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Analysis Ready Data specification for Canadian SAR data

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N.H. Short[1], F. Charbonneau[1], R. Peiman[1], and R. De Abreu[1]

[1]Canada Centre for Mapping and Earth Observation, 560 Rochester Street, Ottawa, Ontario K1S 5K2

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Executive Summary

This report examines the current and upcoming Canadian satellite SAR mission data holdings and considers how best to make these data available for analysis in the new era of 'Big Data'. The report considers relevant international endeavours, the unique contribution that Canada may be able to make, and the practical steps necessary to bring a Canadian vision to fruition. Three Analysis Ready Data (ARD) options are presented and the interdependent issues of data cube computing environment choice are addressed.

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β^o Beta-nought (calibrated radar backscatter in the slant range plane)

σ^o_E Sigma-nought (radar backscatter normalized by ground area based on the ellipsoid)

σ^o_T Terrain corrected sigma-nought (radar backscatter normalized by local ground area based on digital elevation/surface model)

γ^o_T Terrain corrected gamma-nought (terrain normalized radar backscatter in the plane perpendicular to the line-of-sight based on digital elevation/surface model)

List of Acronyms

ALOS	Advanced Land Observing Satellite
ARD	Analysis Ready Data
CARD4L	CEOS Analysis Ready Data for Land
CCD	Coherent Change Detection
CEOS	Committee on Earth Observation Satellites
CM	Covariance Matrix
CP	Compact Polarimetry
CPU	Central Processing Unit
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DInSAR	Differential Interferometric Synthetic Aperture Radar
DSM	Digital Surface Model
EDOT	Enhanced Definitive Orbit Tool
EO	Earth Observation
GA	Geoscience Australia
GCC	Geocoded Complex
GCD	Geocoded Detected
GeoTiff	Georeferenced Tagged Image File Format
GRC	Ground Range Complex
GRD	Ground Range Detected
GUI	Graphical User Interface
HPC	High Performance Computing
InSAR	Interferometric Synthetic Aperture Radar
LUT	Look-Up Table
NCM	Normalized Covariance Matrix
NITF	National Imagery Transmission Format
NRB	Normalized Radar Backscatter
PALSAR	Phased Array L-band Synthetic Aperture Radar
RCM	RADARSAT Constellation Mission
RGB	Red-Green-Blue
RTC	Radiometrically Terrain Corrected
SAR	Synthetic Aperture Radar
SCF	ScanSAR Fine
SCN	ScanSAR Narrow
SCS	ScanSAR Sampled
SCW	ScanSAR Wide
SGF	Path Image
SGX	Path Image Plus
SLC	Single Look Complex
SPG	Precision Map Image
SSG	Map Image
WGS84	World Geodetic System 1984

1. Introduction

The use of Earth Observation (EO) satellite data is evolving rapidly as the result of several converging factors. The EO satellite data record is now 30 to 40 years long, this is long enough to conduct meaningful analysis of change. The rapid advance of computing technologies now makes large volumes of data immediately accessible and facilitates analysis of these large volumes of data in acceptably short periods of time. Increasingly open data polices are breaking down licensing and cost barriers to access EO data, and the expansion and improvements in internet connectivity are enabling increased numbers of users to take advantage of the availability of EO data. In addition, the accumulating decades of research and development into EO methods have reliably demonstrated the value and usefulness of EO derived information and delivered tools and approaches for EO community use.

In this new era of "Big Data" the old models of data delivery and analysis are being rethought.
To capitalize on new opportunities for time series EO analysis, data sets need to be in a common location (or cloud computing environment) and in a common format, to allow quick comparisons and detection of change. To serve the expanding pool of potential users, many with little specific EO expertise, the data need to be pre-processed to an analysis ready level for easy and consistent interpretation. The solutions emerging for this new era are new data analysis frameworks, such as data cubes. In a data cube the EO data have basic corrections applied and are geocoded to a common grid. The data are stored in a common location and some form of user interaction is enabled, either scripting or a graphical user interface (GUI). Users can then mine the data for trends or events.

To date most of the international data cube initiatives have focused on optical EO data, as this is where much of the trend analysis work originated due to the long data record, free data access and user-friendly, intuitive image interpretation. However, radar EO archives are now also large and offer certain advantages such as cloud free data and northern hemisphere winter coverage, thus SAR data are beginning to be incorporated into data cubes. To harmonize formats and potentially enable cube interoperability, the Committee on Earth Observation Satellites (CEOS) has been working towards international standards for Analysis Ready Data (ARD) for SAR.

This report looks specifically at the characteristics of the Canadian SAR data holdings and proposes three SAR ARD specifications that could preserve the unique properties and potential of data from the Canadian RADARSAT missions. A basic SAR ARD Normalized Covariance Matrix (NCM-1) and two extended versions (NCM-2 and NCM-3) are presented, along with their advantages and disadvantages and the considerations for data cube architecture.

2. Canadian SAR Data

The Canadian SAR missions began in 1995 with RADARSAT-1 (see Table 1). This C-band SAR with HH polarization was designed initially to optimize sea ice discrimination, but land applications also evolved. In 2007 RADARSAT-2 was launched offering HH continuity, other single polarizations, dual-polarization and fully polarimetric data. Polarimetric and interferometric applications expanded significantly with this new SAR. The RADARSAT Constellation Mission (RCM), to be launched in 2019, will further expand the polarimetric and interferometric capabilities by adding dual co-polarization and compact polarimetry configurations, as well as three satellites to increase coverage frequency and shorten the revisit interval for repeat-pass interferometry. RADARSAT applications now include agricultural, ecological, hydrological, cryospheric, terrain subsidence, and hazard mapping applications, as well as ocean wind speed and ship detection, in addition to the still primary purpose of sea ice detection. All of these applications require different SAR data types, which causes the existing RADARSAT archives to be comprised of many different SAR products. Table 1 shows the variety of products constituting the Canadian SAR archive. Bringing these data to a consistent analysis ready format would be essential for time series analysis within a data cube.

Table 1. RADARSAT product diversity

Satellite	# of beam modes	Polarization configurations	Products	# of LUT	File Formats / Pixel Representation
RADARSAT-1 (1995-2013)	7	HH	RAW, SLC, SGX, SGF, SSG, SPG, SCN, SCF, SCS, SCW	1	CEOS 8 & 16 bits
RADARSAT-2 (2007 -)	20	HH, HV, VV, VH, [HH-HV], [VH-VV], [HH-HV-VH-VV]	SLC, SGX, SGF, SSG, SPG,SCN, SCF, SCS, SCW	15	GeoTIFF & NITF 2.1 8 & 16 bits
RADARSAT Constellation Mission (2019 -)	10	HH, HV, VV, VH, [HH-HV], [VH-VV], [HH-HV-VH-VV], [HH-VV], [CH-CV]	SLC, GRD, GRC, GCD, GCC	16	GeoTIFF & NITF 2.1 16 & 32 bits

3. The Value of Multi-polarization Data

Many of the SAR data cube implementations to date have focused on radar intensity only. This keeps the layers simple, consistent and data volumes to a minimum. However, fully polarimetric data are a significant component of Canadian SAR data and have proven very useful in land applications. In addition, polarimetric information from the upcoming RCM compact polarimetric mode (CP) will also be of interest (Charbonneau et al., 2017). Table 2 lists established SAR land applications with the minimum polarization requirements for the variables of interest. The table shows that including polarimetric information (intensities and relative phases) in a data cube would double the number of potential applications compared to single polarization as well as improve several others. As such, it should be a priority to preserve polarimetric phase within Canadian SAR ARD.

Table 2. Land applications possible with C-band SAR data types (✓ = possible, + = improved)

Application and variable of interest	Single polarization	Dual polarization	Fully polarimetric
Glaciology			
Glacier facies	✓		
Snowline	✓		
Ice extent		✓	
River and lake ice			
River ice off	✓	+	
Lake ice off		✓	+
Ice on			✓
Ice type		✓	+
Frozen to the bed	✓		
Frozen ground			
Seasonally frozen/unfrozen	✓	+	+
Water/Wetlands			
Lake/Flood extent	✓	+	+
Wetland type			✓
Wetland delineation			✓
Boreal peatland mapping			✓
Forestry			
Change detection /Deforestation	✓	+	+
Burnt area	✓	+	+
Forest type			✓
Agriculture			
Rice mapping	✓	+	+
Crop type (excluding rice)		✓	+
Crop phenology			✓
Crop yield			✓
Hydrology			
Cropland soil moisture		✓	+
Peatland soil moisture			✓
Snowpack			✓
Urban			
Change detection	✓	+	+
Additional applications		**5 (+7)**	**9 (+10)**
Total applications	**10**	**15**	**24**

4. Analysis Ready Data

Analysis Ready Data (ARD) means data that have been preprocessed to a common quality standard and co-registered to a common geo-referencing frame, such that pixel values at any location can be easily and reliably compared. Great strides have been made in the international community to converge on an ARD specification for radar through the CEOS CARD4L initiative. Figure 1 shows the current standards being used around the world for SAR data cubes, including the CEOS standard. Essentially, the orbit information is improved to the best possible, basic noise corrections are applied, pixel values are radiometrically calibrated, terrain corrected and then ortho-rectified to bring them to the common geo-referencing grid. The full CEOS specification for Normalized Radar Backscatter (NRB) is included in Appendix 1 for reference.

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

Figure 1. Processing steps for existing data cubes (From Brian Killough, used with permission)

Some of these steps have been applied, for example, in global ALOS PALSAR products as described by Shimada *et al.* (2014) and Small (2011). Through the use of a rigorous terrain-based model of the geometry of illumination and backscatter, improved terrain flattening is achieved and issues of lay-over and foreshortening are addressed. The resulting data are more highly comparable through time, across viewing geometries (ascending / descending) and between sensors.

As shown in Section 3 and Table 2, while many applications can be accomplished with SAR backscatter intensity alone, preserving relative polarization phase would more than double the number of potential applications and would also improve the performance of some applications partially fulfilled by intensity alone. A Canadian SAR data cube and hence SAR ARD specification should thus ideally, preserve full polarimetric potential.

