

CARD4L Concrete Examples: Sentinel-2, Landsat and Sentinel-1

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Outline

- **Copernicus Sentinel-2**
 - ✓ ARD products (L2A, L2H and L2F)
 - ✓ CARD4L assessment
 - ✓ Way Forward
- **Landsat**
 - ✓ ARD product
 - ✓ CARD4L assessment
 - ✓ Way Forward
- **Copernicus Sentinel-1**
 - ✓ ARD product
 - ✓ CARD4L assessment
 - ✓ Way Forward

Sentinel-2 / ARD Products

Type	Code	Description	Users	Coverage	Distribution
Core Products	Level-1B	Top-of-atmosphere radiances in sensor geometry	Expert users	Alps and Norway	FTP (rolling archive) available on request
	Level-1C	Top-of-atmosphere reflectances in cartographic geometry	All users	Global	Copernicus Data Hubs (full archive)
	Level-2A	Surface reflectances in cartographic geometry			
Pilot Products	Level-2H	Harmonised Landsat-8+Sentinel-2 surface reflectances in cartographic geometry	QWG + S2VT participants	Set of sample tiles	FTP
	Level-2F	Fused Landsat-8+Sentinel-2 surface reflectances in cartographic geometry			

ARD

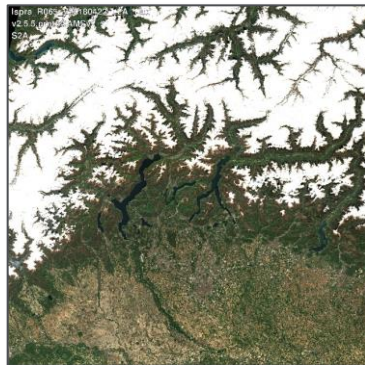
Sentinel-2 / ARD Products / Level-2A



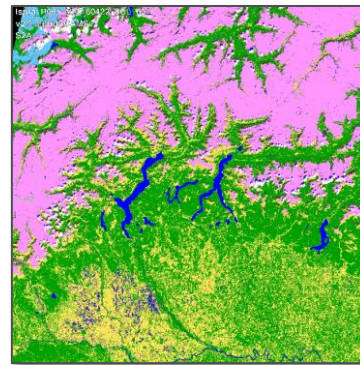
→ VH-RODA 2021 online workshop



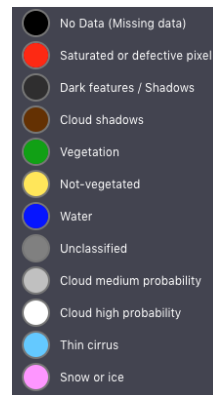
Top-of-atmosphere
Reflectance



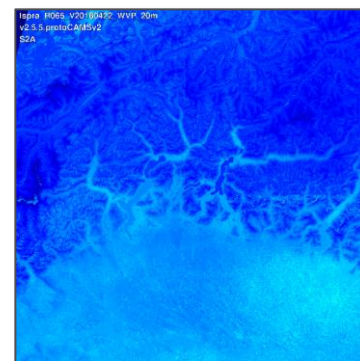
Surface Reflectance



Scene Classification



Aerosol Optical
Thickness



Water Vapour

Sentinel-2 / ARD Products / Level-2A






<http://ceos.org/ard>

CEOS Analysis Ready Data

Overview Framework Specifications Resources **CEOS ARD Strategy** Information for: Data Producers **Data Distributors** Data Users

Product Family Specifications

Surface Reflectance	Surface Temperature	Radar Backscatter
		
Data collected with multispectral sensors operating in the VIS/NIR/SWIR wavelengths. These typically operate with ground sample distance and resolution in the order 10-100m however the Specification is not inherently limited to this resolution.	Data collected with multispectral sensors operating in the thermal Infra-red (TIR) wavelengths. These typically operate with ground sample distance and resolution in the order 10-100m.	Data collected by Synthetic Aperture Radar (SAR) sensors. Polarimetric and interferometric SAR PFS are also being developed. These are expected to be complete by early 2019.
Product Family Specification: PDF Word	Product Family Specification: PDF Word	Product Family Specification: PDF Word

Sentinel-2 / Level-2A CARD4L Assessment

CARD4L Product Family Specifications for Surface Reflectance include requirements regarding:

- General metadata
- Per-pixel metadata
- Radiometric and atmospheric correction
- Geometric correction



For each requirement:

- ❑ THRESHOLD – minimum requirement considered sufficient to render the product ready for analysis;
- ❑ TARGET – more stringent requirement that further improves the product quality/usefulness.

Sentinel-2 / Level-2A CARD4L Assessment



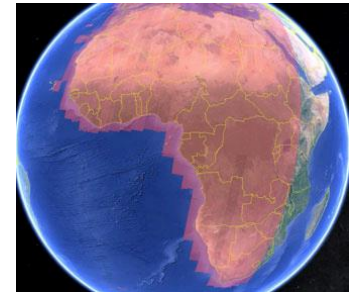
- ✓ Process initiated to certify Sentinel-2 Level-2A products.
- ✓ Sentinel-2 products expected to be compliant with CARD4L threshold requirements by mid-2021, after:
 - Global activation of geometric refinement meeting multi-temporal registration performances <0.5 pixel 95% Circular Error.
 - Inclusion of a DOI (Digital Object Identifier) in the metadata.

