Minutes v1.0
LSI-VC-9 Teleconference #3: CARD4L and the Product Family Specifications

Tuesday 12 May 2020

Participants

CONAE:	Danilo Dadamia
ESA:	Ferran Gascon
EC/JRC:	Zoltan Szantoi
GA:	Adam Lewis, Andreia Siqueira, Medhavy Thankappan, Fuqin Li
Labsphere:	Chris Durell, Brandon Russell
JAXA:	Takeo Tadono, Ake Rosenqvist
KARI:	Chiho Kang, Daehoon Yoo
LAPAN:	Kustiyo, Danang
LSI-VC Sec:	Matt Steventon
NOAA:	Kevin Gallo
SEO:	Brian Killough
UK Catapult for UKSA:	Electra Panagoulia
University of Zurich:	David Small
USGS:	Steve Labahn (Chair), Jenn Lacey, Tim Stryker, Chris Barnes

The presentation slides compiled for this meeting are attached in Appendix A.

Introduction

- Steve Labahn (USGS, LSI-VC Co-Lead, Chair) welcomed everyone to the third call of the LSI-VC-9 meeting. PFS updates, the status of CARD4L, and agency plans with regard to CARD4L are the focus for today's call.

PFS Updates

- Andreia Siqueira (GA) presented background on the first update cycle for the original three PFS (slides 3-7).
- Feedback was received from various sources and a thorough update process was undertaken. Updates were shared via the LSI mailing lists last week, for review before virtual endorsement. The final documents are available here. Changelogs are available here (also summarised on slides 5-6).
- Andreia requested all feedback to be sent to her by May 22. Virtual endorsement via email is targeted for June 2020.
- Steve thanked Andreia for her great effort coordinating the annual updates of the PFS.

SAR Normalised Radar Backscatter (NRB) CARD4L

- Ake Rosenqvist (JAXA) presented developments in both SAR missions and the user base (slide 9). CARD4L for SAR is particularly helpful at lowering the barrier of entry for users with SAR data, even more so than for optical data.

- The NRB PFS has been updated and the Polarimetric Radar (POL) PFS is to be endorsed for the first time today. Other PFS are in the pipeline (Geocoded SLC, aiming for endorsement in 2021 and Interferometric Radar (InSAR) also targeting endorsement in 2021, perhaps at LSI-VC-11).
- The NRB document has been updated and v4.7 was shared with the LSI-VC mailing list on March 16. No comments were received. Ake proposes endorsement of v4.8 (minor modifications from v4.7 – all outlined in the changelog) today and its adoption as v5.0.
- Ake reviewed the changes to the NRB PFS in v4.8 (see slides 15-16). Overall the format was adjusted to tailor the PFS structure to better fit SAR (rather than the original optical basis). The SAR team has also worked to accommodate cases where multiple observations are used for a product, and in future are seeking to accommodate multi-source inputs.
- He reviewed some different metadata contributions. The SAR PFS team developed a metadata specification to accompany the NRB PFS. It is not mandatory (target requirement). Alignment with IEEE, STAC, OGC, or ISO standards will be considered (possibly by LSI-VC-11). The metadata specification is itself referenced in the PFS as a target requirement for metadata.
- Chris Durell (Labsphere) asked if there is any coordination between CEOS CARD4L and IEEE P4002 and SICD efforts. He noted that Leland Pierce is leading the IEEE P4002. Ake noted there is no coordination yet, but he is very interested in making sure at least the terminology in the PFS is consistent with their terminology. Ake has been contacted by Leland Pierce.

DECISION 01	Normalised Radar Backscatter (NRB) Product Family Specification v4.8 was endorsed.	
LSI-VC-9-04	USGS to undertake an editorial check of NRB v4.8, before advancing the document to v5.0. Matt to post NRB PFS v5.0 on ceos.org/ard when ready.	**ASAP**

- Adam Lewis (GA, LSI-VC Co-Lead) commended the great effort of Ake and the whole SAR PFS team. He suggested that the importance of this work is perhaps not recognised as much as it should be in both CEOS and outside. There is great value in reducing the barriers associated with SAR data and the SAR community is doing a great service with this work. LSI-VC should look for further opportunities to flag this effort and communicate the benefits.
- The next big challenge is to encourage agency uptake of the SAR PFS. Ake noted there has been a great shift in acceptance of the ARD concept in the SAR community since this work started.

SAR Polarimetric Radar (POL) CARD4L

- Ake Rosenqvist (JAXA) also presented the initial POL PFS for endorsement.
- POL v2.8 was shared with the LSI-VC mailing list on March 16. No comments were received. Ake proposes endorsement of v2.9 (minor modifications from v2.8 – all outlined in the changelog) today and its adoption as v3.0.

- The POL PFS covers both polarimetric decomposition and polarimetric covariance matrix products. The structure is based on the NRB PFS and metadata specifications were also developed for this PFS. Ake reviewed both types of product (slide 26 and 28) and different types of metadata.
- Sample datasets have been produced but we still need some way to link these long-term on the CEOS ARD website.
- Ferran Gascon (ESA) noted the need to make it clear that these are sample products only. Non-sample products will only be advertised on the CEOS ARD website once they are fully assessed and operationally available.
- Ake added that the target audience for the sample products is the data providers themselves, rather than users. He suggested that agencies could host the data but have it linked on the CEOS ARD website.

LSI-VC-9-05	Matt and Ake to revisit the action on hosting and linking sample datasets for SAR products on the CEOS ARD website.	**ASAP**

- Adam Lewis (GA, LSI-VC Co-Lead) asked if CEOS Agencies are looking to produce data to the specifications. Ake confirmed that JAXA are on the way towards this, however with many of the other agencies it is still up to us to persuade them. In many cases mission development has gone on in parallel (e.g., ALOS-4) and the various data processing systems are already set. If CARD4L is not considered from the outset and built into these processing chains, external approaches are necessary (could be software/tool-based solutions).

DECISION 02	Polarimetric Radar (POL) Product Family Specification v2.9 was endorsed.	
LSI-VC-9-06	USGS to undertake an editorial check of POL v2.9, before advancing the document to v3.0. Matt to post POL PFS v3.0 on ceos.org/ard when ready.	**ASAP**

Aquatic Reflectance (AR) PFS

- Steve Labahn (USGS, LSI-VC Co-Lead) covered two topics: the AR PFS and Landsat's provisional AR product (see slides 36-37).
- An initial draft of the AR PFS was completed in January 2020. Various reviews and expert inputs are ongoing and planned. A science expert review is planned by the end of June.

LSI-VC-9-07	All to consider nominations for the Aquatic Reflectance PFS science expert review, which is planned by end-June.	**End-May**

- Steve hopes to provide a final draft of the AR PFS for LSI-VC review by the end of July, ahead of its planned endorsement at LSI-VC-10.
- Ferran Gascon (ESA) asked how the Landsat AR product compares to the standard surface reflectance over land. He noted that ESA is planning to have a single product for both land and coasts/inland waters. ESA plans to use the same units for each of these. Steve has also been pushing for an integrated product, but initially they will be handled separately. The products will however be in the same units (unitless).
- Steve noted the backup slides (80-83) on the measurement approach.

LSI-VC-9-08	Steve to send Ferran some more information regarding how USGS is handling the Landsat Aquatic Reflectance provisional products and how the approach differs from land cover observations.	**ASAP**

- Ferran also asked whether there is any coordination with OCR-VC on the AR PFS. Steve would like to involve them in the science expert review and he is also closely coordinating with the CEOS-COAST project, which could be a key source of feedback.
- Ferran noted the ACIX-Aqua exercise which is comparing different approaches for Landsat and Sentinel-2 over aquatic environments.

Status of CARD4L Datasets

- Matt Steventon presented an overview of the status of CARD4L assessments, expected future assessments, efforts to produce CARD4L and ARD, and some issues (slides 38-45). He noted that data is often fragmented across the world with many different datasets, locations and access options. Commitment to global, top-down production is needed, otherwise users are left to create subsets of CARD4L themselves in an *ad hoc* manner. Data accessibility is also key, and cloud hosting of CARD4L is particularly efficient in this regard. He asked about the prospect of increasing cloud availability of agency-produced CARD4L.
- Matt suggested two actions for LSI-VC along these lines: to see if NASA could consider the possibility of assessing MODIS and VIIRS products against the CARD4L specifications – noting industry demand on informal consultation call, and for LSI-VC to encourage a Sentinel-1 CARD4L assessment by ESA.
- Brian Killough (NASA, SEO) reported on efforts he has undertaken to get an analysis-ready form of Sentinel-1 NRB. He originally contracted e-GEOS to pre-process the data, but this has fallen through. He is now working with Sinergise for Sentinel-1 processing. The intent is to establish an on-demand cloud processing flow for Sentinel-1 data to supply various Data Cube instances. Part of the contract will include looking at CARD4L compliance of the resulting products.
- Adam Lewis (GA, LSI-VC Co-Lead) reported that Element 84 are contracted by Digital Earth Africa to process Sentinel-2 into COG and STAC format, and to undertake a CARD4L assessment for this data.

- Ake Rosenqvist (JAXA) reported that the Geocoded SLC PFS (GSLC, in development) is based on the NISAR product documentation. He believes that CARD4L GSLC will be based on the NISAR products to a large extent, so we expect that to have CARD4L compliance.
- Medhavy Thankappan (GA) reported on the CARD4L compliance of Digital Earth Australia products. GA's Landsat Collection 3 should meet all the requirements for the Threshold level of CARD4L. GA's Sentinel products will inherit what comes from ESA.

LSI-VC-9-09	LSI-VC Leads to coordinate a communication from LSI-VC to EC/Copernicus regarding the need for Sentinel-1 NRB CARD4L as a core product, citing examples of various *ad hoc* efforts ongoing to create Sentinel-1 NRB CARD4L – as evidence of demand for this type of product. Zolti to confirm the best approach from the EC side (convincing Copernicus services of utility could be an approach).	**ASAP**
LSI-VC-9-10	Brian and Adam to share their Sentinel-1 NRB CARD4L examples (e.g., Sinergise, DEAfrica, other use cases) to help inform the communication called for in action **LSI-VC-9-08**.	**ASAP**
LSI-VC-9-11	Steve/USGS to follow up NASA LSI-VC contacts regarding the possibility of assessing MODIS and VIIRS products against the CARD4L specifications.	**ASAP**

WGCV CARD4L Peer Reviews

- Medhavy Thankappan (GA) reported an update on the WGCV CARD4L peer review process and the status of the Landsat and Sentinel-2 assessments (slides 47-54). He noted a summary of feedback from the CARD4L evaluations (slide 55) and suggested that the LSI-VC Leads and Andreia schedule a teleconference with WGCV representatives to review this feedback.

LSI-VC-9-12	Andreia to set up a telecon between the LSI-VC Leads and WGCV contacts to review the points on slide 55 of the LSI-VC-9 Telecon #3 presentation (Summary of Feedback from CARD4L Evaluation).	**ASAP**

- Steve Labahn (USGS, LSI-VC Co-Lead) thanked Medhavy for his effort on the process and thanked WGCV for the support.

USGS CARD4L Update

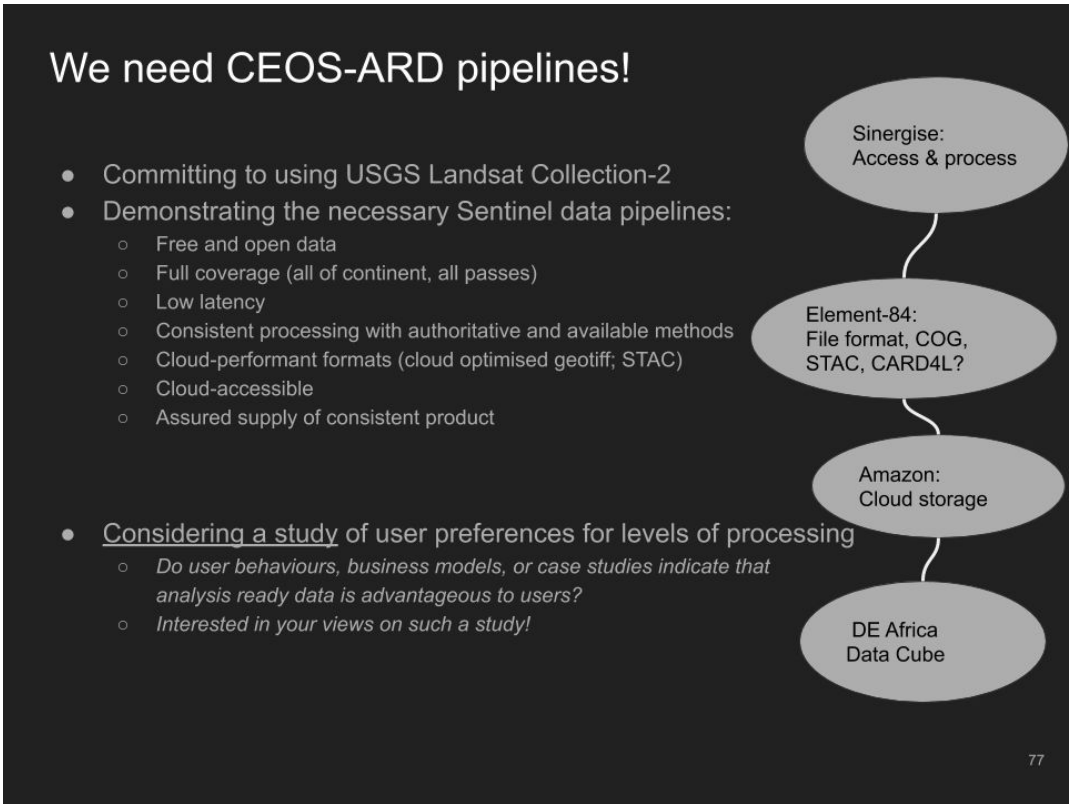
- Steve Labahn (USGS, LSI-VC Co-Lead) presented an update on USGS Landsat Collection 2, the CARD4L self-assessments for Collection 2, and trials with Amazon Web Service hosting and processing of this data (slides 57-64).
- He confirmed that USGS will provide tools like EarthExplorer and a machine-to-machine gateway on AWS. If users take advantage of these systems, USGS will cover any egress costs. If users choose to use their own tools, there may be egress costs associated with using Collection 2 on AWS.
- Digital Earth Africa was used as a test for trial production of ARD. The first scaling test processed 183,077 Landsat 8 scenes from 2013-2019 over Africa to Level-2 for approximately $5700 USD.