While the CEOS CARD4L group is also working on additional specifications for other SAR product families, including polarimetric decomposition layers, InSAR coherence and interferogram layers, and geocoded single look complex data for the preservation of interferometric phase, this multi-product approach has some drawbacks. Users would not have the ability to optimize parameters for their application if only specific preprocessed layers are stored, and storing several product types implies duplicating acquisitions and hence increasing the required data storage volume.

5. Covariance Matrix SAR ARD Specification

In order to preserve the inter-channel polarimetric phase and thus the full information content of coherent dual-pol and fully polarimetric data, the covariance matrix is proposed as the data storage format. Covariance matrices are generated from the complex cross product of polarimetric channels, as shown in Equation 1 for fully polarimetric data (C3) and in Equation 2 for dual polarization data (C2). Since these matrices are complex symmetrical, only the upper diagonal elements (bold elements) need to be stored in the ARD database.

Fully polarimetric

$$C3 = \begin{bmatrix} |\boldsymbol{HH}|^{\mathbf{2}} & \sqrt{\mathbf{2}} \cdot \boldsymbol{HH} \cdot \boldsymbol{HV}^* & \boldsymbol{HH} \cdot \boldsymbol{VV}^* \\ \sqrt{2} \cdot HV \cdot HH^* & \mathbf{2} \cdot |\boldsymbol{HV}|^{\mathbf{2}} & \sqrt{\mathbf{2}} \cdot \boldsymbol{HV} \cdot \boldsymbol{VV}^* \\ VV \cdot HH^* & \sqrt{2} \cdot VV \cdot HV^* & |\boldsymbol{VV}|^{\mathbf{2}} \end{bmatrix} \qquad \textbf{Eq. 1}$$

Where HV = VH, under the reciprocity assumption. | | and * mean respectively complex modulus and the complex conjugate.

Dual polarization

HH-HV

$$C2 = \begin{bmatrix} |\boldsymbol{HH}|^{\mathbf{2}} & \boldsymbol{HH} \cdot \boldsymbol{HV}^* \\ HV \cdot HH^* & |\boldsymbol{HV}|^{\mathbf{2}} \end{bmatrix} \quad or$$

VV-VH

$$C2 = \begin{bmatrix} |\boldsymbol{VH}|^{\mathbf{2}} & \boldsymbol{VH} \cdot \boldsymbol{VH}^* \\ VH \cdot VH^* & |\boldsymbol{VV}|^{\mathbf{2}} \end{bmatrix} \quad or \qquad \textbf{Eq. 2}$$

CH-CV

$$C2 = \begin{bmatrix} |\boldsymbol{CH}|^{\mathbf{2}} & \boldsymbol{CH} \cdot \boldsymbol{CV}^* \\ CV \cdot CH^* & |\boldsymbol{CV}|^{\mathbf{2}} \end{bmatrix}$$

Where CH and CV refer to dual polarization transmitting a circular polarized signal. [CH, CV] can be replaced by [LH, LV] or [RH, RV] for left (L) or right (R) hand circular transmission respectively, although RCM will offer only right hand circular transmission. The coherent HH-VV configuration available on TerraSAR-X could also be represented as C2 format.

Polarimetric decomposition methods like Yamaguchi et al. (2011) for fully polarimetric, or m-chi (Raney et al., 2012) for compact polarimetric data, can be applied directly on averaged (speckle filtered) C3 and C2 matrices respectively. These decompositions enhance scattering information, bring it to a more comprehensible level for end users, and raise the performance of thematic classification methodologies.

For SAR products that were acquired with single polarization the use of the covariance matrix does not result in superfluous storage requirements, since only the matrix elements that are populated are kept and the diagonal matrix elements are the backscatter intensities. Thus a single channel intensity product would yield only one matrix element and the storage needs would not change.

In order to harmonize the data structure and the metadata between C3 and C2, Equation 1 can be redefined as Equation 3. "< >" means that ARD matrix elements are speckle filtered.

$$C3\,modified\ \ C3m = \begin{bmatrix} \langle|\boldsymbol{HH}|^2\rangle & \langle\boldsymbol{HH}\cdot\boldsymbol{HV}^*\rangle & \langle\boldsymbol{HH}\cdot\boldsymbol{VV}^*\rangle \\ \langle HV\cdot HH^*\rangle & \langle|\boldsymbol{HV}|^2\rangle & \langle\boldsymbol{HV}\cdot\boldsymbol{VV}^*\rangle \\ \langle VV\cdot HH^*\rangle & \langle VV\cdot HV^*\rangle & \langle|\boldsymbol{VV}|^2\rangle \end{bmatrix} \qquad \textbf{Eq. 3}$$

Furthermore, for RCM compact polarimetric data, it is recommended to store them, by simple transformation, under the circular-circular basis, since RR and RL polarizations (Equation 4) permit faster and more intuitive RGB visualizations (R=RR, G=RR/(RR+RL), B= RL).

CH-CV

$$\textbf{C2 circular}\ \ C2c = \begin{bmatrix} \langle|\boldsymbol{RR}|^2\rangle & \langle\boldsymbol{RR}\cdot\boldsymbol{RL}^*\rangle \\ \langle RL\cdot RR^*\rangle & \langle|\boldsymbol{RL}|^2\rangle \end{bmatrix} \qquad \textbf{Eq. 4}$$

In order for the covariance matrix format to be accessible the metadata must specify which matrix elements have been stored. Table 3 lists the proposed format for quick reference. Polarization search in the metadata could be done by "layer ID", "Matrix element" or by "Layer description".

Table 3. SAR ARD covariance matrix storage structure (RADARSAT-2 & RCM)

SAR ARD layer ID	Matrix element	Layer description
1	C3m11	HH backscatter [intensity]
2	C3m12	HH × conj(HV) [complex]
3	C3m13	HH × conj(VV) [complex]
4	C3m22	HV backscatter [intensity]
5	C3m23	HV × conj(VV) [complex]
6	C3m33	VV backscatter [intensity]
7	C2c11	RR backscatter [intensity]
8	C2c12	RR × conj(RL) [complex]
9	C2c22	RL backscatter [intensity]

6. NCM-1 Processing Roadmap

While the covariance matrix is the suggested fundamental storage structure, several other data processing steps are required to fully form the ARD specification and these are consistent with the CEOS CARD4L specification:

1. Apply the best possible orbit parameters to give the most accurate product possible. These will have been projected to an ellipsoidal model such as WGS84. In order to achieve the threshold levels of geometric accuracy required of CARD4L, precise orbit determination will be required.

2. Apply instrument calibrations to produce beta-naught ($\beta^{o)}$ values.

3. Generate the covariance matrix from the complex cross product of polarimetric channels as described in Section 5. For single channel intensity data just port directly to the appropriate ARD-SAR-CM layer.

4. Perform radiometric normalization (gamma flattening to $\gamma^{o}{}_{T}$) on the covariance matrix by applying the local surface normalization factor to each matrix element (Small, 2011).

5. Perform polarimetric speckle filtering, before ortho-rectification, in order to optimally preserve the polarimetric information. Most popular polarimetric decomposition methodologies are incoherent in nature, which requires averaging the covariance matrix for stationarity. A polarimetric filter that preserves local point targets and locally averages extended ones is recommended e.g. Sigma Lee filter with 7x7 window and 3 point target (Lee et al., 2009).

6. Geometric terrain correction is applied to the filtered and normalized covariance matrix. The resampling methodology should be nearest-neighbour or bilinear in order to preserve integrity of the covariance matrix as other resampling functions can introduce artefacts due to the mix of intensity and complex number elements in the matrix. Ortho-rectification can be either to a common grid structure with specified pixel spacings for true data cube format, or simply left in native resolution, but reprojected to a common reference system as is used in other instances.

7. Generate CEOS format metadata to accompany product layers. Per-pixel metadata includes map layers containing information on valid and non-valid data (shadow, layover, no data), local and global (normal to ellipsoid) incident angle, the digital elevation model used and noise equivalent σ^{o}.

The pre-processed data are then stored in an ARD cloud data cube and are available for quick download to a local computer or for direct spatial analysis and/or multi-temporal analysis with other ARD products in the cloud, from a Graphical User Interface (GUI). The full CEOS SAR ARD Normalized Covariance Matrix specification (NCM-1), which includes all metadata, is included in Appendix 2.

The NCM-1 processing chain requires multiple steps and is visualized in Figure 2 (left). Table 4 lists the logic, existing software tools (mostly Gamma software (GAMMA, 2018)) and scripting tasks that would form the SAR ARD NCM-1 processing roadmap.

Table 4. SAR ARD NCM-1 processing roadmap and software options

Step	Implementation option
1. Orbit data refinement	Check xml date and delivered format. RADARSAT-2, pre EDOT (July 2015), update orbit. Post July 2015, check if 'DEF', otherwise update. (Gamma - RSAT2_vec)
2. Apply radiometric correction to β^o	Specification of LUT on ingest. (Gamma - par_RSAT2_SLC/SG)
3. Generate covariance matrix elements	Gamma – COV_MATRIX
4. Radiometric terrain normalization ($\gamma^o{}_T$)	Gamma - geo_radcal
5. Speckle filtering (Sigma Lee)	Custom scripting
6. Geometric terrain correction/Ortho-rectification	Gamma – gc_map and geocode_back
7. Create metadata	Custom scripting

7. NCM-1 Considerations

Preserving multi-polarization data and inter-channel phase obviously expands the data storage needs to several times intensity alone. The use of the covariance matrix and the assumptions of recipriocity mean though that the data storage needs do not become four or eight times intensity only products, but preserve the ability to perform polarimetric decompositions with three or six layers per data set. The expanded data storage requirements are therefore not quite as large as they could be. In addition, the RADARSAT archive contains limited areas of fully polarimetric data, so the increased storage needs are not applicable to the entire archive. Since there are other international data cubes that already offer single polarization SAR intensity over Canada, offering a polarimetry enabled cube with NCM-1 data would be a unique contribution and avoid duplicity.