Product	CARD4L Type	PFS Version	Agency	Mission(s)	Access (DOI)	Info	Self Assessment	Peer Review	Sample Products
Sentinel-2 Level-2A	Surface Reflectance	v5.0	ESA	Sentinel-2A, 2B	Link	Link	TBA	TBA	TBA

Sentinel-2 / Level-2A CARD4L Assessment

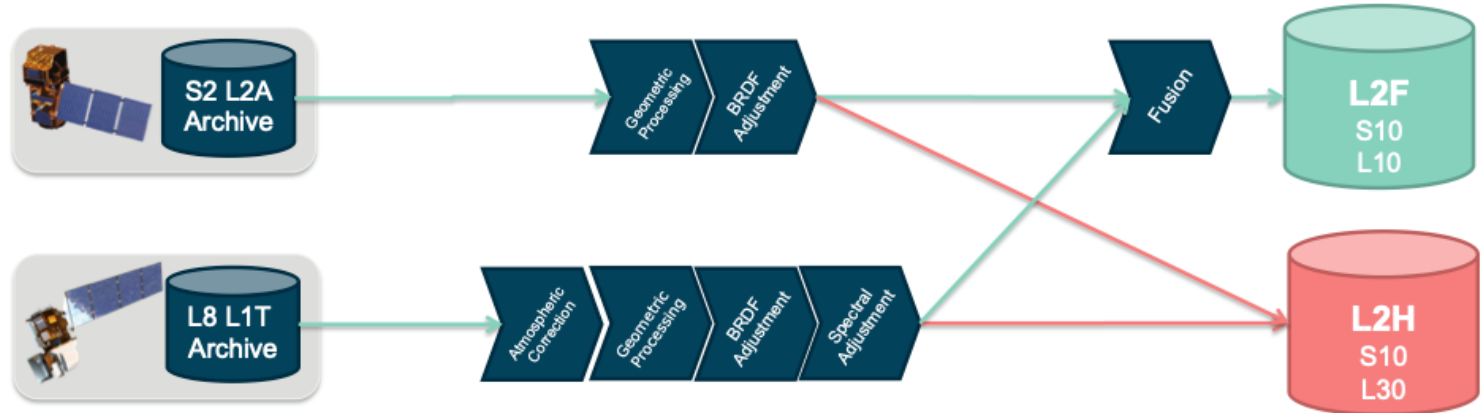


- Since 30 March 2021, geometric refinement already available over Europe and Africa.
- Multi-temporal registration performances $<5\text{m}$ at 95% Circular Error.

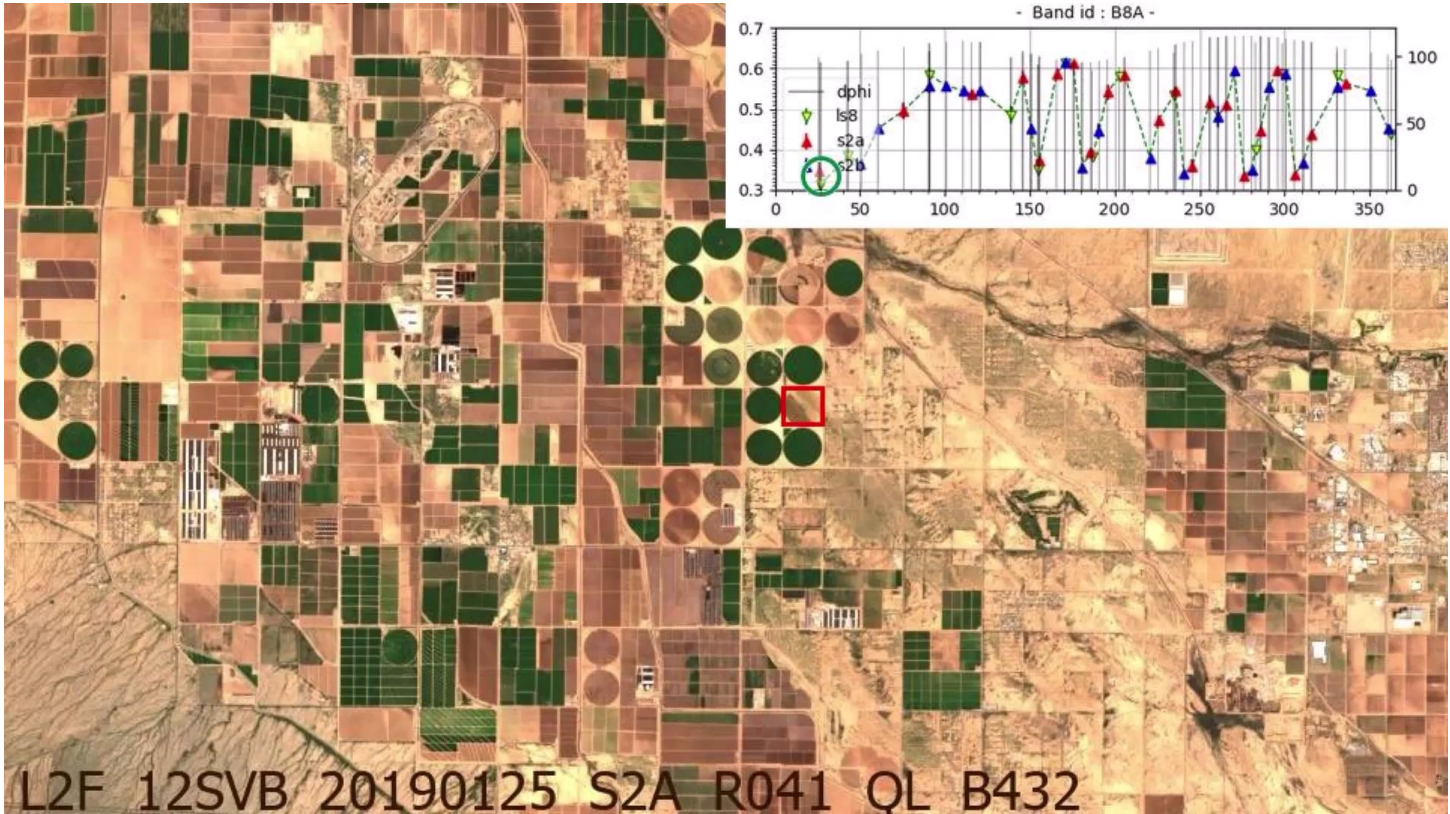


Sentinel-2 / Way Forward / L2H and L2F

- ✓ Goal is to provide S2-like surface reflectances with increased frequency.
- ✓ Surface reflectances will be generated through a harmonisation/fusion process combining data from different sensors (starting with Sentinel-2 and Landsat).