JAXA CARD4L Update

- Takeo Tadono (JAXA) presented an update on JAXA's EO mission portfolio, the ALOS series, and the global mosaics and forest/non-forest maps (slides 65-71). Takeo noted various re-processing efforts to reach CARD4L compliance with the mosaics, and also the planned release of CARD4L format conversion software for scene-based PALSAR and PALSAR-2 data.
- Steve Labahn (USGS, LSI-VC Co-Lead) commended the effort to release conversion software to help users produce CARD4L compliant data. He added that the re-processing effort is resource intensive but should pay off, noting USGS' similar reprocessing efforts.

Digital Earth Africa Update

- Adam Lewis (GA, LSI-VC Co-Lead) presented on Digital Earth Africa (slides 72-77).
- Digital Earth Africa is based on the Open Data Cube model and depends on having a reliable supply of CEOS ARD. It uses continental-scale CEOS ARD, including the ALOS mosaics, provisional Collection 2, and self-processed Sentinel-2 CARD4L (through Element84, not officially assessed as CARD4L). They are also working on establishing a pipeline for Sentinel-1 CEOS ARD (not officially assessed).
- To have impact, Digital Earth Africa needs to be able to produce operational full-resolution products like fractional cover or median surface reflectance in order to generate unique continental-scale information like continental water summaries or continental assessments of coastal changes.
- Adam presented on the data supply chains necessary for Digital Earth Africa and what the project is doing to establish flows of Sentinel data:



- He noted the importance of the action recorded earlier (**LSI-VC-9-08**) on putting together a case for data providers such as EC / ESA encouraging them to establish routine, global supplies of Analysis Ready Data. The proposed study of user preferences for levels of processing would be additional evidence for such requests.
- Ake Rosenqvist (JAXA) supported the idea of such a study, but noted that all we are trying to achieve with CARD4L is improving the radiometric and geometric quality of data – which should be welcomed by all users.
- Steve Labahn (USGS, LSI-VC Co-Lead) noted some statistics from the USGS ESPA system that shows Level-2 data is more in demand than Level-1. Adam said there is also evidence from the Copernicus Sentinel data access annual reports that is consistent with this statement.
- Users are relying on ESA, USGS, JAXA, etc. to produce these globally available data supplies.
- Ferran Gascon (ESA) noted that ESA is planning to meet the CARD4L threshold level with their Level-2A data in 2020. The next big step to reach an ideal level of support for projects like Digital Earth Africa would be back-processing of the entire archive to Level-2A, which is foreseen to start next year.
- Ferran added that ESA is reviewing COG internally, due to strong user demand. ESA is also reviewing the possibility of adding STAC for Sentinel-2. Further examples of user demand for both of these technologies would be helpful.

LSI-VC-9-13	Steve to share USGS Collection 2 work done around COG and STAC (including the format study, slides from ARD19) to support other agencies interested in working in this direction (e.g., ESA/Ferran, EC/Zolti) – including any user feedback / examples of demand. Inputs from others are also welcome. **Context:** Zolti noted the Copernicus User Requirements Reviews and the need for supporting evidence to initiate new work around topics like COG, STAC, etc.	**COMPLETE**

- Ferran reported that there is an ESA activity to investigate a Sentinel-1 ARD product, but there is nothing in the pipeline regarding systematic global production of such an ARD product. Adding a new standard product for Copernicus needs to be agreed by ESA and EC, and this is a lengthy process involving upper management, member states, users, etc. Copernicus is user-driven, and users are represented by the member states. Anything requested by the Copernicus Services are top priorities. Convincing Copernicus Services of the utility of Sentinel-1 CARD4L could be an approach. LSI-VC action on this topic is captured in action **LSI-VC-9-08** above.

Closing

- Steve Labahn (USGS, LSI-VC Co-Lead) thanked everyone for their attendance and contributions to the discussions. He welcomed further updates on agency CARD4L plans via email. There may also be time during LSI-VC-9 teleconference #4.
- LSI-VC-9 Teleconference #4: LSI-GEOGLAM, LSI-Forests & Biomass, CEOS ARD Strategy, Loose Ends & Wrap-up will be held on May 13, 07:00 – 10:00 US East (other local times) [Presentation].

Appendix A: Meeting Presentation Slides

CARD4L and the Product Family Specifications (PFS)

LSI-VC-9 Teleconference #3

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Overview

- Consider for endorsement the first updates to the original three CARD4L PFS: Surface Reflectance, Surface Temperature, Normalised Radar Backscatter
- Consider the new Synthetic Aperture Radar Polarimetric Radar (POL) PFS for endorsement
- Discuss the new Aquatic Reflectance CARD4L PFS
- Review status and trajectory of CARD4L datasets
- WGCV report on ongoing CARD4L assessments
- Hear from participants the latest agency plans regarding CARD4L

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PFS Annual Updates

Surface Reflectance, Surface Temperature
A. Siqueira

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Background on the PFS documents update

- Feedback received from USGS and ESA
  - Formal self-assessment
  - SR and LST products (Landsat, Sentinel 2 and Sentinel 3)
- Discussions and PFS consensus update
  - 3 Teleconferences (27 February and 6 and 7 May 2020)
  - Additional communication via emails
- Updated PFS documents
  - Minor editorial changes throughout the document
  - Specific requirements updated
  - https://tinyurl.com/y8empss3
- Details on each requirement update can be seen in the links below:
  - Surface Reflectance: https://tinyurl.com/y8qxblhd
  - Land Surface Temperature: https://tinyurl.com/y84ftwmz

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SR PFS doc main requirements updates

Requirement	Update
General Metadata	
1.2 Metadata machine readability	- Rewording the threshold level
1.3 Data collection time	- Rewording the threshold level
1.7 Geometric correction methods	- Change word ancillary to auxiliary in target level
1.12 Radiometric accuracy	- Change the word ***data*** to "***version of the data or product"*** in the target level
1.13 Algorithms	- Added Note 2 (from target level) to the threshold level
1.14 Auxiliary Data	- Change word ancillary to auxiliary in the Threshold level (as per definition table) - Rewording Target level
1.16 Data access	- Change Target requirement to be the same as the threshold requirement
Per-Pixel Metadata	
2.1 Metadata Machine Readability	- Target reverts to threshold - Remove reference to the ISO standard
2.11 Illumination and viewing geometry	*- Delete from target level the following: " including coefficients used for terrain illumination correction"* - Introduce a new requirement terrain illumination correction 2.12: ***Threshold*** (not required), ***Target*** "Coefficients used for terrain illumination correction are provided for each pixel"
2.12 Aerosol Optical Depth Parameters	- Introduced a new requirement ***Terrain Illumination Correction*** as ***2.12***
2.13 Aerosol Optical Depth Parameters	- re-numbered ***Aerosol Optical Depth Parameters*** as ***2.13***
Radiometric and Atmospheric Corrections	
3.3 Measurement Normalisation	- Add reference to DOI - Rewording target level

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LST PFS doc main requirements updates

Requirement	Update
General Metadata	
1.2 Metadata Machine Readability	- Rewording the threshold level
1.14 Auxiliary Data	- Change word ancillary to auxiliary in the Threshold level (as per definition table) - Rewording Target level
1.16 Data access	- Change Target requirement to be the same as the threshold requirement
Per-Pixel Metadata	
2.1 Metadata Machine Readability	- Target reverts to threshold - Remove reference to the ISO standard

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Next Steps

- Email sent on May 9 seeking for further comments/feedback from the LSI-VC community
- Feedback due to COB May 22
  - Send to: *andreia.siqueira@ga.gov.au*
- Comments received until May 22 will be considered for this review cycle and
- Aiming for virtual endorsement by the LSI-VC community in the beginning of June 2020

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CARD4L SAR background & Normalised Radar Backscatter (NRB) PFS Annual Update

T. Tadono / A. Rosenqvist

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SAR mission development

- Wider swaths
- Increased spatial resolution
- Systematic wall-to-wall obs strategies,
- Polarimetric and interferometric options.

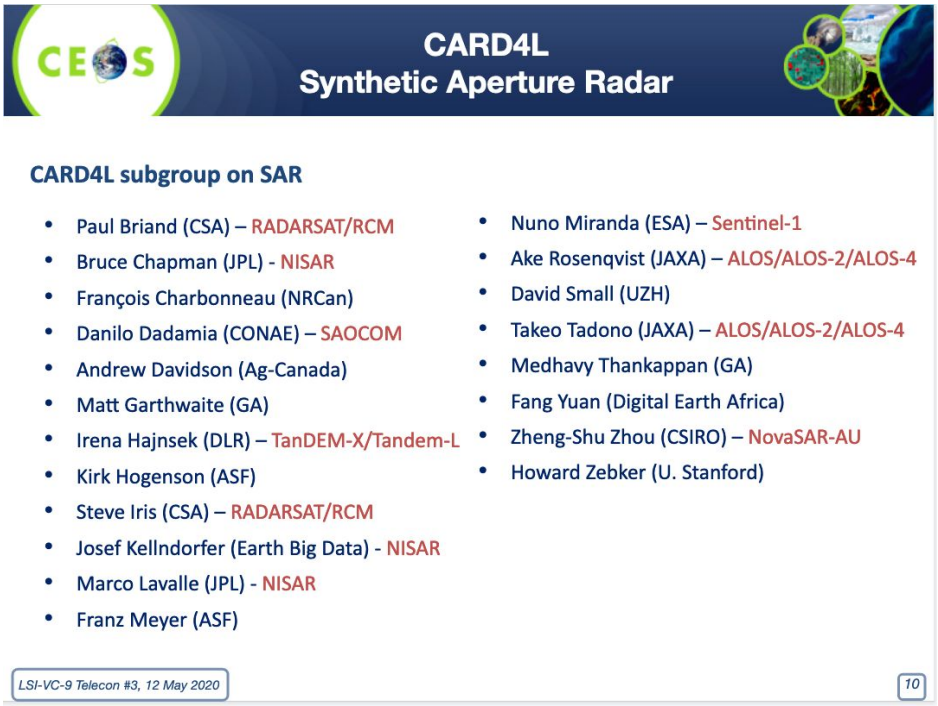
User development

- Dense time-series analyses
- National-global scales
- Increasing computing power

→ **Users and Producers risk drowning in Data Heaven!**

CARD4L for SAR

- Close collaboration between LSI-VC and WGCV
- CARD4L objective to broaden the user community by provision of data products that do not require expert knowledge is particularly relevant for radar, where the SAR user community remains small and expert-oriented even after > 25 years of operational SAR missions!



SAR PFSs in the pipeline:

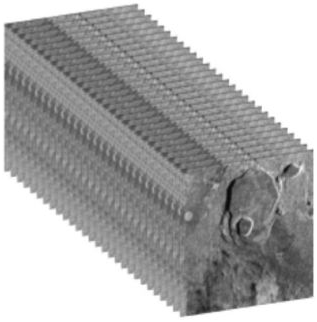
- Normalised Radar Backscatter (NRB)
  - More soon...
- Polarimetric Radar (POL)
  - More soon...
- Geocoded SLC (GSLC)
- Interferometric Radar (InSAR)

(In addition, CARD4L group on spaceborne LiDAR initiated in 2019)

CARD4L Synthetic Aperture Radar

Geocoded Single-Look Complex (GSLC)

- Geocoding SAR data already in basic complex and slant range geometry (SLC) format
- Simplifies generation of interferograms (One Master to Rule Them All!)
- Leads: C. Chapman & H. Zebker
- Aiming for endorsement 2021 (LSI-VC-11?)