While the CEOS CARD4L group is also working towards an ARD specification for polarimetric decomposition layers, and such layers would speed up general time series analysis and thematic classification, such layers would also limit users to specific decompositions at specific resolutions (in order to maintain database homogeneity). The NCM-1 format presented here would permit a wider range of methodologies. By preserving access to the original data users have more freedom to choose their decomposition method, optimize the processing parameters for their application, as well as have access to the original layers for other operations such as ratios or development of their own algorithms and models.

In addition, since spatially (speckle) filtered covariance matrices are resampled by nearest-neighbour or bilinear methodology, polarimetric decompositions applied directly on a covariance matrix (without further averaging) should give exactly the same outputs as generating them from the original SLC projection and then doing the ortho-rectification.

Given that many of the Government of Canada operational land applications are included in Table 2, the NCM-1 SAR ARD specification would theoretically satisfy a large number of federal government users. In addition, we need to be mindful that two online systems will shortly be available to support Canadian mission users in the production of "on demand" SAR value added products (ortho rectification, polarimetric decompositions, speckle filtering etc.) and DInSAR terrain deformation (Samsonov et al., 2017). A defined Canadian ARD format and proposed data cube should be complementary to these two systems and not unnecessarily duplicate capacity.

8. Extended SAR ARD Options (NCM-2 and NCM-3)

SAR applications are developed based on different SAR analysis techniques, for example, intensity change detection, polarimetric decomposition, coherent change detection, InSAR etc., all of which require specific SAR data formats, see Appendix 3 for technique specific requirements. It is possible to expand the range of potential SAR analysis techniques in a data cube simply by keeping the data in their slant range projection accompanied with their corresponding ortho-rectification model. With a predefined ortho-rectification model, delivering geocoded ARD to an end user would likely be a fraction of second using High Performance Computing infrastructure (HPC) (time to be confirmed in upcoming tests). This opens the door to two potential extended ARD formats: NCM-2 and NCM-3. Figure 2 shows the processing chain for the NCM-1 format as previously discussed, and introduces NCM-2 and NCM-3.

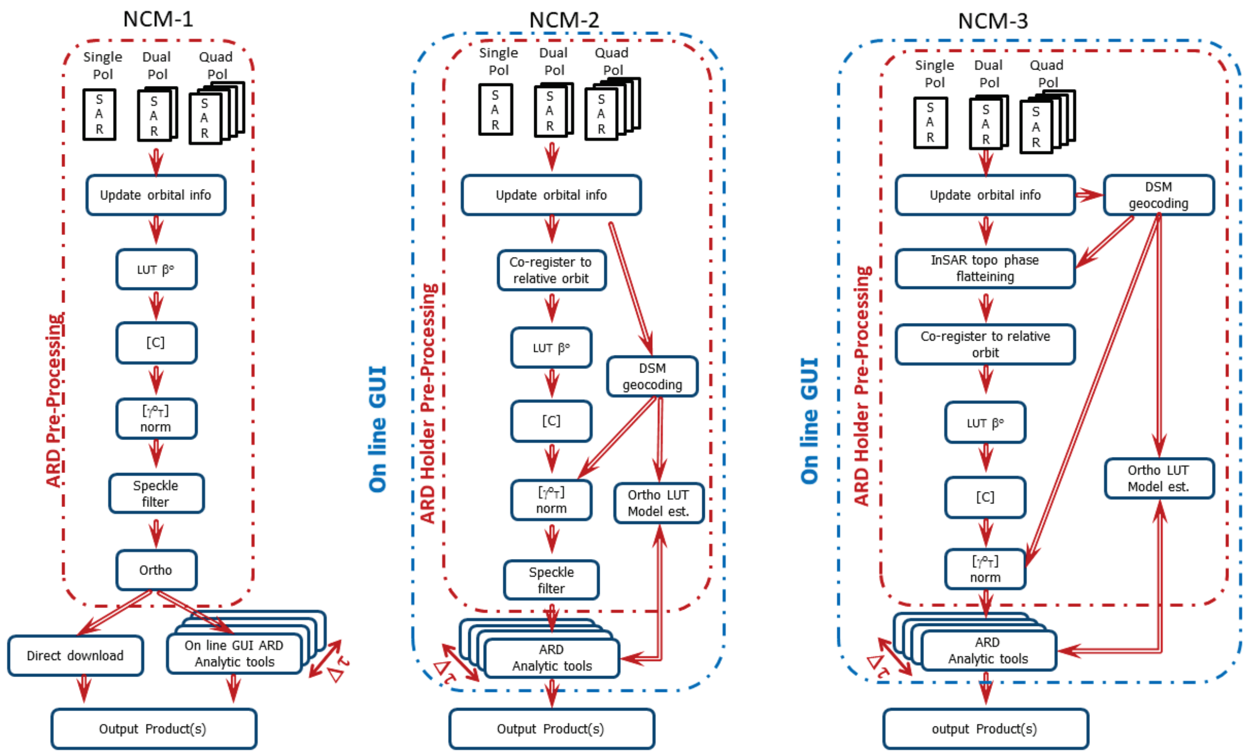

Figure 2. Potential SAR ARD processing chains. [C] indicates covariance matrix generation.

The NCM-2 format (Figure 2, middle) shares the same preprocessing steps as NCM-1, except the ortho-rectification is not performed until a user requests it, although the ortho-rectification model is pre-generated and saved as a 2D Look-up Table (LUT). This allows polarimetric decompositions to be performed in slant range, which is the preference of some SAR users. In addition, scenes sharing the same relative orbit are shifted to a master orbit while still in slant range, this improves the performance of coherent change and polarimetric change detection. Preserving InSAR relative phase is currently under consideration. One advantage of not pre-geocoding the data is the possibility of easily updating the gamma-flattening and the ortho-rectification model when a more accurate digital surface model (DSM) becomes available, instead of reprocessing the ARD product from its original SLC format.

The third format, NCM-3 (Figure 2, right), is similar to NCM-2 but with the InSAR topographic phase removed (Zheng and Zebker, 2017) and no speckle filtering applied. All scenes sharing the same relative orbit are co-registered and the ortho-rectification model LUT is generated and saved but not applied. Since analysis can be performed on full resolution and unfiltered data while also preserving InSAR phase, NCM-3 satisfies all the SAR analysis techniques listed in Table 5 and provides more flexibility to advanced users (e.g. later selection of speckle filter specifications). This format also has the advantage of allowing simple updates when a new DSM becomes available without reprocessing from original data. The drawback of NCM-3 is an increase in the processing time latency for the ARD user, mainly impacted by the speckle filter selection, as well as more SAR knowledge required on the part of the user. This latter issue could be resolved by a user friendly GUI offering analytical tools with preconfigured parameters. This format would support basic InSAR analysis, although advanced InSAR might still be better supported with specific InSAR software or online tools for interferogram filtering, baseline refinement, common band filtering and so on.

NCM-2 and -3 would have the identical data structure as the NCM-1 product except that additional layers would be included for relative InSAR sample phase and the geocoding LUT, and orbital information would be added to the metadata.

Since both the NCM-2 and -3 data reside inside "ARD Holder" structures, an online GUI would manage the analytical tools. Depending on the type of spatial and/or multi-temporal analysis requested by the user, ARD scenes would be treated following default-processing paths and output products would be automatically delivered to the user as geocoded. The user would always interact with a geocoded display on the GUI. Advanced users should be able to define their own ARD processing methodologies (defining parameters options or providing their scripts) from options available in the GUI. Table 5 summarizes the analysis techniques possible with different SAR ARD formats, from the basic CEOS ARD Normalized Radar Backscatter γ^o_T (NRB) format (CEOS, 2019) through NCM-1 to NCM-2 and -3.

Table 5. SAR analysis techniques possible with different ARD product formats.

	NRB	NCM-1	NCM-2	NCM-3
Intensity (usage e.g. model inversion)	Optimal	Optimal	Optimal	Optimal
Intensity Change Detection	Possible	Possible	Optimal	Optimal
Coherent Change Detection	Not Possible	Limited: If pseudo phase preserved	Possible	Optimal
Polarimetric Change Detection	Not Possible	Limited: If pseudo phase preserved	Possible	Optimal
Multi-Polarization Change Detection	Possible	Optimal	Optimal	Optimal
Polarimetric Decomposition	Not Possible	Optimal: If no add. averaging	Optimal	Optimal
InSAR	Not Possible	Not Possible	Limited: If pseudo phase preserved	Possible
Pol/CP-InSAR	Not Possible	Not Possible	Limited: If pseudo phase preserved	Possible
Classification	Possible	Optimal	Optimal	Optimal

Application Feasibility

Optimal	Done using established methods
Possible	Acceptable quality, but concerns SAR purists
Limited	Possible with some assumptions/biases
Not Possible	Not enough information for analysis

NRB and NCM-1 both fulfill the ARD data cube definition by having all the data lying on a common grid of specified sample spacing. This could be a single spacing choice, or multiple options as integers of each other, to permit perfect overlap at different scales, e.g. 2.5, 5 and 10 m. This becomes more important in a data cube comprised of multiple resolution sources, as would be the case for RADARSAT products. NRB reduces the volume storage while maintaining valuable information. Speckle is still present in the NRB products which will require spatial and/or temporal filtering by the user before analysis. This format can generate biases for non-specialized SAR users. With prefiltered data, NCM-1 maximizes the amount of pre-processing which minimizes the CPU cost to analyse ARD on a commercial cloud, while maintaining a high level of polarimetric information. Applying an advanced speckle filter like Sigma Lee would not degrade significantly the target detection performance. However, in both formats overall performance is limited to the fact that data are averaged and geocoded. As shown in Table 5, NCM-1 has a slightly wider range of SAR techniques than NRB format and NCM-2 and -3 further expand the options for SAR data analysis as indicated by the increasing number of green blocks.

