CEOS Analysis Ready Data for Land

Normalized Radar Polarimetric Covariance Matrix and Polarimetric Radar Decomposition

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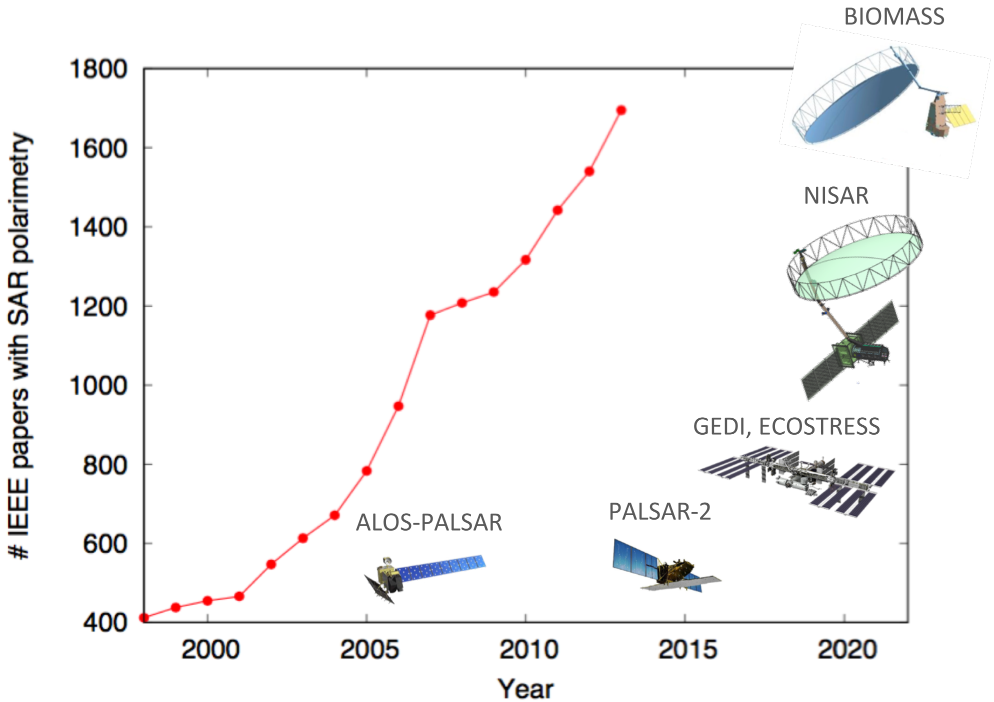
Polarimetry in Analysis Read Data (ARD)

- In the continuity of CARD4L normalized radar backscatter (A. Rosenqvist)
- CARD4L specification should inxlude coherent polarimetric content for
  - ALOS-2/4
  - RADARSAT-2/RADARSAT Constellation
  - TerraSAR-X
  - SAOCOM
  - NISAR
  - Sentinel-1
  - Several future missions (ROSE-L, etc.)
- Polarimetric ARD product definitions
  1. Normalized Covariance matrix
  2. Polarimetric Decomposition



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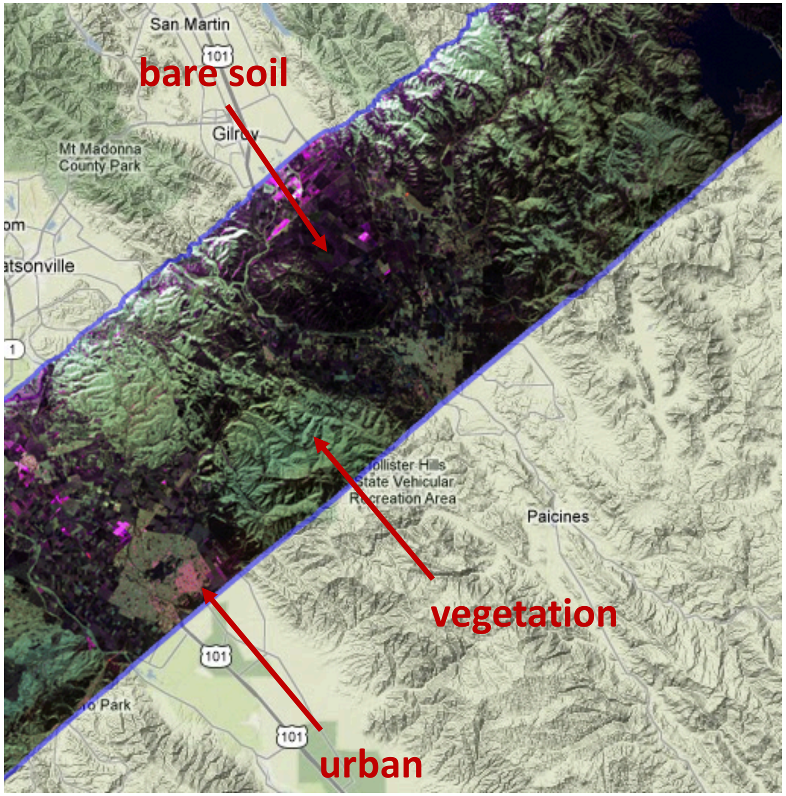
Benefits of Polarimetric Measurements