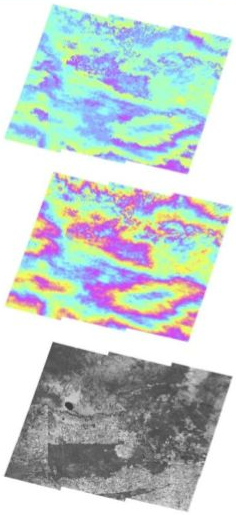


ALOS PALSAR SLC stack
(H. Zebker)

CARD4L Synthetic Aperture Radar

Interferometric Radar (InSAR)

- InSAR CARD4L includes:
  - Wrapped interferograms
    - Studying large deformation events e.g. earthquakes
    - Time series analysis, using Persistent Scatterers
  - Unwrapped interferograms
    - Time series analysis, using DInSAR-SBAS algos
  - Interferometric coherence
    - Change detection, land cover applications
- Lead: M. Thankappan & GA team
- Aiming for endorsement 2021 (LSI-VC-11?)



Sentinel 1 interferometric products
(Geoscience Australia team)

Normalised Radar Backscatter (NRB) Annual Update

- First NRB version (v4.1.1) endorsed @ LSI-VC-7 (Hanoi, Feb 2019)
- Document leads: D. Small, A. Rosenqvist, T. Tadono
- Dedicated engagement by whole CARD4L SAR team
  - 11 Telecons, ~10 members at each call (despite Alaska-Canberra time zone range)
  - 2 Physical meetings (WGCV-SAR ws @ERSIN)

- Revision 1 (NRB v4.8) for endorsement @ LSI-VC-9#3 (today)
  - V4.7 shared with LSI-VC team for comments on March 16, 2020
  - No comments received
  - Minor modifications in April/May (outlined in PFS change log) 4.7 → 4.8
  - Suggest to rename endorsed PFS version 5.0

- PFS v4.8 and NRB Metadata Specs available @ https://tinyurl.com/yah8gj3n

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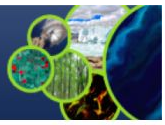
CARD4L SAR NRB PFS Annual Update



NRB 4.8
For endorsement today

General Metadata

#	Item
1.1	Traceability
1.2	Metadata Machine Readability
1.3	Product type
1.4	Document Identifier
1.5	Data Collection Time
1.6	Source Data Attributes
1.6.1	Source Data Access
1.6.2	Instrument
1.6.3	Source Data Acquisition Time
1.6.4	Source Data Acquisition Parameters
1.6.5	Source Data Orbit Information
1.6.6	Source Data Processing Information
1.6.7	Source Data Image Attributes
1.6.8	Sensor Calibration
1.6.9	Performance Indicators
1.6.10	Source Data Polarimetric Calibration Matrices
1.6.11	Mean Faraday Rotation Angle
1.6.12	Ionosphere Indicator
1.7	Product Attributes
1.7.1	Product Data Access
1.7.2	Ancillary Data
1.7.3	Product Sample Spacing
1.7.4	Filtering
1.7.5	Geographical Bounding Box
1.7.6	Geographic Image Extent
1.7.7	Product Image Size
1.7.8	Pixel Coordinate Convention
1.7.9	Coordinate Reference System
1.7.10	Map Projection

NRB 4.1.1
Endorsed 2019

General Metadata

#	Item
1.1	Traceability
1.2	Metadata Machine Readability
1.3	Data Collection Time
1.9	Instrument
1.3	Data Collection Time
1.10	Acquisition Parameters
1.10	Acquisition Parameters
1.16	Processing Chain Provenance
1.12	Sensor Calibration
1.19	Performance Indicators
1.20	Ionosphere indicator
1.17	Data Access
1.15	Ancillary Data
1.11	Processing Parameters
1.11	Processing Parameters
1.4	Geographical Area
1.5	Coordinate Reference System
1.6	Map Projection
1.18	Overall Data Quality

Normalised Radar Backscatter (NRB)

- Annual revision #1, NRB version 4.8
- Considerable restructuring of the PFS
- SAR-specific terminology applied
- Accommodating for cases where the CARD4L product is not generated from a single observation (e.g. single source multi-temporal composites)
- Work continuing in 2020 to accommodate multi-source input
- General Metadata
  - Separated into *Source Data Attributes* and *Product Attributes* (i.e. the CARD4L product)
  - New items added, both generic and SAR specific

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CARD4L SAR NRB PFS Annual Update

NRB 4.8
For endorsement today

Per-Pixel Metadata

#	Item
2.1	Metadata Machine Readability
2.2	Data Mask Image
2.3	Scattering Area Image
2.4	Local Incident Angle Image
2.5	Ellipsoidal Incident Angle Image
2.6	Noise Power Image
2.7	Gamma-to-Sigma Ratio Image
2.8	Acquisition Date Image

Radiometric Terrain Corrected Measurements

#	Item
3.1	Backscatter Measurements
3.2	Scaling Conversion
3.3	Noise Removal
3.4	Radiometric Terrain Correction Algorithms
3.5	Radiometric Accuracy

Geometric Terrain Corrections

#	Item
4.1	Geometric Correction Algorithms
4.2	Digital Elevation Model
4.3	Geometric Accuracy
4.4	Gridding convention

NRB 4.1.1
Endorsed 2019

Per-Pixel Metadata

#	Item
2.1	Metadata Machine Readability
2.2	No Data
2.3	Layover
2.4	Shadow
2.5	Local Incidence Angle
2.6	Global Incidence Angle
2.8	Noise Equivalent Sigma0

Radiometric Terrain Corrected Measurements

#	Item
3.1	Measurements
3.2	Noise Removal
3.3	Terrain Corrections
1.14	Algorithms
1.13	Radiometric Accuracy
3.4	Accuracy

Geometric Corrections

#	Item
1.7	Geometric Correction
1.14	Algorithms
2.7	Digital Elevation Model
1.8	Geometric Accuracy
4.1	Accuracy

Normalised Radar Backscatter NRB v4.8

- Per-pixel Metadata (image data)
  - SAR-specific new items added
    - Local Scattering Area (Threshold)
    - Gamma-to-Sigma Ratio (Target)
    - Acquisition Date img (Threshold for multi-temp composite products)
- Radiometric Measurements
  - SAR-specific new item added and items moved from general metadata
- Geometric Corrections
  - New item added and items moved from per-pixel and general metadata

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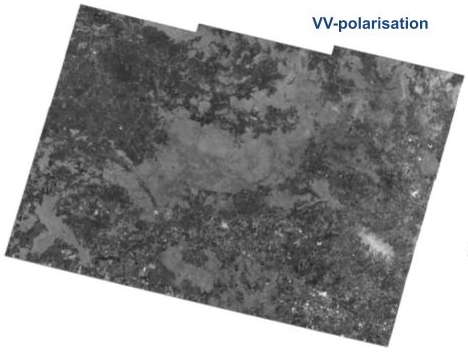
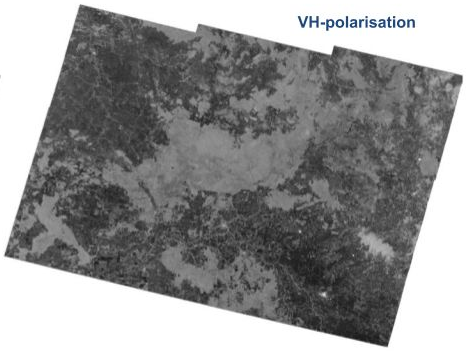
CARD4L SAR - NRB Backscatter Measurement Data

- **Backscatter expressed as Gamma-0**
- **Geometric ortho rectification**
- **Radiometric Terrain Correction (RTC).** Terrain flattening by contributing scattering area normalisation *





Sentinel 1 (ESA/EC)
QLD/Australia
Processing: Z-S Zhou (CSIRO)

* Small (2011), Flattering Gamma: Radiometric Terrain Correction for SAR Imagery, IEEE TGRS 49-8.

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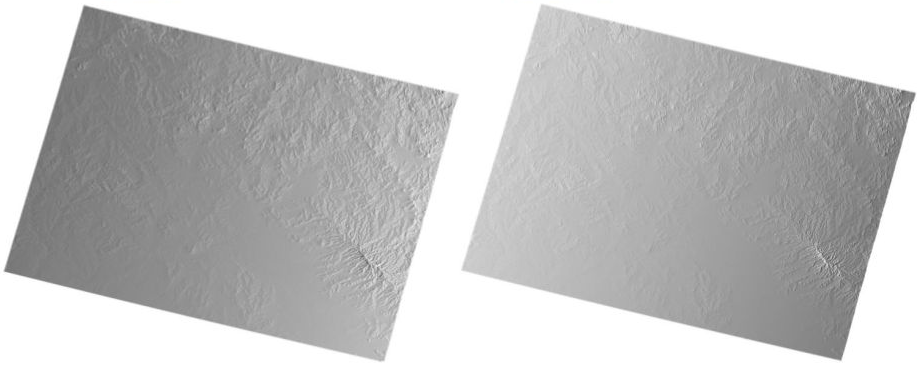
CARD4L SAR - NRB Per-Pixel Metadata

Local Contributing Scattering Area
(Threshold)
Used for the Radiometric Terrain Correction

Local Incident Angle
(Threshold)
Not used in RTC process but provided as still commonly utilised by certain user communities



Sentinel 1 (ESA/EC)
QLD/Australia
Processing: Z-S Zhou (CSIRO)

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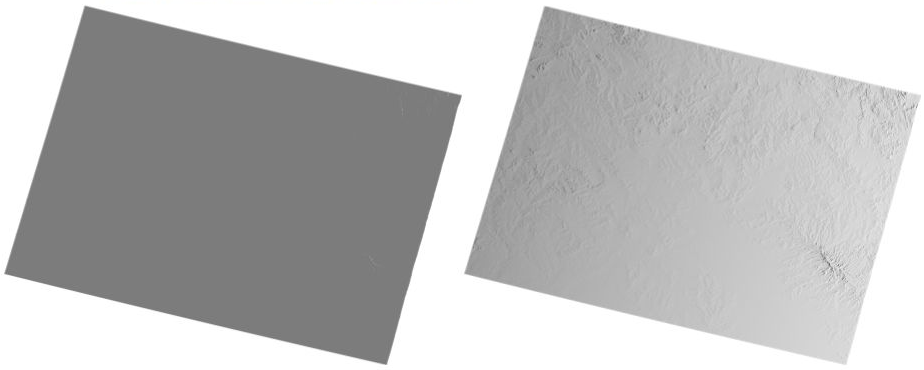
CARD4L SAR - NRB Per-Pixel Metadata

Mask image
(Threshold)
Masks for valid-/Invalid/No-data (Threshold)
OR
incl. layover, shadowing & e.g. water (Target)

Gamma-to-Sigma Ratio
(Target)
For transformation Gamma-0 → Sigma-0



Sentinel 1 (ESA/EC)
QLD/Australia
Processing: Z-S Zhou (CSIRO)

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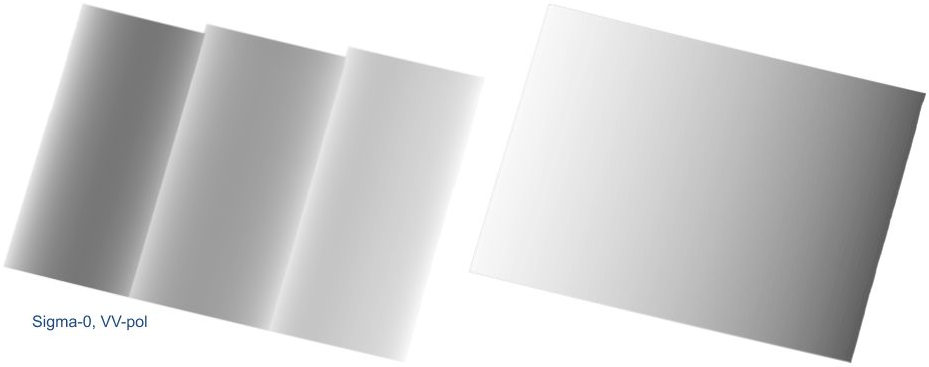
CARD4L SAR - NRB Per-Pixel Metadata

Noise Power image
(Target)
If used for noise removal

Ellipsoidal Incident Angle
(Target)



Sigma-0, VV-pol

Sentinel 1 (ESA/EC)
QLD/Australia
Processing: Z-S Zhou (CSIRO)

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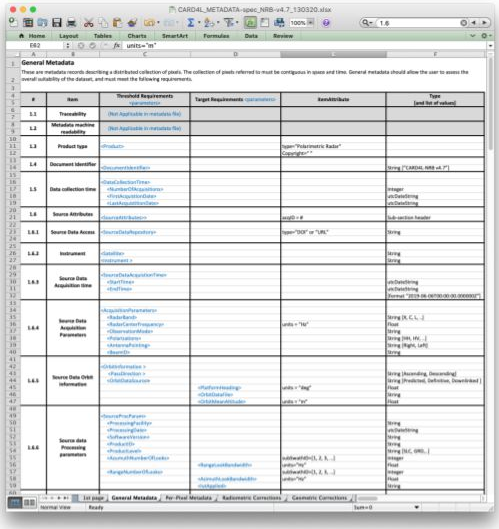
CARD4L SAR NRB Metadata Specs

Metadata Specifications

- Metadata specification developed to accompany the NRB PSF
- Specs for XML format but data provider may select other metadata formats (yaml, json, etc.)
- Non-mandatory (Target req.)