9. Data Cube Options

The three NCM proposed ARD formats could satisfy the needs of government users. The formats are optimized for slightly different balances of the following data cube priorities:

- Information preservation and application potential
- Archive storage volume (storage costs)
- Data homogeneity (for internal consistency and potential external interoperability)
- ARD processing CPU usage (CPU costs)
- ARD processing latency (user experience)

The final SAR ARD choice is a function of what is desirable and acceptable for functionality and processing latency, and how and where the data cube will be built, which is a question of how much we want to invest initially and what we want to pay into the future. Do we want a minimal initial investment, such as a commercial cloud deployment, where the costs come later as CPU cycles? Or do we invest more initially, to own our infrastructure, so that processing expenses in the future are minimized? The data cube architecture and hence cost model will be a key factor in the choice of the SAR ARD for a data cube. Table 6 summarises the advantages and disadvantages to be considered.

Table 6. Evaluation grid for SAR ARD format and system priorities

SAR ARD Format	Storage Volume/Costs	CPU Costs	Processing Latency	Functionality
CEOS NRB[1]	Lowest/Best	Low	Low	Least
CEOS NRB +speckle filter	Lowest/Best	Lowest/Best	Lowest/Best	Least
NCM-1	Medium	Lowest/Best	Lowest/Best	Medium
NCM-2[2]	High/Worse	Low/Medium	Low/Medium	High/Good
NCM-3	High/Worse	Highest/Worst	Highest/Worst	Highest/Best

[1] CEOS NRB are not speckle filtered, the data should be filtered before analysis which increases CPU costs and latency.

[2] NCM-2 are speckle filtered, but not ortho-rectified. The CPU and latency costs of ortho-rectification from a stored LUT are not fully known yet but will be evaluated during prototype development.

In summary, the following can be recommended:

1- If storage volume is not an issue, but processing latency is of concern, a solution containing both NCM-1 and NCM-3 would be optimal.
2- If storage volume, and CPU cost and processing latency are not an issue, NCM-3 offers the greatest functionality.
3- NCM-2 is a good compromise between recommendations 1 and 2
4- NCM-1 is the optimized format for a commercial cloud and heavy ARD analytic processing as it preserves functionality but minimizes computing costs.
5- While the lowest storage cost option, NRB alone is not recommended since other international platforms already offer this functionality over Canada. NRB functionality is embedded in the NCM-1 format (i.e. diagonal matrix elements).

10. Summary

Canadian SAR missions now have a 25 year data archive and are about to embark on an era of increased SAR data collection with the RCM. These SAR data could be made more useful for big data analytics if brought to a consistent analysis ready standard, registered to a common grid and stored in an accessible location. Three potential analysis ready specifications are presented here that would facilitate analysis of archive data to varying degrees, while preserving various levels of signal information for the SAR user. The final choice of the Canadian SAR ARD specification will be dependent on the target computing environment, the desired user experience, the data cube system architecture and the related costing model.

11. Acknowledgements

This work was supported by Natural Resources Canada and the Canadian Space Agency Government Related Initiatives Program. We gratefully acknowledge the internal review by Joost van der Sanden.

12. References

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Zheng, Y. and H. A. Zebker (2017). Phase Correction of Single-Look Complex Radar Images for User-Friendly Efficient Interferogram Formation, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, Vol. 10 (6), pp. 2694-2701.

Appendix 1. CEOS SAR ARD NRB Specification

As at May, 2019

http://ceos.org/ard/files/CARD4L_Product_Specification_Backscatter_v4.0.pdf

Document Status

Product Family Specification, Normalised Radar Backscatter
This Specification should next be reviewed on: December 2019
Proposed revisions may be provided to: lsi@lists.ceos.org

Document History

Version	Date	Description of Change	Author
0.0.2	23-03-2017	Zero Draft based on materials discussed in and leading up to LSI-VC-3, provided by SEO and others.	Lewis
0.1.0	18-04-2017	Various revisions to structure.	Lewis
1.0.0	18-04-2017	Included material provided by Brian Killough/SEO reflecting input from a range of SAR experts/users.	Lewis
1.0.1	20-04-2017	Edits reflecting feedback from SEO, change to the figure/table in 'guidance'; removed item 4.2, which appeared redundant; moved reference to definitive ephemeris to a note under item 4.1; added reference to speckle under table 3 (radiometric corrections).	Lewis and Killough
2.0.0	30-08-2017	Feedback incorporated, circulated to LSI-VC.	Lewis
2.1.0	6-09-2017	Feedback from ESA included.	Lewis
2.1.1	6-09-2017	Edits rolled in.	Lewis
3.0	02-02-2018	Feedback from the teleconference (06/12/2018) and post teleconf (emails) Included.	Siqueira
3.1	03-04-2018	Nuno Miranda (ESA) comments addressed (uncertainty information to be required at the threshold level – 3.4 Radiometric corrections (Accuracy), split sensor acquisition mode).	Siqueira
3.1.1	12-04-2018	Ake Rosenqvist (JAXA) comments (split sensor acquisition mode into acquisition and processing parameters, include "global incidence angle").	Siqueira
3.1.1	04-06-2018	Feedback received from Dr. Ben Lewis (process table update).	Siqueira
3.2	07-08-2018	Feedback from the "SAR ARD definition Team" before	Siqueira

		and at IGRASS 2018.	
3.2	21-08-2018	Feedback on the 2nd SAR ARD definition Team teleconference (20/08/2018): add a sentence on 1.19 that the radiometric performance metadata should be provided for each of the polarization channel when available (from Ake Rosenqvist).	Siqueira
3.2.1	14-12-2018	Clarification about per pixel NESZ provision for each channel when noise removal is implemented.	Chapman
3.2.2	05-02-2019	Abstract updated, metadata definition added and v3.2.2 shared with LSI-VC list and LSI-VC-7 meeting participants.	Rosenqvist & Charbonneau & Siqueira
3.2.3	27-05-2019	Formatting and verbiage updated for consistency.	Metzger
4.0	02.03.2019	Version endorsed at LSI-VC7 meeting (14Feb 2019) with minor amendments to address feedback from the SAR Definition Team	LSI-VC

Description

Product Family Title: Normalised Radar Backscatter (CARD4L-Radar)

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

Abstract

CARD4L (CEOS Analysis-Ready Data for Land) is an effort by the Committee on Earth Observation Satellites (CEOS) to address this Big Data challenge. It provides voluntary standards for satellite data providers with regard to the geometric and radiometric accuracy, and content and availability of relevant meta data. For each parameter, the CARD4L specifications define a minimum (Threshold) requirement, considered sufficient to render the product ready for analysis, and a more stringent (Target) requirement, that further improves the product quality/usefulness. CARD4L also aims to facilitate access to a broader Earth observation user community by definition of data products that do not require expert knowledge to ingest and analyse.

The CARD4L Product Family Specifications for Synthetic Aperture Radar (SAR) data are specifically aimed at users interested in exploring the potential of SAR, but who may lack the expertise or facilities for SAR processing. There are currently five CARD4L SAR products:

- *Normalised Radar Backscatter*
- *Geocoded Single-Look Complex*
- *Polarimetric Radar Decomposition*
- *Normalised Radar Covariance Matrix*
- *Differential Interferometry Products*

The CARD4L Normalised Radar Backscatter product specification described below has been subject to Radiometric Terrain Correction (RTC) and is given in gamma-0 (Υ^0) backscatter, which mitigates the incidence angle effect. It is recommended for most land applications. Sigma-0 (σ^0) backscatter can however be retrieved by using local incidence angle information provided in the per-pixel meta data. As the NRB product contains backscatter values only, it cannot be used for SAR polarimetry or interferometric applications.

It should be noted that while speckle is inherent in SAR acquisitions, speckle filtering has not been applied to the Normalised Radar Backscatter product in order to preserve spatial resolution and user freedom, As a result, the number of looks is very small; most applications (or processing methods) therefore require spatial or temporal filtering for stationary backscatter estimates. Generally, the user cannot process the samples directly and independently as with CARD4L optical products. If no advanced speckle filter is applied by the user, the default recommendation is to apply at least a 7x7 averaging window to the NRB product data layer(s) for common applications.

Definitions

NRB	Normalised Radar Backscatter
Ancillary Data	Data other than instrument measurements, originating in the instrument itself or from the satellite, required to perform processing of the data. They include orbit data, attitude data, time information, spacecraft engineering data, calibration data, data quality information, and data from other instruments.
Auxiliary Data	The data required for instrument processing, which does not originate in the instrument itself or from the satellite. Some auxiliary data will be generated in the ground segment, whilst other data will be provided from external sources.
Metadata	Structured information that describes other information or information services. With well-defined metadata, users should be able to get basic information about data, without the need to have knowledge about its entire content.
MTF	Modulation Transfer Function
Spatial Resolution	The highest magnification of the sensor at the ground surface.
Spatial Sampling Distance	Spatial sampling distance is the barycentre-to-barycentre distance between adjacent spatial samples on the Earth's surface.

Requirements

General Metadata

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

#	Item	Threshold (Minimum Requirements)	Target (Desired) Requirements
1.1	**Traceability**	Not required.	Data must be traceable to SI reference standard. *Note 1. Relationship to 3.2. Traceability requires an estimate of measurement uncertainty.* *Note 2: Information on traceability should be available in the metadata as a single DOI landing page.*
1.2	**Metadata Machine Readability**	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.	As threshold, but metadata is formatted in accordance with ISO 19115-2.
1.3	**Data Collection Time**	The start and stop time of data collection is identified in the metadata, expressed in date/time, to the second, with the time offset from UTC unambiguously identified.	Acquisition time for each pixel is identified (or can be reliably determined) in the metadata, expressed in date/time at UTC, to the second.
1.4	**Geographical Area**	The surface location to which the data relates is identified, typically as a series of four corner points, expressed in an accepted coordinate reference system (e.g.,WGS84).	The geographic area covered by the observations is identified specifically, such as through a set of coordinates of a closely bounding polygon. The location to which each pixel refers is identified (or can be reliably determined) expressed in projection coordinates with reference datum.
1.5	**Coordinate Reference System**	The metadata lists the coordinate reference system that has been used.	As threshold.

