. In addition to the XML metadata file, STAC catalogue enables any client to search/crawl Landsat data.	
1.3	**Data Collection Time**	The start and stop time of data collection 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 are provided. The per-pixel acquisition time is not provided but can be reliably determined from the information provided. Example: <DATE_ACQUIRED	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						>2013-05-03</DATE_ACQUIRED> <SCENE_CENTER_TIME>04:43:58.0429310Z</SCENE_CENTER_TIME> *Note: Each pixel can be calculated from <SCENE_CENTER_TIME>*	
1.4	**Geographical Area**	The surface location to which the data relate is identified, typically as a series of four corner points, expressed in an accepted coordinate reference system (e.g., WGS84 coordinates).	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) expressed in projection coordinates with reference datum.	Yes	Yes	The latitude and longitude of the corner points are provided. Also, the coordinates of the corner points in the projection system (e.g., UTM) are provided, which can be used to determine the location of pixels. Example: <CORNER_UL_LAT_PRODUCT>28.41605</CORNER_UL_LAT_PRODUCT>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						<CORNER_UL_LON_PRODUCT>85.68092</CORNER_UL_LON_PRODUCT> <CORNER_UR_LAT_PRODUCT>28.41882</CORNER_UR_LAT_PRODUCT> <CORNER_UR_LON_PRODUCT>87.99344</CORNER_UR_LON_PRODUCT> <CORNER_LL_LAT_PRODUCT>26.42589</CORNER_LL_LAT_PRODUCT> <CORNER_LL_LON_PRODUCT>85.70436</CORNER_LL_LON_PRODUCT> <CORNER_LR_LAT_PRODUCT>26.42843</CORNER_LR_LAT_PRODUCT> <CORNER_LR_LON_PRODUCT>87.97578</CORNER_LR_LON_PRODUCT> <DATUM>WGS84</DATUM>	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						<ELLIPSOID>WGS 84</ELLIPSOID> <MAP_PROJECTIO N>UTM</MAP_PR OJECTION> <UTM_ZONE>45< /UTM_ZONE>	
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 metadata. Example: <DATUM>WGS84 </DATUM> <ELLIPSOID>WGS 84</ELLIPSOID>	
1.6	**Map Projection**	Not required.	The metadata lists the map projection that has been used, if any, and any relevant parameters required in relation to use of data in that map projection.	Not required.	Yes	The map projection parameters are provided. Example: <MAP_PROJECTIO N>UTM</MAP_PR OJECTION> <UTM_ZONE>45< /UTM_ZONE>	

