FINAL

The Vertical Structure of Vegetated Surfaces from Interferometric and Polarimetric Radar Data

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Remote Sensing and the Kyoto Protocol:
A Review of Available and Future Technology for Monitoring Treaty Compliance
Ann Arbor, Michigan
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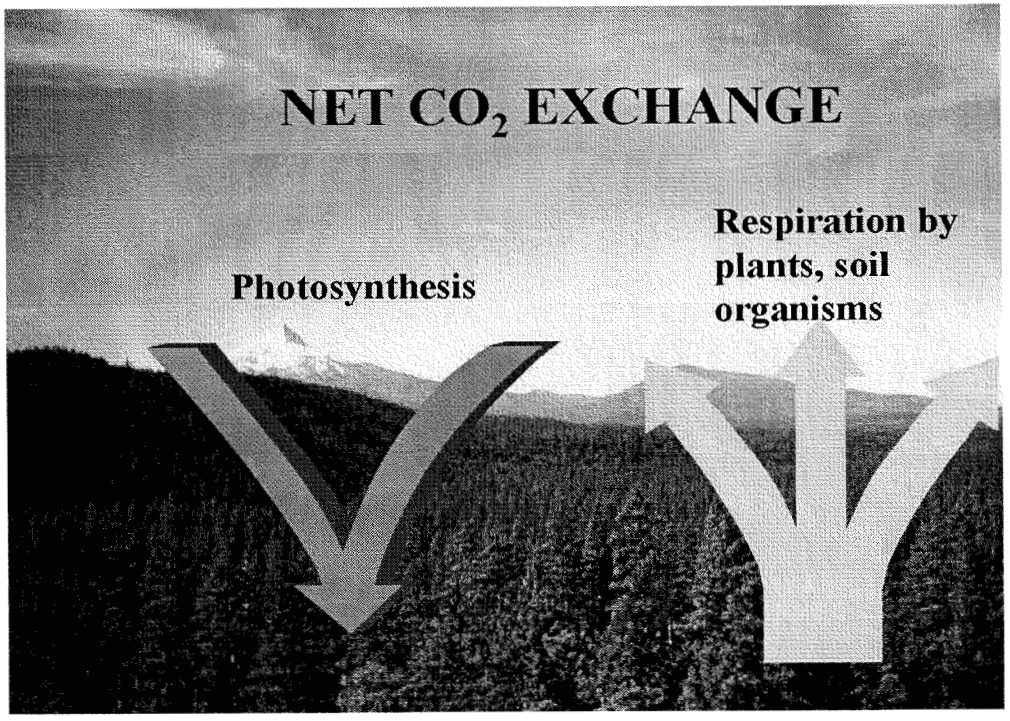
Outline

- Vertical structure $\leftrightarrow$ the Kyoto Protocol: Biomass and dynamics
- Biomass & LAD from Interferometry and Polarimetry
  - –Derivative Magnitude and Diversity
  - –Physical-model parameter estimation scenarios: Data Fusion
  - –Interferometry + polarimetry structure sensitivity
- Structure Demo: Central Oregon, multialtitude int+pol
- Biomass: Power and Interferometry: Derivative Magnitude
- Vertical structure from Int+pol+hyperspectral+VCL fusion
- Summary

Vertical structure and the Kyoto Protocol: Biomass and Dynamics

- Leaf area and biomass $\Rightarrow$ uptake, storage, and emission of $C(O_2)$
- Density profiles: Biomass+LAI; Clearcut detection, successional stage $\Rightarrow$ improved ecosystem dynamics$\Rightarrow$ improved $C(O_2)$ budget



Vertical structure and the Kyoto Protocol: Biomass & LAD from Interferometry and Polarimetry

- Biomass density &LAD $\Rightarrow$

  –Biomass=$\int dz$Biomass density$(z) = \int dz\, \rho_0(z)\, m(z)$ storage and emission

  –LAI=$\int dz$LAD$(z) = \int dz\, \rho_0(z)\, l(z)$: CO_2 uptake

- Example: $\rho_0(z) = \sum_i \rho_i\ S(z_i; \{h_j\})$ and estimate from int + pol:

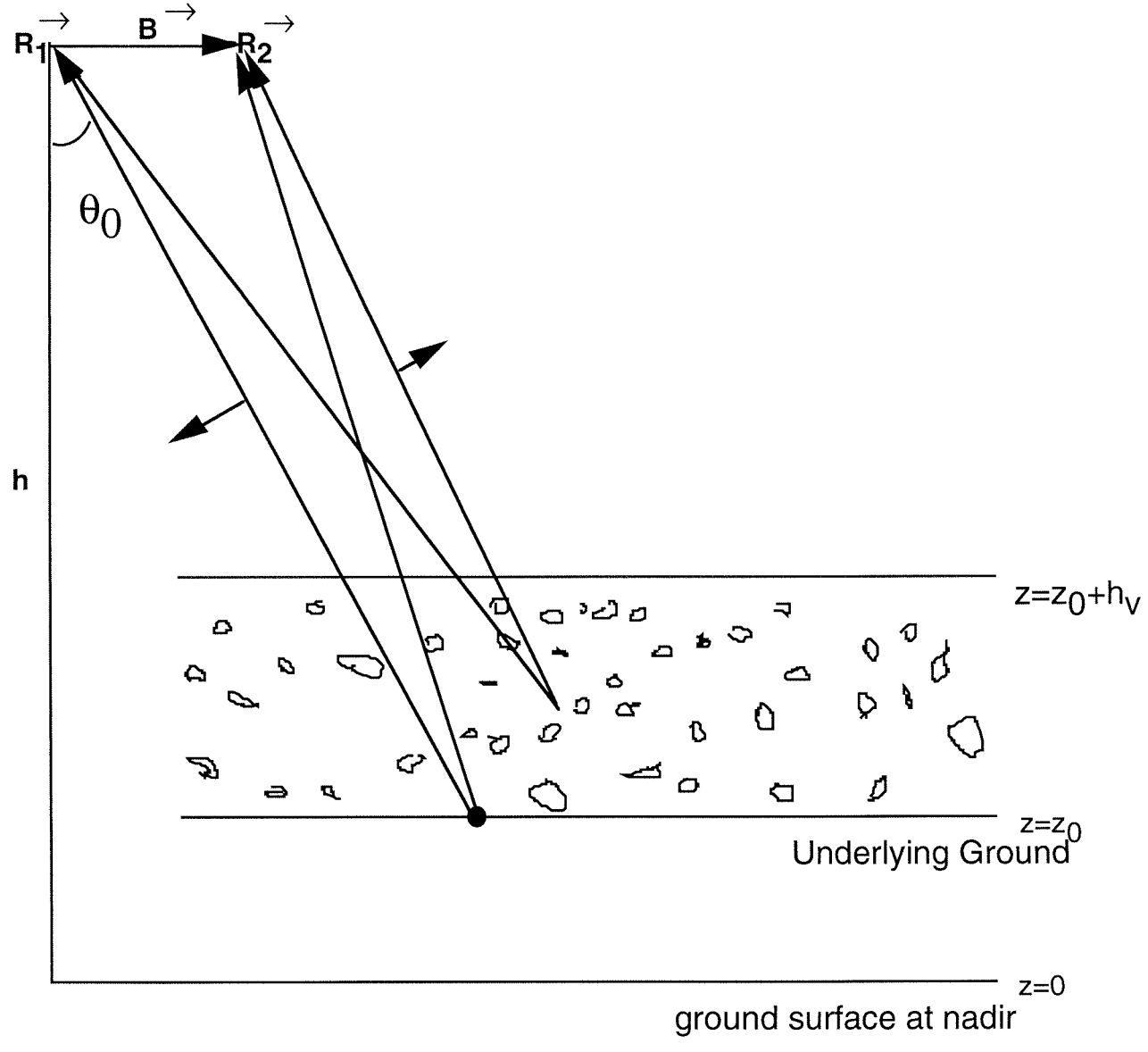
  –Vegetation height (h_v), subcanopy height $(h_{sc})...h_n$

  –Extinction coefficients and density layer ratios $\longrightarrow \rho_i$

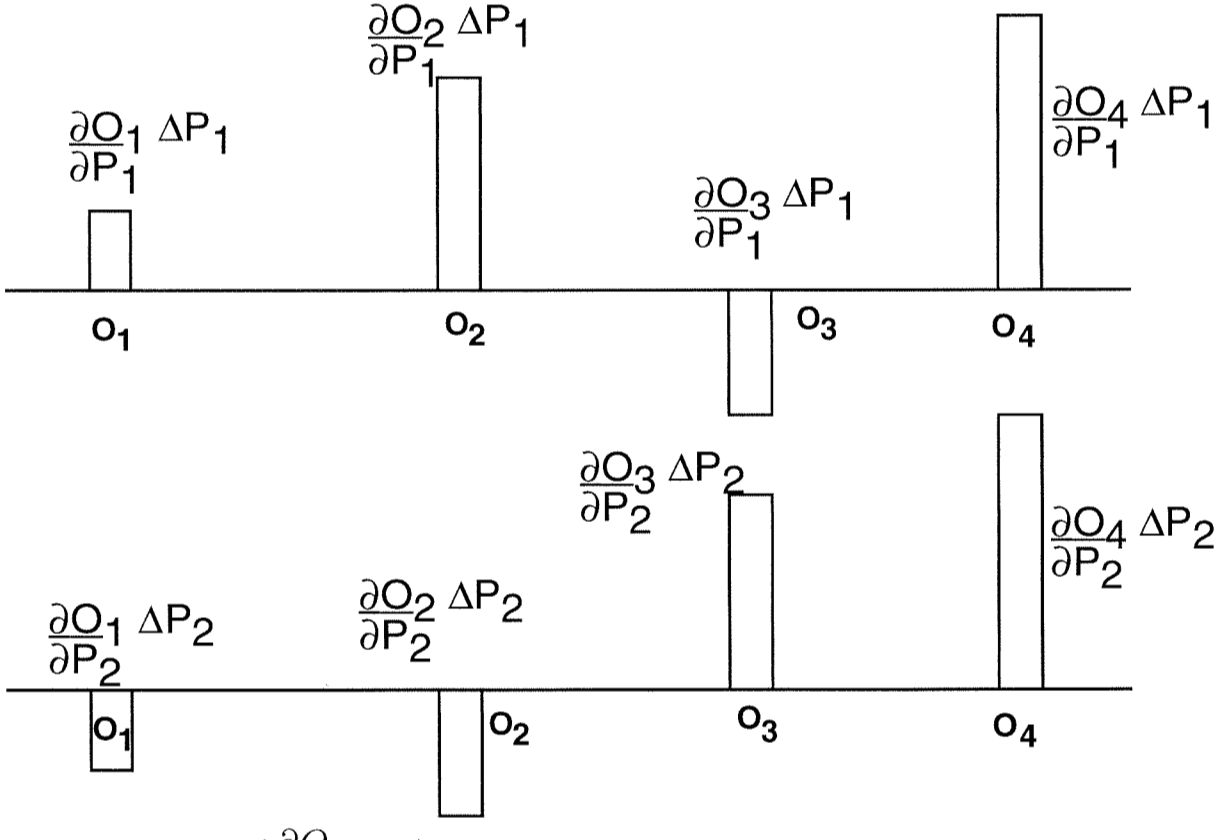
Physical-model parameter estimation scenarios: Data Fusion