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements
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 CARD4L NRB Metadata Specifications, v.5.0, or a community endorsed standard that facilitates machine-readability, such ISO 19115-2

- Alignment with IEEE or ISO standards to be considered (possibly by LSI-VC-11 – TBC)



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Normalised Radar Backscatter (NRB)

DECISION (Y/N):

Endorsement of the Normalised Radar Backscatter PFS Update

ACTIONS:

- Editorial check of NRB v.4.8
- Rename endorsed version v.5.0

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SAR Polarimetric Radar (POL) PFS

T. Tadono / A. Rosenqvist

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Polarimetric Radar (POL) PFS

- Document leads: F. Charbonneau, M. Lavalle, Z-S Zhou
- Dedicated engagement by whole CARD4L SAR team
  - Telecons & Physical meetings jointly with NRB
- Version 1 (POL v2.9) for endorsement @ LSI-VC-9#3 (today)
  - V2.8 shared with LSI-VC team for comments on March 16, 2020
  - No comments received
  - Minor modifications in April/May (outlined in PFS change log) 2.8 → 2.9
  - Suggest to rename endorsed PFS version 3.0
- PFS v2.9 & POL Metadata specs available @ https://tinyurl.com/ycaq79ww

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CARD4L SAR Polarimetric Radar (POL)

	Threshold	Target
1. General Metadata		
1.1 Traceability		
1.2 Metadata Machine Readability		
1.3 Product Type		
1.4 Document Identifier		
1.5 Data Collection Time		
1.6 Source Data Attributes		
1.6.1 Source Data Access		
1.6.2 Instrument		
1.6.3 Source Data Acquisition Time		
1.6.4 Source Data Acquisition Parameters		
1.6.5 Source Data Orbit Information		
1.6.6 Source Data Processing Parameters		
1.6.7 Source Data Image Attributes		
1.6.8 Sensor Calibration		
1.6.9 Performance Indicators		
1.6.10 Source Data Polarimetric Calibration Matrices		
1.6.11 Mean Faraday Rotation Angle		
1.6.12 Ionosphere Indicator		
1.7 Product Attributes		
1.7.1 Product Data Access		
1.7.2 Ancillary Data		
1.7.3 Product Sample Spacing		
1.7.4 Filtering		
1.7.5 Geographic Bounding Box		
1.7.6 Geographical Image Extent		
1.7.7 Product Image Size		
1.7.8 Pixel Coordinate Convention		
1.7.9 Coordinate Reference System		
1.7.10 Map Projection		
2. Per-Pixel Metadata		
2.1 Metadata Machine Readability		
2.2 Data Mask Image		
2.3 Scattering Area Image		
2.4 Local Incidence Angle Image		
2.5 Ellipsoid Incident Angle Image		
2.6 Noise Power Image		
2.7 Gamma to Sigma Ratio Image		
2.8 Acquisition Date Image		
3. Radiometric Corrections		
3.1 Radiometric Measurements		
3.2 Scaling Conversion		
3.3 Noise Removal		
3.4 Radiometric Terrain Correction Algorithms		
3.5 Radiometric Accuracy		
4. Geometric Corrections		
4.1 Geometric Correction Algorithms		
4.2 Digital Elevation Model		
4.3 Geometric Accuracy		
4.4 Gridding Convention		

Polarimetric Radar (POL)

- POL covers two product types
  - Polarimetric Decomposition
  - Polarimetric Covariance Matrix
- POL PFS structure based on NRB to assure consistency
  - Terminology identical to NRB but requirements adapted to polarimetric products
- Dedicated POL Metadata Specs developed

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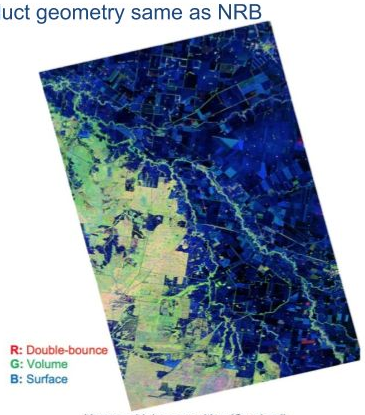
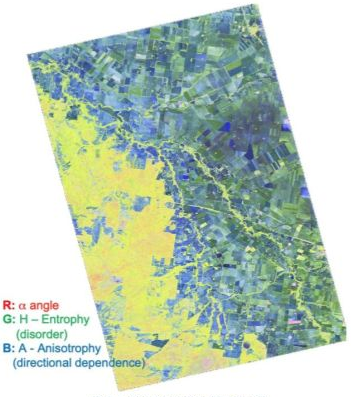
CARD4L Polarimetric Radar (1) Polarimetric Decomposition

- Considerable number of **polarimetric decompositions** available (e.g. H-A-Alpha, Pauli, Freeman-Durden, Pauli, Yamaguchi-3/6, etc.) and POL products therefore anticipated to be generated "on demand". PFS does not prescribe which decompositions to provide.
- Each decomposition channel as a separate data file
- Product geometry same as NRB



Yamaguchi decomposition (Quad-pol)



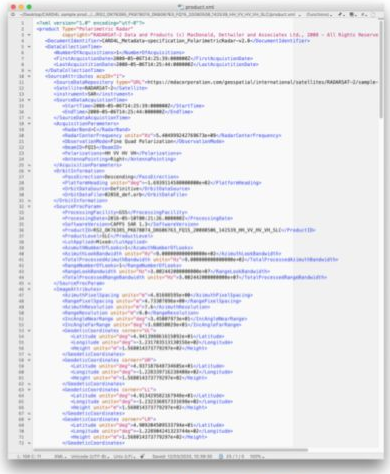
H-A-α decomposition (Quad-pol)

ALOS-2 PALSAR-2 (JAXA)
Processing: Z-S Zhou (CSIRO)

CARD4L Polarimetric Radar Metadata Specifications

Metadata specification developed to accompany the POL PSF

Decomposition image
(Yamaguchi decomp., Quad-pol)



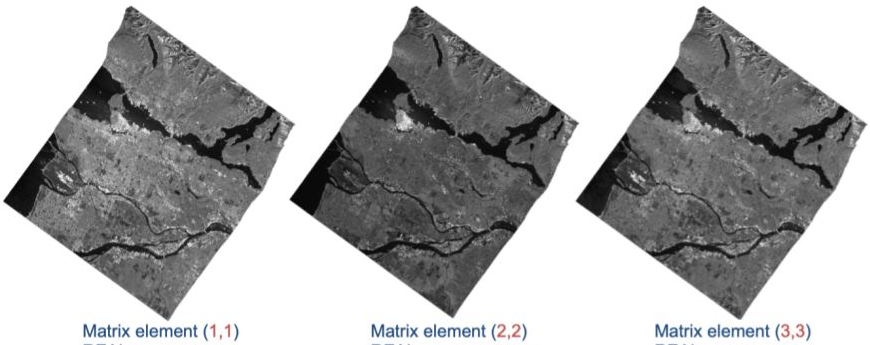
CARD4L compliant metadata file (XML)

RADARSAT-2 (MDA)
Processing: F. Charbonneau (NRCan)

CARD4L Polarimetric Radar (2) Polarimetric Covariance Matrix

- **POL-CovMat** preserves amplitude and polarimetric phase information
- "CovMat" measurement data provided as set of image files (QP:6, DP:3)

$$\begin{bmatrix} |HH|^2 & \sqrt{2}\cdot HH\cdot HV^* & HH\cdot VV^* \\ \sqrt{2}\cdot HV\cdot HH^* & 2\cdot|HV|^2 & \sqrt{2}\cdot HV\cdot VV^* \\ VV\cdot HH^* & \sqrt{2}\cdot VV\cdot HV^* & |VV|^2 \end{bmatrix}$$



Matrix element (1,1)
REAL
HH intensity

Matrix element (2,2)
REAL
HV intensity

Matrix element (3,3)
REAL
VV intensity

Matrix elements (1,2) (1,3) & (2,3)
COMPLEX (Re + Im): Polarimetric phase

Note: The HH, HV and VV intensity (power) images are fully compliant CARD4L NRB products

RADARSAT-2 (MDA)
Processing: F. Charbonneau (NRCan)

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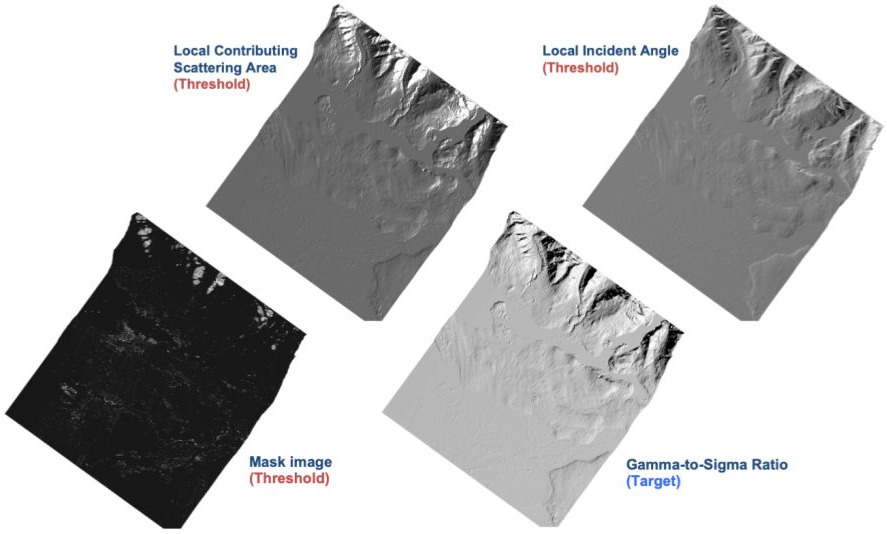
CARD4L Polarimetric Radar Per-Pixel Metadata



RADARSAT-2 (MDA)
Processing: F. Charbonneau (NRCan)

\+ **Ellipsoidal Incident Angle** (Target) & **Noise Power** (Target)

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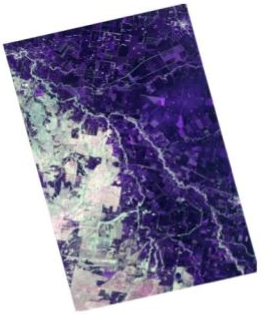
CARD4L SAR Sample Datasets

CARD4L SAR Sample Datasets

- Polarimetric Decomposition (POL-PD)
  - RADARSAT-2 (QP), Vancouver/Canada [Yamaguchi-3] (POL 2.9 compliant)
  - ALOS-2 PALSAR-2 (QP), QLD/Australia [Yamaguchi-3, H-A-Alpha] (requires update)
  - Sentinel-1 (DP), QLD/Australia [H-A-Alpha] (requires update)
- Polarimetric Covariance Matrix (POL-CovMat)
  - RADARSAT-2 (QP), Vancouver/Canada (POL 2.9 compliant)
- Normalised Radar Backscatter (NRB)
  - Sentinel-1, QLD/Australia (NRB 4.8 compliant)
  - RADARSAT-2, Vancouver/Canada (NRB 4.8 compliant)
  - ALOS-2 PALSAR-2, QLD/Australia (requires update)
- Geocoded SLC (GSLC)
  - ALOS PALSAR (requires update)
- Interferometric Radar (InSAR)
  - Sentinel-1 (DP), QLD/Australia (requires update)
- **Sample Data currently on local servers. Large datasets (1-2 GB/product). Need long-term solution to link to CEOS ARD www.**



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Polarimetric Radar (POL) PFS

DECISION (Y/N):

Endorsement of the Polarimetric Radar PFS

ACTIONS:

- Editorial check of POL PFS v.2.9
- Rename endorsed version v.3.0

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Aquatic Reflectance CARD4L PFS

S. Labahn

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Topics

- **LSI-VC Aquatic Reflectance (AR) CEOS ARD for Land (CARD4L) Product Family Specification (PFS)**
- **USGS Landsat Provisional Aquatic Reflectance (AR) Product**