#	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 containing information on geodetic correction methods used, including reference database and auxiliary data such as elevation model(s) and reference chip-sets.	Not required.	Yes	The version, model, and number of GCPs used for processing along with the source of elevation data are provided in the metadata. Example: <GROUND_CONTROL_POINTS_VERSION>4</GROUND_CONTROL_POINTS_VERSION> <GROUND_CONTROL_POINTS_MODEL>344</GROUND_CONTROL_POINTS_MODEL> <GROUND_CONTROL_POINTS_VERIFY>93</GROUND_CONTROL_POINTS_VERIFY> A single Level-1 product DOI landing page is provided in the Level-2 metadata,	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						which can be used to determine the geometric correction methods applied. Example: <DIGITAL_OBJECT_IDENTIFIER> L1-5: https://doi.org/10.5066/P9AF14YV L4-5: https://doi.org/10.5066/P918ROHC L7: https://doi.org/10.5066/P9TU80IG L8: https://doi.org/10.5066/P975CC9B	
1.8	**Geometric Accuracy of the Data**	Not required. The user is not provided with results of geometric correction processes 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 as root mean square	Not required.	Yes	The metadata provides the RMSE of the geometric correction. The RMSE_VERIFY parameter provides an independent	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			error (RMSE) or Circular Error 90% Probability (CEP90). *Note 1: Information on geometric accuracy of the data should be available in the metadata as a single DOI landing page.*			assessment of the geometric accuracy. The DOI landing page of the Level 1 processing is provided. Example: <GEOMETRIC_RMSE_MODEL>8.493</GEOMETRIC_RMSE_MODEL> <GEOMETRIC_RMSE_MODEL_Y>6.911</GEOMETRIC_RMSE_MODEL_Y> <GEOMETRIC_RMSE_MODEL_X>4.936</GEOMETRIC_RMSE_MODEL_X> <GROUND_CONTROL_POINTS_VERIFY>119</GROUND_CONTROL_POINTS_VERIFY> <GEOMETRIC_RMSE_VERIFY>6.558</GEOMETRIC_RMSE_VERIFY> *Note: See Item 1.1 for complete Landsat*	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						instrument DOI listings	
1.9	**Instrument**	The instrument used to collect the data is identified in the metadata.	As threshold, but information on instrument 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	There is reference to the instrument used to collect the data in the metadata and to the CEOS MIM on the DOI landing page. Example: <SPACECRAFT_ID>LANDSAT_8</SPACECRAFT_ID> <SENSOR_ID>OLI_TIRS</SENSOR_ID> *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
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	Yes	Yes	The central wavelength information is not provided in the metadata but is accessible using the DOI landing. The Landsat Spectral	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			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.*			Characteristics Viewer link is provided on the DOI landing pages. *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
1.11	**Sensor Calibration**	Not required.	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 sensory calibration should be available in the metadata as a single DOI landing page.*	Not required.	Yes	CPFs are provided. Example: <FILE_NAME_CPF>LC08CPF_20130401_20130627_02.01</FILE_NAME_CPF>	
1.12	**Radiometric Accuracy**	Not required. The general metadata does not include information on the radiometric accuracy of the data.	Information on radiometric accuracy should be available in the metadata as a single DOI landing page providing information on metrics describing the assessed absolute radiometric accuracy of the data, expressed as absolute radiometric uncertainty relative to a known reference standard. *Note 1: For example, this may come from comparison with*	Not required.	Yes	The absolute radiometric accuracy of each scene is not provided but general information about the radiometric accuracy can be found using the DOI link.	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			routine and rigorously collected in situ measurements.			*Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
1.13	**Algorithms**	All algorithms and versions, and the sequence in which they were applied in the generation process, are identified in the metadata.	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	Yes	Level 2 product DOI landing pages provide direct access to the atmospheric correction algorithms and citable papers. Example: <ALGORITHM_SOURCE_SURFACE_TEMPERATURE>st_1.3.0</ALGORITHM_SOURCE_SURFACE_TEMPERATURE> *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
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.	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	Yes	Yes	The information about the elevation model, reanalysis grid, etc. are provided in the metadata,	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
		Note 1: Auxiliary data includes DEMs, aerosols, etc. data sources.	product or through a link to the source.			can be found using the DOI link, and can be downloaded from the provider's webpage. Example: <DATA_SOURCE_REANALYSIS>GEOS-5 FP-IT</DATA_SOURCE_REANALYSIS> <DATA_SOURCE_ELEVATION>GLS2000</DATA_SOURCE_ELEVATION> *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
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 description of the processing chain used to generate the product, including the versions of the software used and information on the data	Not required.	Yes	The processing software version is provided in the metadata. Level 2 product DOI landing pages provide direct access to	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			collection baseline, giving full transparency to the users.			documentation and citable papers. Example: PROCESSING_SOFTWARE_VERSION >LPGS_15.2.0</PROCESSING_SOFTWARE_VERSION> *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
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	Yes	The metadata includes a single DOI landing page. *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
1.17	**Overall Data Quality**	Not applicable.	The metadata includes details of the quality of the product based on quantitative assessment of the product with respect to high quality reference data with full traceability of the uncertainties. Validation and intercomparison	Not required.	Yes	The information on the composite image quality of the sensor, percentage of scene cloud cover, land could cover, etc. are provided	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			statistics can provide the necessary quantification.			which are machine readable through XML parsing. Example: <CLOUD_COVER>13.82</CLOUD_COVER> <CLOUD_COVER_LAND>13.82</CLOUD_COVER_LAND> <IMAGE_QUALITY_OLI>9</IMAGE_QUALITY_OLI> <IMAGE_QUALITY_TIRS>9</IMAGE_QUALITY_TIRS> *Note: See Item 1.1 for citable peer-reviewed estimate of measurement uncertainty publication.*	