- Microwave scattering changes coherently with transmit/receive polarization
- Polarization is sensitive to different structural and dielectric components of complex targets
- Improved target classification and retrieval accuracy of bio-physical quantities (e.g., soil-moisture)
- Overall increased algorithmic performance compared to equivalent single-polarimetric imagery
- Additional "dimension" for mission products inter-comparison or fusion



L-band UAVSAR polarimetric false color composition, Central San Andreas Fault, May 21, 2012

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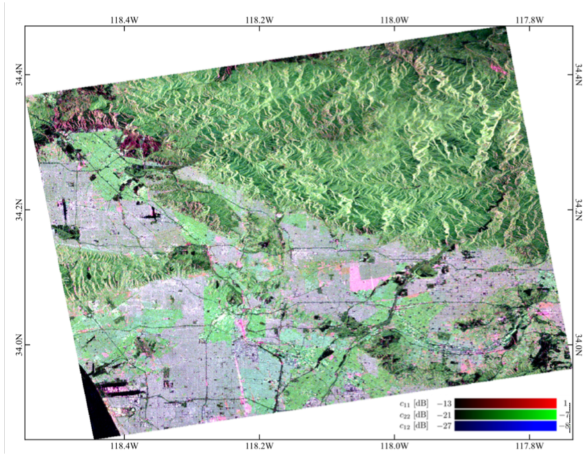
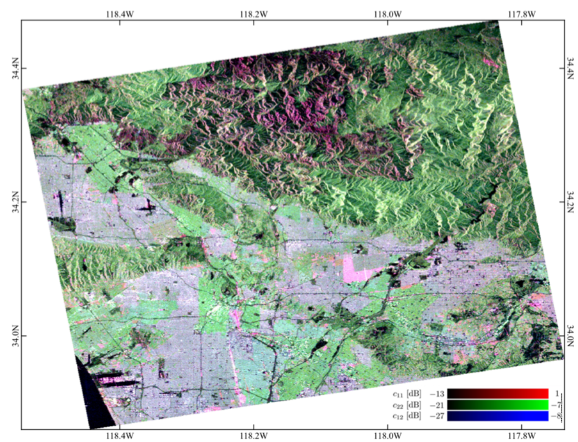
Why we need Polarimetric ARDs

Pre-fire dataset 1: ALOS-1 23 Aug 2009



Post-fire dataset 2: ALOS-1 10 Oct 2009

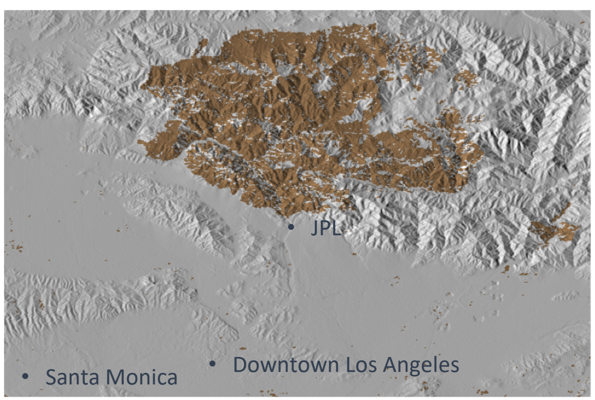


Example: Forest disturbance detection with coherent dual-pol SAR images

$$g = \begin{pmatrix} s_{hh} \\ s_{vh} \end{pmatrix}, \quad C = \langle g g^* \rangle = \begin{pmatrix} c_{11} & c_{12} \\ c_{12}^* & c_{22} \end{pmatrix}$$

$$\alpha = \sum_{i=1}^{2} \frac{\alpha_i \lambda_i}{\lambda_1 + \lambda_2}$$

ALOS-1 dual-polarimetric change detection

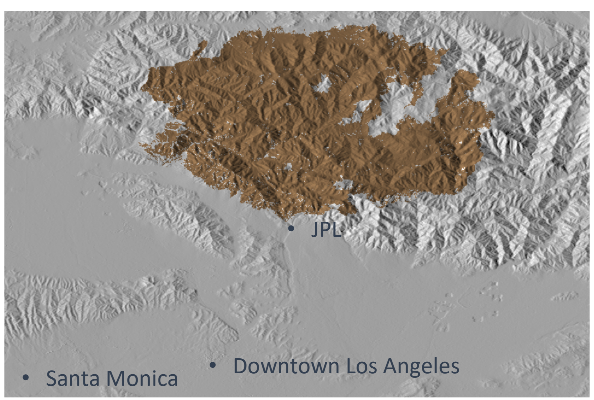


Fire scar

SRTM terrain slope

Compare to geocoded Landsat map for validation

Landsat-based fire scar (USGS/USFS MTBS)



