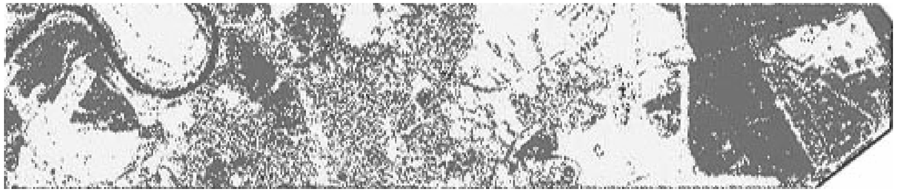
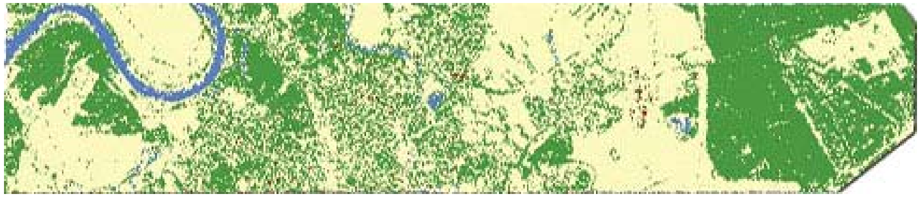
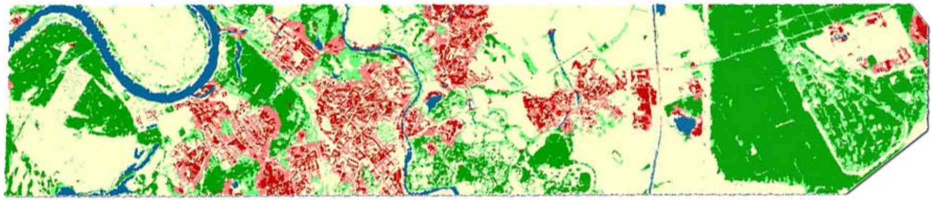


Polarimetric SAR

Applications and Calibration





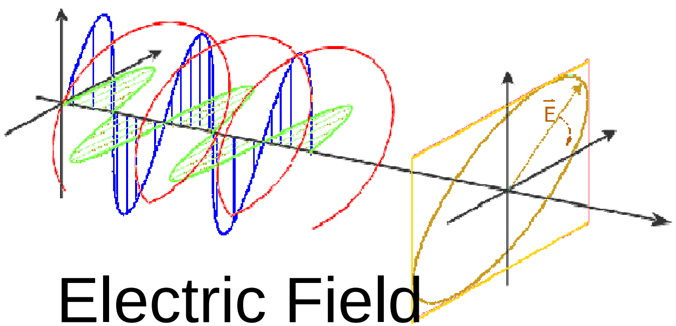
UNIVERSITY OF ALASKA FAIRBANKS

Introduction

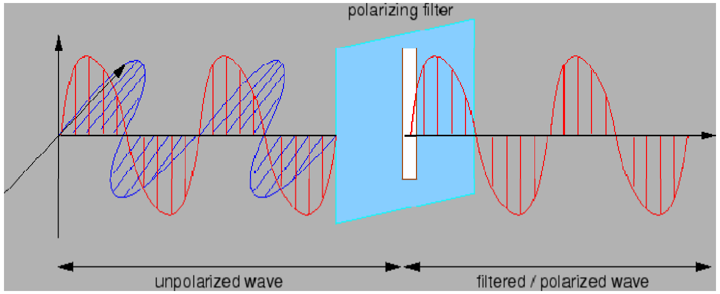
- What is Polarimetry
- Why we care
  - Extract information of radar targets
    - Land use, Deforestation, Hydrology, Sea Ice, Oil Spills
  - Separate targets from background noise
    - Ship detection, Search and Rescue, Mineral Exploration
- Calibration of polarimetric SAR systems
  - Ground based calibrations
  - Space based calibrations
  - Faraday Rotation

What is Polarimetry?

- Polarimetric information holds details of the scattering target.
- Discriminates between specific targets and background noise.
- Emerging science/art enabled by increased processing power
- Allows automated classification of images



Electric Field



Polarizing Filter

Radar Target

- **Polarized radar pulse interacts with the scattering target**
- **Return signal received contains polarization information imparted by the target.**
- **Matrices describe the scattering target**

$$\overline{S} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

Basic Scattering Matrix

$$E^{re} = [S]\,E^{tr} = \begin{bmatrix} E_h^{re} \\ E_v^{re} \end{bmatrix} = \frac{e^{ik_0 r}}{r} \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} E_h^{tr} \\ E_v^{tr} \end{bmatrix}$$

Jones Matrix

$$\frac{1}{r^2} \begin{bmatrix} S_{vv}^* S_{vv} & S_{vh}^* S_{vh} & S_{vh}^* S_{vv} & S_{vv}^* S_{vh} \\ S_{hv}^* S_{hv} & S_{hh}^* S_{hh} & S_{hh}^* S_{hv} & S_{hv}^* S_{hh} \\ S_{hv}^* S_{vv} & S_{hh}^* S_{vh} & S_{hh}^* S_{vv} & S_{hv}^* S_{vh} \\ S_{vv}^* S_{hv} & S_{vh}^* S_{hh} & S_{vh}^* S_{hv} & S_{vv}^* S_{hh} \end{bmatrix} \begin{bmatrix} |E_v^t|^2 \\ |E_h^t|^2 \\ E_h^t E_v^{t*} \\ E_v^t E_h^{t*} \end{bmatrix}$$

Stokes Matrix

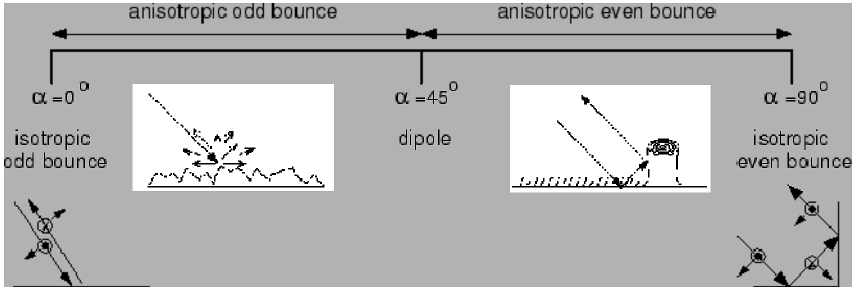
Stokes Matrix

$$\begin{bmatrix} g_0 \\ g_1 \\ g_2 \\ g_3 \end{bmatrix} = \begin{bmatrix} |E_v|^2 + |E_h|^2 \\ |E_v|^2 - |E_h|^2 \\ 2\Re(E_v^* E_h) \\ 2\Im(E_v^* E_h) \end{bmatrix} = \begin{bmatrix} |E_{v0}|^2 + |E_{h0}|^2 \\ |E_{v0}|^2 - |E_{h0}|^2 \\ 2E_{v0}E_{h0}\cos(\delta) \\ 2E_{v0}E_{h0}\sin(\delta) \end{bmatrix}$$

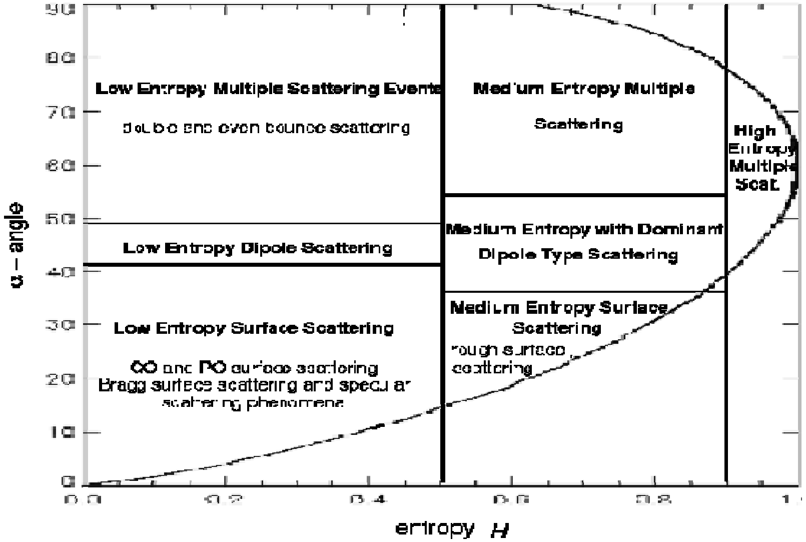
- g_0 is the total power in the wave.
- g_1 is the difference in energy between the two orthogonal components of the wave.
- g_2 and g_3 jointly represent the phase difference between the real and imaginary cross terms

Classification Terms

- α – Alpha Angle is an interpretation of type of scattering
- Anisotropy – Properties that deferrer according to direction of measurement
- Entropy, *H* - a measure of the randomness Polarimetric response of terrain is dependent on several parameters: frequency, incidence angle, dielectric properties and dielectric geometry of the scene.



