Committee on Earth Observation Satellites	**Analysis Ready Data** ***For Land***	**Product Family Specification:** **Normalised Radar Backscatter**

Document status

For Adoption as: **<u>Product Family Specification, Normalised Radar Backscatter</u>**

This Specification should next be reviewed at: September 2018.

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 discussed in and leading up to LSI-VC-3, provided by SEO and others.	Lewis
0.1.0	18-04-2017	Various revisions to structure	Lewis
1.0.0	18-04-2017	Included material provided by Brian Killough / SEO reflecting input from a range of SAR experts / users.	Lewis
1.0.1	20-04-2017	Edits reflecting feedback from SEO, change to the figure / table in 'guidance'; removed item 4.2 which appeared redundant; moved reference to definitive ephemeris to a note under item 4.1; added reference to speckle under table 3 (radiometric corrections)	Lewis and Killough
2.0.0	30-08-2017	Feedback incorporated, circulated to LSI-VC	Lewis
2.1.0	6-09-2017	Feedback from ESA included	Lewis
2.1.1	6-09-2017	Edits rolled in	Lewis
3.0	02-02-2018	Feedback from the teleconference (06/12/2018) and post teleconf (emails) included	Siqueira
3.1	03-04-2018	Nuno Miranda (ESA) comments addressed (uncertainty information to be required at the threshold level – 3.4 Radiometric corrections (Accuracy), split sensor acquisition mode)	Siqueira
3.1.1	12-04-2018	Ake Rosenqvist (JAXA) comments (split sensor acquisition mode into acquisition and processing parameters, include "global incidence angle")	Siqueira

Description

Product family title: **Radar Backscatter (CARD4L-Radar)**

Applies to*:* *Data collected by synthetic aperture radar sensors.*

Abstract

Synthetic aperture radar imagery enables a growing range of applications of radar data that draw on multiple observations from multiple instruments and viewing modes. The necessary data preparation steps are well established in the literature and have been demonstrated in practice (see Guidance section). This CARD4L product specification reflects these data preparation steps.

CARD4L-Radar product will enable a set of new, generalist, users to access and apply these data in geographical analyses to produce improved products, thus increasing the impact of CEOS Agencies' data. The CARD4L product is not relevant to interferometric studies.

Definitions

NRB	Normalised Radar Backscatter
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.
MTF	Modulation Transfer Function
Spatial Resolution	The highest magnification of the sensor at the ground surface
Spatial Sampling Distance	Spatial sampling distance is the barycentre-to-barycentre distance between adjacent spatial samples on the Earth's surface.

Requirements

1. General Metadata

These are metadata records describing a distributed collection of pixels. The collection of pixels referred to must be contiguous in space and time. General metadata should allow the user to assess the overall suitability of the dataset, and must meet the following requirements:

	Item	Threshold (minimum) requirements	Target (desired) requirements
1.1	**Traceability**	Not required.	Data must be traceable to SI reference standard. For further information see, for example, http://l-a-b.com/information/traceability/
1.2	**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, but metadata is formatted in accordance with ISO 19115-2.
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.
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) expressed in projection coordinates with reference datum.
1.5	**Coordinate reference system**	The metadata lists the coordinate reference system that has been used.	As threshold
1.6	**Map projection**	The metadata lists the map projection that has been used, and any relevant parameters required in relation to use of data in that map projection.	As threshold
1.7	**Geometric correction**	The metadata describes the geodetic correction methods used, including reference database and ancillary data such as elevation model(s) and reference chip-sets. DOIs are used.	As threshold

1.8	**Geometric accuracy**	A single-figure estimate of the Geometric accuracy is provided. The user is not necessarily 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 error (RMSE) or Circular Error Probability (e.g., CEP90, CEP95).
1.9	**Instrument**	The instrument used to collect the data is identified in the metadata.	As threshold, but including a reference to the relevant CEOS Missions, Instruments and Measurements Database record.
1.10	**Acquisition parameters**	Acquisition parameters details: - look direction (L, R) - polarizations - resolution (range x azimuth) - orbit direction of data-take (ascending or descending)	As threshold.
1.11	**Processing parameters**	Processing parameters details: - pixel spacing (range x azimuth) - number of looks and equivalent number of looks	As threshold.
1.12	**Sensor calibration**	Sensor calibration details / list of scientific papers and articles websites describing the calibration approach/method used	As threshold.
1.13	**Radiometric accuracy**	Not required. The general metadata does not include specific information on the radiometric accuracy of the data. OR, A global uncertainty estimate is provided	The metadata includes metrics describing the assessed absolute radiometric accuracy of the data, expressed as absolute radiometric uncertainty relative to a known reference standard (e.g., pseudo-invariant calibration sites) *Note 1: for example, this may come from comparison with rigorously collected in situ measurements*
1.14	**Algorithms**	All algorithms, 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: 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.*