Fire scar

SRTM terrain slope

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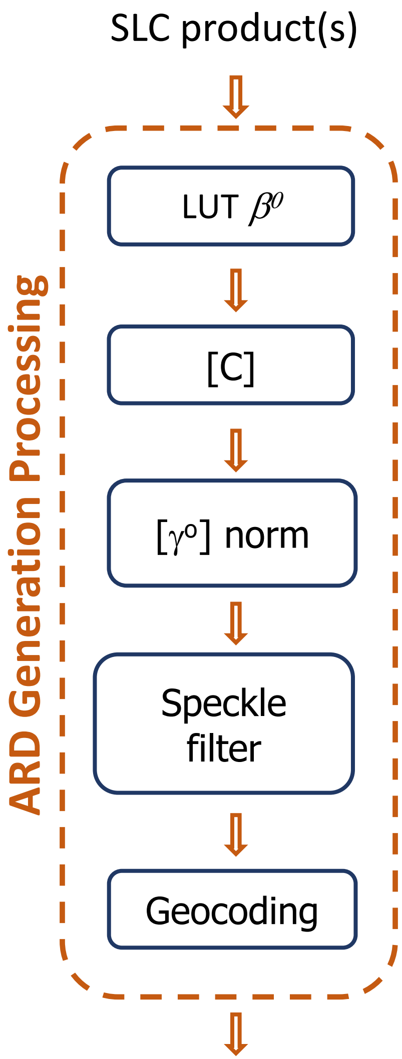
Normalized Covariance Matrix ARD



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

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

scattering vector

2. Covariance matrices from calibrated β^0 data

dual-pol portion (NISAR)

$$[C] = \frac{1}{N} \sum_{i}^{N} k_i k_i^H = \begin{pmatrix} \langle |S_{HH}|^2 \rangle & \sqrt{2} \langle S_{HH} S_{HV}^* \rangle & \langle S_{HH} S_{VV}^* \rangle \\ \sqrt{2} \langle S_{HV} S_{HH}^* \rangle & 2 \langle |S_{HV}|^2 \rangle & \sqrt{2} \langle S_{HV} S_{VV}^* \rangle \\ \langle S_{VV} S_{HH}^* \rangle & \sqrt{2} \langle S_{VV} S_{HV}^* \rangle & \langle |S_{VV}|^2 \rangle \end{pmatrix}$$

covariance matrix

dual-pol portion (S-1)