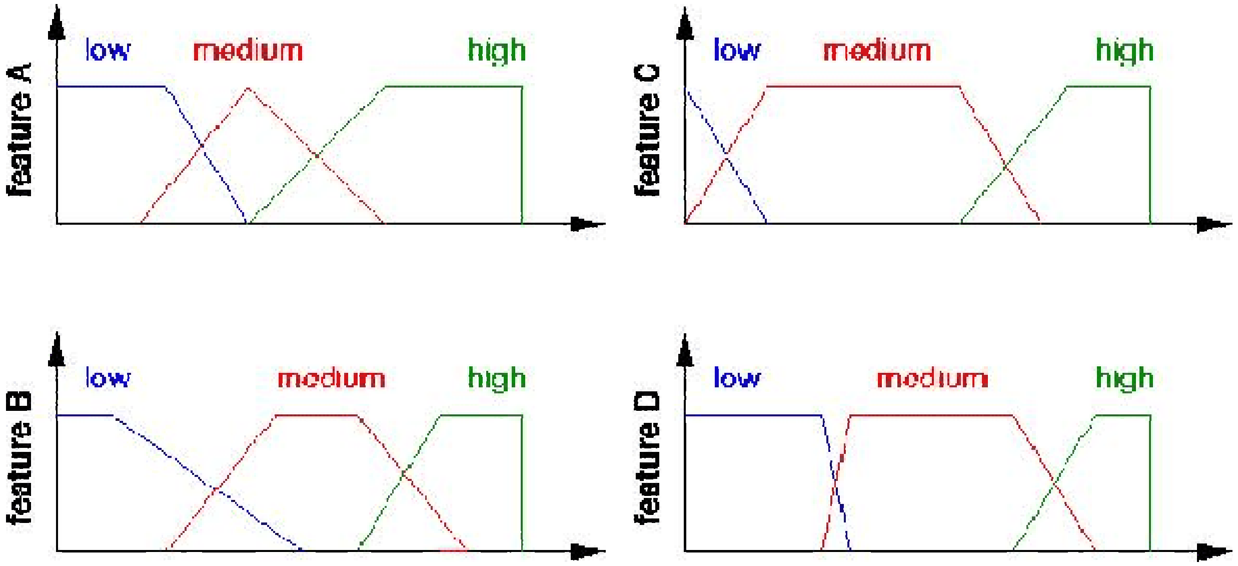
Alpha Angle & Anisotropy



Entropy vs. α Angle

Polarimetry Witchcraft (Fuzzyfication)

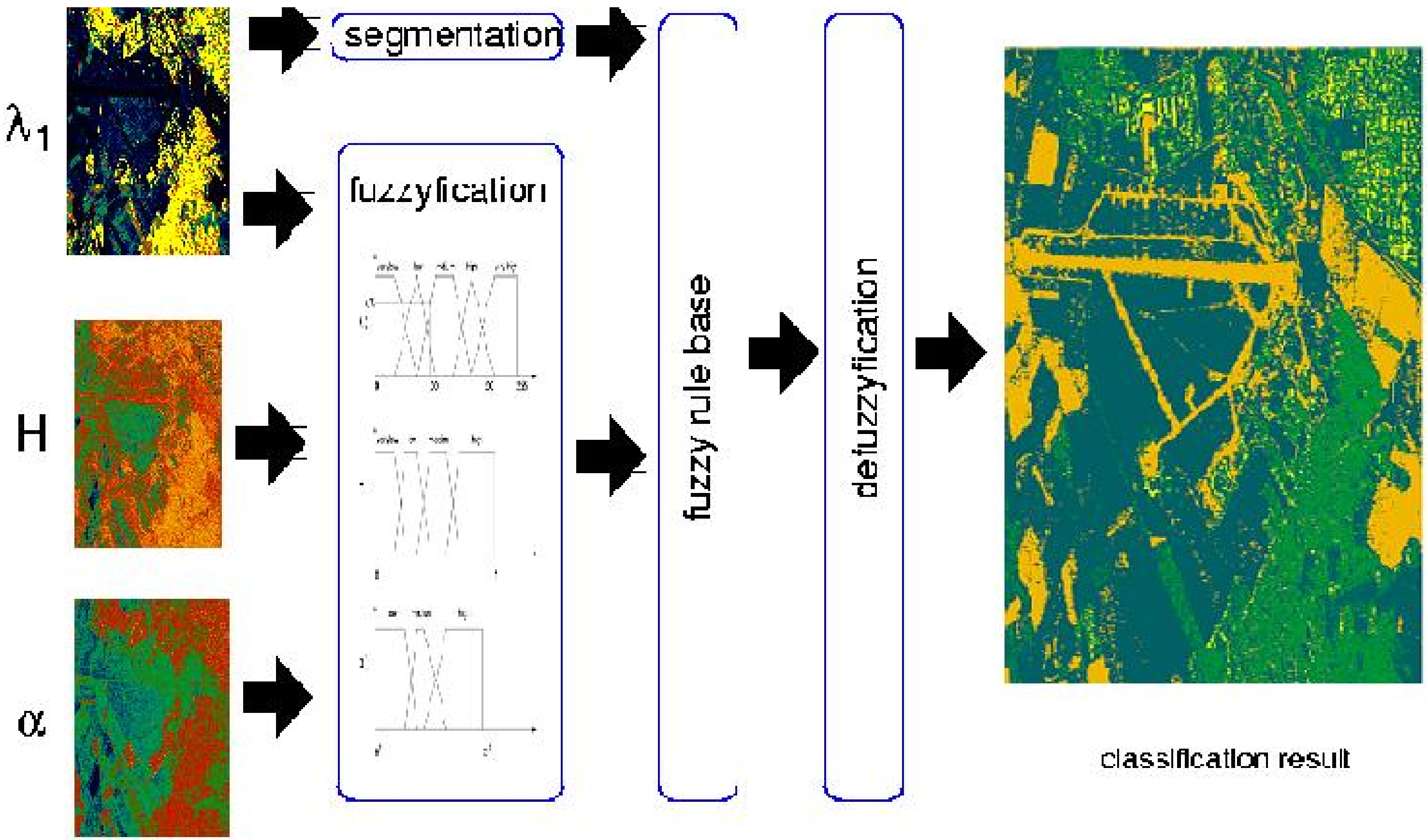
- Fuzzy Logic is a multi-valued logic
  - Fuzzy sets can be defined by analyzing polarimetric response to known targets
    (Rule1: If A is low AND H is med AND α high THEN Pixel is class 1)