1.6	**Map Projection**	The metadata lists the map projection that has been used and any relevant parameters required in relation to use of data in that map projection.	As threshold.
1.7	**Geometric Correction**	The metadata describes the geodetic correction methods used, including reference database and ancillary data such as elevation model(s) and reference chip-sets. DOIs are used.	As threshold.
1.8	**Geometric Accuracy**	A single-figure estimate of the Geometric accuracy is provided. The user is not necessarily provided with results of geometric correction processes pertaining to the dataset.	The metadata includes metrics describing the assessed geodetic accuracy of the data and the expressed units of the coordinate system of the data. Accuracy is assessed by independent verification (as well as internal model-fit where applicable). Uncertainties are expressed as root mean square error (RMSE) or Circular Error Probability (e.g., CEP90, CEP95).
1.9	**Instrument**	The instrument used to collect the data is identified in the metadata.	As threshold, but including a reference to the relevant CEOS Missions, Instruments and Measurements Database record.
1.10	**Acquisition Parameters**	Acquisition parameters details: Look direction (L, R). - polarizations - resolution (range x azimuth) - Orbit direction of data-take (ascending or descending) - Satellite heading angle (at scene centre)	As threshold.
1.11	**Processing Parameters**	Processing parameters details: - pixel spacing (range x azimuth) Number of looks (range x azimuth)	As threshold.
1.12	**Sensor Calibration**	Sensor calibration details/list of scientific papers and articles websites describing the calibration approach/method used.	As threshold.

1.13	**Radiometric Accuracy**	Not required. The general metadata does not include specific information on the radiometric accuracy of the data. OR, A global uncertainty estimate is provided.	The metadata includes metrics describing the assessed absolute radiometric accuracy of the data, expressed as absolute radiometric uncertainty relative to a known reference standard (e.g., pseudo-invariant calibration sites). *Note: For example, this may come from comparison with rigorously collected in situ measurements.*
1.14	**Algorithms**	All algorithms and the sequence in which they were applied in the generation.	As threshold, but only algorithms that have been published in a peer-reviewed journal. *Note: It is possible that high quality corrections are applied through.*
1.15	**Ancillary Data**	The metadata identifies the sources of ancillary data used in the generation process, ideally expressed as DOIs. *Note: Ancillary data includes DEMs, etc. data sources.*	As threshold, but the ancillary data is also available for free online download, contemporaneously with the product.
1.16	**Processing Chain Provenance**	Not required.	The metadata includes a description of the processing chain used to generate the product, including the versions of the software used.
1.17	**Data Access**	The metadata identifies the location from where the product can be retrieved, expressed as a DOI. *Note: Manual and* offline *interaction action (e.g. log in) may be required.*	The metadata identifies an online location from where the data (including any available new records) can be consistently and reliably retrieved by a computer algorithm without any manual intervention being required. *Note: Some manual interaction action may be required <u>in the first instance</u> ('one off' basis) to establish ongoing access to the data.*
1.18	**Overall Data Quality**	Not applicable.	TBD. There is a perceived need for machine-readable metrics describing the overall quality of the data, however the specifications for these are yet to be determined. If there is not a clear case and clear specifications for such metadata, then "Overall data quality" will be removed.

#	Item	Threshold (Minimum Requirements)	Target (Desired) Requirements
1.19	**Performance Indicators**	Provide performance indicators on resolution, SLR, NESZ and ENL. Those are not to be estimated on each product, but estimated once and annotated on all products. That information should be provided for each polarization channel when available.	As threshold.
1.20	**Ionosphere indicator**	Not applicable	Flag indicating whether the backscatter imagery is "significantly impacted" by the ionosphere (0- no, 1 – yes). Significant impact would imply that the ionospheric impact on the backscatter exceeds the radiometric calibration requirement or goal for the imagery.

Per-Pixel Metadata

The following minimum metadata specifications apply to each pixel. Whether the metadata are provided in a single record relevant to all pixels, or separately for each pixel, is at the discretion of the data provider. Per-pixel metadata should allow users to discriminate between (choose) observations on the basis of their individual suitability for application.

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements
2.1	**Metadata Machine Readability**	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.	As threshold, but metadata is formatted in accordance with relevant international Standards (ISO 19115-2).
2.2	**No Data**	Pixels or grid cells that do not correspond to an observation ('empty pixels') are clearly flagged.	As threshold.
2.3	**Layover**	Layover flags or mask is provided.	As threshold.
2.4	**Shadow**	Shadow flags or mask is provided.	As threshold.
2.5	**Local Incidence Angle**	Local Incidence angle image is provided.	As threshold.
2.6	**Global Incidence Angle**	Global incidence angle is provided.	As threshold.
2.7	**Digital Elevation Model**	Digital Elevation Model used for Radiometric Terrain Correction.	As threshold.
2.8	**Noise Equivalent Sigma0**	Noise equivalent σ^o used for Noise Removal, if applied, for each channel.	Noise equivalent σ^o for each channel.

Radiometric Corrections

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

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements
3.1	**Measurements**	Gamma-0 (Υ^0) backscatter coefficient is provided for each polarisation (e.g. HH, HV, VV, VH). *Note: transformation to the logarithm decibel scale is not required or* desired *as this step can be easily completed by the user if necessary.*	As threshold.
3.2	**Noise Removal**	Optional.	Thermal noise removal and image border noise removal (when applicable) to remove overall scene noise and scene edge artefacts, respectively.
3.3	**Terrain Corrections**	Adjustments are made for terrain by modelling the local illuminated reference area using the preferred choice of peer reviewed models to produce a radiometrically terrain corrected (RTC) Υ^0. Metadata references: - a citable peer-reviewed algorithm - technical documentation regarding the implementation of that algorithm expressed as DOIs - the sources of ancillary data used to make corrections *Note 1: Examples of technical documentation include an Algorithm.* Theoretical Basis Document, product user guide, etc. *Note 2: Requirement for metadata are better placed in 1.13 and 1.14 (Radiometric accuracy and Algorithms).*	Require resolution of DEM no worse than (TBD) the SAR backscatter resolution when applying terrain corrections. Require validation that any change in DEM or landcover between the date of the DEM determination and the date of the SAR backscatter acquisition does result in violating the radiometric or geometric accuracy.
3.4	**Accuracy**	Uncertainty (e.g., bounds on Υ^0) information is provided. SI traceability is achieved.	As threshold.

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

Geometric Corrections

Geometric corrections must place the measurement accurately on the surface of the Earth (that is, geolocate the measurement) allowing measurements taken through time to be compared.

#	Item	Threshold (Minimum) Requirements	Target (Desired) Requirements
4.1	**Accuracy**	a) Sub-pixel accuracy is taken to be less than or equal to 0.2-pixel radial root mean square error (rRMSE) or equivalent in Circular Error Probability (CEP) relative to a defined reference. b) A given data provider shall use the same DEM (DEM of their choice) to ensure consistency of the data stack. c) A consistent gridding/sampling frame is used, including common cell size, origin, and nominal sample point location within the cell (centre, ll, ur). *Note 1. Relevant metadata must be provided under 1.7 and 1.8 (Geometric correction and Geometric accuracy).* *Note 2. Accurate geolocation is a prerequisite to radar processing to correct for terrain. To enable interoperability between radar sensors, absolute accuracy is required. Orbit ephemeris updates (precise ephemeris) are required prior to any orthorectification steps to ensure accuracy.*	a) Sub-pixel accuracy is achieved relative to an identified absolute independent terrestrial referencing system (such as a national map grid). b) A DEM with comparable or better resolution to the resolution of the output ARD imagery shall be used. c) A consistent gridding/sampling frame is necessary to meet this requirement. *Note 3. Relevant metadata must be provided under 1.7 and 1.8 (Geometric correction and Geometric accuracy).*

Guidance

This section aims to provide background and specific information on the processing steps that can be used to achieve analysis ready data. This Guidance material does not replace or over-ride the specifications.

Introduction to CARD4L

What are CEOS Analysis Ready Data for Land (CARD4L) products?

CARD4L products have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort. These products would be resampled onto a common geometric grid (for a given product) and would provide baseline data for further interoperability both through time and with other datasets.

CARD4L products are intended to be flexible and accessible products suitable for a wide range of users for a wide variety of applications, including particularly time series analysis and multi-sensor application development. They are also intended to support rapid ingestion and exploitation via high-performance computing, cloud computing, and other future data architectures. They may not be suitable for all purposes, and are not intended as a 'replacement' for other types of satellite products.

When can a product be called CARD4L?

The CARD4L branding is applied to a particular product once:

The product has been assessed as meeting CARD4L requirements by the agency responsible for production and distribution of the product.
The assessment has been peer reviewed by the CEOS Land Surface Imaging Virtual Constellation in consultation with the CEOS Working Group on Calibration and Validation.

Agencies or other entities considering undertaking an assessment process should contact the co-leads of the Land Surface Imaging Virtual Constellation (hyperlink).

A product can continue to use CARD4L branding as long as its generation and distribution remain consistent with the peer-reviewed assessment.

What is the difference between Threshold and Target?

Products that meet all threshold requirements should be immediately useful for scientific analysis or decision-making.

Products that meet target requirements will reduce the overall product uncertainties and enhance broad-scale applications. For example, the products may enhance interoperability or provide increased accuracy through additional corrections that are not reasonable at the *threshold* level. Target requirements anticipate continuous improvement of methods and evolution of community expectations, which are both normal and inevitable in a developing field. Over time, *target* specifications may (as subject to due process) become accepted as *threshold* requirements.

Reference Papers

The following papers provide scientific and technical guidance:

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

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

Small D. Flattening Gamma: Radiometric Terrain Correction for SAR Imagery, *IEEE Transactions on Geoscience and Remote Sensing*, 2011, Vol. 49 (8), pp. 3081-3093.

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

Small D., Miranda N., Meier E. [2009] (presentation), Local Incidence Angle Considered Harmful, *Proc. of CEOS SAR 2009 Workshop,* Pasadena, California, USA, Nov. 17-19, 2009.

D. Small, N. Miranda and E. Meier, "A revised radiometric normalisation standard for SAR," 2009 *IEEE International Geoscience and Remote Sensing Symposium*, Cape Town, 2009, pp. IV-566-IV-569. doi: 10.1109/IGARSS.2009.5417439.

Appendix 2. CEOS SAR ARD NCM Specification

As at May, 2019

CARD4L_Product_Specification-CovarianceMatrix-v1.3

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

Document status

For Adoption as: *Product Family Specification, Normalised RADAR Covariance Matrix*

This Specification should next be reviewed at: .

