RADAR RESPONSE OF VEGETATION:
AN OVERVIEW

S12-43
N94-15898
P- 33

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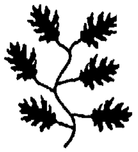
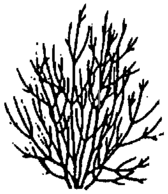
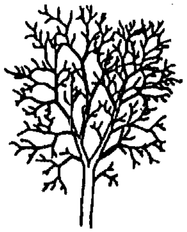
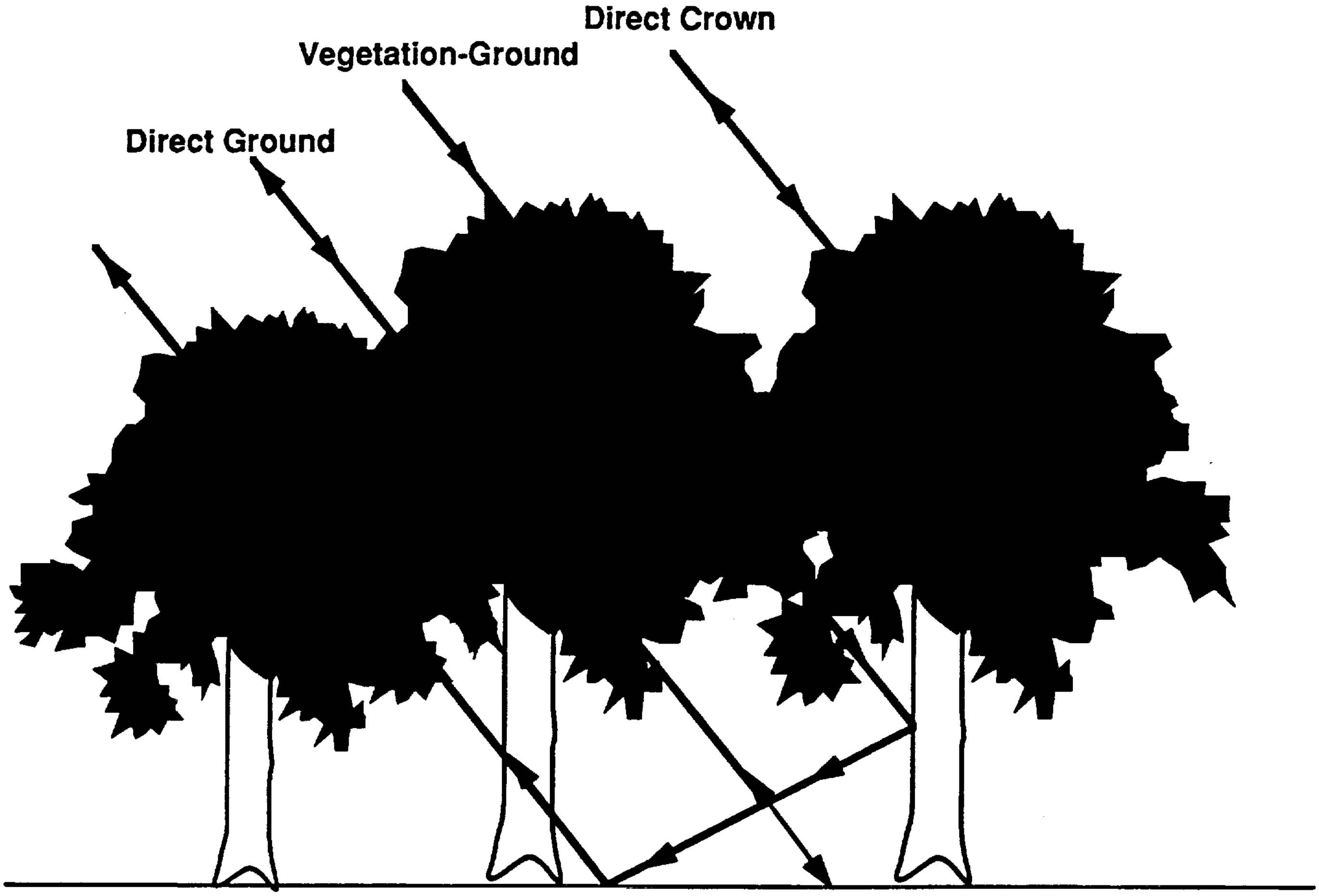
The University of Michigan