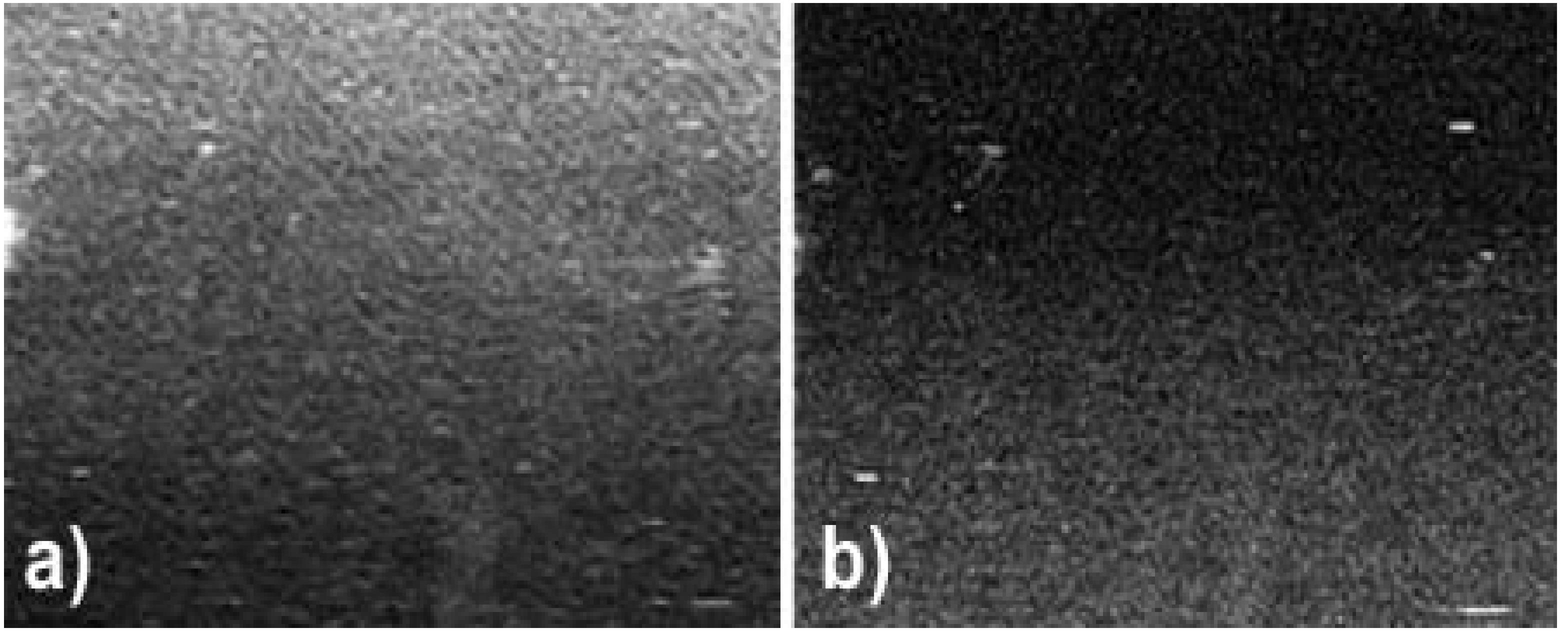
Fuzzy Rule Base

λ	H	α	*Decision*
Very High	Medium		Urban
High or Very High	Very Low	Medium/High	Urban
High	High		Forest
Medium	High	Medium/High	Forest
Medium	Medium	Medium/Low	Vegetation
Medium	Low or Very Low	Low	Vegetation
(Very) Low			Runway

Defuzzyfication (Feature Classification)

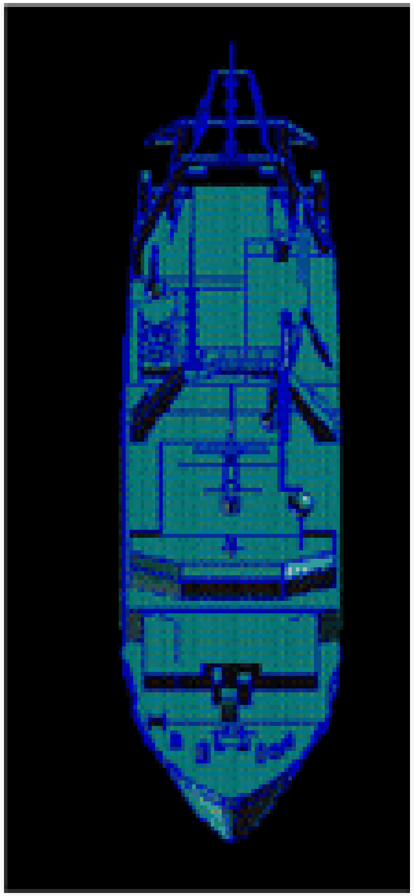


Ship Tracking

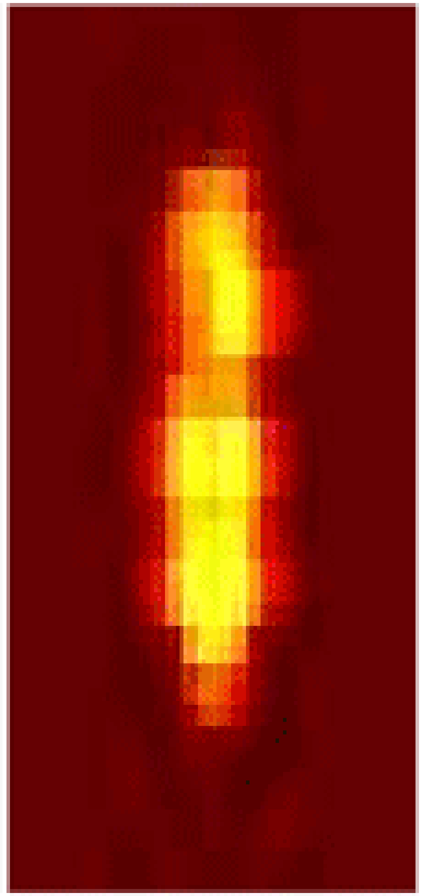


a) C-HH image b) corresponding polarization entropy image showing improved ship detection using the polarization entropy. Data from C-SAR on Canadian CV-580