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

Document history

Version	Date	Description of change	Author
1.0	31-07-2018	Draft based on CARD4L PFS Normalised RADAR Backscatter v3.1.1	Charbonneau
1.1	20-08-2018	Update Draft based on CARD4L PFS Normalised RADAR Backscatter v3.2, Polarimetric Decomposition v1.0 documents and discussion during "SAR ARD definition Team" telecons.	Charbonneau
1.2	28-01-2019	- New abstract - Add Notice and Limitation section - Update References section - Change threshold requirement on Faraday rotation, distortion matrix and multi-looking metadata	Charbonneau
1.3	16-04-2019	- Update based on latest CARD4L PFS Normalised RADAR Backscatter v4.0 - Replace "procedural examples" section by "Note on Covariance Matrices" - Add a draft metadata example in .xml format	Charbonneau

Description

Product family title: Radar Covariance Matrix (CARD4L-Radar)

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

Abstract

This covariance matrix analysis ready data (ARD) product format is an extension of the CARD4L-SAR Normalised Radar Backscatter format. This extension is required in order to better support fully polarimetric data (RADARSAT-2, ALOS-2 and future missions) and circular-linear dual-polarized configurations (i.e. Compact Polarimetric mode available on upcoming RCM, NISAR, SAOCOM missions). The covariance matrix representation (C2 – C3), as an ARD product format, preserves the inter-channel polarimetric phase(s) and maximizes the available information for users. Interoperability within current CARD4L-SAR backscatter only definition is retained, since diagonal elements of the covariance matrix are backscatter magnitudes. Scattering information enhancement can be achieved by applying incoherent polarimetric decomposition techniques (Freeman-Durden, van Zyl, Cloude-Pottier, Yamaguchi based, etc.) directly on the C2 or C3 matrix.

ARD creation processing steps are detailed and specific examples of polarimetric decomposition results derived from fully polarimetric and compact polarimetric covariance matrix ARD products are shown.

Notice and Limitation

It is well known that optimal incoherent polarimetric decomposition should be performed in the slant range projection (Gens et al. 2013, Toutin et al. 2013). Since speckle filtering and averaging of the covariance matrix is performed in slant range and its elements are geocoded with nearest neighbor resampling, this CARD4L-SAR covariance matrix product minimizes the bias. Specifically, nearest neighbor resampling ensures that the averaged covariance matrix elements in slant range and in geocoded ground projection are exactly the same. Consequently, the polarimetric derived parameters are EXACTLY equal in both approaches (assuming that no further averaging is performed on the ARD product for decomposing the polarimetric information). Bilinear resampling is also suitable for resampling the covariance matrix, but some differences with polarimetric parameters generated in slant range and then resampled (bilinear) might be observed on slope terrain. Even if the Sinc function is more robust for spatial resampling, it doesn't preserve the covariance matrix integrity, consequently it should not be used for this ARD product.

This ARD product is not suitable for all purposes, and is not intended as a 'replacement' for other types of satellite products. This product format is not suitable for coherent polarimetric decomposition algorithms, interferometric analyses, or Pol-InSAR techniques.

Definitions

NRB	Normalised Radar Backscatter
NRCM	Normalised Radar Covariance Matrix
Ancillary Data	The data required for instrument processing, which does not originate in the instrument itself or from the satellite. Some auxiliary data will be generated in the ground segment, whilst other data will be provided from external sources.
Auxiliary Data	The data required for instrument processing, which does not originate in the instrument itself or from the satellite. Some auxiliary data will be generated in the ground segment, whilst other data
Metadata	Structured information that describes other information or information services. With well-defined metadata, users should be able to get basic information about data, without the need to have knowledge about its entire content.
MTF	Modulation Transfer Function
Spatial Resolution	The highest magnification of the sensor at the ground surface
Spatial Sampling Distance	Spatial sampling distance is the barycentre-to-barycentre distance between adjacent spatial samples on the Earth's surface.

Requirements

General Metadata

These are metadata records describing a distributed collection of pixels. The collection of pixels referred to must be contiguous in space and time. General metadata should allow the user to assess the overall suitability of the dataset, and must meet the following requirements, which are common to the Normalized Radar Backscatter ARD from which the Covariance Matrix ARD is derived.

	Item	Threshold (minimum) requirements	Target (desired) requirements
1.1	**Traceability**	Not required.	Data must be traceable to SI reference standard. Note 1. Relationship to 3.2. Traceability requires an estimate of measurement uncertainty. Note 2: Information on traceability should be available in the metadata as a single DOI landing page.
1.2	**Metadata machine readability**	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.	As threshold, but metadata is formatted in accordance with ISO 19115-2.
1.3	**Data collection time**	The start and stop time of data collection is identified in the metadata, expressed in date/time, to the second, with the time offset from UTC unambiguously identified.	Acquisition time for each pixel is identified (or can be reliably determined) in the metadata, expressed in date/time at UTC, to the second.
1.4	**Geographical area**	The surface location to which the data relates is identified, typically as a series of four corner points, expressed in an accepted coordinate reference system (e.g.,WGS84).	The geographic area covered by the observations is identified specifically, such as through a set of coordinates of a closely bounding polygon. The location to which each pixel refers is identified (or can be reliably determined) expressed in projection coordinates with reference datum.
1.5	**Coordinate reference system**	The metadata lists the coordinate reference system that has been used.	As threshold

1.6	**Map projection**	The metadata lists the map projection that has been used, and any relevant parameters required in relation to use of data in that map projection.	As threshold
1.7	**Geometric correction**	The metadata describes the geodetic correction methods used, including reference database and ancillary data such as elevation model(s) and reference chip-sets. DOIs are used.	As threshold
1.8	**Geometric accuracy**	A single-figure estimate of the Geometric accuracy is provided. The user is not necessarily provided with results of	The metadata includes metrics describing the assessed geodetic accuracy of the data, expressed units of the coordinate system of the data. Accuracy is assessed by independent verification (as well as internal model-fit where
1.9	**Instrument**	The instrument used to collect the data is identified in the metadata.	As threshold, but including a reference to the relevant CEOS Missions, Instruments and Measurements Database record.
1.10	**Acquisition parameters**	Acquisition parameter details: Look direction (L, R). - polarizations - resolution (range x azimuth) - Orbit direction of data-take (ascending or descending) - Satellite heading angle (at - scene centre)	As threshold.
1.11	**Processing parameters**	Processing parameter details: - pixel spacing (range x azimuth) - number of looks	As threshold.
1.12	**Sensor calibration**	Sensor calibration details / list of scientific papers and articles websites describing the calibration approach/method used.	As threshold.

1.13	**Polarimetric calibration matrices**	If available, not required This information is not always released by data provider.	The complex-valued polarimetric distortion matrices with the channel imbalance and the cross-talk applied for the polarimetric calibration
1.14	**Radiometric accuracy**	Not required. The general metadata does not include specific information on the radiometric accuracy of the data. OR, A global uncertainty estimate is provided.	The metadata includes metrics describing the assessed absolute radiometric accuracy of the data, expressed as absolute radiometric uncertainty relative to a known reference standard (e.g., pseudo-invariant calibration sites). Note 1: for example, this may come from comparison with rigorously collected in situ measurements.
1.15	**Mean Faraday Rotation angle**	For larger wavelength SAR systems (i.e. L and P bands), the mean Faraday rotation angle estimated from the polarimetric data and/or from models with reference to the method or paper used to derive the estimate.	As threshold and for all SAR wavelengths.
	Algorithms	All algorithms, and the sequence in which they were applied in the generation process, are identified in the metadata.	As threshold, but only algorithms that have been published in a peer-reviewed journal *Note: It is possible that high quality corrections are applied through non-disclosed processes*. *CARD4L does not per-se require full and open data and methods.* DOIs for each algorithm are identified in the metadata. The versions of the algorithms are identified.

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

1.20	**Ionosphere indicator**	Not applicable	Flag indicating whether the backscatter imagery is “significantly impacted” by the ionosphere (0- no, 1 – yes). Significant impact would imply that the ionospheric impact on the backscatter exceeds the radiometric calibration requirement or goal for the imagery.

Per-pixel metadata

The following minimum metadata specifications apply to each pixel. Whether the metadata are provided in a single record relevant to all pixels, or separately for each pixel, is at the discretion of the data provider. Per-pixel metadata should allow users to discriminate between (choose) observations on the basis of their individual suitability for application.

	Item	Threshold (minimum) requirements	Target (desired) requirements
2.1	**Metadata machine readability**	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.	As threshold, but metadata is formatted in accordance with relevant international standards (ISO 19115-2).
2.2	**No data**	Pixels or grid cells that do not correspond to an observation ('empty pixels') are clearly flagged	As threshold.
2.3	**Layover**	Layover flags or mask is provided	As threshold.
2.4	**Shadow**	Shadow flags or mask is provided	As threshold.
2.5	**Local Incidence Angle**	Local Incidence angle image is provided	As threshold.
2.6	**Global Incidence Angle**	Global incidence angle is provided	As threshold.
2.7	**Digital Elevation Model**	Digital Elevation Model used for Radiometric Terrain Correction	As threshold.
2.8	**Noise Equivalent Sigma0**	Noise equivalent σ^o used for Noise Removal, if applied	Noise equivalent σ^o

Radiometric corrections

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

	Item	Threshold (minimum) requirements	Target (desired) requirements
3.1	**Measurements**	Diagonal and upper diagonal elements of the Gamma-0 (Υ_0) covariance matrix are provided for coherent dual (e.g. CH-CH) and fully polarimetric (e.g. HH, HV, VH, VV) acquisitions. Note: transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.	As threshold.
3.2	**Noise removal**	Optional	Thermal noise removal and image border noise removal (when applicable) to remove overall scene noise and scene edge artefacts, respectively.