3. γ^0 normalization to “flatten” radar backscatter

4. Optional filtering (e.g., 7x7 sigma Lee speckle)

5. Geocoding (e.g., with nearest-neighbor or bilinear resampling to preserve matrix elements integrity

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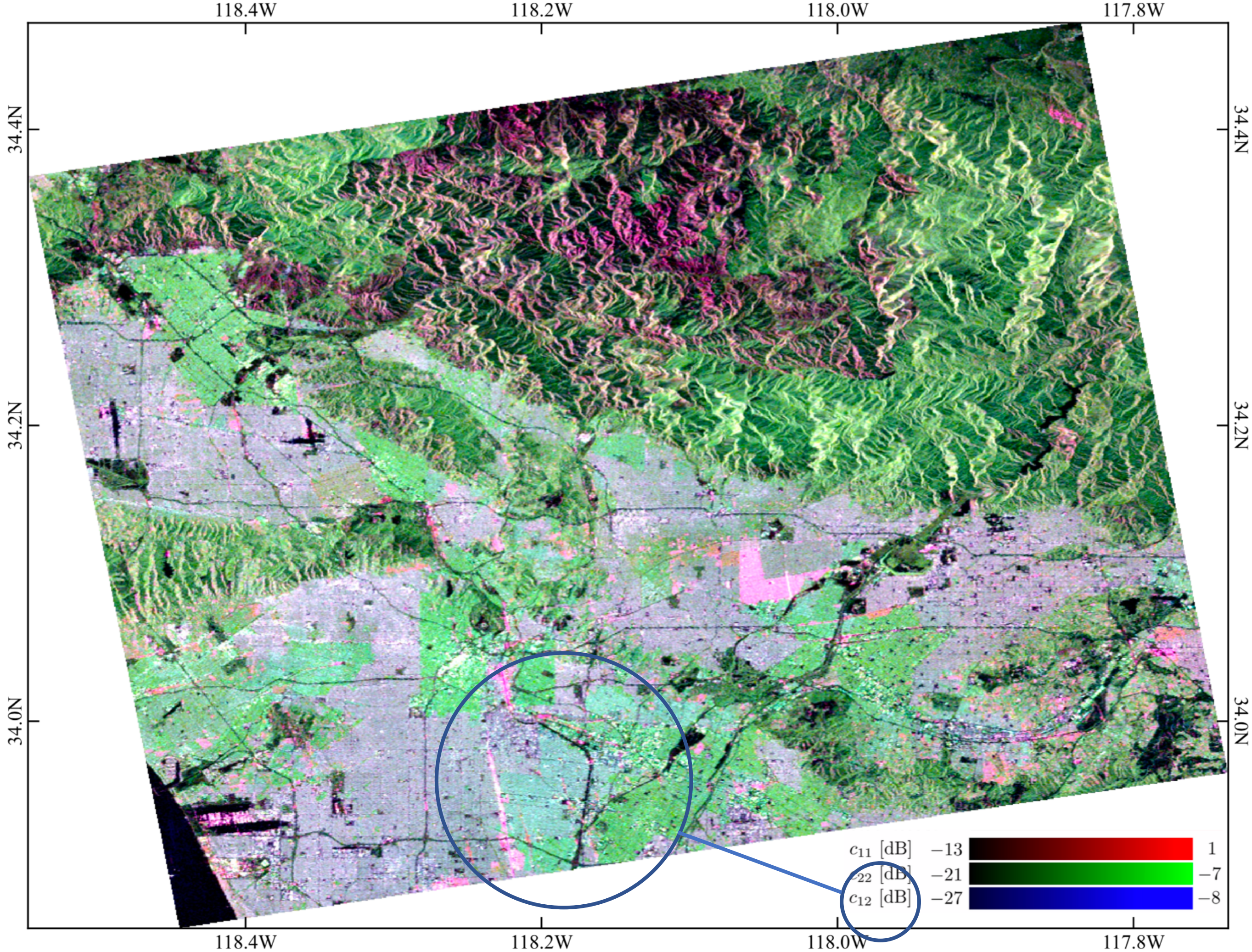
Normalized Covariance Matrix ARD - Example

ALOS-2 dual-pol acquired over Los Angeles, no radiometric terrain normalization applied



amplitude of complex off-diagonal element

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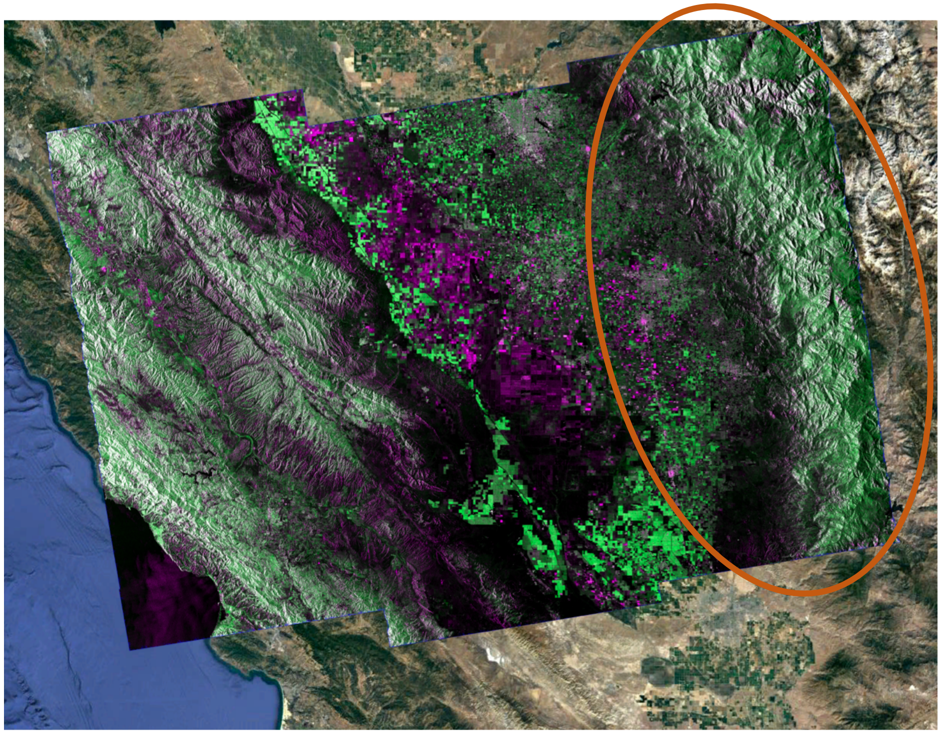
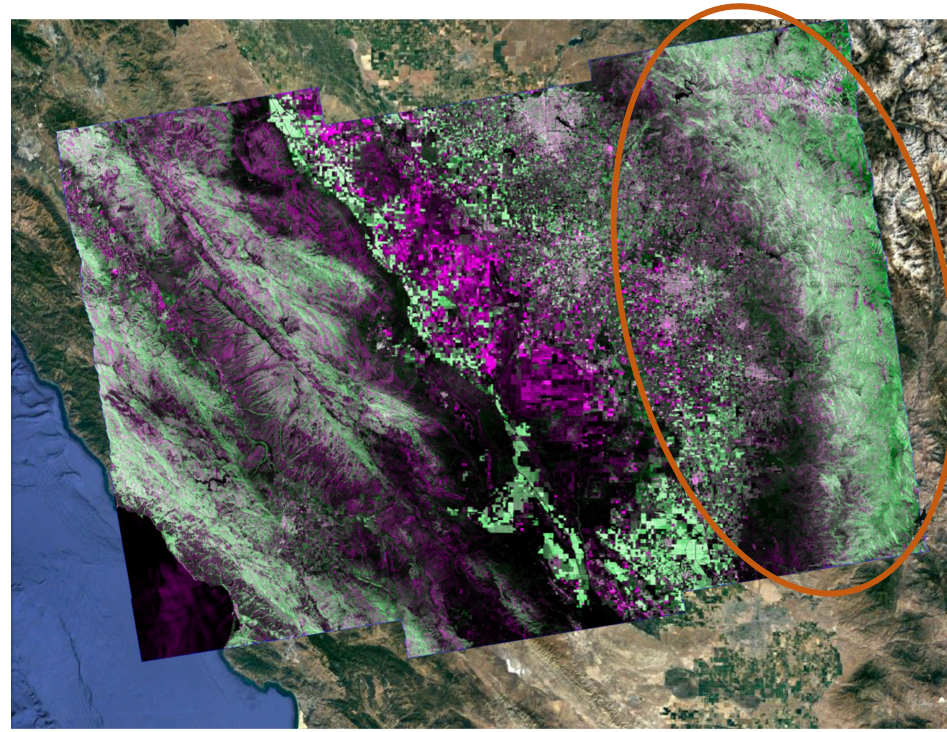
Gamma-naught Covariance Matrix ARD - Example