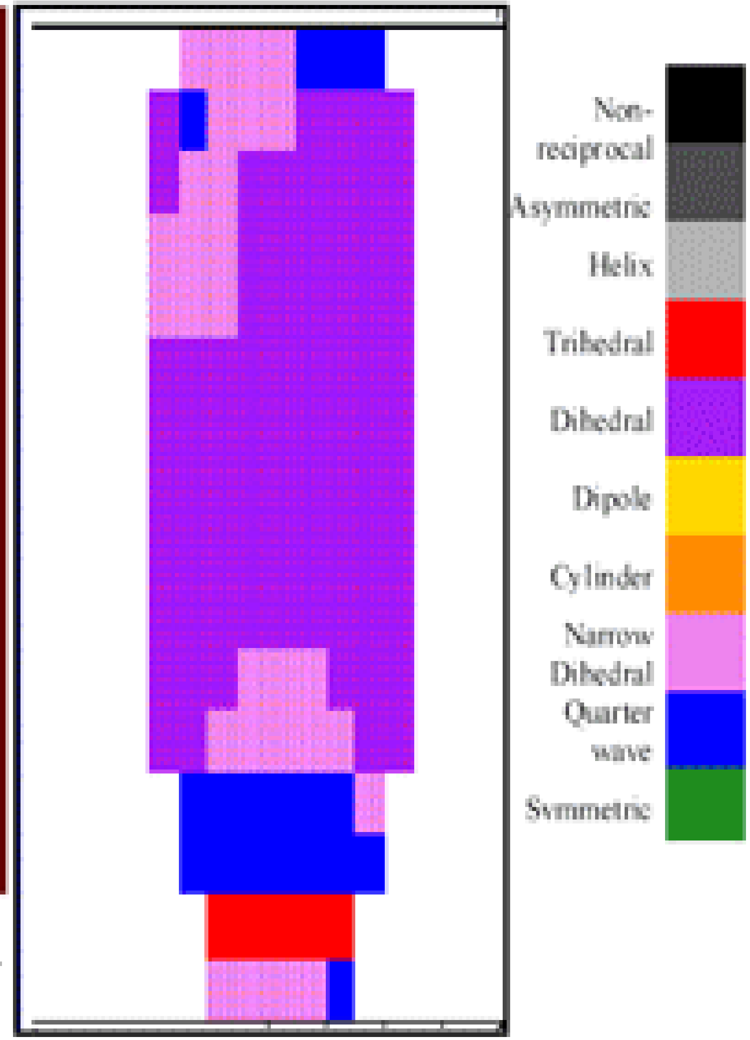
Ship Identification



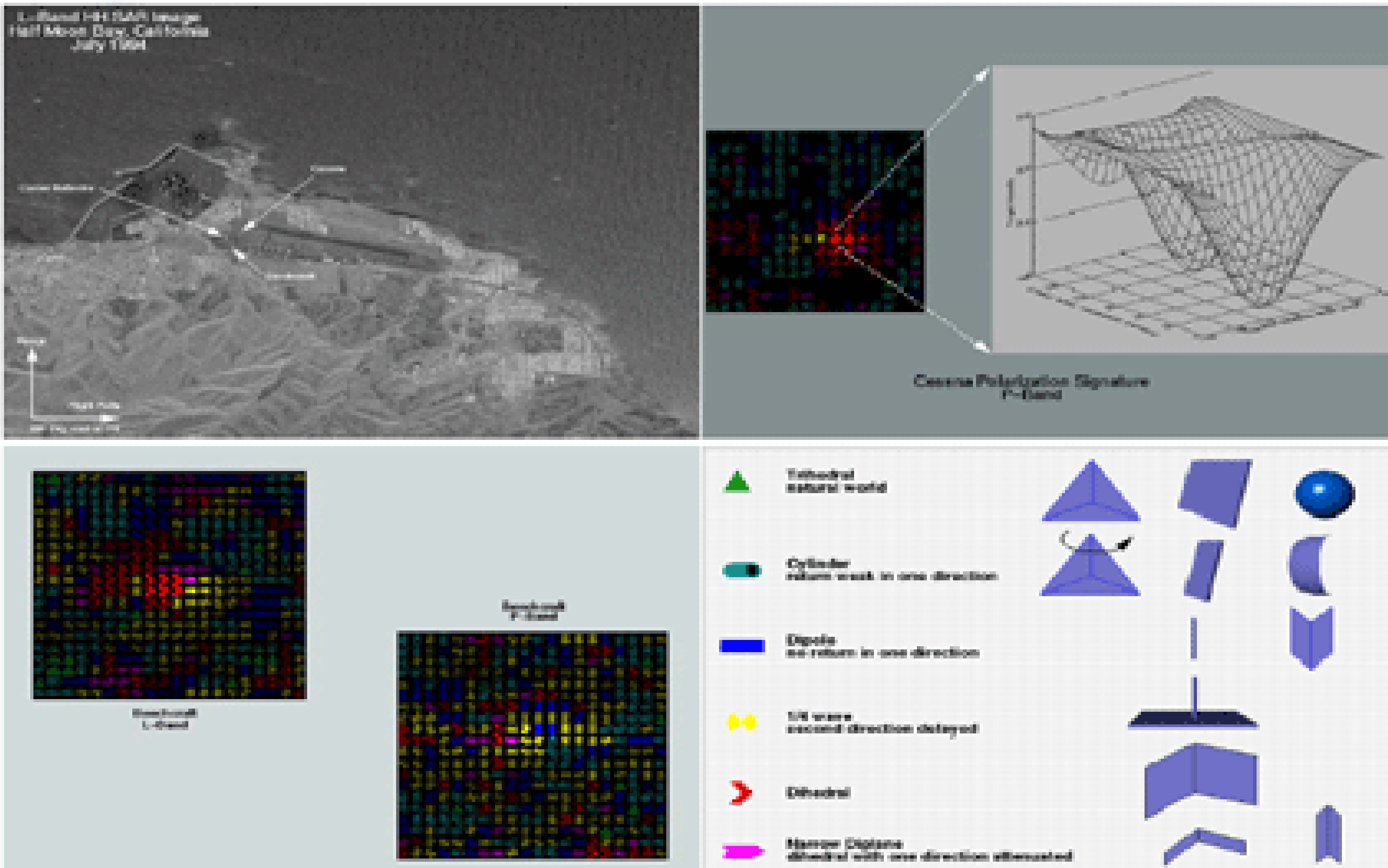
CAD Model

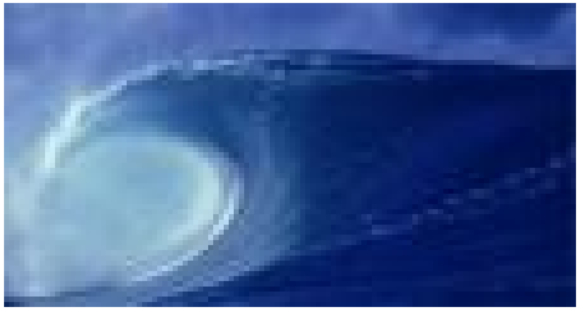


Simulated SAR Signature



Target Identification

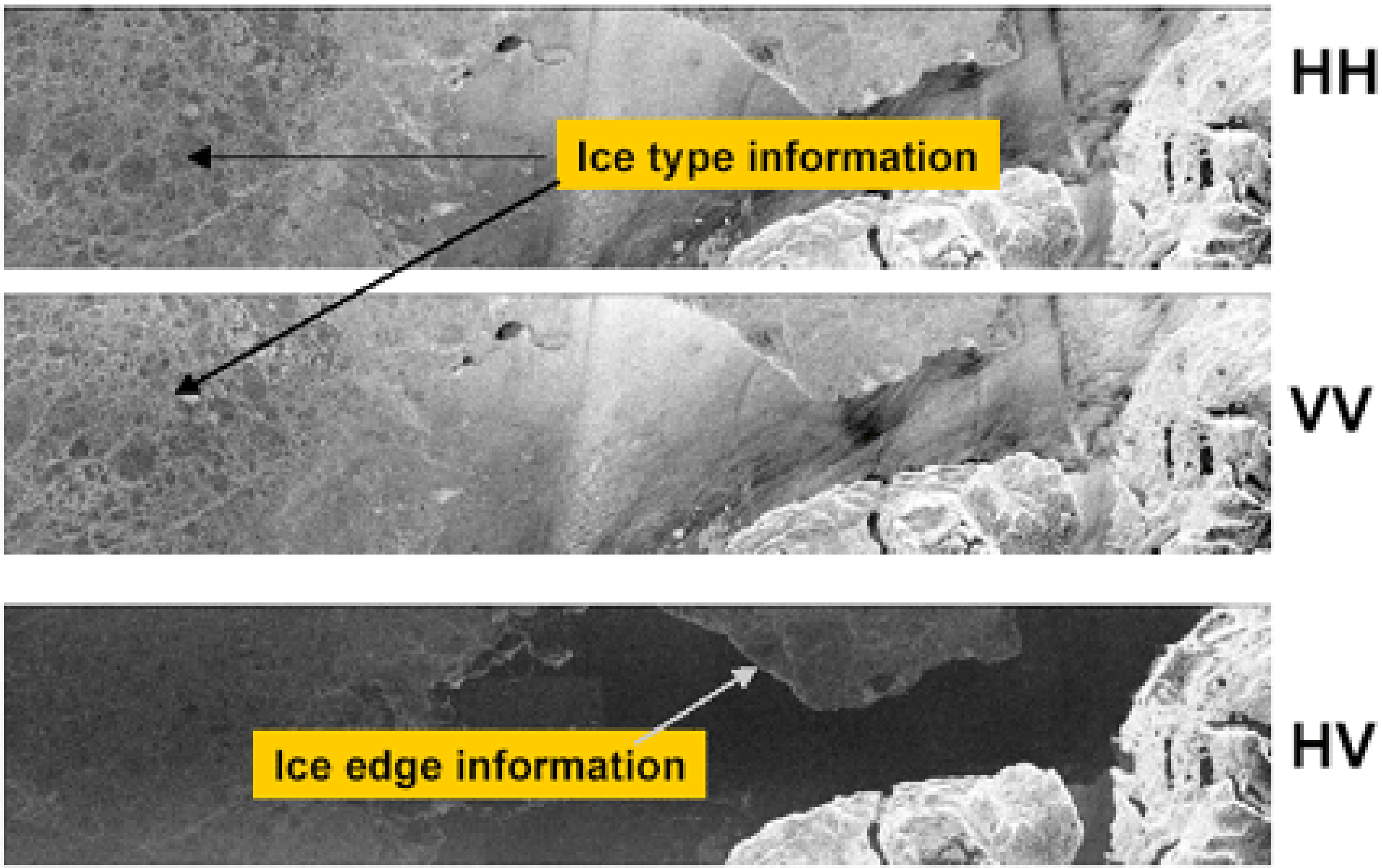




Oceans

Winds	VV	Better SNR for higher incidence angles benefits lower wind speed scenario's. Models use VV polarizations
Ship surveillance	VV - VH	VH gives point target info against dark background, VV should allow wake analysis for most incidence angles.
	HH - HV	Optimal ship detection based on the target to clutter ratio was: - HV for incidence angles < 45 degrees - HH for incidence angles > 45 degrees
	QUADPOL	Improve ship detection & classification
Intertidal zone	HV	Enhance shoreline mapping
	Dual pol	Enhance coastal zone sensitivity mapping (tidal and near shore mapping)