$$\begin{pmatrix} \text{Forest height} \\ \text{Extinction Coef.} \\ \text{Ground/vegetation backscat} \\ \text{Real ground dielectric} \\ \text{Underlying topography} \end{pmatrix} = \mathbf{M}^{-1} \begin{pmatrix} \text{Int. Ampl.} \\ \text{Int. Phase} \\ \text{Int. Ampl.} - \text{ping} \\ \text{Int. Phase} - \text{ping} \\ \text{HHHH/VVVV Ratio} \end{pmatrix}$$

Simple Physical Models-->Small # of Parameters



Quantitative Parameter Estimation: Derivative Magnitude and Diversity



$\Rightarrow$ Need $|\frac{\partial O}{\partial P}\Delta P|$ >Observaton Error

$\Rightarrow$ Need $\partial O/\partial P$ diverse

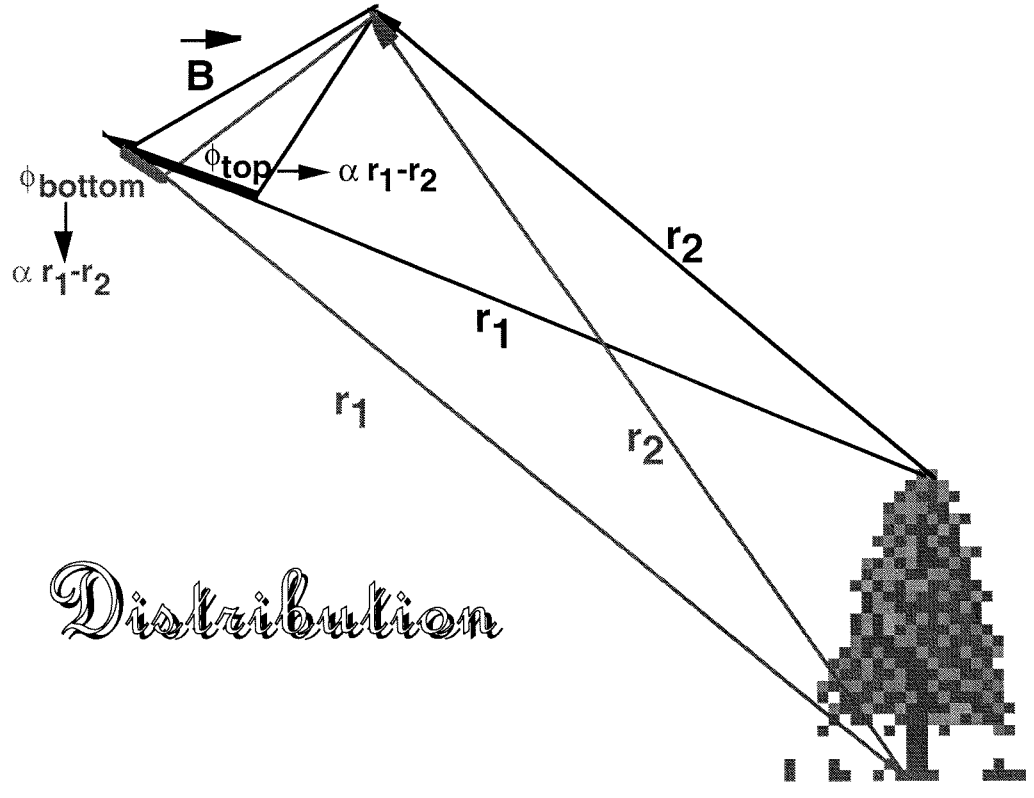
The Sensitivities of Interferometry and Polarimetry

- Interferometry is primarily sensitive to the the mean *spatial location* (phase) *and distribution* (amplitude) of vegetated land surfaces