Sentinel-2 / Way Forward / L2H and L2F



USGS Landsat Collection 2

- **Landsat Collection 2 released to the public on 1 December 2020!**
 - Level-1 Top of Atmosphere/At Sensor
 - Level-2 Surface Reflectance and Surface Temperature
- **Products available through all standard USGS interfaces**
 - EarthExplorer (<https://earthexplorer.usgs.gov/>)
 - M2M (Machine-to-Machine)
 - Bulk Metadata Service
- **Products also available for direct cloud access within Amazon Web Services (AWS) – S3/COG/STAC**
- **Product generation commenced in September 2020 and entire Landsat archive (~8.8 million scenes) processed in ~5 weeks**
- **Now, focus is on generation of Collection 2 U.S. ARD tiles**

Collection 1 vs. Collection 2 Summary Geometry

Geometry	Collection 1		Collection 2		
Coverage	Global	U.S.	Global	Global *	U.S.
Geometric Registration Base	Global Land Survey (GLS) 2000		Landsat 8 OLI Harmonized w/ Sentinel-2 Global Reference Image (GRI)		
Digital Elevation Model	GLS DEM (SRTM / NED / CDED / DTED / NPI / GIMP / RAMP)**		GLSDEM / NASADEM / Alaska NED / CDEM / SNF / NPI / GIMP / ArcticDEM / RAMP**		
Map Projection	Universal Transverse Mercator / Polar Stereographic	Albers ***	Universal Transverse Mercator / Polar Stereographic		Albers ***
Resampling	Cubic Convolution		Cubic Convolution		
Pixel Size (Reflective) (MSS / TM, ETM+, OLI)	60m / 30m		60m / 30m		
Pixel Size (Thermal) (TM / ETM+ / TIRS)	30m / 30m / 30m		30m / 30m / 30m		
Datum	WGS84		WGS84		
Precision Correction Methodology	Baseline		Improved usage of Ground Control Points (GCPs) to produce more Level-1 Terrain Precision (L1TP) Products		

Collection 1 vs. Collection 2 Summary

Radiometry / Level-2 Processing

Radiometry	Collection 1		Collection 2	
Per-Pixel Solar Angle Corrections	None (based on scene center)	Full Per-Pixel Correction Applied	None (based on scene center)	Full Per-Pixel Correction Applied
Solar / Sensor Viewing Angle Information	Angle Coefficient File	None (Per-Pixel Correction Already Applied)	Angle Coefficient File + Band 4 Solar / Sensor Angle Bands	None (Per-Pixel Correction Already Applied)
TIRS Stray Light Correction (L8 Only)		Yes		Yes
TIRS Post-Stray Light Correction Adjustment (L8 Only)		None	Post-Stray Light Residual Bias Applied	Post-Stray Light Residual Bias Applied
Atmospheric Correction / Level-2 Processing				
Surface Reflectance Algorithm Version	N/A	LEDAPS v3.2.1 (TM / ETM+) LaSRC v1.3.0 (OLI / TIRS)	N/A	LEDAPS v3.4.0 (TM / ETM+) LaSRC v1.5.0 (OLI / TIRS)
Surface Temperature Algorithm Version	N/A	Landsat Single-Channel Surface Temperature v1.3.0	N/A	Landsat Single-Channel Surface Temperature v1.3.0
Surface Reflectance Fill Value	N/A	-9999	N/A	0
Surface Temperature Fill Value	N/A	-9999	N/A	0
Data Type / Scaling Factor (Surface Reflectance)	N/A	Signed 16-bit integer 0.0001 (no offset)	N/A	Unsigned 16-bit integer 0.0000275 + -0.2
Data Type / Scaling Factor (Surface Temperature)	N/A	Signed 16-bit integer 0.1 (no offset)	N/A	Unsigned 16-bit integer 0.00341802 + 149.0
L7 ETM+ SurfaceTemperature Band	N/A	Band 6L Only	N/A	Bands 6L and 6H Combined (6H if unsaturated, 6L otherwise)
Pressure Source	N/A	NCEP Grid (TM / ETM+) / Internally Calculated (OLI / TIRS)	N/A	NCEP Grid (TM / ETM+) / Internally Calculated (OLI / TIRS)

Collection 1 vs. Collection 2 Summary

Level-2 Processing (Continued)