LSI-VC CARD4L Framework

http://ceos.org/ard/

CARD4L Definition

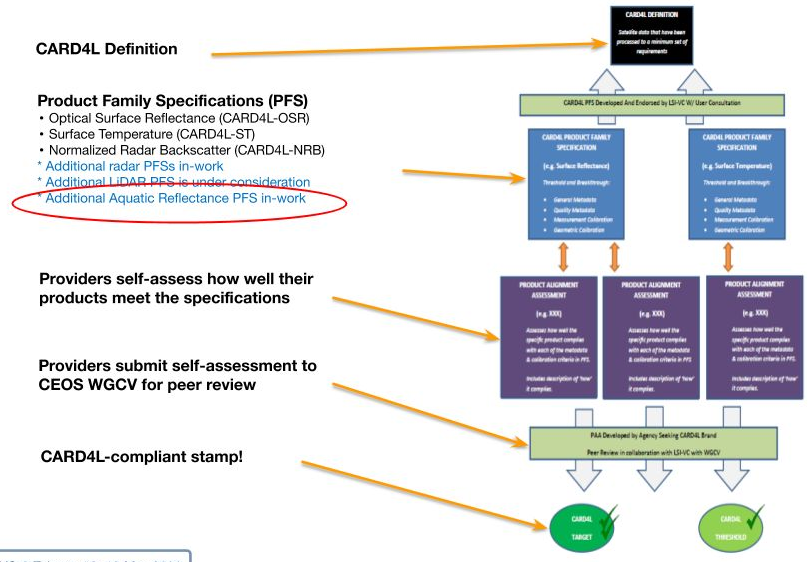
Product Family Specifications (PFS)
- Optical Surface Reflectance (CARD4L-OSR)
- Surface Temperature (CARD4L-ST)
- Normalized Radar Backscatter (CARD4L-NRB)

* Additional radar PFSs in-work
* Additional LiDAR PFS is under consideration
* Additional Aquatic Reflectance PFS in-work

Providers self-assess how well their products meet the specifications

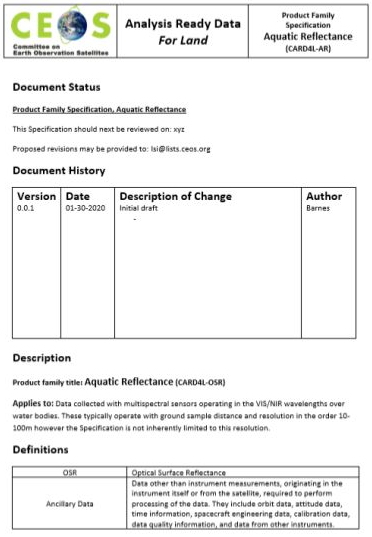
Providers submit self-assessment to CEOS WGCV for peer review

CARD4L-compliant stamp!



Aquatic Reflectance CARD4L PFS Notional Schedule

- ✓ **By 31 January 2020 – Prepare "*Aquatic Reflectance CARD4L PFS*" initial draft (Chris Barnes)**
- ✓ **3-7 February 2020 – Meet with Dr. Nima Pahlevan on the margins of the Landsat Science Team (LST) to do an initial sanity check (Chris Barnes, Steve Labahn)**
- **By 15 May 2020 – Review and provide feedback to finalize initial draft (Dr. Nima Pahlevan) => Actively in-progress (Nima Pahlevan, Chris Barnes, Steve Labahn)**
- **By 30 June 2020 – Conduct science expert review of the PFS (Andreia Siqueira lead)**
  - Paul DiGiacomo (NOAA/COAST), Steve Greb (GEO AquaWatch), Carsten Brockmann (IVOS), Steffen Dransfeld (IVOS), Magnus Wettle (EO Map), Steve Sagar (Australia), Others
- **By 31 July 2020 – Conduct tech edit and distribute final draft PFS for LSI-VC review (Steve Labahn)**
- **By September 2020 – Review and endorse final "*Aquatic Reflectance CARD4L PFS*" at LSI-VC-10**



CEOS Committee on Earth Observation Satellites | Analysis Ready Data For Land | Product Family Specification Aquatic Reflectance (CARD4L-AR)

Document Status

Product Family Specification, Aquatic Reflectance

This Specification should next be reviewed on: xyz

Proposed revisions may be provided to: lsi@lists.ceos.org

Document History

Version	Date	Description of Change	Author
0.0.1	01-30-2020	Initial draft	Barnes

Description

Product family title: Aquatic Reflectance (CARD4L-OSR)

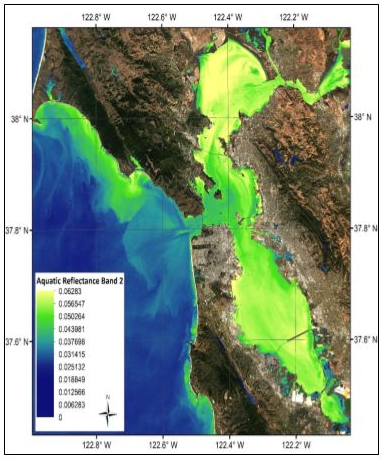
Applies to: Data collected with multispectral sensors operating in the VIS/NIR wavelengths over water bodies. These typically operate with ground sample distance and resolution in the order 10-100m however the Specification is not inherently limited to this resolution.

Definitions

OSR	Optical Surface Reflectance
Ancillary Data	Data other than instrument measurements, originating in the instrument itself or from the satellite, required to perform processing of the data. They include orbit data, attitude data, time information, spacecraft engineering data, calibration data, data quality information, and data from other instruments.

Landsat Provisional Aquatic Reflectance (AR) Product

- **Aquatic Reflectance is a provisional product that provides nondimensional normalized remote-sensing reflectance for coastal and inland waters, assuming a perfectly Lambertian surface (made available 1-Apr-2020)**
  - **https://www.usgs.gov/land-resources/nli/landsat/april-1-2020-landsat-8-provisional-aquatic-reflectance-science-product**
- **Potential to make valuable contribution to:**
  - Ocean color science
  - Environmental monitoring capabilities for coastal and inland aquatic ecosystems
- **Expected users are:**
  - Ecologists and limnologists
  - Water resource managers
  - Other aquatic remote sensing user communities
- **USGS Water Resources Mission Area**
  - Effective management of water resources and water quality condition



Landsat 8 Provisional Aquatic Reflectance Science Product
OLI Band 2 (Blue band)
San Francisco Bay, CA - Scene ID: LC80440342018280LGN00

History of Algorithm Development & Product Characteristics

- **Principal Investigator (PI): Dr. Nima Pahlevan (NASA GSFC)**
- **Atmospheric correction algorithm is directly derived from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) Data Analysis System (SeaDAS) package distributed by NASA's Ocean Biology Processing Group**
- **Initially, Aquatic Reflectance product will be available for Landsat 8 visible bands (i.e., bands 1-4) globally, using Landsat Collection 1 data**
  - Near Infrared (NIR) and Short-Wave Infrared (SWIR) bands are consumed by atmospheric compensation and hence are not delivered in the final product (PI recommendation)
- **Processing flags (containing detailed information about the atmospheric correction), Landsat Level-2 Pixel Quality Assessment (QA), and metadata are also delivered within the product file package**

Status of CARD4L Datasets

M. Steventon

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Assessments Underway

- USGS Landsat Collection 2 (SR & ST)
  - WGCV review panel stage
- ESA Sentinel-2 (SR)
  - self-assessment verified by WGCV POC
  - assessment panel being assembled

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Future CEOS Agency CARD4L

Expected

- JAXA ALOS Mosaics
- ALOS PALSAR scenes and certain ALOS-2 PALSAR-2 tile-based data
- NovaSAR-1 (CARD4L standard product flagged by CSIRO)

Possibilities

- ALOS-3 (JAXA, TBC)
- NISAR? (CARD4L standard product? L and S band products?)
- Resourcesat? (ISRO/India)
- KOMPSAT? (KARI/Korea)
- NASA HLS?
- MODIS (MOD09) and VIIRS?
- Sentinel-3 Synergy Product (SR)?
- PROBA-V?

Follow-up needed

- THAICOTE and THEOS-2 (GISTDA/Thailand)
- CBERS (CRESDA/INPE)

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Global 'CARD4L' (once fully assessed)

	SR	ST	NRB	Location(s)	Cloud	STAC	COG
USGS Landsat Collection 2	✔	✔		AWS EROS	✔	✔	✔
ESA Sentinel-2 Level-2A	✔			Copernicus Hub* Frankfurt AWS#	✔		
JERS-1/ALOS/ ALOS-2 Mosaics			✔	JAXA EORC			

* Global data for December 2018 onwards
# Sinergise is processing Sentinel-2 data back to Jan-2017 for the AWS Frankfurt archive (JPEG-2000 format)

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Ad Hoc ‘CARD4L’ Availability Efforts

That is, for certain regions / times / projects only:

- Sentinel-2 Level-2A Various Mirrors
  - CloudFerro, CODE-DE, CNES PEPS
  - https://forum.sentinel-hub.com/t/sentinel-2-l2a-archive-going-global/1877
- Element-84 (US company) is converting Sentinel-2 AWS Frankfurt data to COG (for Africa) and moving it to the AWS US-West hub. User then pays to egress or use on AWS.
- Digital Earth Africa?
- Sinergise S-1 ?
- DIAS?

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Other ARD Efforts Using CEOS Agency Data (not yet formally CARD4L)

- Swiss Data Cube
  - Sentinel-2 ARD
  - Own processing workflow using sen2cor
- Digital Earth Australia
  - GA’s Landsat Collection 3
  - Sentinel-1/2/3 ARD (over Australia)
  - MODIS
  - VIIRS
  - Himawari-8
- UK Catapult S-1 and S-2?
- Digital Earth Africa, Sentinel-2, and Sentinel-1

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Issues

- Data often fragmented across the world with many different datasets, locations and access options
- Commitment to global, top-down production needed, otherwise users are left to create subsets of CARD4L themselves (ad hoc)?
- Data accessibility is key, and cloud hosting of CARD4L is particularly efficient in this regard. What are the prospects of increasing cloud availability of agency-produced CARD4L?
- Sentinel-1
  - No CARD4L self-assessment forthcoming?
  - Global GRD files since Jan-2017 sit on AWS Frankfurt in COG format (Sinergise)
  - Backscatter intensity data from Google Earth Engine questionable?
  - No good regional or global S-1 ARD solutions?
  - Availability of the Copernicus DEM for Radiometric Terrain Corrections?

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Suggested Actions

- NASA to consider the possibility of assessing MODIS and VIIRS products against the CARD4L specifications – noting industry demand on informal consultation call

- S-1 CARD4L assessment?

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WGCV Report: CARD4L Assessments

M. Thankappan

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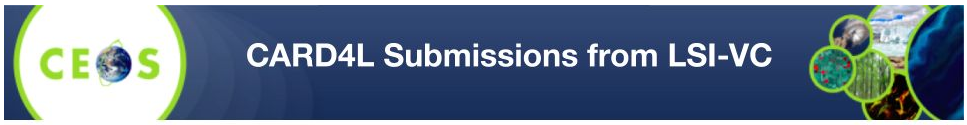
- Data provider completes self-assessment against CARD4L
- Data provider submits request for CARD4L endorsement to LSI-VC
- WGCV receives CARD4L peer-review request from LSI-VC
- WGCV verifies submitted CARD4L documentation
- WGCV Acceptance Review Panel specific to PFS is set up
- WGCV PoC interacts with data provider for any clarifications
- Review Panel provides recommendation for a vote by WGCV
- WGCV membership votes on recommendation
- WGCV communicates outcome to LSI-VC
- Data provider notified of outcome by LSI-VC



- USGS Landsat Surface Reflectance (Collection 2)
- USGS Landsat Surface Temperature (Collection 2)
- ESA Sentinel-2 Surface Reflectance (self-assessed at 'Threshold' only)
- CARD4L Review Panels for Landsat and Sentinel-2 products

Landsat CARD4L Review Panel

Nigel Fox
Valentina Boccia
Darren Ghent
Jeffrey Czapla-Myers
Medhavy Thankappan

Sentinel-2 CARD4L Review Panel

Nigel Fox
Cody Anderson
Darren Ghent
Fernando Camacho
Medhavy Thankappan

CARD4L Review Status: USGS Landsat Surface Reflectance (Collection 2)

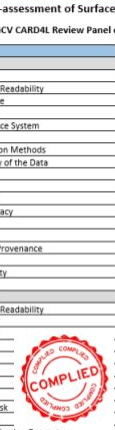
- ✔ Data provider completes self-assessment against CARD4L
- ✔ Data provider submits request for CARD4L endorsement to LSI-VC
- ✔ WGCV receives CARD4L peer-review request from LSI-VC
- ✔ WGCV verifies submitted CARD4L documentation
- ✔ WGCV Acceptance Review Panel specific to PFS is set up
- ✔ WGCV PoC interacts with data provider for any clarifications
- ✔ Review Panel provides recommendation for a vote by WGCV [Complied at Threshold]
  - WGCV membership votes on recommendation
  - WGCV communicates outcome to LSI-VC
  - Data provider notified of outcome by LSI-VC

USGS CARD4L self-assessment of Surface Reflectance (Collection 2)