Ice Classification

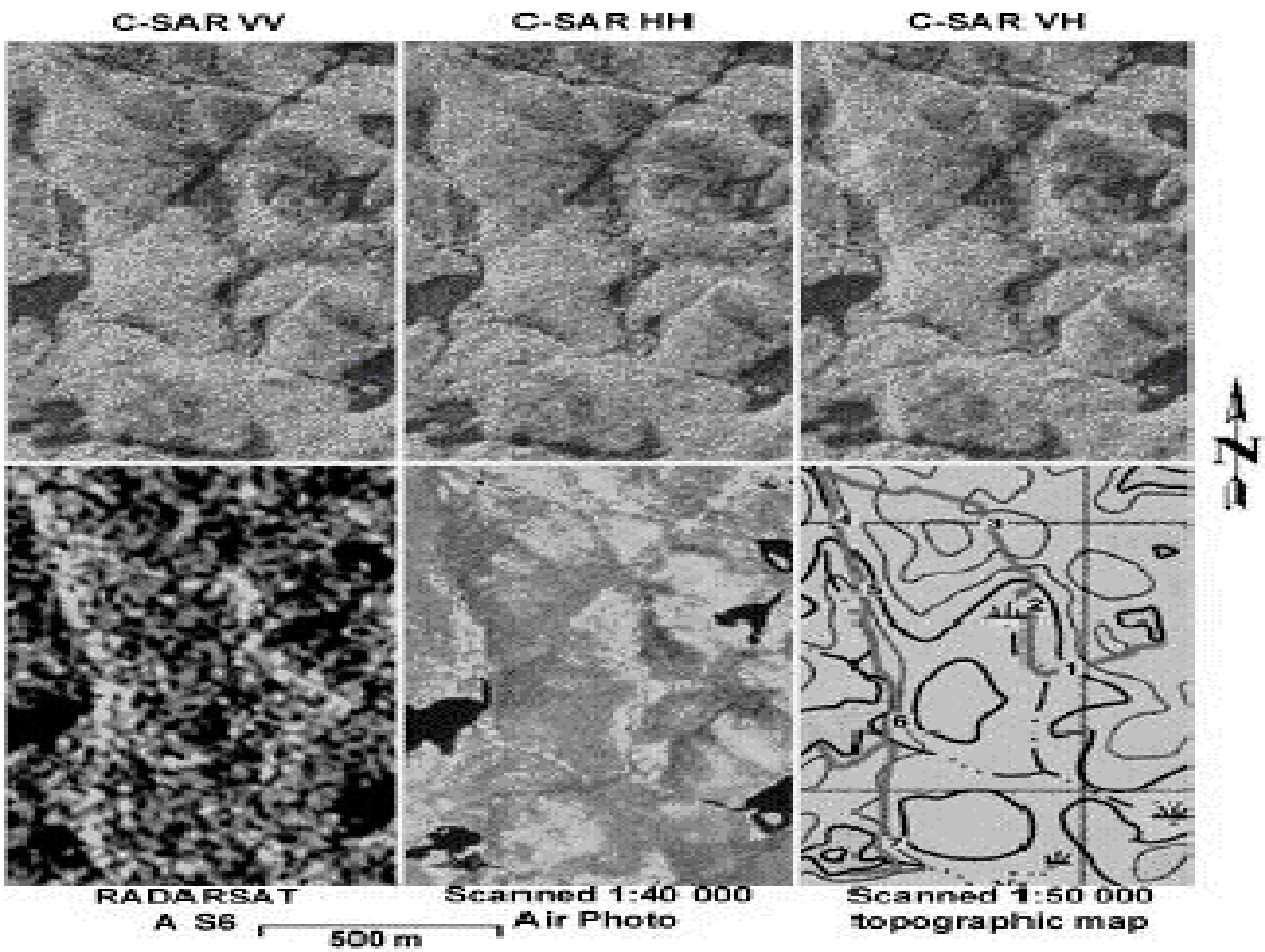


SIR-C Gulf of St. Lawrence

Ice

	Dual pol	HV improves distinction of ice edge.
	HH-HV	HH / HV ratio improve discrimination of multi-year from first year ice
	HH and VV	co-polarized ratio to distinguish between thin and new ice types from open water
Ice	HV	Ice topography and structure, discrimination of smooth & deformed ice
Icebergs	HV	Detecting icebergs, particularly at steeper incidence angles & in higher seas

Geologic Mapping



Geology

Terrain Mapping	Ultra-fine	Permit more detailed mapping
	Dual pol & quad pol	Mapping surface deposits & rock units in vegetated terrains- different structural properties
	HV	Mapping recharge terrains in arid environments, HV provided better contrast than HH and VV
Structure	HV	Sensitive to extreme surface roughness or abrupt changes in relief. Bedrock fracture zones & fault scarps are highlighted.
Lithology	HH/HV or VV/HV	Better discrimination of different geological units

Hydrology

Soil moisture	HH	HH is preferable to VV - greater penetration of vegetation cover
Wetlands	VV or HH	Both are good for detecting flooding conditions, literature suggests: - Both for detecting flooding in dense marsh - VV better than HH for low density marsh - HH better than VV for flooded forest - Both for non-woody & herbaceous wetlands
	Quadpol	Improve the discrimination of wetland classes