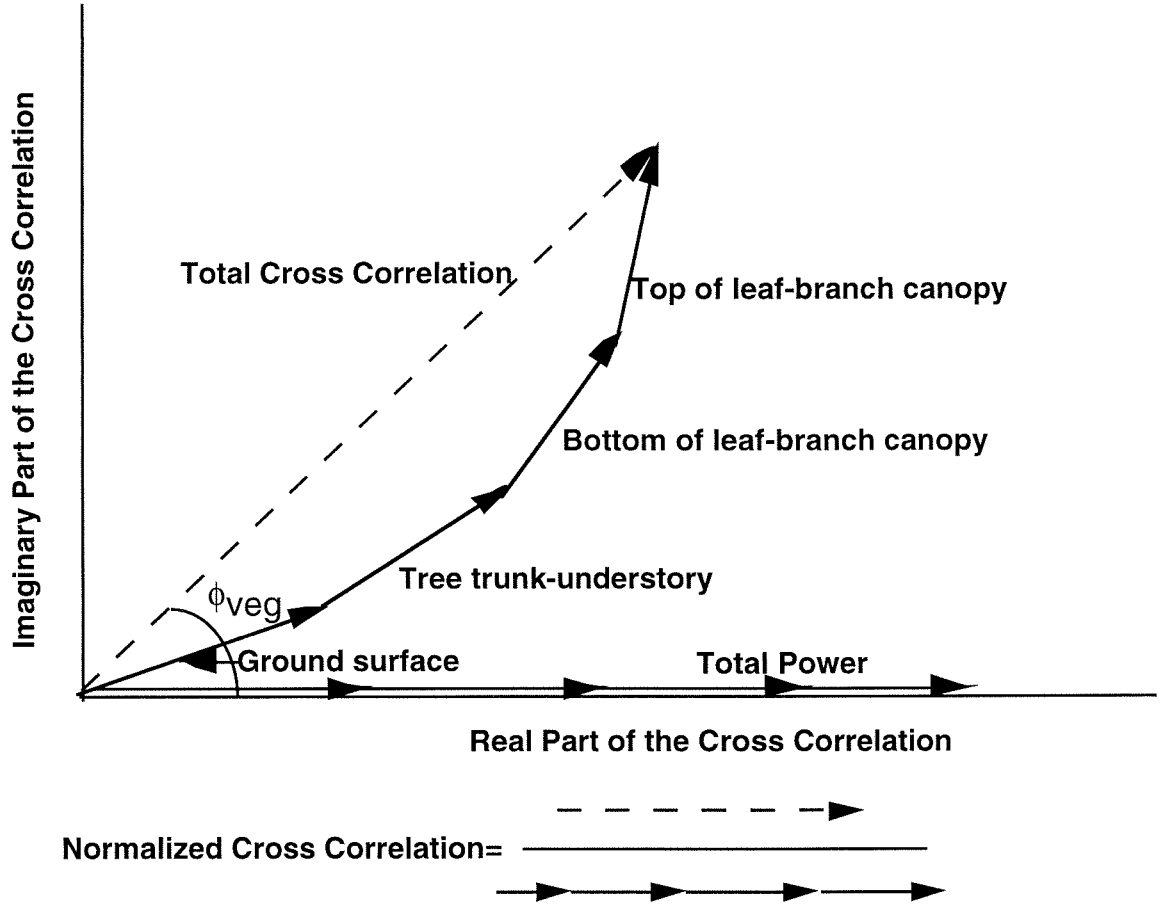
- Polarimetry is primarily sensitive to the *shape and orientation* of objects in the vegetated land surface

$\Rightarrow$ Oriented objects at characteristic vertical locations induce polarimetric vertical-structure sensitivity

The Sensitivity of Interferometry to Vertical Structure



The Sensitivity of Interferometry to Vertical Structure



$\Rightarrow$ Vertical Vegetation Distribution: Amplitude $\downarrow$ Phase $\uparrow$