Summary Table: WGCV CARD4L Review Panel evaluation

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

*See explanation provided in the notes below



LSI-VC9 Telecon #3 12 May 2020

CARD4L Review Status: USGS Landsat Surface Temperature (Collection 2)

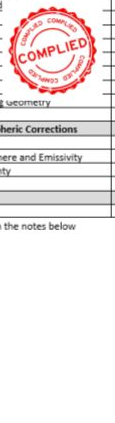
- ✔ Data provider completes self-assessment against CARD4L
- ✔ Data provider submits request for CARD4L endorsement to LSI-VC
- ✔ WGCV receives CARD4L peer-review request from LSI-VC
- ✔ WGCV verifies submitted CARD4L documentation
- ✔ WGCV Acceptance Review Panel specific to PFS is set up
- ✔ WGCV PoC interacts with data provider for any clarifications
- ✔ Review Panel provides recommendation for a vote by WGCV [Complied at Threshold]
  - WGCV membership votes on recommendation
  - WGCV communicates outcome to LSI-VC
  - Data provider notified of outcome by LSI-VC

USGS CARD4L self-assessment of Surface Temperature (Collection 2)

Summary Table: WGCV CARD4L Review Panel evaluation

	Threshold	Target
1. General Metadata		
1.1 Traceability	Not required	Not verified*
1.2 Metadata Machine Readability	Verified	Not assessed
1.3 Data Collection Time	Verified	Verified
1.4 Geographical Area	Verified	Verified
1.5 Coordinate Reference System	Verified	Verified
1.6 Map Projection	Not required	Verified
1.7 Geometric Correction Methods	Not required	Verified
1.8 Geometric Accuracy of the Data	Verified	Verified
1.9 Instrument	Verified	Verified
1.10 Spectral Bands	Verified	Verified
1.11 Sensor Calibration	Not required	Verified
1.12 Radiometric Accuracy	Not required	Verified
1.13 Algorithms	Verified	Verified
1.14 Ancillary Data	Verified	Verified
1.15 Processing Chain Provenance	Not required	Verified
1.16 Data Access	Verified	Not assessed
1.17 Overall Data Quality	Not required	Not verified*
2. Per-Pixel Metadata		
2.1 Metadata Machine Read	Verified	Not assessed
2.2 No Data	Verified	Verified
2.3 Incomplete Testing	Verified	Verified
2.4 Saturation	Verified	Verified
2.5 Cloud	Verified	Verified
2.6 Cloud Shadow	Verified	Verified
2.7 Snow/Ice Mask	Not required	Verified
2.8 Illumination and Viewing Geometry	Verified	Not assessed
3. Radiometric and Atmospheric Corrections		
3.1 Measurement	Verified	Not verified*
3.2 Corrections for Atmosphere and Emissivity	Verified	Verified
3.3 Measurement Uncertainty	Not required	Not verified*
4. Geometric Corrections		
4.1 Geometric Correction	Verified	Verified

*See explanation provided in the notes below



LSI-VC9 Telecon #3 12 May 2020

CARD4L Evaluation Timeline: USGS Landsat SR / ST

- **USGS Landsat Surface Reflectance (Collection 2)**
- **USGS Landsat Surface Temperature (Collection 2)**
  - Request received by LSI-VC: **7 Oct 2019**
  - Clarification on documents sought from USGS: **5 Dec 2019**
  - Clarification on SR/ST received from USGS: **30 Jan 2020**
  - Access to sample data organised : **2 Mar 2020**
  - Panel feedback received (from 4 members): **27 Mar 2020**
  - Interim report for Panel : **6 May 2020**
- **WGCV-46 Plenary virtual meetings: 11 May, 15 May 2020**
- **LSI-VC9 Telecons #3, #4: 12 May, 13 May 2020**

CARD4L Review Status: ESA Sentinel-2 Surface Reflectance

- ✔ **Data provider completes self-assessment against CARD4L**
- ✔ **Data provider submits request for CARD4L endorsement to LSI-VC**
- ✔ **WGCV receives CARD4L peer-review request from LSI-VC**
- ✔ **WGCV verifies submitted CARD4L documentation**
- ✔ **WGCV Acceptance Review Panel specific to PFS is set up**
- Interactions with data provider for clarifications
- Review Panel provides recommendation for a vote by WGCV
- WGCV membership votes on recommendation
- WGCV communicates outcome to LSI-VC
- Data provider notified of outcome by LSI-VC

Summary Self-Assessment Table

	Threshold	Target
1. General Metadata		
1.1 Traceability	Yes	
1.2 Metadata Machine Readability	Yes	
1.3 Data Collection Time	Yes	
1.4 Geographical Area	Yes	
1.5 Coordinate Reference System	Yes	
1.6 Map Projection	Yes	
1.7 Geometric Correction Methods	Yes	
1.8 Geometric Accuracy of the Data	Yes	
1.9 Instrument	Yes	
1.10 Spectral Bands	Yes	
1.11 Sensor Calibration	Yes	
1.12 Radiometric Accuracy	Yes	
1.13 Algorithms	Yes	
1.14 Ancillary Data	Yes	
1.15 Processing Chain Provenance	Yes	
1.16 Data Access	Yes	
1.17 Overall Data Quality	Yes	
2. Per-Pixel Metadata		
2.1 Metadata Machine Readability	Yes	
2.2 No Data	Yes	
2.3 Incomplete Ti	Yes	
2.4 Saturation	Yes	
2.5 Cloud	Yes	
2.6 Cloud Shadow	Yes	
2.7 Land/Water M	Yes	
2.8 Snow/Ice Ma	Yes	
2.9 Terrain Shadow mask	Yes	
2.10 Terrain Occlusion	Yes	
2.11 Illumination and Viewing Geometry	Yes	
2.12 Aerosol Optical Depth Parameters	Yes	
3. Radiometric and Atmospheric Corrections		
3.1 Measurement	Yes	
3.2 Measurement Uncertainty	Yes	
3.3 Measurement Normalisation	Yes	
3.4 Directional Atmospheric Scattering	Yes	
3.5 Water Vapour Corrections	Yes	
3.6 Ozone Corrections	Yes	
4. Geometric Corrections		
4.1 Geometric Correction	Yes (in 2020)	

PENDING REVIEW

CARD4L Evaluation Timeline: ESA Sentinel-2 SR

- **ESA Sentinel-2 Surface Reflectance (self-assessment at 'Threshold' only)**
  - Request received by LSI-VC: **6 Feb 2020**
  - Sentinel-2 Review Panel confirmed: **17 Apr 2020**
  - Review of self-assessment documents: **24 Apr 2020**
  - Clarification sought from ESA: **5 May 2020**
- **WGCV-46 Plenary virtual meetings: 11 May, 15 May 2020**
- **LSI-VC9 Telecons #3, #4: 12 May, 13 May 2020**

Summary of Feedback from CARD4L Evaluation

- **Highlighted the need to modify items in the requirements document for clarity e.g. :**
  - adding Terrain Illumination Correction as a separate item
  - articulation of requirements without ambiguity
- **Target requirements for parameters such as Radiometric Traceability and Uncertainty:**
  - need for clear evidence to support claim
- **Partially complete self-assessments:**
  - anticipated future compliance
  - filtering by LSI-VC for completeness
- **Threshold level compliance:**
  - use 'not required' when no requirement is specified
- **PFS modifications post peer-review:**
  - tie peer-review outcome to PFS version

Agency Plans Regarding CARD4L

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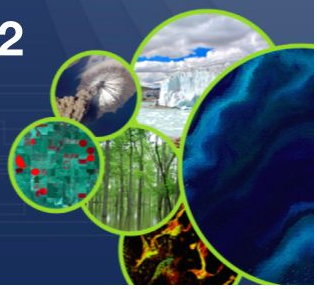
Committee on Earth Observation Satellites

USGS Landsat Collection 2



Steve Labahn, USGS, LSI-VC Co-Lead

Topics

- **USGS Landsat Collection 2 Definition Summary & Schedule**
- **CEOS ARD for Land (CARD4L) Self-Assessments**
  - USGS submitted Surface Reflectance (SR) and Surface Temperature (ST) self-assessments via LSI-VC in late 2019
  - CEOS WGCV peer review team assembled and evaluating submission
  - ESA and USGS self-assessments informing annual SR/ST Product Family Specification (PFS) review/updates
- **Trial Production (AWS) – Digital Earth Africa Lessons Learned**

USGS Landsat Collection 2
Definition Summary

- **Improved Geometric Accuracy, including utilizing Sentinel-2 Global Reference Image (GRI)**
- **Improved Digital Elevation Model (DEM)**
- **Improved Radiometric Calibration**
- **Global Level-2 Data and Atmospheric Auxiliary Products**
- **Consistent Level-1/Level-2 Quality Assessment Bands**
- **Updated and Consistent Level-1/Level-2 Metadata Files**
- **Scene-Based Cloud Optimized GeoTIFF (COG) File Format**

- **USGS Landsat Missions Web Site Collection 2 documentation, including a high-level summary table describing the major differences between Collection 1 and Collection 2, is located here:**
  - https://usgs.gov/land-resources/nli/landsat/landsat-collection-2

- **Public announcement:**
  - https://www.usgs.gov/news/landsat-data-moving-public-cloud-early-2020

USGS Landsat Collection 2
Schedule

✔ Project Kick-Off	September 2017
✔ Preliminary Design Review	April 2019
✔ Critical Design Review	August 2019
✔ Test Readiness Review (Level-2)	January 2020
✔ Test Readiness Review (Collection 2)	April 2020
Operational Readiness Review	May 2020
Internal Product Validation Period	May-June 2020
Public Collection 2 Data Availability	~June 2020
Collection 2 Tiled U.S. ARD Availability	September 2020

CARD4L Framework
http://ceos.org/ard/

CARD4L Definition

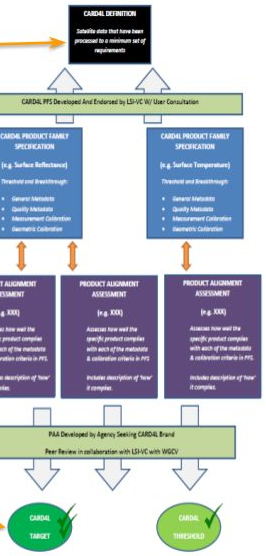
Product Family Specifications (PFS)
- Optical Surface Reflectance (CARD4L-OSR)
- Surface Temperature (CARD4L-ST)
- Normalized Radar Backscatter (CARD4L-NRB)

* Additional radar PFSs are in-work
* Additional LiDAR PFS is under consideration
* Additional Aquatic Reflectance PFS is in-work

Providers self-assess how well their products meet the specifications

Providers submit self-assessment to CEOS WGCV for peer review

CARD4L-compliant stamp!



CARD4L Self-Assessments

Landsat Collection 1 (U.S. ARD) to Collection 2 Improvements

Summary Self-Assessment
USGS Landsat Collection 1 (U.S. ARD) -> Collection 2
Surface Reflectance

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

	Threshold	Target
1. General Metadata		
1.1 Traceability	Yes	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	Yes	Yes
1.7 Geometric Correction Methods	Yes	No -> Yes
1.8 Geometric Accuracy of the Data	Yes	No -> Yes
1.9 Instrument	Yes	No -> Yes
1.10 Spectral Bands	No -> Yes	No -> Yes
1.11 Sensor Calibration	Yes	Yes
1.12 Radiometric Accuracy	Yes	No -> Yes
1.13 Algorithms	Yes	No -> Yes
1.14 Ancillary Data	Yes	No -> Yes
1.15 Processing Chain Provenance	Yes	No -> Yes
1.16 Data Access	No -> Yes	No
1.17 Overall Data Quality	Yes	Yes
2. Per-Pixel Metadata		
2.1 Metadata Machine Readability	Yes	Not assessable
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 Illumination and Viewing Geometry	Yes	No
3. Radiometric and Atmospheric Corrections		
3.1 Measurements	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

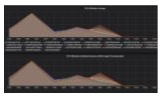
Table Key	
Threshold/Target Now Met in Collection 2	
Target Not Met	
Not assessable	

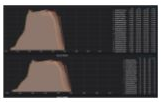
Trial Production (AWS)