Sentinel-1 VV, VH color composite over San Andreas Fault
processed with NISAR ADT's ISCE3

Beta-naught



Gamma-naught



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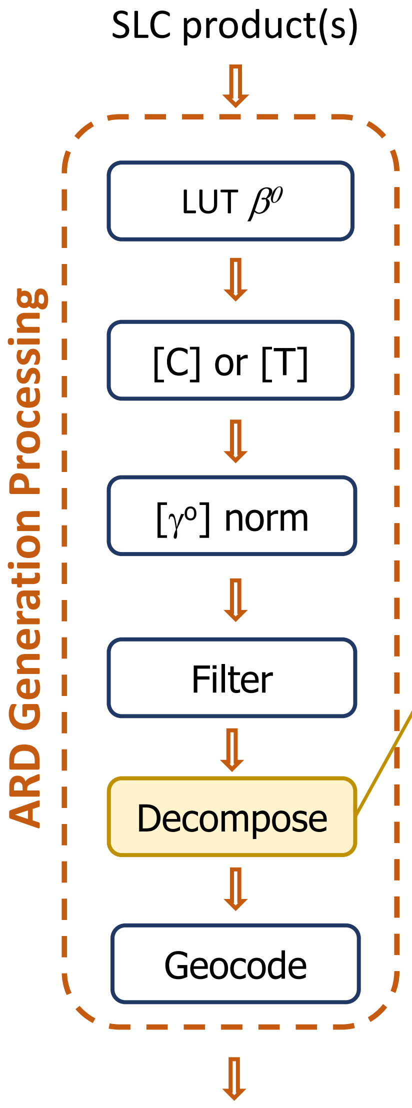
Polarimetric Decomposition ARD



1. Covariance [C] or Coherence [T] matrices from calibrated data(β^o LUT applied)
   - 3x3 to 11x11 sample window in order to achieve 50 to 100 independent looks while preserving resolution
2. γ^o normalization
   - D. Small's approach recommended
3. Polarimetric decomposition
   - Yamaguchi, Cloude-Pottier, van Zyl, Freeman-Durden, Touzi, Generalized Freeman-Durden, etc.
   - Output layers depending on chosen polarimetric decomposition
4. Geocoding
   - Nearest-neighbor interpolation preferred to preserve decomposed parameter integrity, other choices such as average, bilinear, Sinc, etc. allowed