Per-Pixel Metadata

Per-pixel metadata should allow users to discriminate between (choose) observations on the basis of their individual suitability for application and includes 'quality flags'. 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. Similarly, the mechanism or form of the per-pixel metadata (additional data bands, mask layers, etc.) is open to the provider.

#	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. *Note 1: e.g., due to missing ancillary data for some pixels.*	The metadata identifies which tests have, and have not, been successfully completed for each pixel.	Yes	Yes	No bit was assigned to flag unsuccessful testing of saturation or cloud detection. All pixels are tested successfully, or the processing fails.	
2.4	**Saturation**	Metadata indicates where one or more pixel in the input 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. *Note: TIRS bands 10 and 11 are not tested for saturation*	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
						because they do not saturate.	
2.5	**Cloud**	Metadata indicates whether a pixel is assessed as being cloud.	As threshold, but 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. The product guides within the DOI landing page provide information on the cloud detection algorithm. *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
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. The product guide within the DOI landing page provides information on the cloud shadow detection algorithm. *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
2.7	**Snow/ Ice mask**	Not required.	The metadata indicates whether a pixel is assessed as being snow/ice or not.	Yes	Yes	QA_PIXEL band bit 5 indicates snow. Snow/Ice confidence	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			Information on snow/ice mask should be available in the metadata as a single DOI landing page.			are provided in QA_PIXEL band bit 12 and 13. *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
2.8	**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	The average solar and sensor viewing azimuth and zenith angle coefficient files are provided. *Note: the per-pixel solar and sensor viewing azimuth and zenith angles are provided in the Landsat Level 1 product package.*	

Radiometric and Atmospheric Corrections

The following requirements must be met for all pixels in a collection. Radiometric corrections must lead to a valid measurement of surface temperature.

#	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 are expressed as a measurement of the Surface Temperature of the land, expressed as Kelvin.	Surface temperature measurements are SI traceable (see also 1.1).	Yes	Yes	Surface Temperature is provided in the SI base unit of thermodynamic temperature (Kelvin), with multiplicative factor of 0.00341802 and additive factor of 149. The Surface Temperature is SI traceable because the uncertainty is provided. The Level 2 product DOI landing page provides additional information. *Note: See Item 1.1 for citable peer-reviewed estimate of measurement uncertainty publication and for complete Landsat instrument DOI listings.*	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
3.2	**Corrections for Atmosphere and Emissivity**	Retrieval methods for estimating surface temperature are provided. *Note 1: The metadata references (may be through a single DOI landing page) a citable peer-reviewed algorithm.*	As threshold.	Yes	Yes	The atmospheric parameters (transmittance, upwelled radiance, and downwelled radiance) and emissivity are used to calculate the Surface Temperature. The Level 2 product DOI landing page provides the retrieval methods. *Note: See Item 1.1 for complete Landsat instrument DOI listings.*	
3.3	**Measurement Uncertainty**	Not required.	Uncertainty, in Kelvin, of the surface temperature measurement for each pixel is provided. *Note 1: Some of the intent of the initial wording (below), which refers to atmospheric windows, may have been lost: Uncertainty, in units Kelvin, of the surface temperature for each pixel is also accompanied by distance from cloud (above) and atmospheric transmission*	Yes	Yes	The Surface Temperature product includes an uncertainty band (ST_QA), which is a combination of pixel distance to cloud, emissivity uncertainty, instrument uncertainty, etc. *Note: See Item 1.1 for citable peer-reviewed estimate of*	

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements	Threshold Self-Assessment	Target Self-Assessment	Self-Assessment Explanation/ Justification	Recommended Requirement Modification
			(intervals, i.e., 0.4 - 0.55, 0.55 - 0.7, etc.).			*measurement uncertainty publication.*	

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 necessary to meet this requirement. 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.*	Yes	Yes	0.5-pixel radial RMSE is met through use of only Tier 1 data and some Tier 2 data.	