3.3	**Terrain Corrections**	Adjustments are made for terrain by modelling the local illuminated reference area using the preferred choice of peer reviewed models to produce a radiometrically terrain corrected (RTC) Υ_0. Metadata references: ● a citable peer-reviewed algorithm, ● technical documentation regarding the implementation of that algorithm expressed as DOIs ● the sources of ancillary data used to make corrections. Note 1: examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc. Note 2: requirement for metadata are better placed in 1.13 and 1.14 (Radiometric accuracy and Algorithms).	Require resolution of DEM no worse than (TBD) the SAR backscatter resolution when applying terrain corrections. Require validation that any change in DEM or landcover between the date of the DEM determination and the date of the SAR backscatter acquisition does result in violating the radiometric or geometric accuracy.
3.4	**Accuracy**	Uncertainty (e.g., bounds on Υ_0) information is provided. SI traceability is achieved	As threshold.
3.5	**Speckle Filtering**	Advanced polarimetric filter preserving covariance matrix properties should be applied. Metadata should include - Reference to algorithm - Input filtering parameters	As threshold.

Geometric corrections

Geometric corrections must place the measurement accurately on the surface of the Earth (that is, geolocate the measurement) allowing measurements taken through time to be compared.

	Item	Threshold (minimum) requirements	Target (desired) requirements
4.1	**Accuracy**	a) Sub-pixel accuracy is taken to be less than or equal to 0.2-pixel radial root mean square error (rRMSE) or equivalent in Circular Error Probability (CEP) relative to a defined reference. b) A given data provider shall use the same DEM (DEM of their choice) to ensure consistency of the data stack. c) A consistent gridding / sampling frame is used, including common cell size, origin, and nominal sample point location within the cell (centre, ll, ur) *Note 1. Relevant metadata must be provided under 1.7 and 1.8 (Geometric correction and Geometric accuracy)* *Note 2. Accurate geolocation is a prerequisite to radar processing to correct for terrain. To enable interoperability between radar sensors absolute accuracy is required. Orbit ephemeris updates (precise ephemeris) are required prior to any orthorectification steps to ensure accuracy.*	a) Sub-pixel accuracy is achieved relative to an identified absolute independent terrestrial referencing system (such as a national map grid). b) A DEM with comparable or better resolution to the resolution of the output ARD imagery shall be used. c) A consistent gridding / sampling frame is necessary to meet this requirement. *Note 3.Relevant metadata must be provided under 1.7 and 1.8 (Geometric correction and Geometric accuracy)*

Guidance

This section aims to provide background and specific information on the processing steps that can be used to achieve analysis ready data. This Guidance material does not replace or over-ride the specifications.

Introduction to CARD4L

What is CEOS Analysis Ready Data for Land (CARD4L) products?

CARD4L products have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort. These products would be resampled onto a common geometric grid (for a given product) and would provide baseline data for further interoperability both through time and with other datasets.

CARD4L products are intended to be flexible and accessible products suitable for a wide range of users for a wide variety of applications, including particularly time series analysis and multi-sensor application development. They are also intended to support rapid ingestion and exploitation via high-performance computing, cloud computing and other future data architectures. They may not be suitable for all purposes, and are not intended as a 'replacement' for other types of satellite products.

When can a product be called CARD4L?

The CARD4L branding is applied to a particular product once:

8. that product has been assessed as meeting CARD4L requirements by the agency responsible for production and distribution of the product.
9. that assessment has been peer reviewed by the CEOS Land Surface Imaging Virtual Constellation in consultation with the CEOS Working Group on Calibration and Validation.

Agencies or other entities considering undertaking an assessment process should contact the co-leads of the Land Surface Imaging Virtual Constellation (hyperlink).

A product can continue to use CARD4L branding as long as its generation and distribution remain consistent with the peer-reviewed assessment.

What is the difference between Threshold and Target?

Products that meet all threshold requirements should be immediately useful for scientific analysis or decision-making.

Products that meet target requirements will reduce the overall product uncertainties and enhance broad-scale applications. For example, the products may enhance interoperability or provide increased accuracy through additional corrections that are not reasonable at the *threshold* level.

Target requirements anticipate continuous improvement of methods and evolution of community expectations which are both normal and inevitable in a developing field. Over time, *target* specifications may (and subject to due process) become accepted as *threshold* requirements.

Note on Covariance Matrices

In order to preserve the inter-channel polarimetric phase and thus the full information content of coherent dual-pol and fully polarimetric data, the covariance matrix is proposed as the data storage format. Covariance matrices are generated from the complex cross product of polarimetric channels, as shown in Equation 1 for fully polarimetric data (C3) and in Equation 2 for dual polarization data (C2). Since these matrices are complex symmetrical, only the upper diagonal elements (bold elements) need to be stored in the ARD database.

Fully polarimetric

$$C3 = \begin{bmatrix} |\boldsymbol{HH}|^2 & \sqrt{\boldsymbol{2}} \cdot \boldsymbol{HH} \cdot \boldsymbol{HV}^* & \boldsymbol{HH} \cdot \boldsymbol{VV}^* \\ \sqrt{2} \cdot HV \cdot HH^* & \boldsymbol{2} \cdot |\boldsymbol{HV}|^2 & \sqrt{\boldsymbol{2}} \cdot \boldsymbol{HV} \cdot \boldsymbol{VV}^* \\ VV \cdot HH^* & \sqrt{2} \cdot VV \cdot HV^* & |\boldsymbol{VV}|^2 \end{bmatrix} \qquad \textbf{Eq. 1}$$

Where HV = VH, under the reciprocity assumption. | | and * mean respectively complex modulus and the complex conjugate.

Dual polarization

HH-HV

$$C2 = \begin{bmatrix} |\boldsymbol{HH}|^2 & \boldsymbol{HH} \cdot \boldsymbol{HV}^* \\ HV \cdot HH^* & |\boldsymbol{HV}|^2 \end{bmatrix} \quad or$$

VV-VH

$$C2 = \begin{bmatrix} |\boldsymbol{VH}|^2 & \boldsymbol{VH} \cdot \boldsymbol{VH}^* \\ VH \cdot VH^* & |\boldsymbol{VV}|^2 \end{bmatrix} \quad or \qquad \textbf{Eq. 2}$$

CH-CV

$$C2 = \begin{bmatrix} |\boldsymbol{CH}|^2 & \boldsymbol{CH} \cdot \boldsymbol{CV}^* \\ CV \cdot CH^* & |\boldsymbol{CV}|^2 \end{bmatrix}$$

Where CH and CV refer to dual polarization transmitting a circular polarized signal. [CH, CV] can be replaced by [LH, LV] or [RH, RV] for left (L) or right (R) hand circular transmission respectively, although RCM will offer only right hand circular transmission. The coherent HH-VV configuration available on TerraSAR-X could also be represented as C2 format.

Polarimetric decomposition methods like Yamaguchi et al. (2011) for fully polarimetric, or m-chi (Raney et al., 2012) for compact polarimetric data, can be applied directly on averaged (speckle filtered) C3 and C2 matrices respectively. These decompositions enhance scattering information, bring it to a more comprehensible level to end users, and raise the performance of thematic classification methodologies.

For SAR products that were acquired with single polarization the use of the covariance matrix does not result in superfluous storage requirements, since only the matrix elements that are populated are kept and the diagonal matrix elements are the backscatter intensities. Thus a single channel intensity product would yield only one matrix element and the storage needs would not change.

In order to ease the data structure and the metadata in between C3 and C2, Equation 1 should be redefined as Equation 3. Users will have to take care of this non-standard representation when applying their polarimetric analytic tools. “< >” means that ARD matrix elements are speckle filtered.

$$C3\,modified\;\; C3m = \begin{bmatrix} \langle|\boldsymbol{HH}|^{2}\rangle & \langle\boldsymbol{HH}\cdot\boldsymbol{HV}^{*}\rangle & \langle\boldsymbol{HH}\cdot\boldsymbol{VV}^{*}\rangle \\ \langle HV\cdot HH^{*}\rangle & \langle|\boldsymbol{HV}|^{2}\rangle & \langle\boldsymbol{HV}\cdot\boldsymbol{VV}^{*}\rangle \\ \langle VV\cdot HH^{*}\rangle & \langle VV\cdot HV^{*}\rangle & \langle|\boldsymbol{VV}|^{2}\rangle \end{bmatrix} \qquad \textbf{Eq. 3}$$

Furthermore, for RCM compact polarimetric data, it is recommended to store them, by simple transformation, under the circular-circular basis, since RR and RL polarizations (Equation 4) permit faster and more intuitive RGB visualizations (R=RR, G=RR/(RR+RL), B= RL).

In

CH-CV **C2 circular** $C2c = \begin{bmatrix} \langle|\boldsymbol{RR}|^{2}\rangle & \langle\boldsymbol{RR}\cdot\boldsymbol{RL}^{*}\rangle \\ \langle RL\cdot RR^{*}\rangle & \langle|\boldsymbol{RL}|^{2}\rangle \end{bmatrix}$ **Eq. 4**

order for the covariance matrix format to be accessible the metadata must specify which matrix elements have been stored. Table 3 lists the proposed format for quick reference. Polarization search in the metadata could be done by “layer ID”, “Matrix element” or by “Layer description”.

Table 7. SAR ARD covariance matrix storage structure (RADARSAT-2 & RCM)

SAR ARD layer ID	Matrix element	Layer description
1	C3m11	HH backscatter [intensity]
2	C3m12	HH × conj(HV) [complex]
3	C3m13	HH × conj(VV) [complex]
4	C3m22	HV backscatter [intensity]
5	C3m23	HV × conj(VV) [complex]
6	C3m33	VV backscatter [intensity]
7	C2c11	RR backscatter [intensity]
8	C2c12	RR × conj(RL) [complex]
9	C2c22	RL backscatter [intensity]

Specific product examples derived from Covariance Matrix ARD

From fully polarimetric covariance matrix ARD format, it is possible to apply any version of the popular Yamaguchi methodology, which decomposes the polarimetric information under relative intensities of 4 scattering types: Odd bounce, Even bounce, Random (volume) and helix. Figure 1b) shows HH intensity of a RADARSAT fully polarimetric acquired over a Spanish area. Decomposition using Yamaguchi methodology [Yamaguchiet al. 2011] can be expressed in RGB color composite (figure 1c) where Red channel refers to even bounce scattering like urban area; Green channel is random scattering like vegetation; and Blue channel is odd bounce scattering like bare soil. Figure 1d) is equivalent to 1c) where radiometric normalization (terrain flattening) has been applied with the help of the DEM of the scene (figure 1a).

