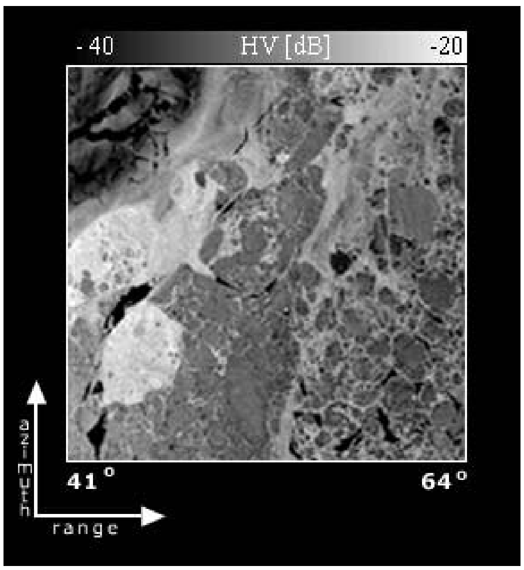
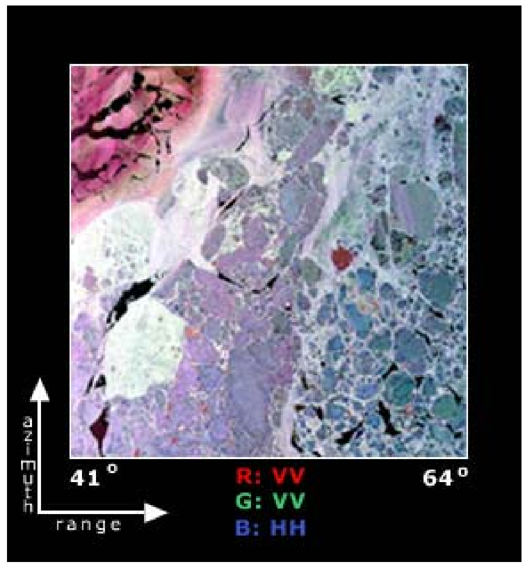
Much of the following has been extracted from a prototype Polarimetric Tutorial developed by MacDonald Dettwiler and Associates and RADARSAT International under contract to the Canadian Space Agency (No. 9F028-0-4902/06) as part of the Earth Observation Applications Development Program

Polarimetric Parameters

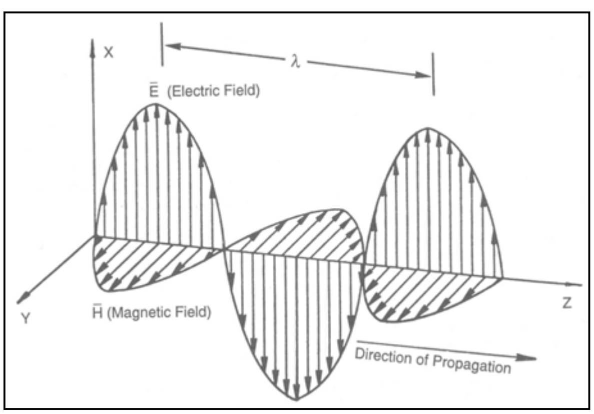
Co-Polarization: The observed signature when the transmit and receive polarizations are the same (HH or VV)

Cross-Polarization: The observed signature when the transmit and receive polarizations are orthogonal (e.g. HV).



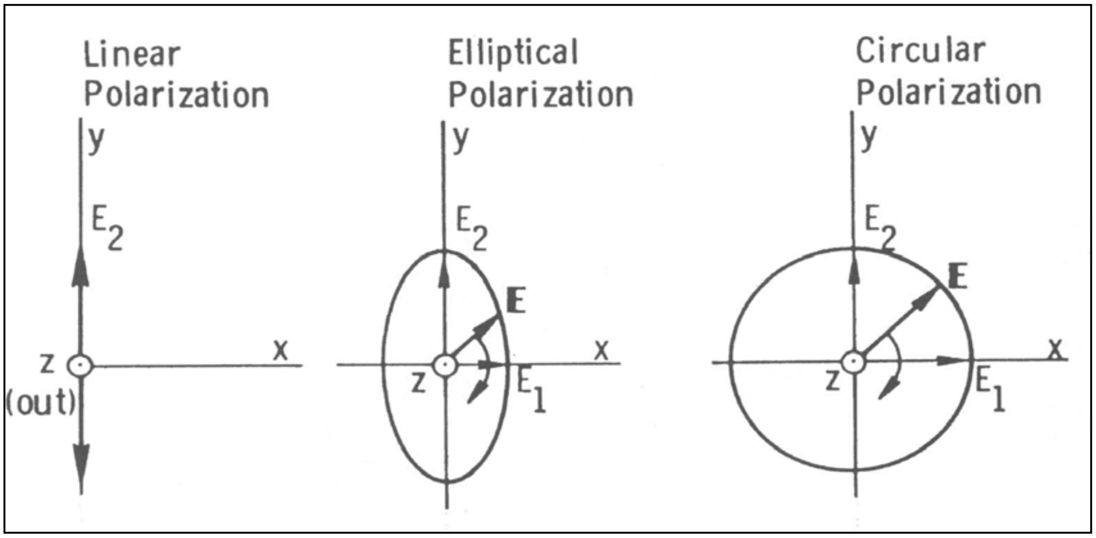


Wave Polarization:



Electromagnetic waves have an electric and magnetic component. Of interest to SAR imaging is the electric field **E** (or the E-vector), and the orientation of the electric field relative to its propagation direction. The polarization of the plane wave describes the shape and locus of the tip of the E-vector in a plane orthogonal to the direction of propagation.

Polarization States:



The most general polarization state is elliptical: the locus of the E-vector in the plane orthoganal to the direction of propagation is an ellipse. Special cases of elliptical polarization occur when the ellipse collapses to a circle (circular polarization) or a straight line (linear polarization).

Interchannel Phase Information:

Phase: Conceptually, *phase* can be thought of as the travel time for the SAR signal: the travel time is the two-way time of the signal between the sensors and the Earth, and includes any propagation delays as a result of surface or volume scattering.

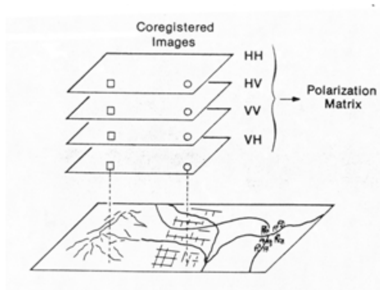
Co-Pol Phase: This represents the phase difference between the co-polarized channels (HH and VV). Three dominant scattering situations are described:

- relatively smooth surfaces (e.g. sea surface or bare ground), the radar wave undergoes one reflection with typically a 0º co-pol phase difference
- dihedral or double-bounce target (e.g. urban), the co-pol phase difference is typically +/- 180º
- diffuse target (e.g. vegetation), the co-pol phase difference is roughly distributed between -180º and 0º

Cross-Pol Phase: This represents the difference between the cross-polarized channels (e.g. HH and HV). For the most part, the difference is uniformly distributed between -180° and +180° phase, and therefore contains no target-specific information.

Derived Polarization Terms

Polarization Synthesis: The four measurements (HH, VV, VH and HV) permit the calculation of the power received from a resolution cell of transmitting and receiving polarizations.



Total Power : The magnitude of the HH, VV, VH, and HV polarization response. The total power is also the span (diagonal elements of the matrix) of the covariance or coherency matrix.

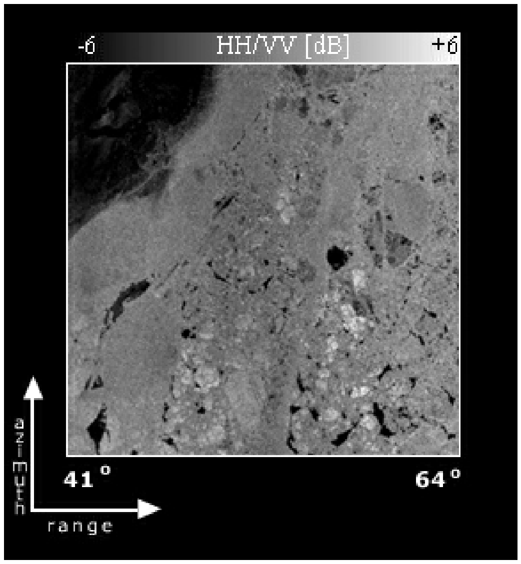
Scattering Mechanisms and Polarimetric Response Guidelines:

There are a number of polarimetric parameters that can be used to develop an understanding of the features present in an image. The following is a summary of a number of these features and the expected response for a specific type of surface. Each of the parameters are defined further below:

Parameter	**Co-polarised ratio**	**Cross-polarised ratio**	**Co-polarised correlation coefficient**
	$\frac{\langle \lvert S_{hh} \rvert^2 \rangle}{\langle \lvert S_{vv} \rvert^2 \rangle}$	$\frac{\langle \lvert S_{hv} \rvert^2 \rangle}{\langle \lvert S_{vv} \rvert^2 \rangle}$	$\frac{\langle S_{hh} S_{vv}^* \rangle}{\sqrt{\langle \lvert S_{hh} \rvert^2 \rangle \langle \lvert S_{vv} \rvert^2 \rangle}}$
Use	Measurement of surface roughness	Discrimination between surface and volume scattering	Detection of depolarisation and double bounce
Surface scatter	Low for smooth surfaces tending to 1 as roughness increases	Very low for smooth surfaces, increases with surface roughness	High amplitude (low depolarisation), small phase difference
Volume scatter	~ 1	Relatively high	Low amplitude (high depolarisation), poorly-defined phase difference
Dihedral (double bounce)	> 1	Low	Phase difference close to 180°