Atmospheric Correction / Level-2 Processing (Cont.)	Collection 1		Collection 2	
Water Vapor Source	N/A	NCEP Grid (TM / ETM+) / MODIS CMA (OLI / TIRS)	N/A	NCEP Grid (TM / ETM+) / MODIS CMA (OLI / TIRS)
Air Temperature Source	N/A	NCEP Grid (TM / ETM+) / MODIS CMA (OLI / TIRS)	N/A	NCEP Grid (TM / ETM+) / MODIS CMA (OLI / TIRS)
Aerosol Source	N/A	Internally Calculated (TM / ETM+) / MODIS CMA (OLI / TIRS)	N/A	Internally Calculated (TM / ETM+) / MODIS CMA (OLI / TIRS)
Ozone Source	N/A	OMI / TOMS (TM / ETM+) / MODIS CMG (OLI / TIRS)	N/A	OMI / TOMS (TM / ETM+) / MODIS CMG (OLI / TIRS)
Atmospheric Elevation Model	N/A	Global Climate Model DEM	N/A	Global Climate Model DEM
Atmospheric Reanalysis Source (Surface Temperature)	N/A	North American Regional Reanalysis (NARR)	N/A	GEOS-5 FP-IT (new data) / MERRA-2 (archive data)
Emissivity Source	N/A	ASTER GED	N/A	ASTER GED
Surface Temperature Retrieval Method	N/A	Single-Channel (Landsat 4-8)	N/A	Single-Channel (Landsat 4-9)

Collection 1 vs. Collection 2 Summary

Packaging and Metadata

General Metadata	Collection 1		Collection 2		
Format	ODL	XML	ODL + XML + SpatioTemporal Asset Catalog (STAC)		
Landsat Metadata Standards Compliance	Fully Compliant	Limited	Improved Level-1 / Level-2 Consistency, Fully Compliant		Limited
IC Shutter Intrusion Detection	None	None	In Metadata		
Pixel-Level Metadata					
Cloud Masking	Cloud, Cloud Confidence, Cloud Shadow Confidence, Cirrus Confidence (L8 only)		Cloud, Cloud Confidence, Cloud Shadow, Cloud Shadow Confidence, Dilated Cloud, Cirrus (L8 /L9 only), Cirrus Confidence (L8 /L9 only)		
Land Characterization Bits	Snow / Ice Confidence		Snow, Snow / Ice Confidence, Water		
Radiometric Saturation	High-Level (Number of Impacted Bands Only)		Per-Band Saturation Bits		
Terrain Occlusion	Yes (L8 only)		Yes (L8 / L9 only)		
Product Format / Packaging					
Processing Level	L1TP / L1GT / L1GS	L2SP	L1TP / L1GT / L1GS	L2SP / L2SR [^]	L2SP / L2SR [^]
Format	GeoTIFF		Cloud-Optimized GeoTIFF (COG)		
Data Availability	WRS-2 Scene-Based	U.S. ARD Tile-Based	WRS-2 Scene-Based		U.S. ARD Tile-Based
Band Subsetting	All Bands Included in Product		User-Selectable Bands		
Data Access / Visualization Tools	EarthExplorer Glovis LandsatLook Viewer Machine-to-Machine (M2M) Bulk Download		EarthExplorer Machine-to-Machine (M2M) Bulk Download Direct Access via AWS S3 ^{^^}		

Summary Self-Assessment

USGS Landsat Collection 1 (U.S. ARD) -> Collection 2
Surface Reflectance – CARD4L PFS v5.0

	Threshold	Target
1. General Metadata		
1.1 Traceability	Not required	No
1.2 Metadata Machine Readability	Yes	Yes
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	No -> Yes
1.8 Geometric Accuracy of the Data	Not required	No -> Yes
1.9 Instrument	Yes	No -> Yes
1.10 Spectral Bands	No -> Yes	No -> Yes
1.11 Sensor Calibration	Not required	Yes
1.12 Radiometric Accuracy	Not required	No -> Yes
1.13 Algorithms	Yes	No -> Yes
1.14 Ancillary Data	No -> Yes	No -> Yes
1.15 Processing Chain Provenance	Not required	No -> Yes
1.16 Data Access	No -> 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	No -> Yes
2.6 Cloud Shadow	Yes	No -> Yes
2.7 Land/Water Mask	Not required	Yes
2.8 Snow/Ice Mask	Not required	No -> Yes
2.9 Terrain Shadow Mask	Not required	No
2.10 Terrain Occlusion	Not required	Yes
2.11 Solar and Viewing Geometry	No -> Yes	No
2.12 Terrain Illumination Correction	Not required	No
2.12 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 Normalization	Not required	Yes
3.4 Directional Atmospheric Scattering	No -> Yes	No -> Yes
3.5 Water Vapour Corrections	No -> Yes	No -> Yes
3.6 Ozone Corrections	Not required	No -> Yes
4. Geometric Corrections		
4.1 Geometric Correction	Yes	Yes

Table Key	
Threshold/Target Now Met in Collection 2	
Target Not Met	
Not assessable	

Summary Self-Assessment
USGS Landsat Collection 1 (U.S. ARD) -> Collection 2
Surface Temperature – CARD4L PFS v5.0

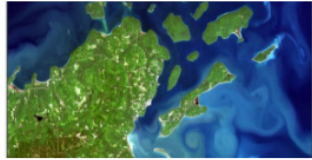
	Threshold	Target
1. General Metadata		
1.1 Traceability	Not required	Yes
1.2 Metadata Machine Readability	Yes	Yes
1.3 Data Collection Time	Yes	Yes
1.4 Geographical Area	Yes	Yes
1.5 Coordinate Reference System	Yes	Yes
1.6 Map Projection	Not required	Yes
1.7 Geometric Correction Methods	Not required	No -> Yes
1.8 Geometric Accuracy of the Data	Not required	No -> Yes
1.9 Instrument	Yes	No -> Yes
1.10 Spectral Bands	No -> Yes	No -> Yes
1.11 Sensor Calibration	Not required	Yes
1.12 Radiometric Accuracy	Not required	No -> Yes
1.13 Algorithms	Yes	No -> Yes
1.14 Ancillary Data	Yes	No -> Yes
1.15 Processing Chain Provenance	Not required	No -> Yes
1.16 Data Access	No -> 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	No -> Yes	No -> Yes
2.4 Saturation	Yes	Yes
2.5 Cloud	Yes	No -> Yes
2.6 Cloud Shadow	Yes	No -> Yes
2.7 Snow/Ice Mask	Yes	No -> 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

Table Key	
Threshold/Target Now Met in Collection 2	
Target Not Met	
Not assessable	

Landsat Collection 2

Landsat Collection 2 Level-1 and Level-2 surface reflectance and surface temperature scene-based products are available.