Summary Self-Assessment Table

	Threshold	Target
1. General Metadata		
1.1 Traceability	Not required	Yes
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	Not required	Yes
1.7 Geometric Correction Methods	Not required	Yes
1.8 Geometric Accuracy of the Data	Not required	Yes
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 Snow/Ice Mask	Yes	Yes
2.8 Solar and Viewing Geometry	Yes	No
3. Radiometric and Atmospheric Corrections		
3.1 Measurement	Yes	Yes
3.2 Corrections for Atmosphere and Emissivity	Yes	Yes
3.3 Measurement Uncertainty	Yes	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 the CEOS Working Group on Calibration and Validation.

Agencies or other entities considering undertaking an assessment process should contact the co-leads of 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 Temperature CARD4L-ST:

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

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

Specific Examples

Processes to produce Threshold Surface Temperature CARD4L-ST:

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

Reference papers

The following papers provide scientific and technical guidance:

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

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

Annex 1 – CARD4L Requirement Examples (Surface Temperature)

General Metadata

#	Item	Example 1	Example 2
1.1	**Traceability**	Example of measurement traceability in metadata: <band add_offset="0.000000" category="image" data_type="INT16" fill_value="-9999" name="ST" nlines="5000" nsamps="5000" product="st" scale_factor="0.100000" <short_name>LC08ST</short_name> <long_name>Surface Temperature</long_name> <file_name>ST</file_name> <pixel_size units="meters" x="30" y="30"/> <resample_method>none</resample_method> <data_units>temperature (kelvin)</data_units> <valid_range max="3730.000000" min="1500.000000"/> <app_version>st_1.3.0</app_version> <production_date>2018-11-30T04:47:38Z</production_date> </band> Example of measurement uncertainty in metadata: <band category="qa" data_type="INT16" fill_value="-9999" name="STQA" nlines="5000" nsamps="5000" product="st_qa" scale_factor="0.010000" source="toa_refl"> <short_name>LC08STQA</short_name> <long_name>Surface temperature quality band</long_name>	NA

#	Item	Example 1	Example 2
		<file_name>STQA</file_name> <pixel_size units="meters" x="30" y="30"/> <resample_method>none</resample_method> <data_units>temperature (kelvin)</data_units> <valid_range max="32767.000000" min="0.000000"/> <app_version>st_1.3.0</app_version> <production_date>2018-11-30T04:47:38Z</production_date> </band>	
1.2	**Metadata Machine Readability**	NA	NA
1.3	**Data Collection Time**	Example of scene center time (UTC): <scene_center_time>17:23:57.201686Z</scene_center_time>	The granule start and end times are contained in the XML metadata: <metadataObject ID="acquisitionPeriod" classification="DESCRIPTION" category="DMD"> <metadataWrap mimeType="text/xml" vocabularyName="Sentinel-SAFE" textInfo="Acquisition Period"> <xmlData> <sentinel-safe:acquisitionPeriod> <sentinel-safe:startTime>2018-10-07T05:04:50.425838Z</sentinel-safe:startTime> <sentinel-safe:stopTime>2018-10-07T05:07:50.425838Z</sentinel-safe:stopTime> </sentinel-safe:acquisitionPeriod> </xmlData> </metadataWrap> </metadataObject> Per pixel times are derived using information from the "time_in.nc" and “indices_in.nc” datafiles following a