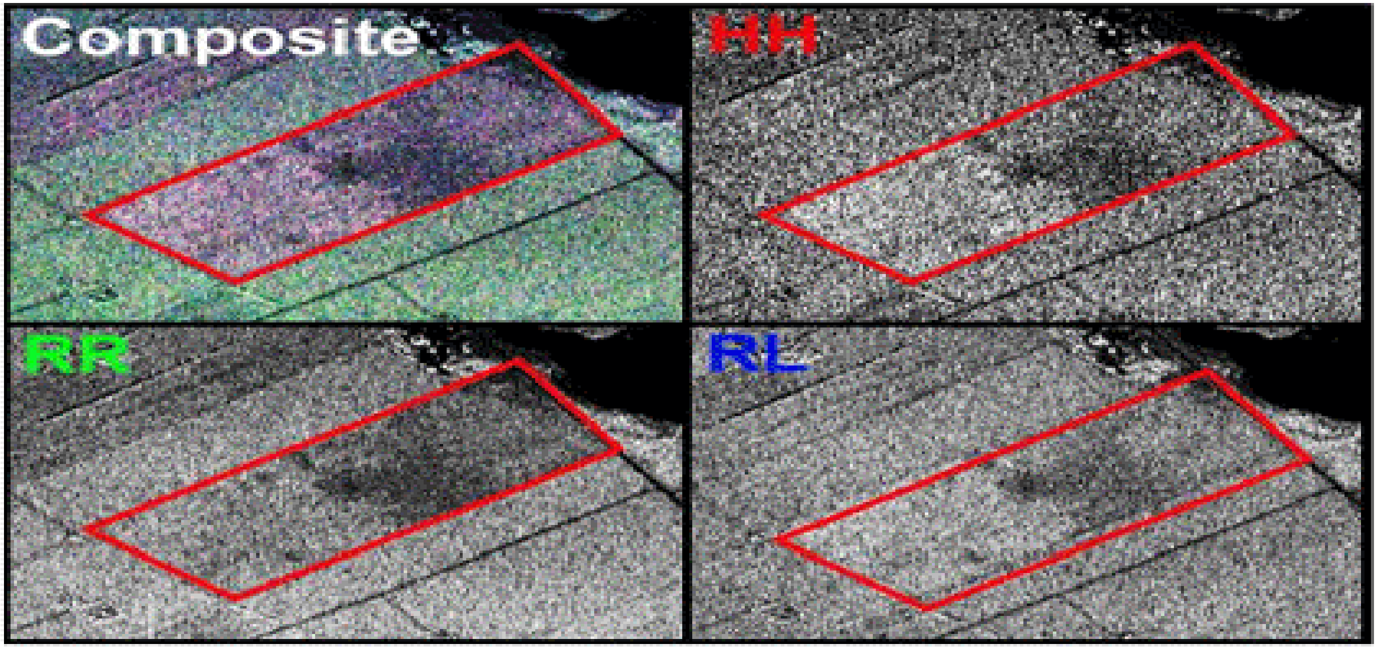
Disaster Management

Floods	HH	Greatest difference at HH. Contrast increases with decreasing incidence angle
Geological Hazards	Ultrafine	More accurate mapping of landslides and earthquakes
Hurricanes	HH / HV or VV / VH	Co and cross-pol ratio may estimate rain rate- quantitative information on hurricane state and evolution.
	VV	Better contrast than either HH or HV
Oil Spills	Ultrafine	Enhance potential for tracking oil slicks and measure extent.

Forestry

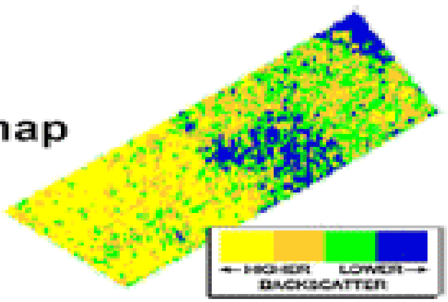
	Ultra fine	Increased accuracy of boundary placement
	HV or VH	Cross pol improves contrast (HH or VV) Using dual pol (HH and HV or VV and VH) will further improve potential (Hoekman, 2001)
Clear cut mapping	QUADPOL	Promise for distinguishing clear cut from mature forest (Pairman, 2002)
Fire-scar mapping	HV or VH	Best potential for burn mapping -sensitive to structural damage to forest canopy.
Biomass	HV or VH	Areas of low biomass can be monitored

Agricultural Assessment



CV-580 SAR Image acquired July 9, 1998, Ottawa, Canada

Classification map



after McNair;

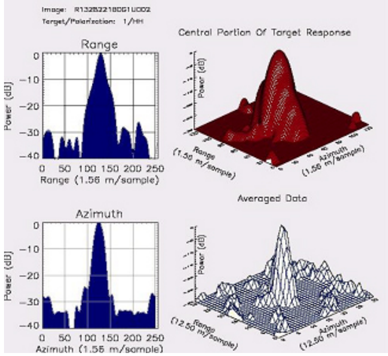
Images courtesy of CCRS

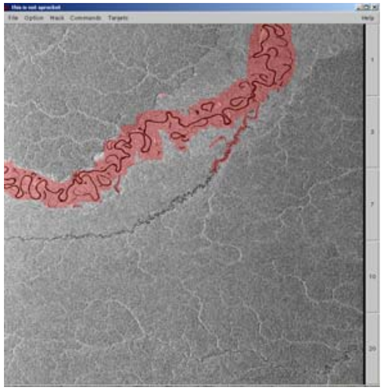
Agriculture

Crop type	HH	Penetrate canopy- more information about the underlying soil condition
	HV	Good contrast of vegetation types with different canopy structures
	VV	Sensitive to crop structure- complementary information to HH and VV
Classification	Dual pol	Improvement in crop discrimination with two polarizations (45% with one, 78% with two)
Land use	HV	Differentiating vegetative surfaces from bare

Methods of Calibration

- **Ground Based – Minimize crosstalk**
  - Antenna Transmission and Receive Modules
  - Gain and Internal Electronics (channel cross-talk, amplitude and phase balance, electronic noise, analog to digital converter)
- **Space Based – Internal Calibrations**
  - Calibration Ground Targets
    - Point targets – Geolocation, Resolution, PSLR
      - Transponders (PARCs), Corner Reflectors
    - Distributed Targets – Gain Patterns, Noise Level
      - Isotropic Volume Scatters, Dark Water Bodies
  - Processor – Antenna Gain Pattern, Symmetrization of Polarization Cross Terms
- **Faraday Rotation – Correction**

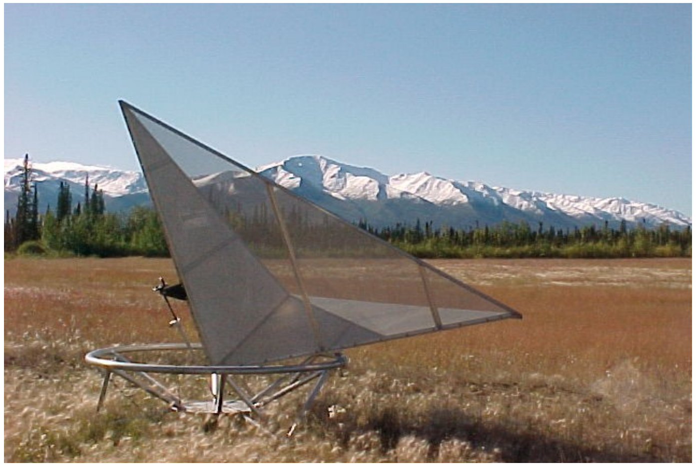




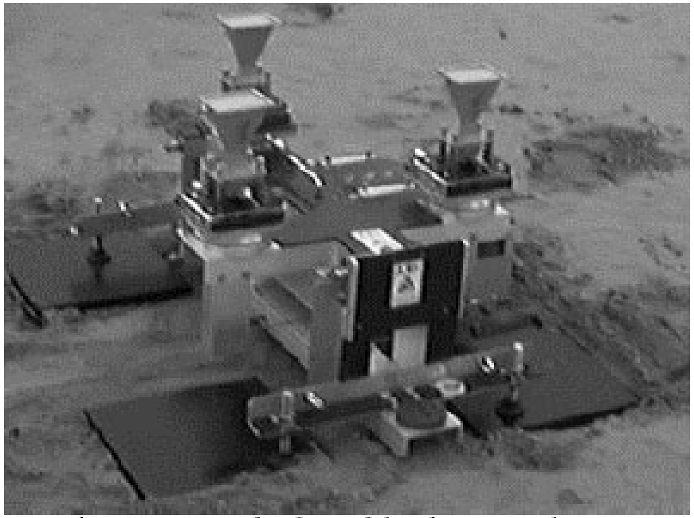
Calibration Targets

Point Targets

- **Passive Reflectors**
  - 2.45m Trihedral
  - 3 m Conical Dihedral



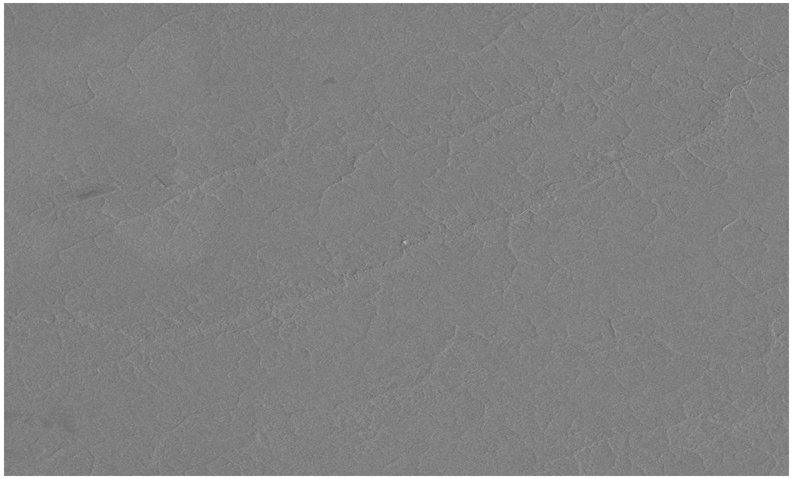
- **Polarimetric Active Radar Calibration Transponder**
  - Receives radar pulse
  - Adjusts phase & Polarization
  - Returns strong signal