The Sensitivity of Polarimetry to Vertical Structure

Polarimetry

Polarimetric Interferometry

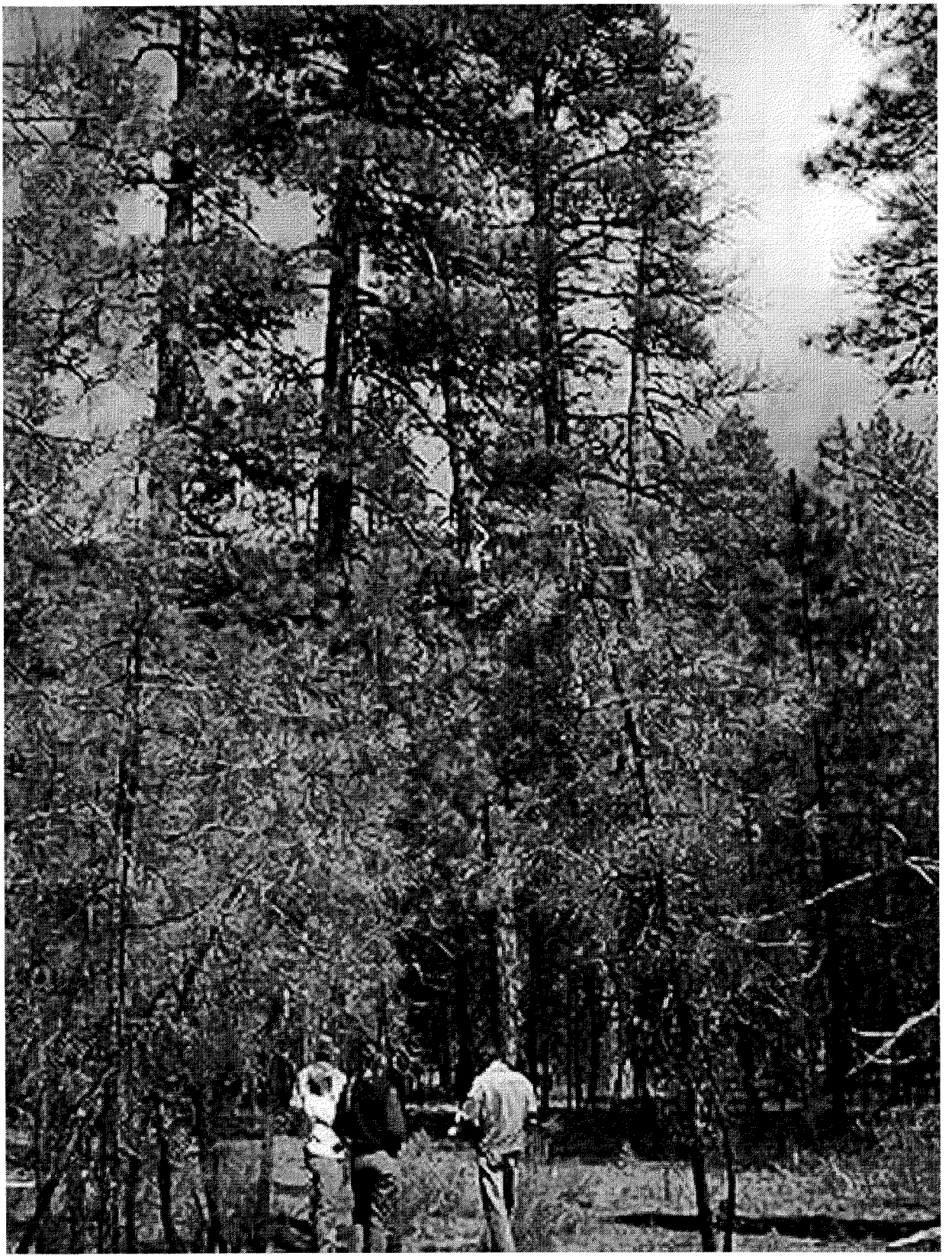
Orientation and Shape

Central-Oregon 6-"Baseline" Layer Demo

$$\begin{pmatrix} \textbf{Vegetation height} \\ \textbf{Canopy extinction} \\ \textbf{Subcanopy height} \\ \textbf{Subcanopy extinction} \\ \textbf{Canopy/subcanopy backscat} \\ \text{Ground/subcanopy backscat} \\ \text{Real ground dielectric} \\ \text{Underlying topgraphy} \end{pmatrix} = \mathbf{M}^{-1} \begin{pmatrix} \text{Int. Ampl.} - 8 \text{ km} \\ \text{Int. Phase} - 8\text{km} \\ \text{Int. Ampl.} - 8 \text{ km} - \text{ping} \\ \text{Int. Phase} - 8\text{km} - \text{ping} \\ \text{Int. Ampl.} - 4 \text{ km} \\ \text{Int. Phase} - 4\text{km} \\ \text{Int. Ampl.} - 4 \text{ km} - \text{ping} \\ \text{Int. Phase} - 4\text{km} - \text{ping} \\ \text{Int. Ampl.} - 2 \text{ km} \\ \text{Int. Phase} - 2\text{km} \\ \text{Int. Ampl.} - 2 \text{ km} - \text{ping} \\ \text{Int. Phase} - 2\text{km} - \text{ping} \\ \text{HHHH/VVVV Ratio} \end{pmatrix}$$

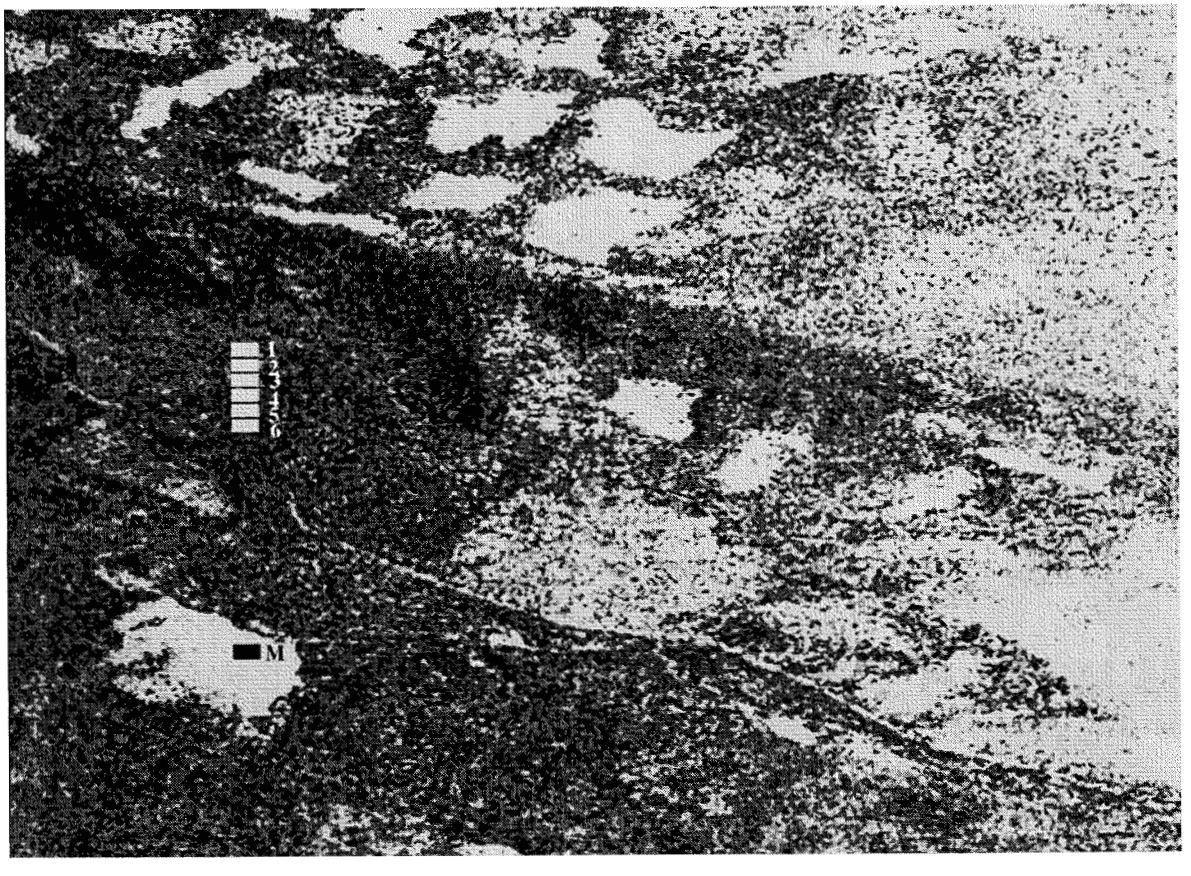
$$\text{Since } \frac{\partial \phi}{\partial z} \propto \frac{B}{h}, \{B_{eff}\} \equiv \begin{pmatrix} 2.5\text{m} \\ 5\text{m} \\ 5\text{m} \\ 10\text{m} \\ 10\text{m} \\ 20\text{m} \end{pmatrix}$$