Polarimetric Decomposition ARD Example

Surface scattering intensity

Double bounce scattering intensity

Volume scattering intensity

L-band UAVSAR, Central San Andreas Fault, May 21, 2012

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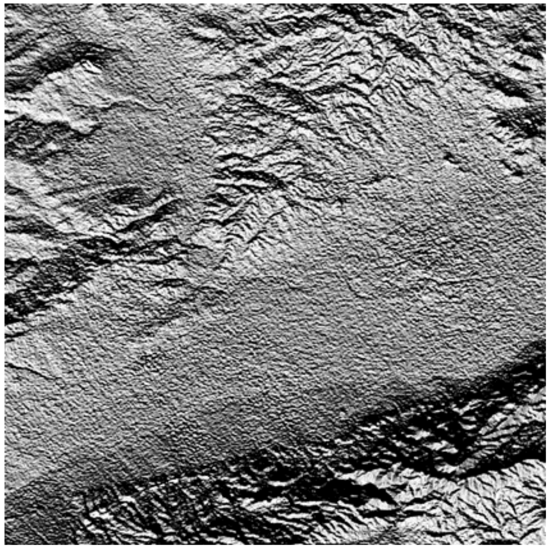
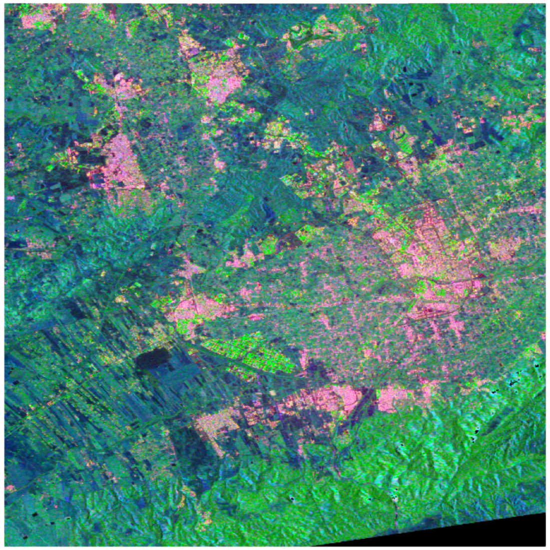
Full Polarimetric Decomposition Examples

RADARSAT-2 FQ18W acquired over Murcia, Spain on 18 June 2014
Generated from Level-1 or -2 ARD format (same results)

DEM

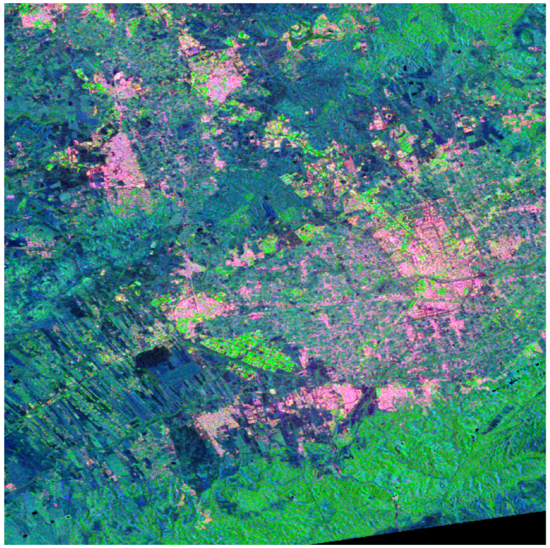


Yamaguchi



RGB Scattering Mechanisms
Red: Even bounce
Green: Random
Blue: Odd bounce

Normalized Yamaguchi



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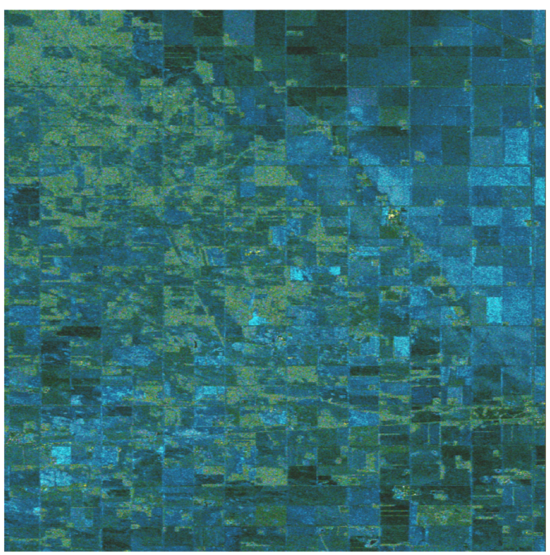
Compact Polarimetry m-χ Agriculture Temporal Analysis Examples