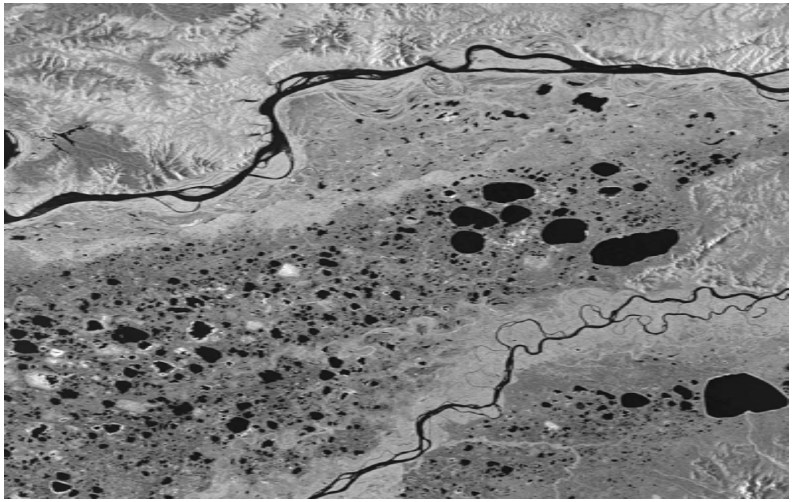
Calibration Targets

Distributed Targets

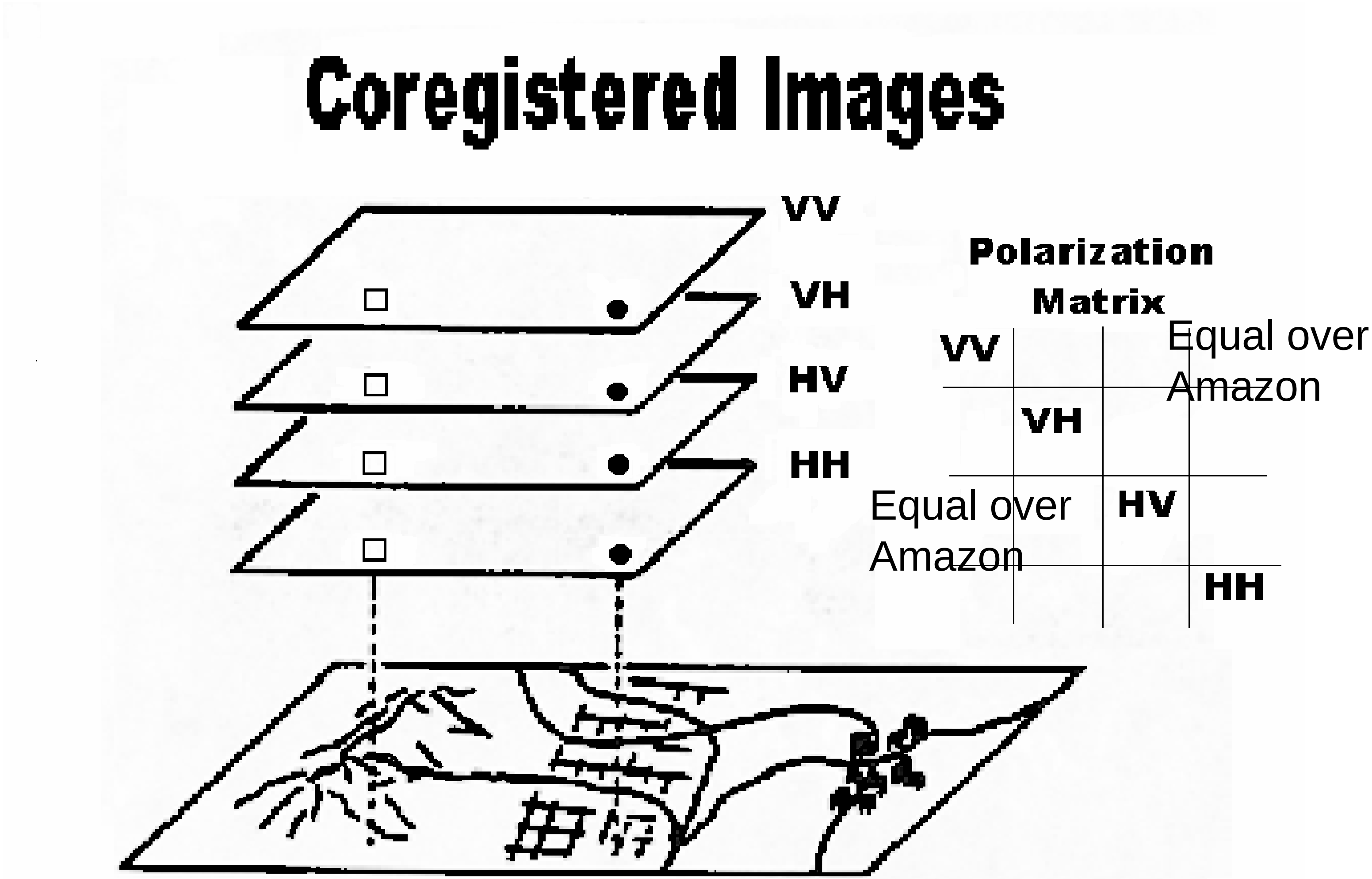
- **Amazon Rainforest**
  - Isotropic Volume Scatter- Provide Homogeneous Calibration Image



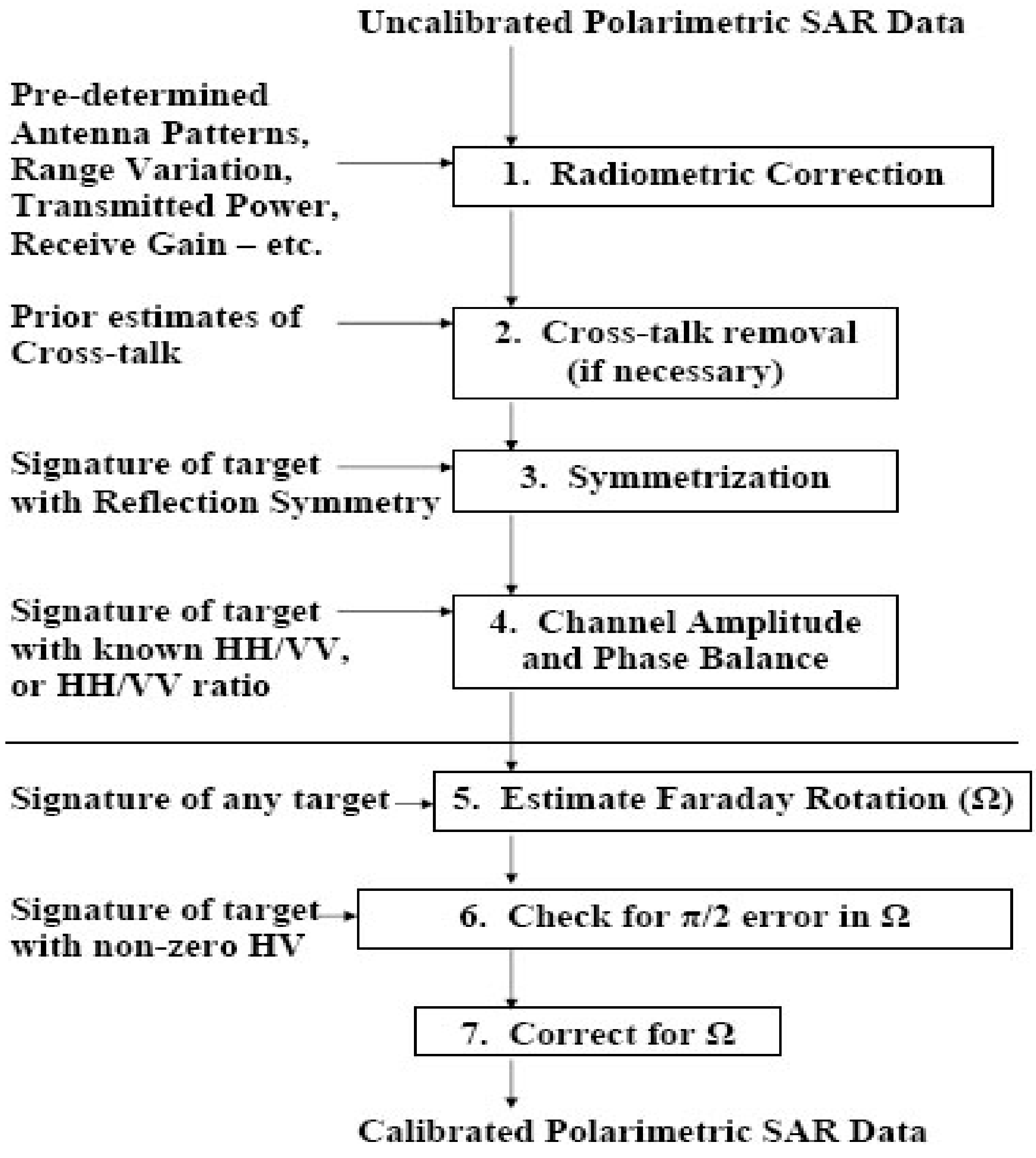
- **Yukon – Kuskokwim**
  - Low backscatter Lakes- Provide a measure of the Noise Level