Two-Level Stand Near Flux Tower
Ponderosa Pine

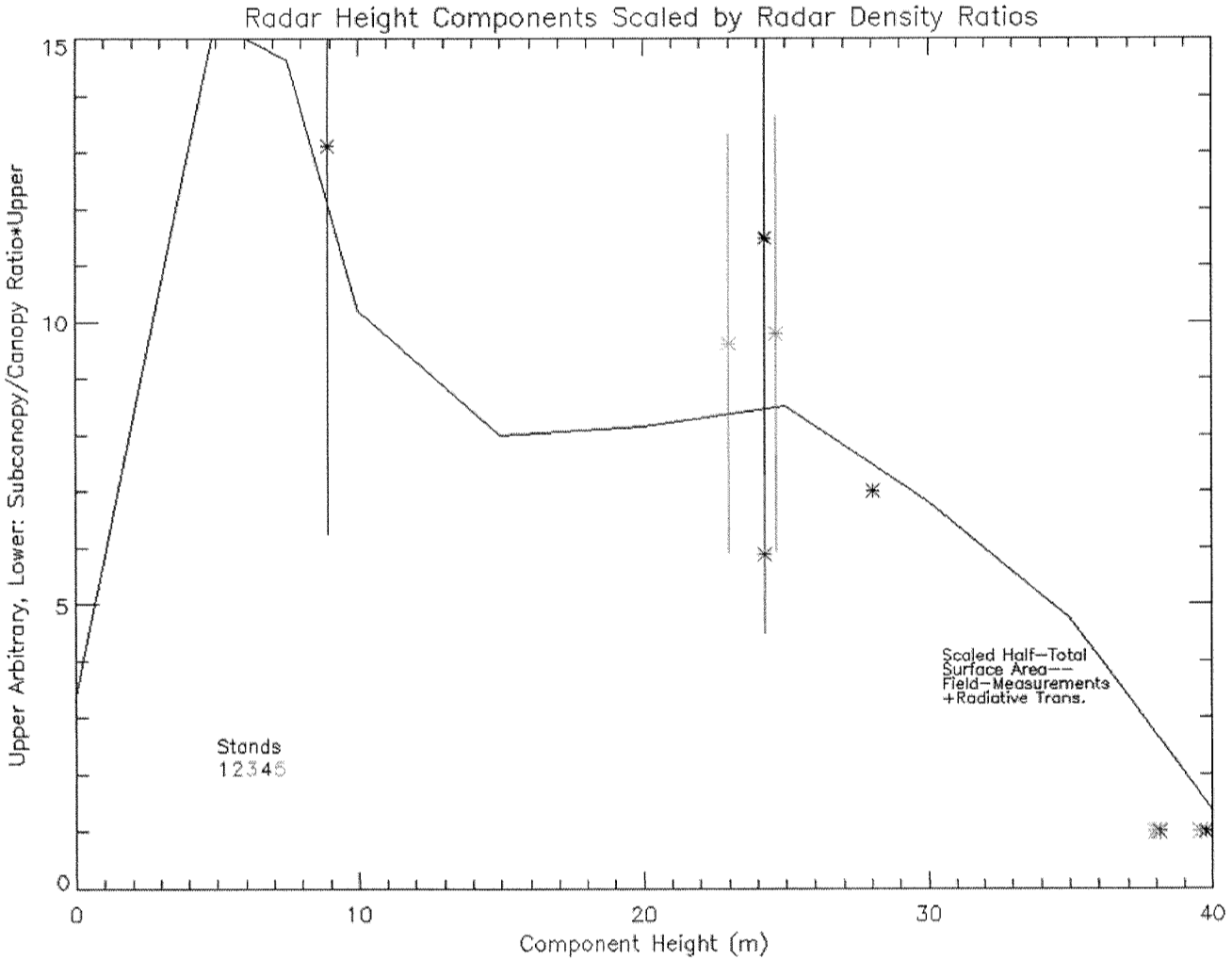


8 June 1999

Central-Oregon 6-"Baseline" Layer Demo



Central-Oregon 6-"Baseline" Layer Demo



Biomass and LAD From Physical Parameters

- Biomass=$\int dz$ Bio dens$(z) = \int dz\, \rho_0(z)\, m(z)$ storage & emission