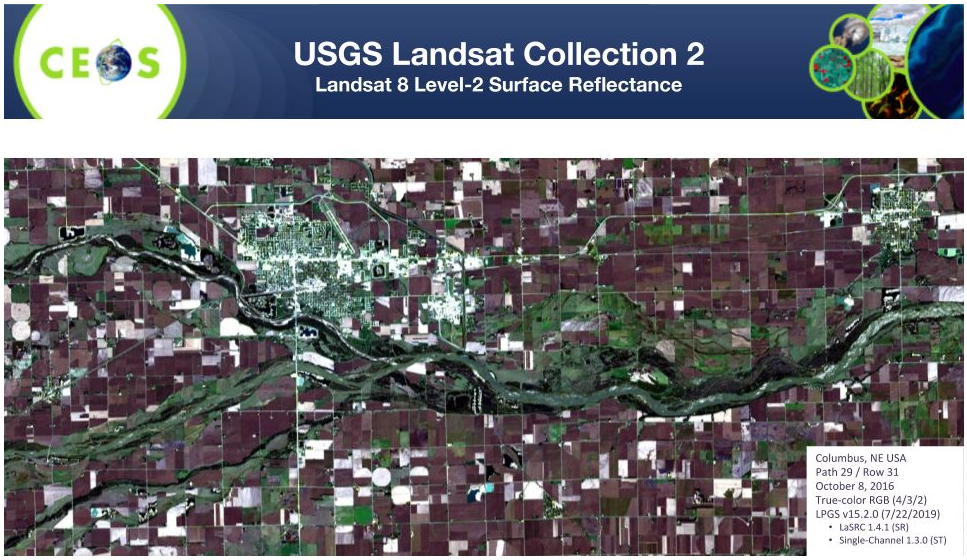
Digital Earth Africa Lessons Learned

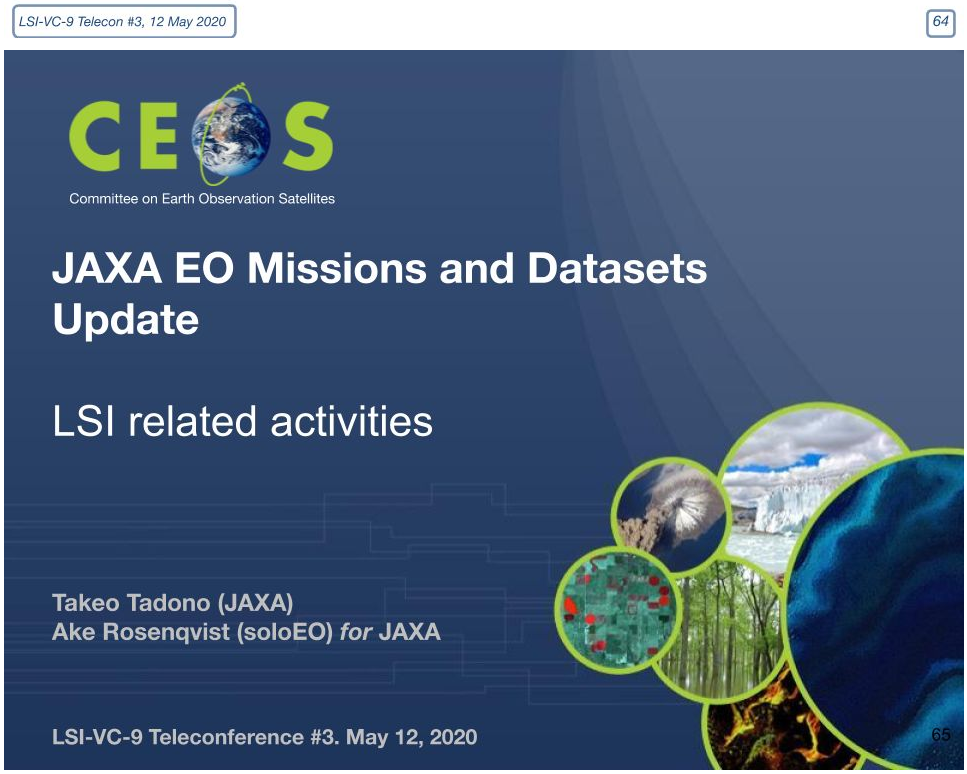
- **Used as first scaling test in Landsat Collection 2 development**
  - Processed 183,077 Landsat 8 scenes from 2013-2019 over Africa to Level-2 for ~$5,700 USD
- **AWS Instance Type Limits**
  - USGS environment had limited ability to scale using Spot instances (Issue resolved)
- **AWS Instance Type Choices**
  - r5d and m5d (lower processing time, lower costs, attached solid state drive)
  - r4 and m4 (higher processing time, older type, adding block storage increases costs, other limits)
- **AWS Resource Issues**
  - Out of Memory errors (Added swap space and increased container memory size, Issue resolved)
- **AWS Simple Storage Service (S3) Issues**
  - Unable to see files during processing (Files are on S3 but unable to see at times, Issue resolved)
  - Failure with rclone piped to tar (Resulted in truncated input data)
  - Adding S3 transfer acceleration to the buckets was good
- **AWS Command Line Interface (CLI) Segmentation Faults**
  - Issue came up at times copying a job control file (Re-ran without any issues but still investigating)

L8 Africa Input Data	
Year	Scenes
2013	19461
2014	28154
2015	29128
2016	29761
2017	29710
2018	29677
2019	17186






USGS Landsat Collection 2
Landsat 8 Level-2 Surface Reflectance
Columbus, NE USA
Path 29 / Row 31
October 8, 2016
True-color RGB (4/3/2)
LPGS v15.2.0 (7/22/2019)
• LaSRC 1.4.1 (SR)
• Single-Channel 1.3.0 (ST)


LSI-VC-9 Telecon #3, 12 May 2020
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Committee on Earth Observation Satellites
JAXA EO Missions and Datasets Update
LSI related activities
Takeo Tadono (JAXA)
Ake Rosenqvist (soloEO) for JAXA
LSI-VC-9 Teleconference #3. May 12, 2020
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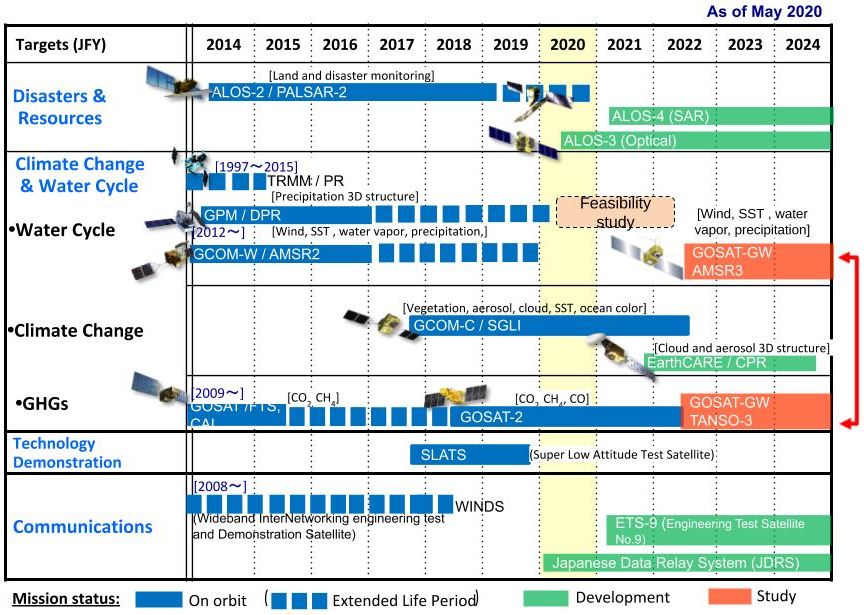
JAXA Missions Update



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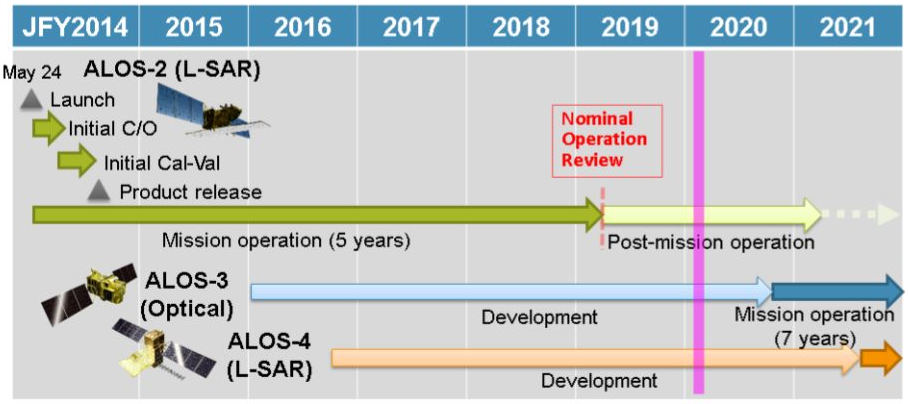
ALOS Series Missions

- Continuous observations successor *"Daichi" (ALOS)* from 2006 to 2011
  - Contribute to ensure the safety and security of citizens, *i.e.* disasters monitoring and management, land deformation monitoring, national developing management, foods and natural resources, environmental issues in global etc. as common issues.
  - Contribute to industrial development based on Earth observation data *i.e.* National Spatial Data infrastructure (NSDI) and new applications.



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ALOS-2 – 2020 updates

ALOS-2/PALSAR-2 duty cycle (maximum observation time per orbit) has been reduced in order to extend observation period to accommodate ALOS-2 and ALOS-4 overlapping observations

- Until Oct. 20, 2019 (137 orbit cycle): Duty cycle 50%
- **From Oct. 21, 2019 (138 orbit cycle): Duty cycle 30%**

Basic Observation Scenario was revised owing to reduce duty cycle with following points

- ✔ Fine Beam global observations (2 obs/year @ high priority
  1 obs/year @ high priority & 1 obs/year @ low priority)
- ✔ FB high priority : gap-filling of non-observed areas
- ✔ ScanSAR observations: 9 obs/year (reduction – focus on pan-tropics)
- ✔ High priority to selected areas with intensive FB observations to promote Japanese L-SAR operational and research usage in cooperation with national and international partners

Further revisions of observation priority and coverage foreseen in 2020

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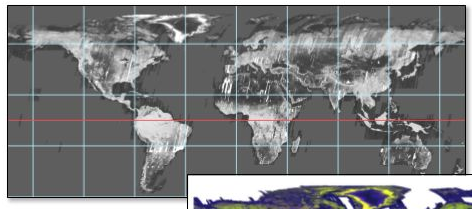
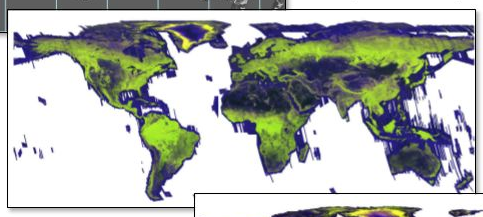
25 m SAR Global Mosaics and Forest/Non-Forest Maps

- ✔ Annual global mosaics – first CARD4L SAR NRB candidate product
- ✔ JERS-1 (1996) & ALOS (2007-2010) & ALOS-2 (2014-2018) >20 years of changes

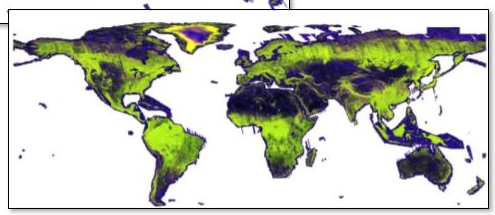


- HH backscatter (gamma-0) 16 bits
- HV backscatter (gamma-0) 16 bits
- Mask image (no-data, water, layover, shadowing.) 8 bits
- Local incidence angle image, 8 bits
- Observation date image (DN = days after mission launch) 16 bits
- Forest/Non-forest map

1996 JERS-1
(only HH-pol.)



2007-2010
ALOS



2015-2018
ALOS-2

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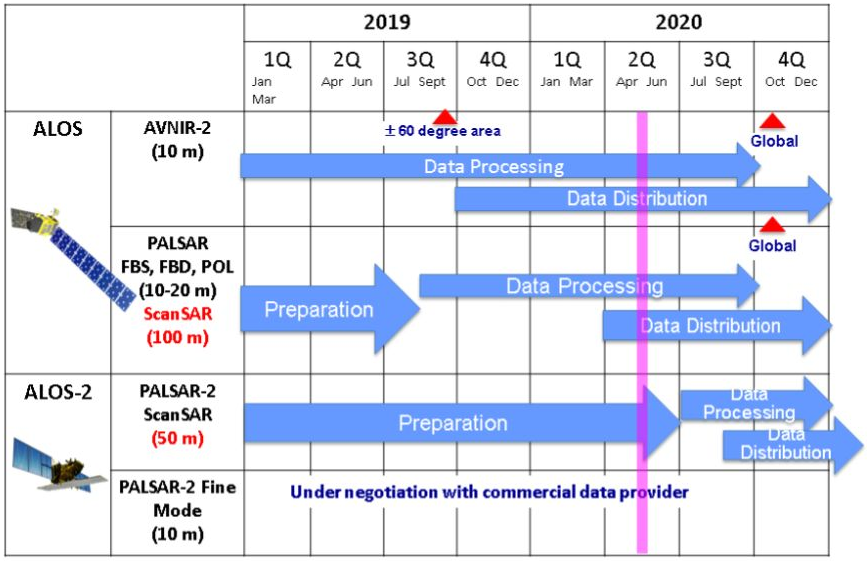
Schedule of ALOS/ALOS-2 Data Processing and Public Free & Open Access

As of May 2020



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Summary – mission & CARD4L status

- JAXA's EO missions and dataset processing status updated:
  - ✔ ALOS-2 is working well in post-operational phase,
  - ✔ ALOS-3/-4 are to be launched in JFYs 2020 and 2021
  - ✔ Demonstration of the joint capabilities of JAXA-ESA-NASA to observe environmental and economic impacts of COVID-19 is on-going.