			DOIs for each algorithm are identified in the metadata. The versions of the algorithms are identified.
1.15	**Ancillary data**	The metadata identifies the sources of ancillary data used in the generation process, ideally expressed as DOIs. *Note 1: ancillary data includes DEMs, etc. data sources*	As threshold, but the ancillary data is also available for free online download, contemporaneously with the product.
1.16	**Processing chain provenance**	Not required.	The metadata includes a description of the processing chain used to generate the product, including the versions of the software used.
1.17	**Data access**	The metadata identifies the location from where the product can be retrieved, expressed as a DOI. *Note 1: Manual and offline interaction action (e.g. log in) may be required.*	The metadata identifies an online location from where the data (including any available new records) can be consistently and reliably retrieved by a computer algorithm without any manual intervention being required. *Note 1: Some manual interaction action may be required <u>in the first instance</u> ('one off' basis) to establish ongoing access to the data.*
1.18	**Overall data quality**	Not applicable	TBD. There is a perceived need for machine-readable metrics describing the overall quality of the data, however the specifications for these are yet to be determined. If there is not a clear case and clear specifications for such metadata, then "Overall data quality" will be removed.

2. 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
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, but metadata is formatted in accordance with relevant international standards (ISO 19115-2).
2.2	**No data**	Pixels or grid cells that do not correspond to an observation ('empty pixels') are clearly flagged	As threshold.
2.3	**Layover**	Optional	Layover flags or mask is provided
2.4	**Shadow**	Optional	Shadow flags or mask is provided
2.5	**Local Incidence Angle**	Optional	Local Incidence angle image is provided
2.6	**Global Incidence Angle**	Global incidence angle is provided	As threshold.

3. Radiometric corrections

The following requirements must be met for all pixels in a collection. The requirements indicate the necessary outcomes and to some degree the minimum steps necessary to be deemed to have achieved those outcomes. Radiometric corrections must lead to normalised measurement(s) of backscatter intensity.

	Item	Threshold (minimum) requirements	Target (desired) requirements
3.1	**Measurements**	Gamma-0 (Υ_0) backscatter coefficient is provided for each polarisation pair (e.g. HH, HV, VV, VH) Note: transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.	As threshold.
3.2	**Noise removal**	Optional	Thermal noise removal and image border noise removal (when applicable) to remove overall scene noise and scene edge artefacts, respectively.
3.3	**Terrain Corrections**	An ellipsoid-model is used to determine calculate Υ_0, with adjustments for local terrain through incident angle correction factors.	Superior adjustments are made for terrain by modelling the local illuminated reference area using the preferred choice of peer reviewed models to produce a radiometrically terrain corrected (RTC) $\Upsilon_{0.}$ This will have increased terrain flattening and improved comparability (more accurate measurements).
3.4	**Accuracy**	Uncertainty (e.g., bounds on Υ_0) information is provided. SI traceability is achieved	As threshold.

Note: Speckle filtering is not addressed here, as this process removes noise but alters the original backscatter values. Some users may desire this processing step, but it is not accepted as a common product for the majority of applications.

4. 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
4.1	**Accuracy**	Sub-pixel accuracy is taken to be less than or equal to 0.2-pixel radial root mean square error (rRMSE) or equivalent in Circular Error Probability (CEP) relative to a defined reference. Relevant metadata must be provided under 1.7 and 1.8 (Geometric correction and Geometric accuracy) *Note 1. Accurate geolocation is a prerequisite to radar processing to correct for terrain. To enable interoperability between radar sensors absolute accuracy is required. Orbit ephemeris updates (precise ephemeris) are required prior to any orthorectification steps to ensure accuracy.*	Sub-pixel accuracy is achieved relative to an identified absolute independent terrestrial referencing system (such as a national map grid). Relevant metadata must be provided under 1.7 and 1.8 (Geometric correction and Geometric accuracy) *Note 2: In practice, a Geocoded Terrain Corrected (GTC) product is expected to meet this requirement. Corrections for the local illuminated reference area will also require accurate geo-location.*

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.
- 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 (hyperlink).

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 Normalised Radar Backscatter CARD4L-Radar

The following general process would typically be applied to produce CARD4L-Radar Threshold.

- Apply the best possible orbit parameters to give the most accurate product possible. These will have been projected to an ellipsoidal model such as WGS84. In order to achieve the threshold levels of geometric accuracy required of CARD4L it is generally considered that precise orbit determination will be required.
- Apply instrument calibrations to produce Beta-naught values
- Remove thermal noise
- Apply ellipsoidal incidence angle and local incidence angle corrections to give Threshold level terrain-flattened Gamma-naught backscatter
- Apply geometric terrain corrections (ortho-rectify)

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

- Apply full Radiometric Terrain Correction by modelling the illuminated area using a digital elevation model (also known as a digital height model or a digital surface model), giving direct estimates of the Gamma-naught normalisation areas.