Figure 2 is a compact polarimetric m-chi decomposition [Raney et al., 2012] simulated from two Canadian prairies Radarsat-2 fully polarimetric scenes acquired in May and June 2012. In May, before the growing season (Figure 2a), m-chi shows mainly surface scattering from bare soil (blue channel) and vegetation interaction from forested areas (green channel), while in June (figure 2b) growth of vegetation modifies the radar signal with interacting media function of the vegetation density and geometry which increase the amount of even bounce (red channel) and random scattering.

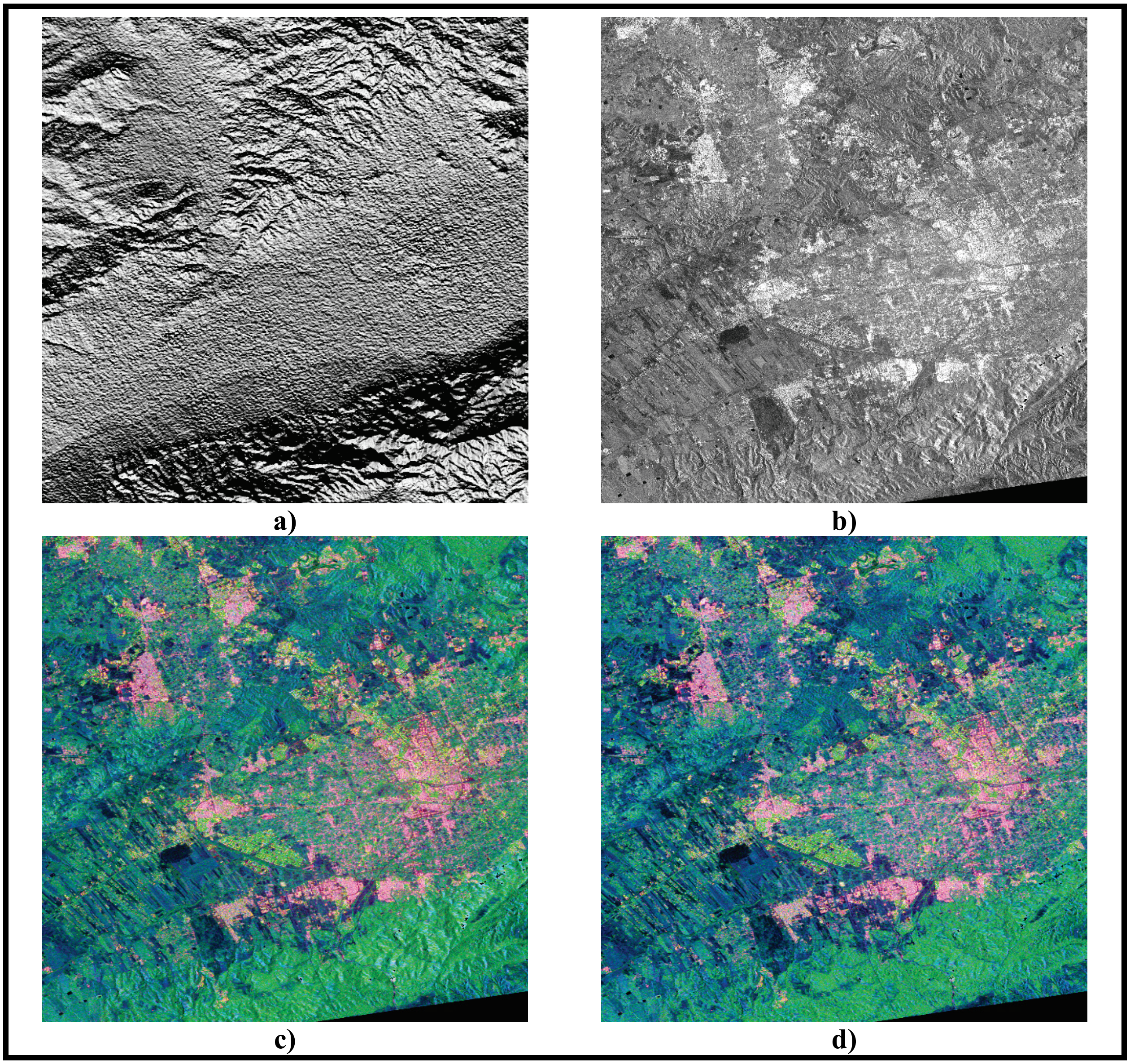
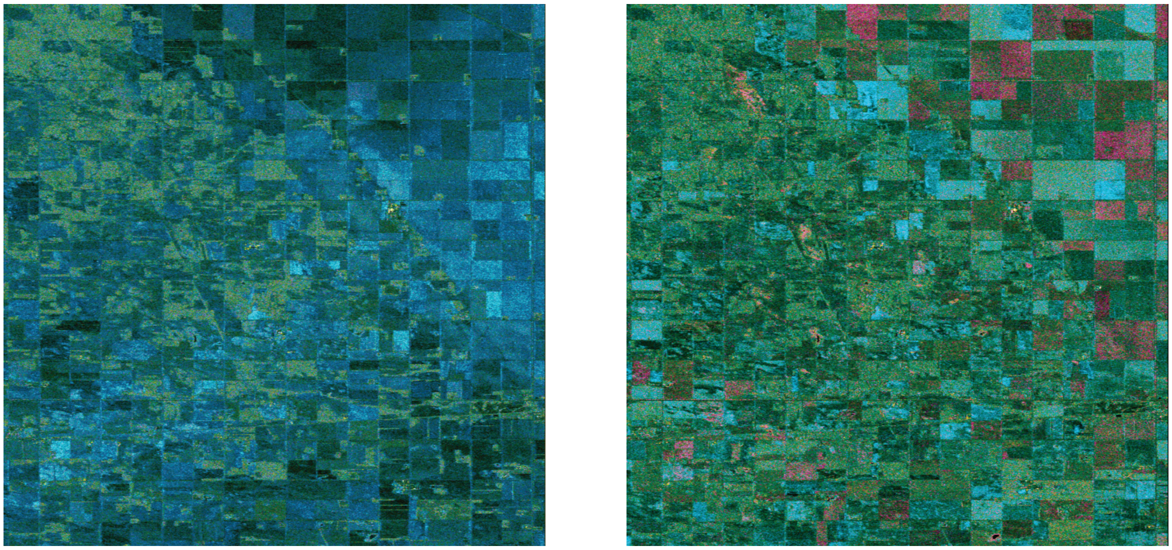


Figure 1 Example of polarimetric decomposition generated from ARD covariance format. **a)** Shaded DEM of the area; b) RADARSAT-2 HH intensity; **c)** Yamaguchi decomposition color composite (Red: even bounce, Green: random, Blue: odd bounce); **d)** Same as c) with terrain flattening option.



a) b)

Figure 2 m-chi decomposition color composite of simulated compact polarimetry from Radarsat-2 over an agriculture area. RGB representation: Red: even bounce, Green: random, Blue: odd bounce. **a)** 3 May 2012 and **b)** 18 June 2012

Reference papers

The following papers provide scientific and technical guidance:

Gens, R., D. K. Atwood and E. Pottier (2013) Geocoding of polarimetric processing results: Alternative processing strategies, Remote Sensing Letters, Vol. 4, No. 1, pp. 38-44.

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

Lee,J.-S., J.-H. Wen, T. L. Ainsworth, K.-S. Chen, and A. J. Chen (2009) Improved Sigma Filter for Speckle Filtering of SAR Imagery, IEEE Transactions on Geoscience and Remote Sensing, vol. 47, no. 1, pp. 202-213.

Raney, R. K., J. T. S. Cahill, G. W. Patterson and D. B. J. Bussey (2012) The m-chi decomposition of hybrid dual-polarimetric radar data with application to lunar craters, Journal of Geophysical Research: Planets 117(E5)

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

Small D. (2011) Flattening Gamma: Radiometric Terrain Correction for SAR Imagery, IEEE Transactions on Geoscience and Remote Sensing, vol. 49, no. 8, pp. 3081-3093.

Toutin, T., H. Wang, P. Chomaz and E. Pottier (2013) Orthorectification of Full-Polarimetric Radarsat-2 Data Using Accurate LIDAR DSM, IEEE Transactions on Geoscience and Remote Sensing, vol. 51, no. 12, pp. 5252-5258.

Yamaguchi, Y., A. Sato, W. M. Boerner, R. Sato and H. Yamada (2011). "Four-Component Scattering Power Decomposition with Rotation of Coherency Matrix." IEEE Transactions on Geoscience and Remote Sensing, vol. 49, no. 6, pp. 2251-2258.

Example of CARD4L-SAR NRCM product.xml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<?xml version="1.0" encoding="utf-8"?>
<product Type="Normalized Radar Covariance Matrix" copyright="RADARSAT-2 Data and Products (c)
MacDonald, Dettwiler and Associates Ltd., 2008 - All Rights Reserved.">
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Appendix 3. Data Format Requirements for SAR Analysis Techniques

1- Intensity: Calibrated backscattering intensity
2- Intensity change detection: Performed on calibrated backscattering intensity; Optimized when full spatial resolution is used (not downsampled and geocoded)
3- Coherent change detection: Requires sample phase; Optimized with original spatial resolution
4- Polarimetric change detection: Calibrated backscattering intensity; Preservation of relative polarimetric phases; Optimized with original spatial resolution
5- Multipolarization change detection: Performed on calibrated backscattering intensities; Optimized with original spatial resolution
6- Polarimetric decomposition: Calibrated backscattering intensity; Preservation of relative polarimetric phases
7- InSAR: Requires sample phase and orbital information
8- Pol/CP-InSAR: Requires preservation of relative polarimetric phase, sample phase and orbital information. Optimized with original spatial resolution.
9- Classification: Can be done with calibrated intensity only, but best performed with polarimetric information