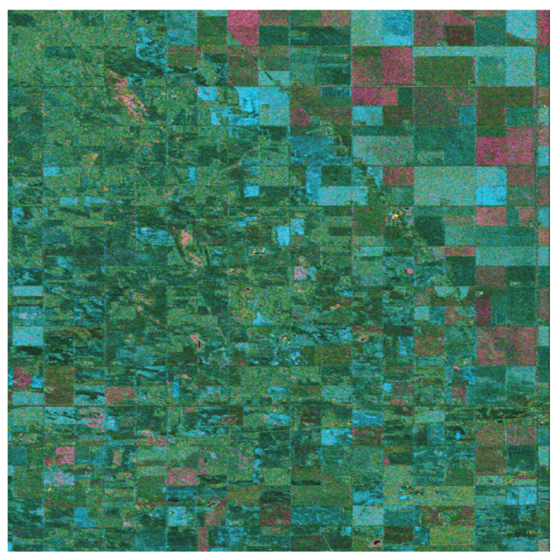
RADARSAT-2 FQ6W over SMAPVEX12 campaign, Manitoba, Canada on 3 May and 20 June 2012

- Compact polarimetric ARD can be decomposed to scattering mechanism representation
- Dominant surface (blue) scattering in May while grown vegetation structure diversity and biomass amount can be characterized in June

3 May 2012



18 June 2012

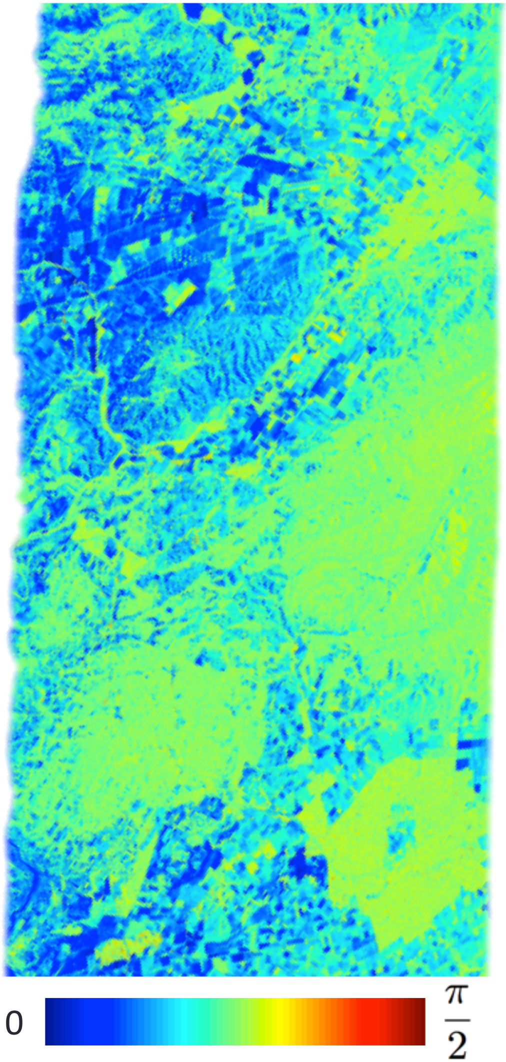


RGB Scattering Mechanisms
Red: Even bounce
Green: Random
Blue: Odd bounce

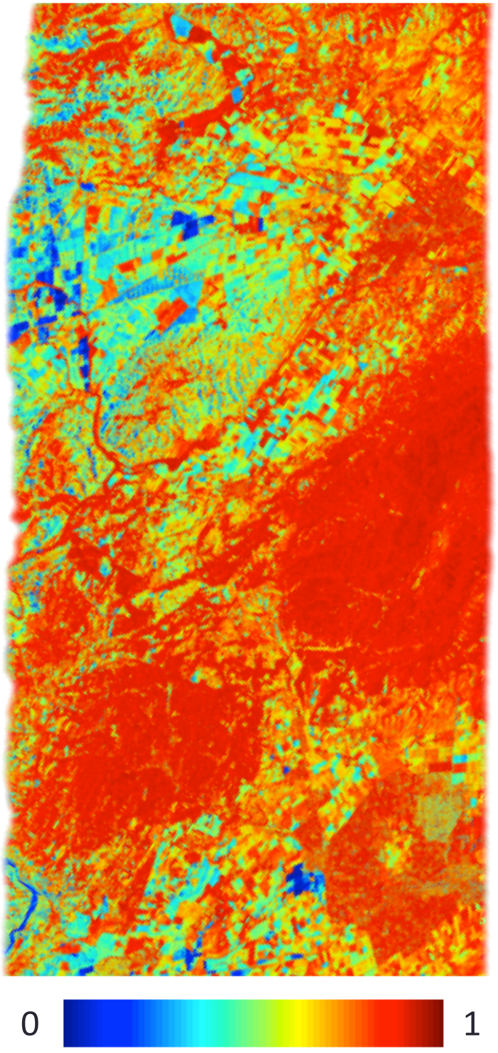
H/A/alpha Decomposition ARD - Classification