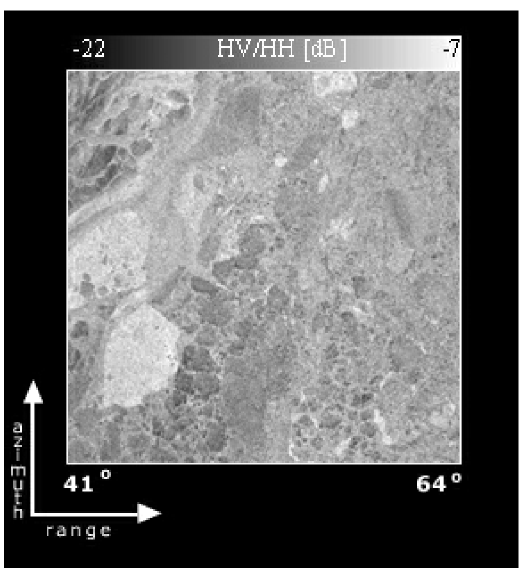
Channel Ratios

- Co-polarized Intensity Ratio (HH/VV): a ratio between HH and VV that can be considered a measure of surface roughness. For surface scattering, the ratio is ≤ 1 for all incidence angles, roughness conditions, and moisture content.



Since HH/VV is a ratio, it generally appears as a scatter plot

- Cross-polarized Intensity Ratio (HV/HH): a ratio between the (HV and HH) or (VV and VH) response that provides a relative measure of volume scattering and surface scattering. This ratio is only weakly dependent on moisture content. Volume scattering generally produces more cross–polarized backscatter than surface scattering, so the cross-polarized ratio provides a good discriminator between these two mechanisms.



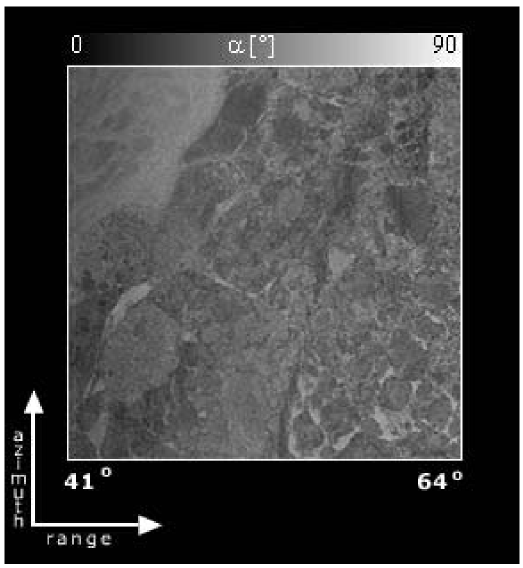
Since HV/HH is a ratio, it generally appears as a scatter plot. However, one could also display as an image to identify the spatial distribution of the ratios resulting in more information than a scatter plot.

Complex Channel Correlation

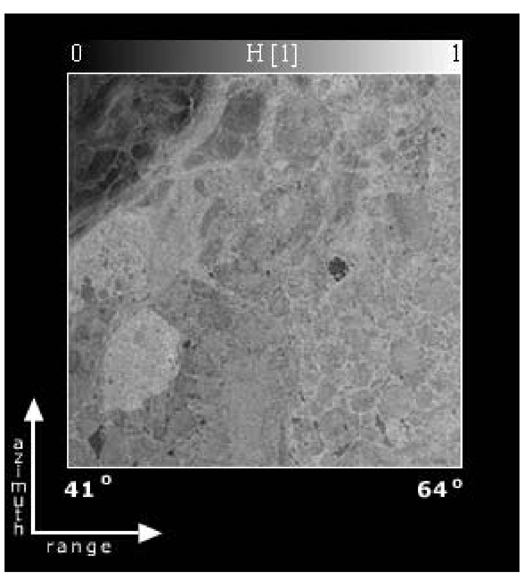
- Correlation: The complex co-pol correlation provides a method to detect depolarization. If the scattering is dominated by surface scattering, one would expect high correlation and a phase difference approaching 0º. In contrast, when depolarization occurs, due to volume scattering, for example, the correlation approaches zero and there is a poorly defined phase difference.

- Coherency Matrix: The coherency matrix is an efficient method that is used to deal with the amplitude and phase information from radar backscattering. For statistical analysis, the equivalent covariance matrix is often used.