- Vegetation Classes
- Soil Scattering: (1) Backscatter
  (2) Forward Scattering
- Radar Response
  - Vegetation Biomass
  - Vegetation Structure
  - Temporal Variations: (1) Short Term (hours to days)
    (2) Long Term (Seasonal)
  - Effect of Rain
- Emergence of a User Community
- Concluding Remarks

STRUCUTRAL CLASSIFICATION OF VEGETATION FROM SAR

	Herbaceous		Woody			
				Trees		
Growth Form	Blade-like	Broadleaf	Shrubs	Excurrent	Decurrent	Columnar
	 (i.e., grass, corn)	 (i.e., soybeans)	 (i.e., alder)	 (i.e., pine and spruce) Gymnosperms	 (i.e., oak and maple) Angiosperms dicotyledons	 (i.e., palm) Angiosperms Monocotyledons
Structural Characteristics Trunks	none	none	Many small trunks with characteristic orientation distributions	conical layered dielectric	cylindrical, forked layered dielectric	cylindrical homogeneous dielectric
Branches	some non-woody stalks or stems	some non-woody stems	many small branches & stems	branch size and orientation varies with height •large branches- planophile •many small stems- erectophile branches tend to be long and thin	many forked with few horizontal elements branches tend to be short and thick	none
Foliage	blade-like erectophile	broad leaves	blade-like or broadleaves	needles	broadleaves	blade-like in clump at top of trunk
General Scattering Properties f < 5 GHz	low to moderate σ^0 dominated by surface scattering $\sigma^0_{VV} \geq \sigma^0_{HH} >> \sigma^0_{HV}$ zero mean $\Delta\phi$		moderate σ^0 $\sigma^0(f,P,\theta)$ dependent upon trunks & branches uniform $\Delta\phi$	very high like-polarized σ^0 moderate σ^0_{HV}, dominated by ground-trunk and few large branches $\sigma^0_{HH} \geq \sigma^0_{VV}$, $\sigma^0_{HH} / \sigma^0_{VV}$=f (trunk biomass) broad distributions of $\Delta\phi$	high σ^0 dominated by large branches, $\sigma^0_{HH} \geq \sigma^0_{VV}$ σ^0_{HV} = f (branch biomass) broad distributions of $\Delta\phi$	moderate σ^0 large crown structures may dominate σ^0 low transmissivity through crown non-zero mean $\Delta\phi$
f > 5 GHz	moderate to high σ^0 dominated by vegetation $\sigma^0_{VV} \approx \sigma^0_{HH} > \sigma^0_{HV}$		mod. to high σ^0 stem orientation and leaf size very important	high σ^0 dominated by branches and stems	mod. to very high σ^0, can vary seasonally with foliage and stem properties	high σ^0 determined by crown

RADAR SCATTERING MECHANISMS



- Direct Ground Backscatter
- Vegetation-Ground Bistatic Scattering
    - Trunks
    - Leaves (needles)
    - Branches
- Direct Crown Backscatter

University of Michigan

MOD-3

SOIL BACKSCATTERING

A. Theoretical Models

- Small Perturbation Model
- Physical Optics Model
- Geometric Optics Model
- Phase Perturbation Method
- Full Wave Model
- Integral Equation Model

Models agree with experimental observations only under certain conditions. Overall, models not useful.