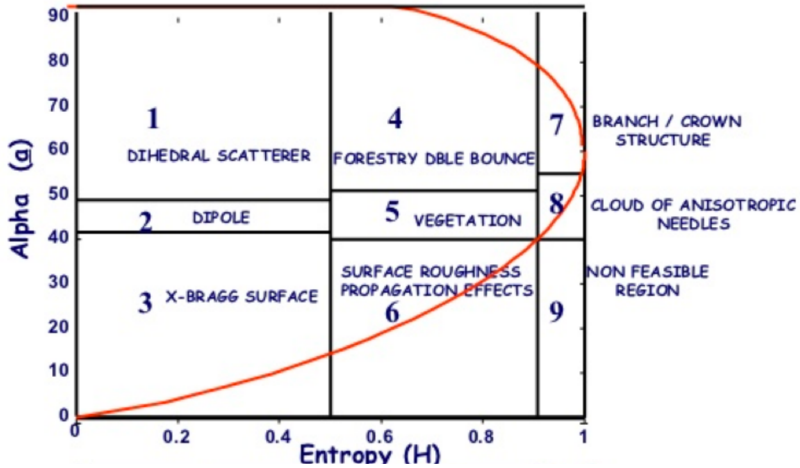
L-band UAVSAR, Central San Andreas Fault, May 21, 2012

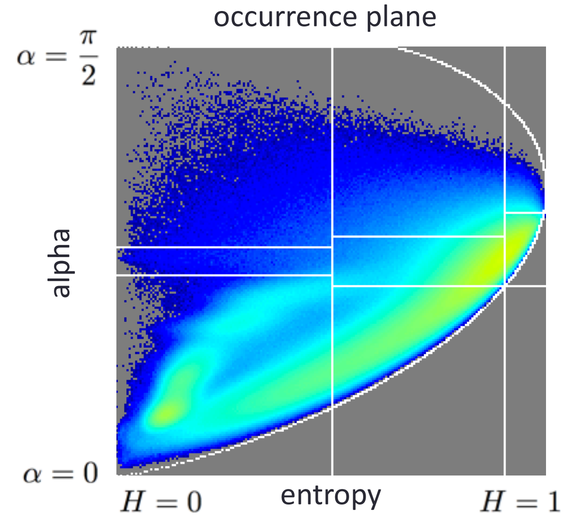
Alpha → scattering mechanism



Entropy → depolarization







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Pro and Cons of Polarimetric ARD Products

→ Covariance Matrix

- **Pros**
  - Access to relative polarimetric phases
  - Keep channel intensities
  - Allow application of various polarimetric decomposition algorithms
  - Interoperability with intensity ARD databases
  - Handles coherent dual and full polarimetric data
- **Cons**
  - Fixed filtering window
  - More sensitive to topography

→ Polarimetric Decomposition

- **Pros**
  - Products ready for interpretation/classification
  - Easier access for non-SAR specialists
  - Faster ARD analysis (if products are already generated)
- **Cons**
  - User restraint to one decomposition algorithm (Which one to choose?)
  - or a heterogeneous mix of decomposition algorithm and processing flow (lack of integrity)

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Update to Pol PFS compared to CEOS 2018

- CARD4L Polarimetric Radar Product Family Specification (PFS) updated through regular telecons within the CEOS SAR subgroup
- Started from Radar Backscatter PFS and augmented to include polarimetry-specific attributes
- Discussions focused mostly on metadata content, threshold vs target requirement, definitions, overall clarifications and recommendations
  - General metadata, mostly common to Radar Backscatter PFS (e.g., radiometric accuracy)
  - Per-pixel metadata (e.g., data validity mask, incidence angle)
  - Radiometric Terrain Corrected Measurements (e.g., covariance matrix elements)
  - Geometric corrections (e.g., reference to DEM)

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Metadata – In addition to CARD4L Backscatter

- Polarimetric calibration matrix
- Mean Faraday rotation angle
- Speckle filter parameters (not planned in CARD4L intensity)
- Measurements
    - Intensity
    - Complex number (amplitude & phase)
    - Polarimetric decomposition components (angle, entropies, individual scattering mechanisms)
    - Details of the applied decomposition
    - References

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Conclusion - Recommendations

- Some recommendations overlap with intensity presentation
- Polarimetric Covariance Matrix
  - standard second-order descriptor for polarimetric information of distributed targets, algorithms are well established
  - Reduced speckle and thermal noise in images
  - Reduced data volume after filtering and multi-looking
  - Enables users to ingest “raw” polarimetric information into their processing flow (e.g., custom decomposition, classification, etc.)
  - Users looking at radar intensities only can still use the pol CovMat
- Polarimetric Radar Decompositions
  - Multiple algorithms available, some require choice of models
  - Provide description of the target closer to the “scattering mechanisms” with information on structural and dielectric parameters of the scene
  - Enable users to readily interpret targets in the scene