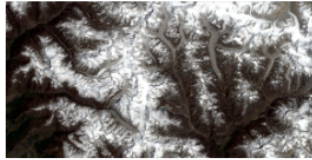
Level-1



Technical Information for Collection 2 Level-1.

[Learn More](#)

Level-2



Technical Information for Collection 2 Level-2.

[Learn More](#)

Collection 1 vs Collection 2



Quick Reference Guide for Changes Between Collection 1 & Collection 2.

[Learn More](#)

[Return to Landsat Collections Overview](#)

[Access Landsat Collection 1 Information](#)

Landsat Collection 2 marks the second major reprocessing effort on the Landsat archive by the USGS that results in several data product improvements that harness recent advancements in data processing, algorithm development, and data access and distribution capabilities.

A primary characteristic of Collection 2 is the substantial improvement in the absolute geolocation accuracy of the global ground reference dataset - which improves interoperability of the Landsat archive through time. Collection 2 also includes updated global digital elevation modeling sources and calibration and validation updates.

Collection 2 includes Landsat Level-1 data for all sensors since 1972, as well as global Level-2 surface reflectance and surface temperature scene-based products from 1982 to present (excluding Landsat 1-5 Multispectral Scanner (MSS)) within defined constraints.

Collection 1 based products, including: Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Collection 1 Level-1, U.S. Landsat ARD and Level-3 Science Products data processing and downloads **will remain available for at least one year after Collection 2 is publicly released.**

Visit this [Landsat Data Access](#) web page to discover how to search and download all Landsat products from USGS data portals.



The USGS are the first recipients of the Committee on Earth Observation Satellites (CEOS) endorsement for Analysis Ready Data for Land (CARD4L)-compliant products for Landsat Collection 2 Level-2 products. This internationally recognized certification ensures that Landsat Collection 2 Level-2 products are more interoperable with other Earth observing platforms, such as Europe's Sentinel-2 satellite, as they too work towards CARD4L-compliant products.

(Used with permission by CEOS.)

CEOS Analysis-Ready Datasets

The following table summarises all of the satellite EO datasets that have been assessed as CEOS Analysis Ready Data for Land (CARD4L). DOI links are provided for access, along with links to further information, sample products, and the completed CARD4L self-assessment and peer review outcome documents.

Product	CARD4L Type	PFS Version	Agency	Mission(s)	Threshold Specification	Target Specification	Access (DOI)	Info	Self Assessment	Peer Review	Sample Products
Landsat Collection 2	Surface Reflectance	v4.1	USGS	Landsat 8, 7, 5, 4	100%	81%	Landsat 4-5, 7, 8	Link	PDF	PDF	Link
Landsat Collection 2	Surface Temperature	v4.2	USGS	Landsat 8, 7, 5, 4	100%	93%	Landsat 4-5, 7, 8	Link	PDF	PDF	Link

Under Development / Assessment

Product	CARD4L Type	PFS Version	Agency	Mission(s)	Access (DOI)	Info	Self Assessment	Peer Review	Sample Products
Landsat Collection 2	Surface Reflectance	v5.0	USGS	Landsat 8, 7, 5, 4	Landsat 4-5, 7, 8	Link	PDF	TBA	Link
Landsat Collection 2	Surface Temperature	v5.0	USGS	Landsat 8, 7, 5, 4	Landsat 4-5, 7, 8	Link	PDF	TBA	Link
Sentinel-2 Level-2A	Surface Reflectance	v5.0	ESA	Sentinel-2A, 2B	Link	Link	TBA	TBA	TBA
Sentinel-2 Level-2A (E84)	Surface Reflectance	v5.0	Element 84	Sentinel-2A, 2B	TBA	TBA	TBA	TBA	TBA
EnMAP	Surface Reflectance	v5.0	DLR	EnMAP	TBA	Link	TBA	TBA	Link

USGS Landsat / Way Forward

- **Complete CARD4L SR/ST PFS v5.0 compliance check**
- **Initiate CARD4L SR/ST PFS v6.0 self-assessment / peer review / compliance check**
 - Latest version pending annual review/update
- **Finalize CARD4L AR PFS v1.0 (May 2021, LSI-VC-10)**
- **Investigate remaining CARD4L “target-level” gaps with USGS Landsat Collection 3**
 - Traceability
 - Uncertainty
 - BRDF Correction
 - Terrain Illumination Correction
 - Terrain Shadow Mask

Copernicus Sentinel-1 CARD4L Products

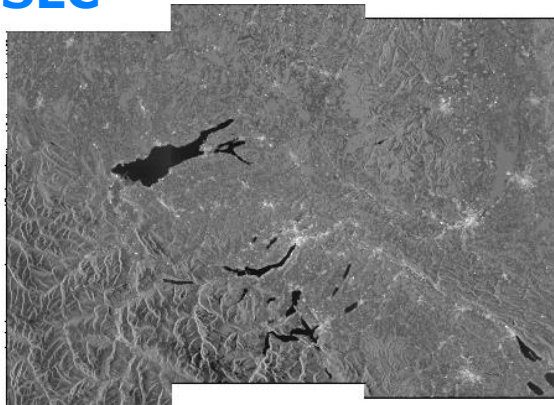
Overview

Before CARD4L (*status quo*):