- Plans for CEOS ARD for Land (CARD4L) NRB compliance:
  - ✔ 25 m SAR Annual Global Mosaics
    - 2019: PALSAR-2 to be completed by Oct 2020, CARD4L compliant
    - 2015-2018: PALSAR-2 re-processing by Dec 2020, CARD4L compliant
    - 2007-2010: PALSAR re-processing by Mar 2021, CARD4L compliant
  - ✔ Scene-based PALSAR (FB & ScanSAR) and PALSAR-2 ScanSAR
    - CARD4L format conversion software will be released
  - ✔ 50 m ScanSAR Pan-tropical Mosaics (presently for K&C Project only)
    - Will start the processing in 2020, in reverse chronological order
    - 2014-2020 (PALSAR-2) & 2006-2011 (PALSAR)
    - Public release TBD

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Digital Earth Africa (DE Africa) (A. Lewis)

Reliable supplies of CEOS ARD are vital if Earth Observation is to have impact in Africa, supporting *Agenda 2063: The Africa We Want*.

Digital Earth Africa is based on the ODC Model

DE Africa has / will use continental ~CARD :

- ALOS continental PALSAR mosaics - NRB (JAXA)
- Provisional Landsat-Collection-2 - Surface Reflectance (USGS)
- From May 4th, Sentinel-2 - Surface Reflectance (*DIY)
- From July?, Landsat Collection-2 - Surface Reflectance (USGS)
- From Late 2020?, Sentinel-1 - NRB, with Sinergise (*DIY)

*DIY = “Demonstrate-It-Yourself”

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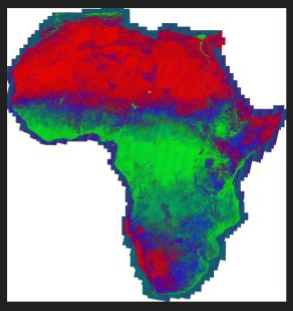
To have impact with EO data, we need to be able to

Produce operational full-resolution products like this:
(fractional cover, Peter Scarth, May 2020), or
This (median surface reflectance, 2018, DE Africa):



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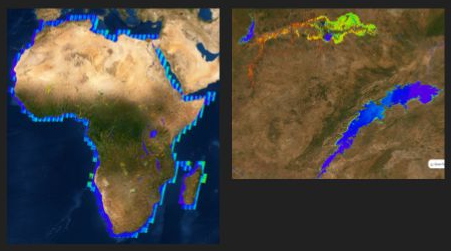
… in order to generate unique continental-scale information

Like this:
(automatic, continental water summary, Africa, routinely updated)



Or this:
(automatic, continental assessment - measurement - of coastal change, Australia)

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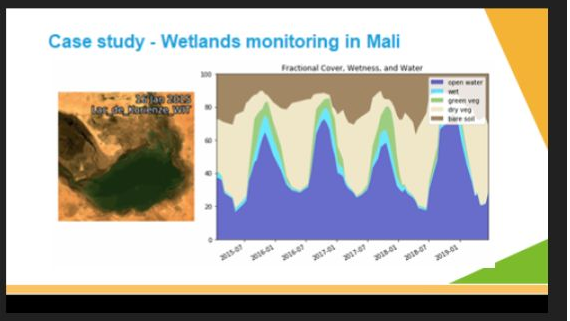
… or rapidly produce site-specific information such as:

Like this:
(Measuring, and visualising, the area of water, bare soil, dry vegetation, green vegetation through time)



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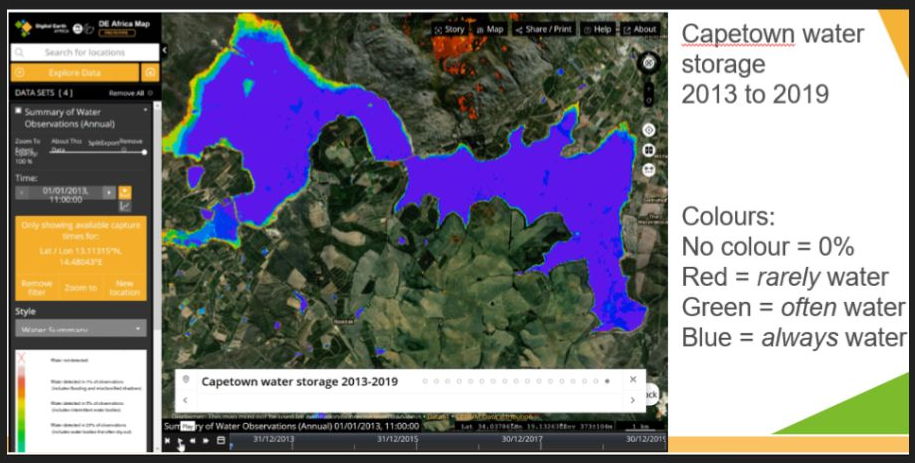
Digital Earth Africa (DE Africa) (A. Lewis)



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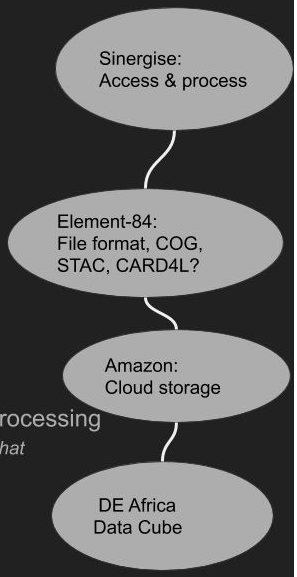
We need CEOS-ARD pipelines!

- Committing to using USGS Landsat Collection-2
- Demonstrating the necessary Sentinel data pipelines:
  - Free and open data
  - Full coverage (all of continent, all passes)
  - Low latency
  - Consistent processing with authoritative and available methods
  - Cloud-performant formats (cloud optimised geotiff; STAC)
  - Cloud-accessible
  - Assured supply of consistent product



- Considering a study of user preferences for levels of processing
  - *Do user behaviours, business models, or case studies indicate that analysis ready data is advantageous to users?*
  - *Interested in your views on such a study!*

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Wrap-up

LSI-VC Leads

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Backup

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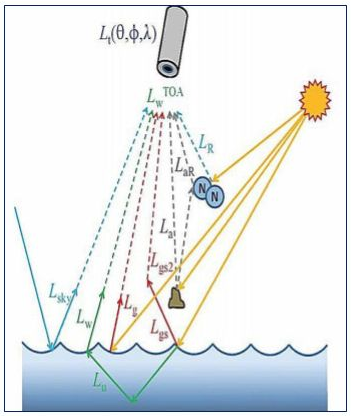
USGS Aquatic Reflectance Atmospheric Correction Algorithm

- **Algorithm is directly derived from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) Data Analysis System (SeaDAS) package distributed by NASA's Ocean Biology Processing Group.**
  - Coupled ocean-atmosphere radiative transfer model
  - Allows various contributions to the Top of Atmosphere (TOA) radiance to be separated out
    - Rayleigh and aerosol path radiance
    - surface reflectance
    - water-leaving radiance, etc.
  - $L_t = L_{atm} + L_{surf}^{TOA} + L_w^{TOA}$
- **Aquatic Reflectance Science Product Generation**
  - Remote Sensing Reflectance (Rrs)
    - First, the ratio of radiance emerging from beneath the water surface to the solar irradiance reaching the water surface is determined:
    - $R_{rs}(\lambda) = \frac{L_u(\lambda,\theta)}{E_d(\lambda)}$
  - Aquatic Reflectance
    - Then the Rrs are normalized by the BRDF of a perfectly reflecting Lambertian surface, to produce the dimensionless Aquatic Reflectance:
    - $Aquatic\ Reflectance = \pi \times R_{rs}$



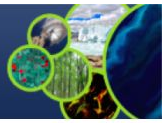
Mobley, Curtis D., et al. "Atmospheric correction for satellite ocean color radiometry." (2016).

USGS Aquatic Reflectance Processing Flags

Description	Range	Valid Range	Scale Factor	Unit	Fill Value	Data Type
Aquatic Reflectance (bands 1 to 4)	-4,720 to 31,420	0 to 31,420	0.00001	Unitless	-9999	INT16
Processing Flags	0 to 2^{31}-1	0 to 2^{31}-1	NA	NA	-9999	INT32
Level 2 Pixel Quality Assessment	0 to 65535	1 to 2047	NA	Bit Index	1 (bit 0)	UINT16
Level 2 XML Metadata file	NA	NA	NA	NA	NA	NA

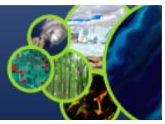
Bit	Attribute	Description
0	ATMFAIL	Atmospheric correction failed
1	LAND	Designated by the input land file (off for Landsat 8 processing)
2	PRODWARN	Intermediate product value falls outside the min/max range
3	HIGLINT	If glint coefficient > glint threshold (0.005). This is not checked for land or night pixels.
4	HILT	Flags high total radiance (Lt) measured by sensor (not used)
5	HISATZEN	View angle > threshold (60 deg)
6	COASTZ	Controlled via the bathymetry file, based on the latitude/longitude of the current pixel
7	SEADAS_CLOUD	Cloud based on SeaDAS algorithm
8	CLOUD_SHADOW	Cloud shadow based on the cloud mask algorithm
9	CLOUD	Cloud based on the cloud mask algorithm
10	COCCOLITH	Flagged based on the coccolithophore algorithm coefficients, detects coccolithophore blooms. (Coccolithophores are a group of phytoplanktons that inhabit a wide variety of marine environments and are distinctive by their production of small calcium plates or coccoliths which are organized around each living cell as an outer covering.)
11	TURBIDW	Flags turbid water. If LwB4 / FonomB4 > 0.0012 Where LwB4: water-leaving band 4 value FonomB4: nominal F0 value for band 4 F0: the mean solar flux
12	HISOLZEN	Solar angle > threshold (70 deg)
13	Unused	NA
14	LOWLW	If water-leaving radiance band 3 (LwB3) value < 0.15 (nlwmin)
15	CHLFAIL	Flags a failure in the chlorophyll calculation
16	NAVWARN	Mainly used for fill pixels
17	Unused	NA
18	RRSWARN	R_{rs} < min_valid or R_{rs} > max_valid
19	MAXAERITER	Number of iterations for the aerosol corrections exceeds the maximum threshold (10)
20	MODGLINT	glint coefficient > minimum glint threshold (0.0001)
21	CHLWARN	chlorophyll < min_valid or chlorophyll > max_valid
22	ATMWARN	If the value is invalid, then set ATMWARN; also set if MAXAERITER is set. Based on ancillary QC flags (ozone, water vapor, RH, wind speed, surface pressure)
23	Unused	NA
24	SEAICE	Controlled via the ice file, based on the latitude/longitude of the current pixel
25	NAVFAIL	If there is an invalid latitude/longitude value
26	FILTER	
27	Unused	NA
28	Unused	NA
29	HIPOL	If degree of polarization for any band is > hipol (0.5)
30	PRODFAIL	Processing failure (data values are outside the legal allowed, too many bands, illegal values, etc.)
31	Unused	NA

USGS Aquatic Reflectance Science Validation by PI



- **Preliminary validation efforts were conducted using the Ocean Color component data of the Aerosol Robotic Network (AERONET) (Pahlevan et al., 2017; Ilori et al., 2019), representing moderately coastal waters**
- **Inter-comparison and cross-calibrations against other sensors ocean color products (MODIS, VIIRS) showed a high degree of fidelity for the Landsat 8 OLI-derived remote sensing reflectance**
- **Performance of the algorithm over highly turbid and eutrophic inland water bodies requires further verification and/or improvement (hence, provisional product)**

USGS Aquatic Reflectance Publications



- **Algorithm**
  - Mobley, C.D., Werdell, J., Franz, B., Ahmad, Z., & Bailey, S. (2016). Atmospheric correction for satellite ocean color radiometry. NASA Tech. Memo, NASA/TM-2016-217551, p. 85 https://ntrs.nasa.gov/search.jsp?R=20160011399
- **Validation**
  - Franz, B.A., Bailey, S.W., Kuring, N., & Werdell, P.J. (2015). Ocean color measurements with the Operational Land Imager on Landsat-8: implementation and evaluation in SeaDAS. Journal of Applied Remote Sensing, 9(1), 096070. https://doi.org/10.1117/1.JRS.9.096070
  - Pahlevan, N., Schott, J.R., Franz, B.A., Zibordi, G., Markham, B., Bailey, S., Schaaf, C.B., Ondrusek, M., Greb, S. & Strait, C.M. (2017). Landsat 8 remote sensing reflectance (Rrs) products: Evaluations, intercomparisons, and enhancements. Remote sensing of environment, 190, 289-301. https://doi.org/10.1016/j.rse.2016.12.030