#	Item	Example 1	Example 2
			prescribed recipe
1.4	**Geographical Area**	Example of the bounding coordinates in decimal degrees (WGS84): <bounding_coordinates> <west>-99.9109607425</west> <east>-98.0134952569</east> <north>43.3609828699</north> <south>41.9778528562</south> </bounding_coordinates> Example of the corner points in the map projection system (Albers): <corner_point location="UL" x="-315585.000000" y="2264805.000000"/> <corner_point location="LR" x="-165585.000000" y="2114805.000000"/>	NA
1.5	**Coordinate Reference System**	Example of the projected coordinate system info: <projection_information datum="WGS84" projection="AEA" units="meters">	NA
1.6	**Map Projection**	Example: <projection_information datum="WGS84" projection="AEA" units="meters"> <corner_point location="UL" x="-315585.000000" y="2264805.000000"/> <corner_point location="LR" x="-165585.000000" y="2114805.000000"/> <grid_origin>UL</grid_origin> <albers_proj_params> <standard_parallel1>29.500000</standard_parallel1>	NA

#	Item	Example 1	Example 2
		<standard_parallel2>45.500000</standard_parallel2> <central_meridian>-96.000000</central_meridian> <origin_latitude>23.000000</origin_latitude> <false_easting>0.000000</false_easting> <false_northing>0.000000</false_northing> </albers_proj_params> </projection_information>	
1.7	**Geometric Correction Source**	Example of elevation source: <elevation_source>GLS2000</elevation_source>	The XML wrapper provides the source of the geometric calibration: <sentinel-safe:resource name="S3A_SL_1_GEC_AX_20160216T000000_20991231T235959_20180202T120000_____MPC_O_AL_007.SEN3" role="SLSTR Geometric Calibration Data File"> <sentinel-safe:processing name="AdfProcessing"> <sentinel-safe:facility name="ESA Mission Performance Coordinating Centre (MPC)" organisation="ESA Mission Performance Coordinating Centre" site="Sophia Antipolis" country="France"> <sentinel-safe:hardware name="OPE"/> <sentinel-safe:software name="ADC" version="1.0"/> </sentinel-safe:facility> </sentinel-safe:processing> </sentinel-safe:resource>
1.8	**Geometric Accuracy of the Data**	Example: <geometric_rmse_model>9.021</geometric_rmse_model> <geometric_rmse_model_x>6.864</geometric_rmse_model_x>	NA

#	Item	Example 1	Example 2
		<geometric_rmse_model_y>5.854</geometric_rmse_model_y>	
1.9	**Instrument**	Example: <satellite>LANDSAT_8</satellite> <instrument>OLI/TIRS_Combined</instrument>	The XML wrapper provides the instrument details: <metadataObject ID="platform" classification="DESCRIPTION" category="DMD"> <metadataWrap mimeType="text/xml" vocabularyName="Sentinel-SAFE" textInfo="Platform Description"> <xmlData> <sentinel-safe:platform> <sentinel-safe:nssdcIdentifier>2016-011A</sentinel-safe:nssdcIdentifier> <sentinel-safe:familyName>Sentinel-3</sentinel-safe:familyName> <sentinel-safe:number>A</sentinel-safe:number> <sentinel-safe:instrument> <sentinel-safe:familyName abbreviation="SLSTR">Sea and Land Surface Temperature Radiometer</sentinel-safe:familyName> <sentinel-safe:mode identifier="EO">Earth Observation</sentinel-safe:mode> </sentinel-safe:instrument> </sentinel-safe:platform> </xmlData> </metadataWrap> </metadataObject>
1.10	**Spectral Bands**	NA	NA
1.11	**Sensor Calibration**	Example: <cpf_name>LC08CPF_20180101_20180331_01.02</cpf_name>	NA