- Radar products typically delivered in slant-range or ground-range
 - e.g. Sentinel-1:
 - Single-Look-Complex (**SLC**) products with backscatter **amplitude** and **phase** in slant range raster(s)
 - Ground-Range-Detected (**GRD**) products with backscatter **amplitude** in ground range raster

S-1A
2019.07.04

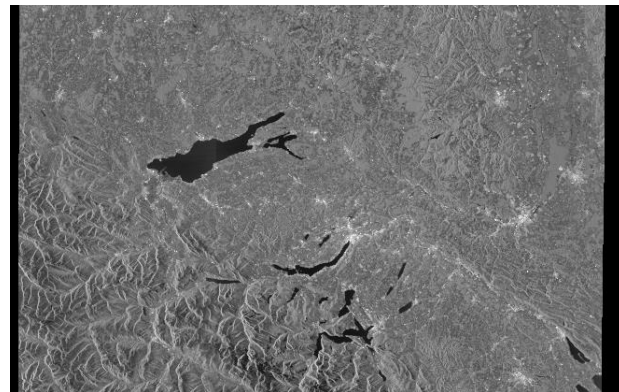
SLC



Azimuth

Slant Range

GRD



Azimuth

Ground Range

Copernicus Sentinel-1 CARD4L Products

Overview

CARD4L Vision for SAR: Radiometric Terrain Correction:
Terrain-flattened Gamma Nought Backscatter

NRB

Wide-area application in e.g.

- **Digital Earth Africa** by Sinergise & GA

<https://www.digitalearthafrika.org/platform-resources/analysis-ready-data/sentinel-1>



Method:

Small, D. (2011). Flattening Gamma: Radiometric Terrain Correction for SAR Imagery. *IEEE TGRS*, 49(8), 3081–3093. doi: 10.1109/TGRS.2011.2120616

Open-source implementations in e.g. ESA SNAP, NASA ISCE



Copernicus Sentinel-1 CARD4L Products

Overview

CARD4L Vision for SAR:

- Image products all delivered in [map coordinates](#)
- Image product brightness calibrated to [terrain-flattened gamma nought](#) standard across all products
- [Multi-track](#) and [multi-sensor](#) integration will be simplified by:
 - Standardised products with *common core properties* in map geometry
 - Terrain-flattening applied throughout to allow comparison across multiple tracks on a “level playing field”

Product		LSI-VC Endorsement
NRB	Normalised Radar Backscatter Radiometrically Terrain Corrected Backscatter Amplitude	V5.0 - 12 May 2020
POL	Polarimetric SAR	V3.0 - 12 May 2020
InSAR	SAR Interferometry in slant range	
GSLC	Geocoded SLC for interferometry	

Copernicus Sentinel-1 CARD4L Products

Overview

CARD4L Vision for SAR:

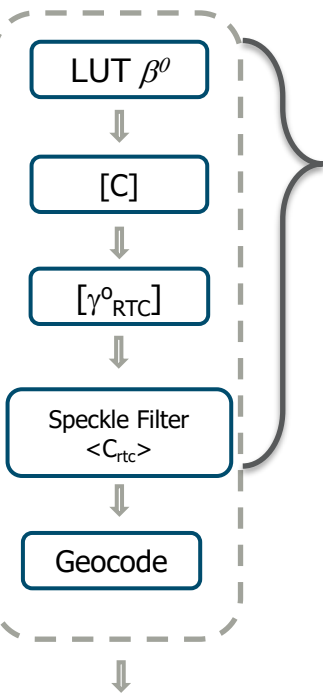
- Image products all delivered in map coordinates in γ_T^0 backscatter convention with terrain-flattening applied
- **Normalised Radar Backscatter (NRB)**
 - Radiometrically Terrain Corrected (RTC) Backscatter
 - Terrain-flattened Gamma Nought (γ_T^0)
 - Revision of PFS 5.x to be submitted for LSI-VC for May 2021
- **Polarimetric Radar (POL)**
 - Preserving coherent polarimetric content (phase information)
- **Interferometry (InSAR)**
 - Interferograms formed in slant-range geometry; Time-series
- **Geocoded SLC (Single-Look-Complex)**
 - Move SLC from slant-range native geometry to map coordinates

POL: Normalised Covariance Matrix ARD

Credit to François Charbonneau (NRCAN) & CARD4L team

ARD Generation Processing

SLC product(s)



1. Full or dual in any basis (linear, circular, compact)

$$k = \begin{pmatrix} S_{HH} \\ \sqrt{2}S_{HV} \\ S_{VV} \end{pmatrix}$$

scattering vector

2. Covariance matrices from calibrated β^0 data

[C2] dual-pol (HH-HV)

$$[C3] = k k^H = \begin{bmatrix} |S_{HH}|^2 & \sqrt{2}S_{HH}S_{HV}^* & S_{HH}S_{VV}^* \\ \sqrt{2}S_{HV}S_{HH}^* & 2|S_{HV}|^2 & \sqrt{2}S_{HV}S_{VV}^* \\ S_{VV}S_{HH}^* & \sqrt{2}S_{VV}S_{HV}^* & |S_{VV}|^2 \end{bmatrix}$$

[C2] dual-pol (VV-VH)

3. γ^0 normalization to "flatten" radar backscatter (RTC)