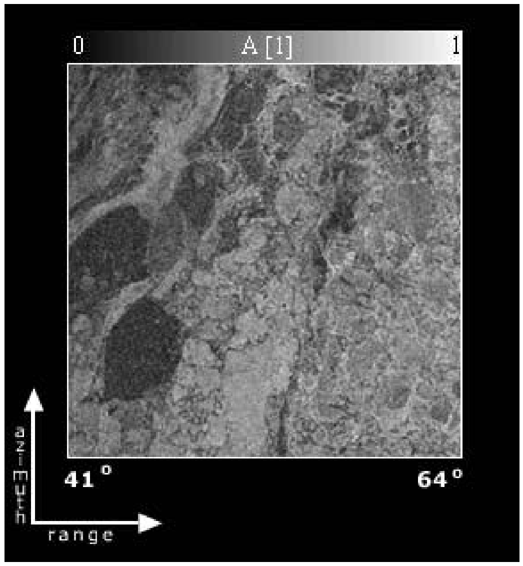
- Anisotrophy: **A:** This is the measure of how homogeneous a target is relative to the radar look direction. For example, the Amazon forest is a very homogeneous target and would have a low anisotropy value. In contrast, row crops would have a high anisotrophy value.



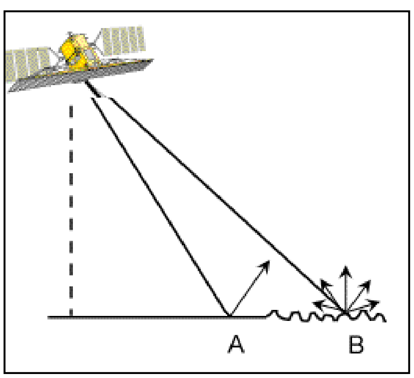
- Entropy: This is a measure of the dominance of a given scattering mechanism within a resolution cell. It is related to the amount of effective scattering mechanisms, and normalized between 0 and 1. A value of 0 identifies that all scattering comes from one mechanism (such as a flat surface or a tall building [double bounce]), and a value of 1 represents a completely random scattering mechanism.



- Alpha: If the Entropy is close to 0, the alpha angle provides the nature or type of the dominant scattering mechanism for that resolution cell. For example it will identify if the scattering is volume, surface or double bounce.



Surface Scattering:

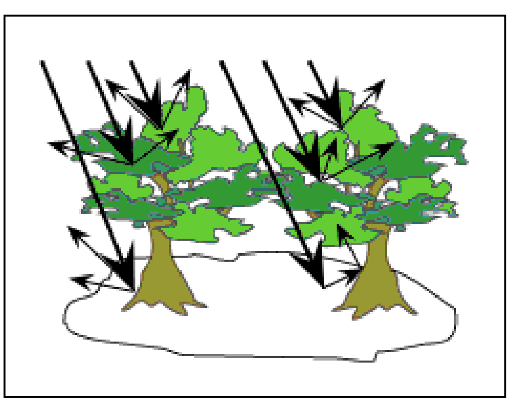


Surface Scattering occurs on the boundary of two homogeneous media. The backscattered signal is a function of:

- dielectric constant (moisture content)
- roughness of the surface

Examples of surface scattering include lakes, oceans, and bare soils.

Volume Scattering

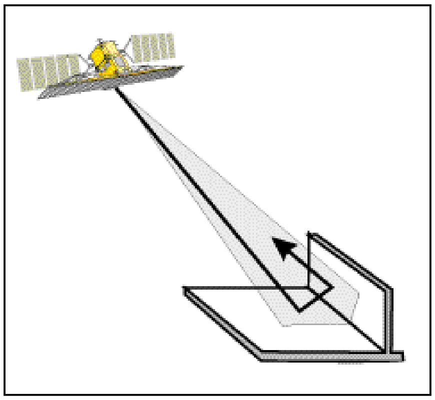


Volume scattering results from many scattering events within a homogeneous media. The backscattered signal is a function of:

- Density of the media
- Geometry of scattering elements
- Dielectric properties of elements

Examples of volume scattering include dense vegetation cover and dry snow.

Double Bounce Scattering



A corner reflector of two perpendicular surfaces creates a strong backscattered signal, known as a *double bounce*. It appears as a very bright tone on the radar image. Examples of typical features that produce a double bounce include urban areas, tree trunks in flooded areas, and ships on water.

Depolarization: Depolarization occurs when the polarization state changes between the transmitted and received signal. For example, changing a HH to a HV response. There are four mechanisms known to cause depolarization:

- quasi-specular reflection as a result of the difference between the Fresnel reflection coefficients for a two-dimensional, smoothly undulating surface
- multi-scattering due to target surface roughness
- multiple scattering due to volume scattering
- anisotropic properties of the targets

The first three depolarization mechanisms are commonly encountered in remote sensing applications:

- the first mechanism applies only to smoothly undulating surface
- the third mechanism produces stronger returns than the first and second
- the fourth mechanism is a function of target geometry