Note that the geometric and radiometric corrections should be undertaken in a single step to minimise the number of resampling steps.

These steps have been applied, for example, in global ALOS PALSAR products as described by Shimada *et. al* (2014) and Small (2011). Through the use of a rigorous terrain-based model of the geometry of illumination and backscatter improved terrain flattening is achieved and issues of lay-over and foreshortening are addressed. The resulting data are more highly comparable through time, across viewing geometries (ascending / descending) and between sensors. Note that these steps alone do not produce, for example, the meta-data expected of a CARD4L product.

Specific examples

The following examples are included to illustrate how corrections may be made for some datasets. They are not intended to be comprehensive or exclusive. Additional examples may be added in time where data providers or processors are able to offer them.

Processes to produce Threshold Radar Backscatter CARD4L-Radar for Sentinel-1

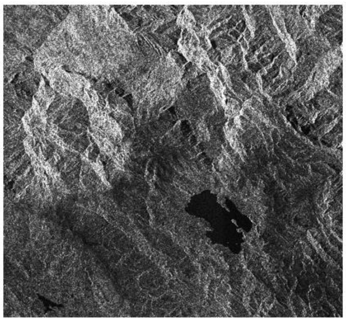
These are based on 'typical' processing of Sentinel-1 data, and can be completed using the Sentinel Tool Box provided by ESA (courtesy Brian Killough, SEO and others listed in the graphic).

- Orbit Updates applied to include the definitive ephemeris for improved geolocation
- Remove GRD Border Noise - Removes processed artifacts at scene edges where non-zero noise values exist.

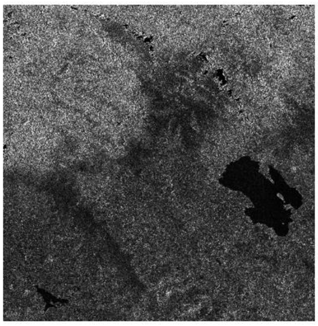
- Remove Thermal Noise – Removes thermal noise using thresholds. Not a significant correction, but commonly used by most users.
- Radiometric Calibration - Converts raw data to backscatter intensity (beta-0 output)
- Radiometric Terrain Correction - Radiometric normalization (terrain flattening) using DEM data (gamma-0 output)
- Speckle Filter – Removes noise but adds blurring to features and reduces resolution. This may be applied as an “advanced ARD” product for select users.
- Geometric Terrain Correction - Orthorectification using DEM topography data (gamma-0 output in preferred grid projection)

A summary of these steps is given below

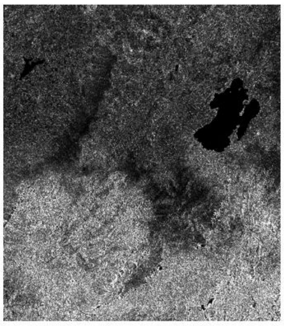
Step	Description	CEOS ARD	Google	Zhou (CSIRO)	Lewis (GA)
1	Orbit Updates	x	x	x	x
2	GRD Border Noise	x	no	no	x
3	Thermal Noise	x	x	x	no
4	Radiometric Calibration	x	x	x	x
5	Radiometric Terrain Correction	x	x	x	x
6	Speckle Filter	no	no	x	no
7	Orthorectification	x	x	x	x



Unprocessed - VH Intensity
Lake: Laguna de Tota
Location: Sogamoso, Colombia



Steps 1 to 6
Gamma-0, VH Intensity



Step 7 - Orthorectification
Gamma-0, VH, UTM-WRS84

(Image courtesy B. Killough, SEO)

Reference papers

The following papers provide scientific and technical guidance:

Small, D. (2011). Flattening Gamma: Radiometric Terrain Correction for SAR Imagery. *IEEE Transactions on Geoscience and Remote Sensing*. **49** (8), AUGUST 2011 3081;

Shimada, M., Takuya Itoh, T., Motooka, T., Watanabe, M., Shiraishi, T., Thapa, R., Lucas, R. cMasanobu et al., (2014) New global forest/non-forest maps from ALOS PALSAR data (2007–2010). *Remote Sensing of Environment* **155** (2014) pp13–31.

Hoekman D. and Reiche, J. *Multi-model radiometric slope correction of SAR images of complex terrain using a two-stage semi-empirical approach.* Remote Sensing of Environment, 2015, Vol. 156, pp. 1-10.

Shimada, M. Ortho-Rectification and Slope Correction of SAR Data Using DEM and Its Accuracy Evaluation. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. Dec. 2010, vol. 3, no. 4, pp 657 – 671.