  –Assume $m(z) = m$ constant and get m from from regression or physical model or LAD(z)

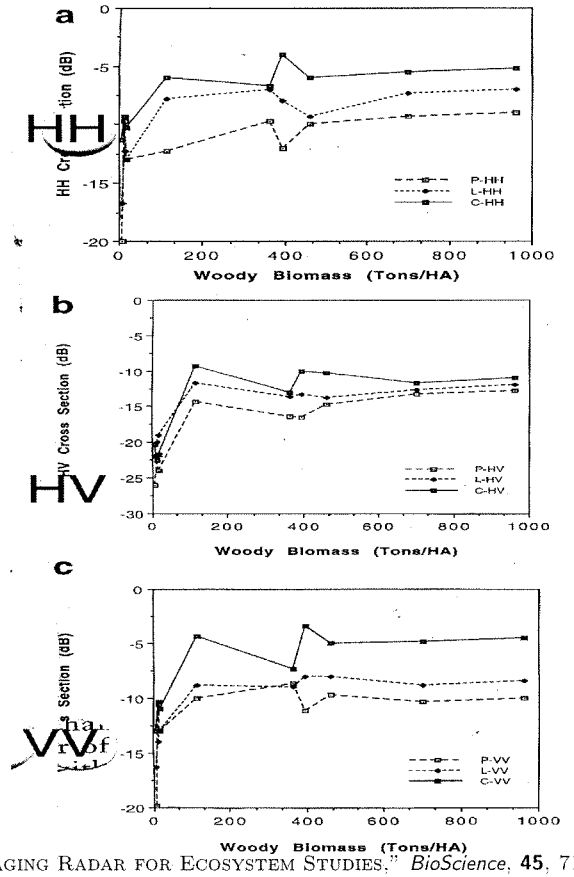
- LAI=$\int dz$LAD$(z) = \int dz\, \rho_0(z)\, l(z)$: CO_2 uptake

  –Assume $l(z)$ constant and use hyperspectral for LAI

  $\rightarrow$LAD(z)=$\rho_0(z)\ I$

- Or make deeper correspondences between radar scattering strength and optical reflectance

Biomass Estimation:
Power Saturation or Insufficient Derivative Magnitude?



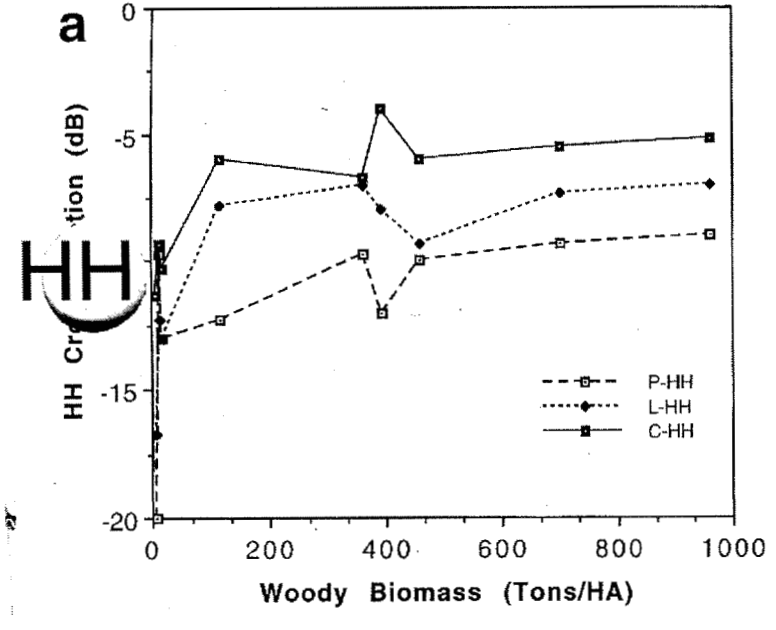
From Waring et al., "Imaging Radar for Ecosystem Studies," *BioScience*, **45**, 715-723, 1995;

Moghaddam et al., "Radar Measurement of Forested Areas During OTTER," *Remote Sens. Environ.*, **47** 154-166, 1994.