#	Item	Example 1	Example 2
1.12	**Radiometric Accuracy**	NA	NA
1.13	**Algorithms**	Example for Surface Temperature algorithm version: <app_version>st_1.3.0</app_version>	NA
1.14	**Auxiliary Data**	NA	All Auxiliary Datafiles (ADFs) are listed in the XML wrapper: <sentinel-safe:resource name="S3__SL_2_LSTBAX_20000101T000000_20991231T235959_20151214T120000_____MPC_O_AL_001.SEN3" role="SLSTR LST biome data file" version="06.16"> <sentinel-safe:resource name="S3__SL_2_LSTVAX_20000101T000000_20991231T235959_20151214T120000_____MPC_O_AL_001.SEN3" role="SLSTR LST vegetation fraction data file" version="06.16"> <sentinel-safe:resource name="S3__SL_2_LSTWAX_20000101T000000_20991231T235959_20151214T120000_____MPC_O_AL_001.SEN3" role="SLSTR LST water vapour data file" version="06.16">
1.15	**Processing Chain Provenance**	NA	Processing chain provenance information is stored in the XML wrapper under the following tag: <metadataObject ID="processing" classification="PROVENANCE" category="PDI">
1.16	**Data Access**	NA	NA
1.17	**Overall Data Quality**	NA	Overall data quality information is stored in the XML wrapper under the following tag: <metadataObject ID="measurementQualityInformation" classification="DESCRIPTION" category="DMD">

Per-Pixel Metadata

#	Item	Example 1	Example 2
2.1	**Metadata Machine Readability**	NA	NA
2.2	**No Data**	Example of the fill_value specified for each band in metadata: <band add_offset="0.000000" category="image" data_type="INT16" fill_value="-9999" name="ST" nlines="5000" nsamps="5000" product="st" scale_factor="0.100000" <short_name>LC08ST</short_name> <long_name>Surface Temperature</long_name> <file_name>ST</file_name> <pixel_size units="meters" x="30" y="30"/> <resample_method>none</resample_method> <data_units>temperature (kelvin)</data_units> <valid_range max="3730.000000" min="1500.000000"/> <app_version>st_1.3.0</app_version> <production_date>2018-11-30T04:47:38Z</production_date> </band>	The "flags_in.nc" datafile contains per-pixel information on "no / bad data through saturation / incomplete testing etc". The following field has an "unfilled" flag: ushort confidence_in(rows, columns) ; confidence_in:flag_masks = 1US, 2US, 4US, 8US, 16US, 32US, 64US, 128US, 256US, 512US, 1024US, 2048US, 4096US, 8192US, 16384US, 32768US ; confidence_in:flag_meanings = "coastline ocean tidal land inland_water unfilled spare spare cosmetic duplicate day twilight sun_glint snow summary_cloud summary_pointing" ;
2.3	**Incomplete Testing**	NA	The "flags_in.nc" datafile contains per-pixel information on "no / bad data through saturation / incomplete testing etc". The following field has an "unfilled" flag: ushort confidence_in(rows, columns) ; confidence_in:flag_masks = 1US, 2US, 4US, 8US, 16US, 32US, 64US, 128US, 256US, 512US, 1024US, 2048US, 4096US, 8192US, 16384US, 32768US ; confidence_in:flag_meanings = "coastline ocean tidal land inland_water unfilled spare spare cosmetic

#	Item	Example 1	Example 2
			duplicate day twilight sun_glint snow summary_cloud summary_pointing”;
2.4	**Saturation**	Example of RADSATQA band showing the saturation information for the thermal bands used for Surface Temperature calculation: <band category="qa" data_type="UINT16" fill_value="1" name="RADSATQA" nlines="5000" nsamps="5000" product="toa_refl" source="level1"> <short_name>LC08RADSAT</short_name> <long_name>saturation mask</long_name> <file_name>RADSATQA</file_name> <pixel_size units="meters" x="30" y="30"/> <resample_method>none</resample_method> <data_units>bitmap</data_units> <bitmap_description> <bit num="0">Data Fill Flag (0 = valid data, 1 = invalid data)</bit> <bit num="1">Band 1 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="2">Band 2 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="3">Band 3 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="4">Band 4 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="5">Band 5 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="6">Band 6 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="7">Band 7 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="8">N/A</bit>	The "flags_in.nc" datafile contains per-pixel information on "no / bad data through saturation / incomplete testing etc". The following field has an "unfilled" flag: ushort confidence_in(rows, columns) ; confidence_in:flag_masks = 1US, 2US, 4US, 8US, 16US, 32US, 64US, 128US, 256US, 512US, 1024US, 2048US, 4096US, 8192US, 16384US, 32768US ; confidence_in:flag_meanings = "coastline ocean tidal land inland_water unfilled spare spare cosmetic duplicate day twilight sun_glint snow summary_cloud summary_pointing" ;