Balancing Cross-terms (Symmetrization)



Processor Calibration

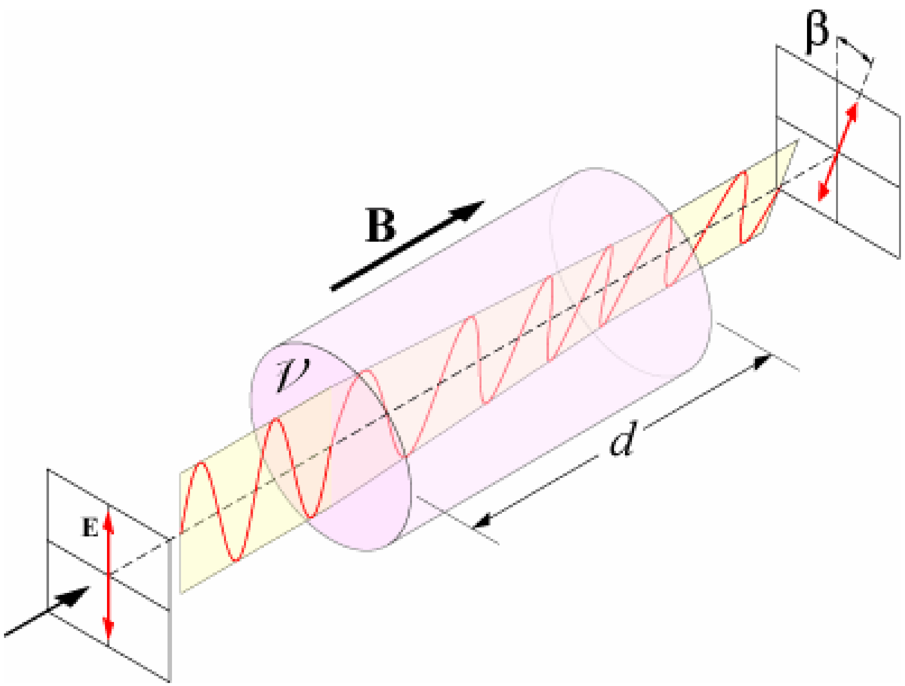


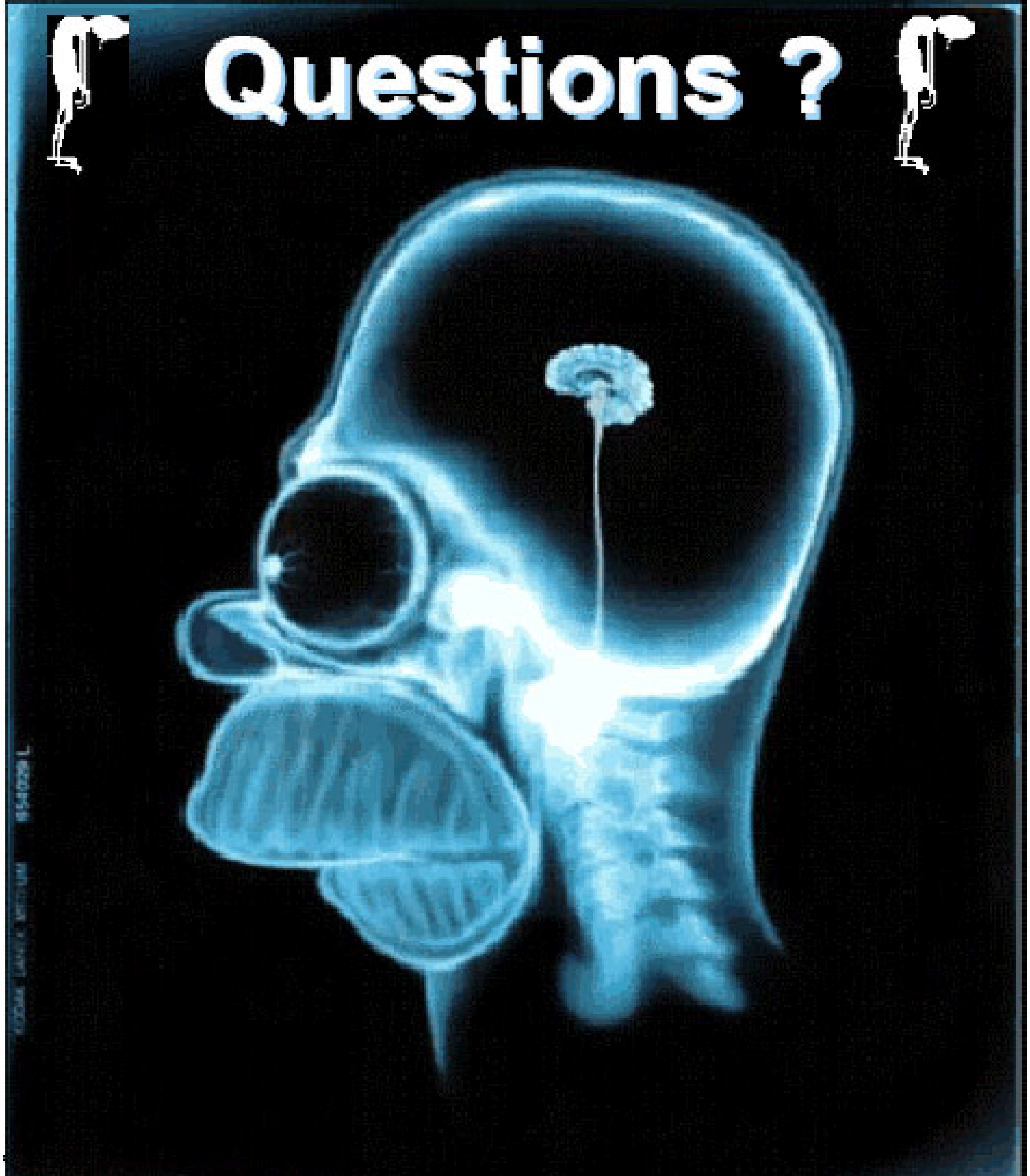
Faraday Rotation

- Ionospheric Change of the Polarization Angle
- Effect is dependent on Solar Activity & Latitude
  - Strength of Field
  - Path length of signal
- Effect is dependent on Wavelength

Estimated Maximum:

- X-Band (3 cm) ≈ Small
- C-Band (6 cm) ≈ 2.5°
- L-Band (24 cm) ≈ 40°
- P-Band (68 cm) ≈ 321°




Questions ?