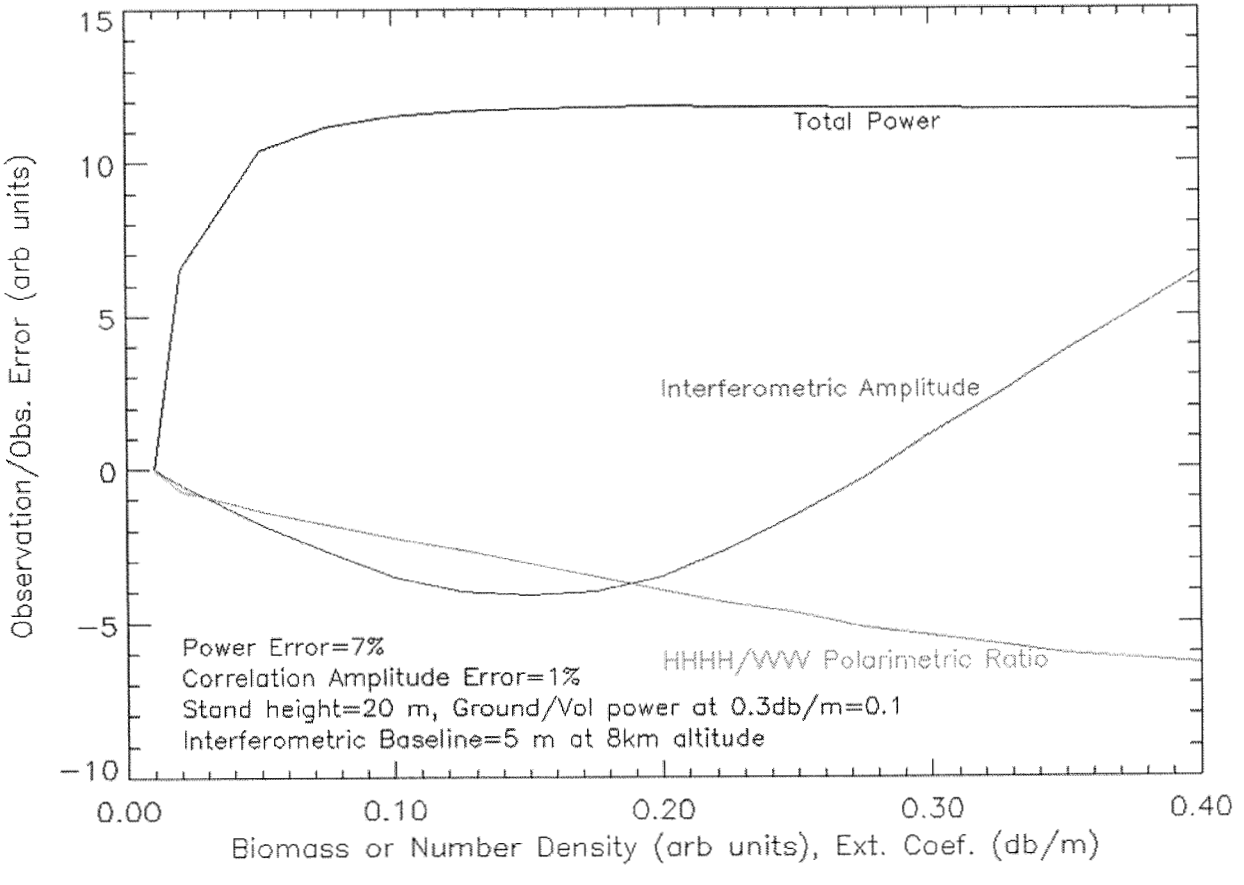
Biomass: Dectection as Parameter Estimation
Signal and Noise Considerations

- A parameter estimate shift is significant if the corresponding observation shift exceeds the noise

$$(\text{Parameter Shift Significance}) \propto \left(\frac{\text{Observation Shift}}{\text{Observation Error}^2} \right)$$



Biomass: Power and Interferometry
$\Delta P\, \partial O/\partial P >$ Observation Error



Vertical structure from data fusion

$$\begin{pmatrix} \text{Biomass Density} \\ \text{LAD} \end{pmatrix} = M^{-1} \begin{pmatrix} \text{Interferometry} \\ \text{Polarimetry} \\ \text{Polarimetric Int} \\ \text{Hyperspectral Optical} \\ \text{Vegetation Can LIDAR} \end{pmatrix}$$

- Derivative Diversity

  –Interferometry: Distribution of microwave scatterers

  –Polarimetry: Orientation and shape$\longrightarrow$distribution

  –Polarimetric Interferometry: Microwave distribution of oriented objects

  –Hyperspectral Optical: Spectral distribution

  –VCL: Geometric optical distribution

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Summary and Conclusions

- Biomass and leaf area density are important vertical-structure inputs to carbon monitoring relevant to the Kyoto Protocol
- Radar interferometry and polarimetry $\longrightarrow$ biomass density

  $+$ hyperspectral$\longrightarrow$leaf area density
- Parameter estimation $\leftrightarrow$ data fusion
- Derivative magnitude and diversity key criteria

$\Rightarrow$ Hypothesis: No one technique is *the* biomass or structure mapper

$\Rightarrow$ Quantitative physical models and error analyses needed for each technique for optimal structure parameter estimation$\equiv$fusion

Questions and Recommendations:
The role of interferometry +... in The Kyoto Protocol

- What is the role of quantitative remote sensing *research*?
- What are the relative needs for "target-blind" remote sensing and regression-based *in situ* training?
- Demonstrate physical-parameter approach to biomass and profiles
- Determine optimal fusion of P, L, &C int., + polarimetry + power
- Determine optimal fusion of int., pol., power, hypspect and VCL
- Demonstrate quantitative error analyis for each technique
- Do not view any *one* technique as a biomass mapper or veg. profiler