#	Item	Example 1	Example 2
		<bit num="9">Band 9 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="10">Band 10 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> <bit num="11">Band 11 Data Saturation Flag (0 = valid data, 1 = saturated data)</bit> </bitmap_description> <app_version>LaSRC_1.3.0</app_version> <production_date>2018-11-30T04:47:38Z</production_date> </band>	
2.5	**Cloud**	Example of PIXELQA showing the bit value for cloud pixels (as well as cloud and cirrus confidence): <band category="qa" data_type="UINT16" fill_value="1" name="PIXELQA" nlines="5000" nsamps="5000" product="level2_qa" source="level1"> <short_name>LC08PQA</short_name> <long_name>level-2 pixel quality band</long_name> <file_name>PIXELQA</file_name> <pixel_size units="meters" x="30" y="30"/> <resample_method>none</resample_method> <data_units>quality/feature classification</data_units> <bitmap_description> <bit num="0">fill</bit> <bit num="1">clear</bit> <bit num="2">water</bit> <bit num="3">cloud shadow</bit> <bit num="4">snow</bit> <bit num="5">cloud</bit> <bit num="6">cloud confidence</bit> <bit num="7">cloud confidence</bit>	The "flags_in.nc" datafile contains all the cloud masking flags Three fields are relevant: i) cloud_in; ii) confidence_in; and iii) bayes_in The "cloud_in" field contains all the individual threshold-based mask: flag_masks = 1US, 2US, 4US, 8US, 16US, 32US, 64US, 128U S, 256US, 512US, 1024US, 2048US, 4096US, 8192US, 16384US, 32768US ; cloud_in:flag_meanings = "visible 1.37_threshold 1.6_small_histo gram 1.6_large_histogram 2.25_small_histogram 2.25_large_histogram 11_spatial_co herence gross_cloud thin_cirrus medium_high fog_low_stratus 11_12_view_differenc e 3.7_11_view_difference thermal_histogram spare spare" The "confidence_in" field contains the "summary_cloud_mask" from the most appropriate cloud_in flags; the value of the bit is 16384US

#	Item	Example 1	Example 2
		<bit num="8">cirrus confidence</bit> <bit num="9">cirrus confidence</bit> <bit num="10">terrain occlusion</bit> <bit num="11">unused</bit> <bit num="12">unused</bit> <bit num="13">unused</bit> <bit num="14">unused</bit> <bit num="15">unused</bit> </bitmap_description> <app_version>generate_pixel_qa_1.6.0</app_version> <production_date>2018-11-30T04:47:38Z</production_date> </band>	The "bayes_in" field contains the "single_moderate" probabilistic cloud flag; the value of the bit is 2UB
2.6	**Cloud Shadow**	Please see the cloud shadow part in the example provided in requirement 2.5	NA
2.7	**Snow/Ice Mask**	Please see the snow part in the example provided in requirement 2.5	NA
2.8	**Solar and Viewing Geometry**	NA	NA

Radiometric and Atmospheric Corrections

#	Item	Example 1	Example 2
3.1	**Measurement**	NA	NA
3.2	**Corrections for Atmosphere (and Emissivity in the Case of ST)**	NA	NA
3.3	**Measurement Uncertainty**	NA	NA

Geometric Corrections

#	Item	Example 1	Example 2
4.1	**Geometric Correction**	NA	NA