4. Speckle filtering (ex.: boxcar and/or Sigma-Lee, 7x7 to 11x11 window). 50 to 100 independent looks required

$$\langle C_{\gamma_{rtc}^0} \rangle = \frac{1}{N} \sum_i [C_{rtc\ i}] = \begin{bmatrix} \langle |S_{HH}|_{rtc}^2 \rangle & \sqrt{2} \langle (S_{HH}S_{HV}^*)_{rtc} \rangle & \langle (S_{HH}S_{VV}^*)_{rtc} \rangle \\ \sqrt{2} \langle (S_{HV}S_{HH}^*)_{rtc} \rangle & 2 \langle |S_{HV}|_{rtc}^2 \rangle & \sqrt{2} \langle (S_{HV}S_{VV}^*)_{rtc} \rangle \\ \langle (S_{VV}S_{HH}^*)_{rtc} \rangle & \sqrt{2} \langle (S_{VV}S_{HV}^*)_{rtc} \rangle & \langle |S_{VV}|_{rtc}^2 \rangle \end{bmatrix}$$

5. Geocoding with nearest-neighbour or bilinear resampling to preserve matrix elements integrity. Layers are real and complex numbers. Only upper triangle matrix elements are saved

NRB

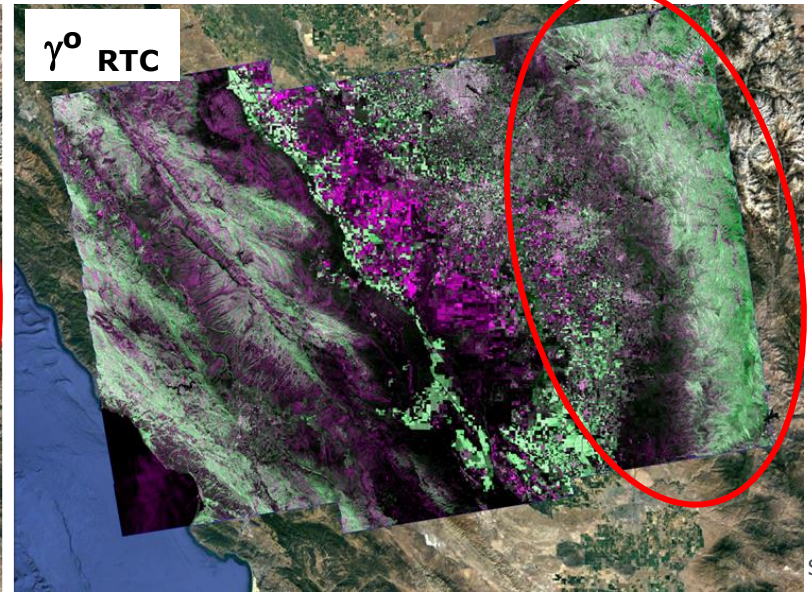
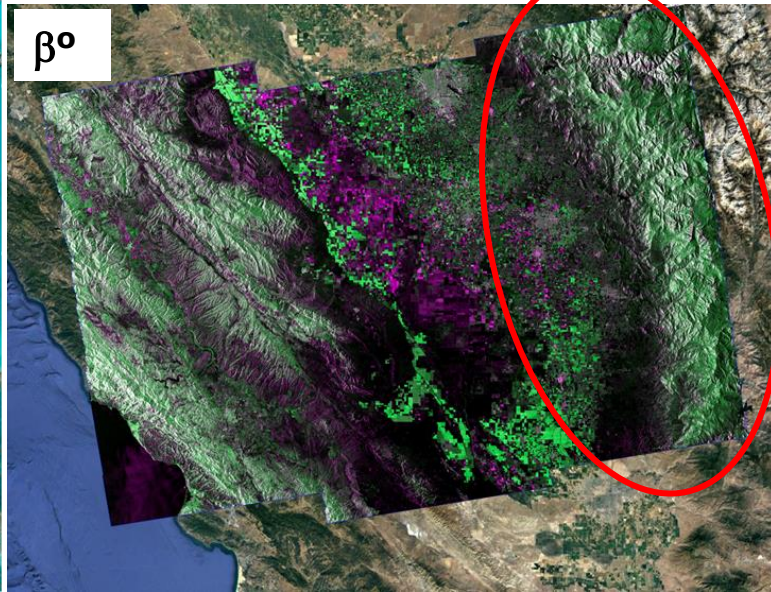
POL: Gamma Nought Covariance Matrix ARD

Credit to François Charbonneau (NRCAN) & CARD4L team

Sentinel-1 VV-VH color composite over San Andreas Fault

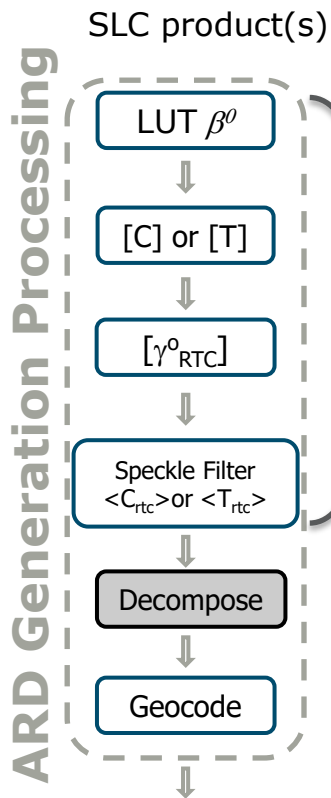
- Diagonal elements of the covariance matrix are equivalent to NRB

$$\langle C_{\gamma_{rtc}^{\circ}} \rangle = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 2\langle |S_{VH}|_{rtc}^2 \rangle & \sqrt{2}\langle (S_{VH}S_{VV}^*)_{rtc} \rangle \\ 0 & \sqrt{2}\langle (S_{VV}S_{VH}^*)_{rtc} \rangle & \langle |S_{VV}|_{rtc}^2 \rangle \end{bmatrix}$$



POL: Polarimetric Decomposition ARD

Credit to François Charbonneau (NRCAN) & CARD4L team



Objective: To raise the polarimetric information to interpretation level

Steps 1 to 4: Exactly the same as for covariance matrix ARD

5. Polarimetric decomposition

- Yamaguchi, Cloude-Pottier, van Zyl, Freeman-Durden, Touzi, Generalized Freeman-Durden, etc.
- Output layers depend on chosen polarimetric decomposition (intensities, angles, classes, ...)

6. Geocoding

Nearest-neighbor (NN) interpolation preferred to preserve decomposed parameter integrity, other choices such as bilinear, Sinc, Bspline, etc. allowed depending on type of data (i.e.: intensities, angles (α, β, χ) , entropy, ...)

IMPORTANT: If NN interpolation is used for CovMat ARD and for Pol. Decomposition ARD, polarimetric decomposition outputs are IDENTICAL

CARD4L InSAR Product Family Specification

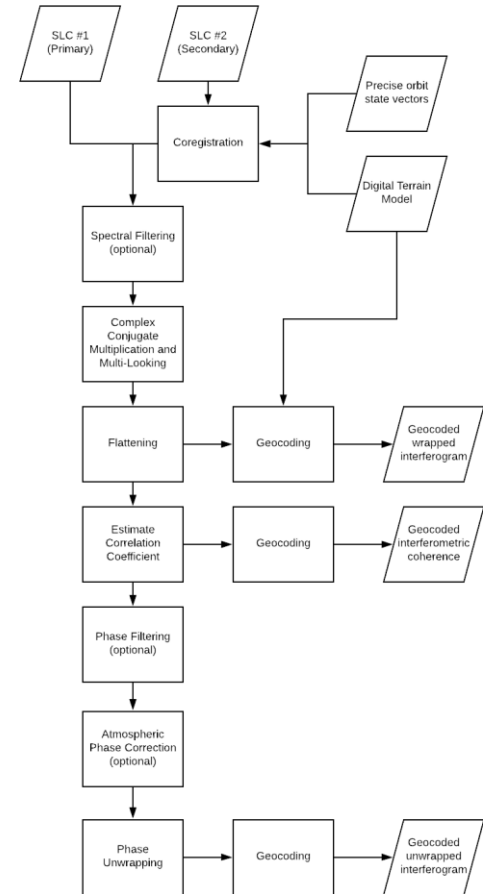
In development, credit to Matthew Garthwaite (GA) and CARD4L team

“Standard” InSAR workflow

- A series of mature algorithms applied in a regular order
- Ideal candidate for CARD4L
 - remove barriers to entry for “novice” users
- PFS will cover stack processing with one primary reference image
- CARD4L products:
 - Geocoded unwrapped interferogram
 - Geocoded wrapped interferogram (optional)
 - Geocoded interferometric coherence

Data centres distributing InSAR products, e.g.:

- COMET-LiCS Sentinel-1 InSAR portal
- Alaska Satellite Facility
- NASA-JPL *“The ARIA Standard Displacement Product is a Geocoded Unwrapped Interferogram product”*
- GA – *plans to systematically process and distribute InSAR products for Australia*



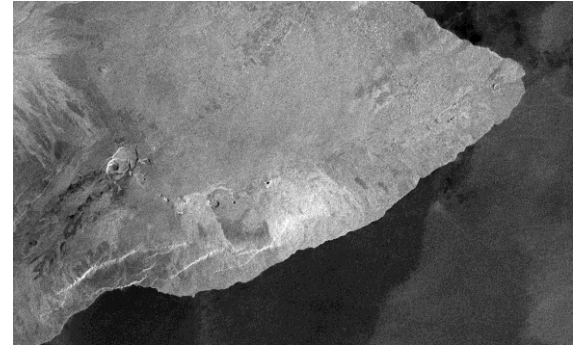
CARD4L GSLC – Geocoded SLC

In development, credit to Howard Zebker (Stanford) and CARD4L team

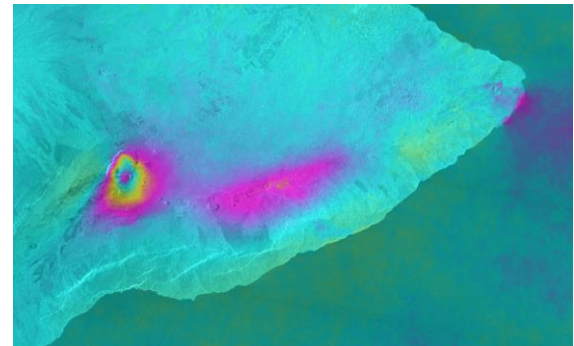
GSGLC, a user-friendly product

- InSAR and other analyses usually start with SLC images
 - Most SLCs are produced in radar coordinates and require significant phase corrections to yield deformation
 - For many users:
 - Radar coordinates are mysterious and require resampling
 - Phase corrections for viewing and topography are complex and need InSAR expertise
 - Avoid these impediments with GSGLC products
 - GSGLC products enable simple ingestion of radar data in common coordinates
 - These are readily combined for InSAR analysis
-
- InSAR vs. GSGLC

Radar backscatter image



InSAR deformation – e.g. Volcanism in Hawaii



CARD4L S

Overview

CARD4L St

Product	
NRB	Northern Radio
POL	Polar
InSAR	SAR
GSLC	Geo
MSB	Mult Multi- ampli Metho Small, D Analysis doi 10..

Composite backscatter from 34 scenes
between 2017/04/01 00:00:00 and 2017/04/02 23:59:59