B. Michigan Empirical Model

- Frequency Range : 1-10 GHz
- Angular Range : 20° - 70°
- Roughness range : $s = 0.32$ cm to $s = 4.0$ cm (expected validity for any $s > 0.3$ cm)
- Moisture range : 0.05 g/cm^3 to 0.31 g/cm^3

Moisture Sampling Depth

L-Band (1.25 GHz) : Average Moisture of Top 10 cm layer

C-Band (5.3 GHz) : Average Moisture of Top 3 cm layer

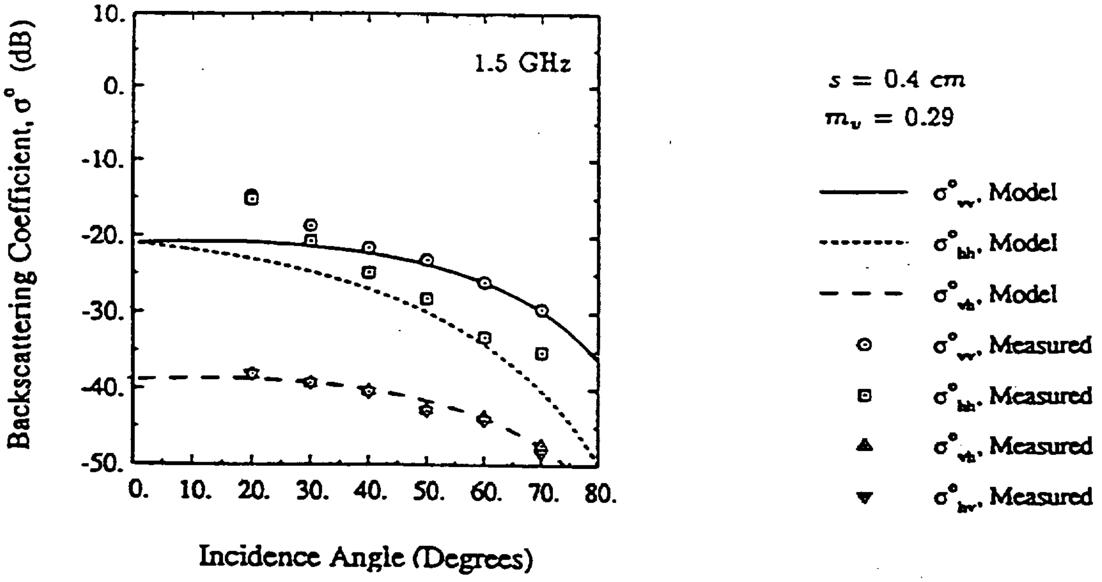
X-Band (9.5 GHz) : Average Moisture of Top 1 cm layer

Sampling Depth $\simeq \lambda / 3$

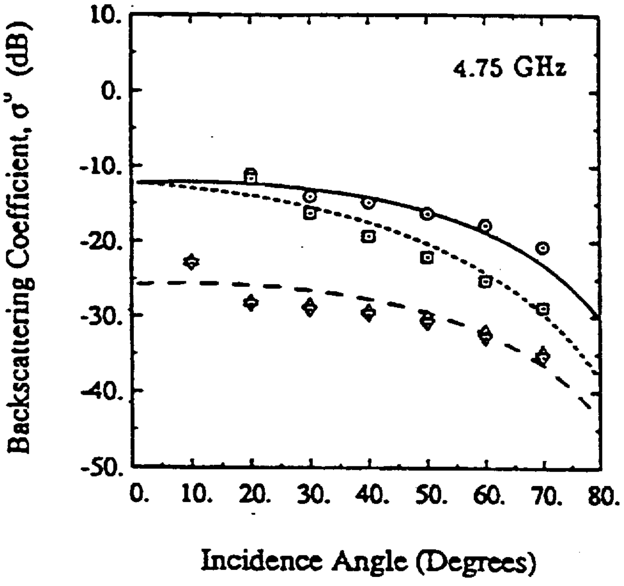
MOD-3

- Model Verification For A smooth Surface (s=0.4 cm)

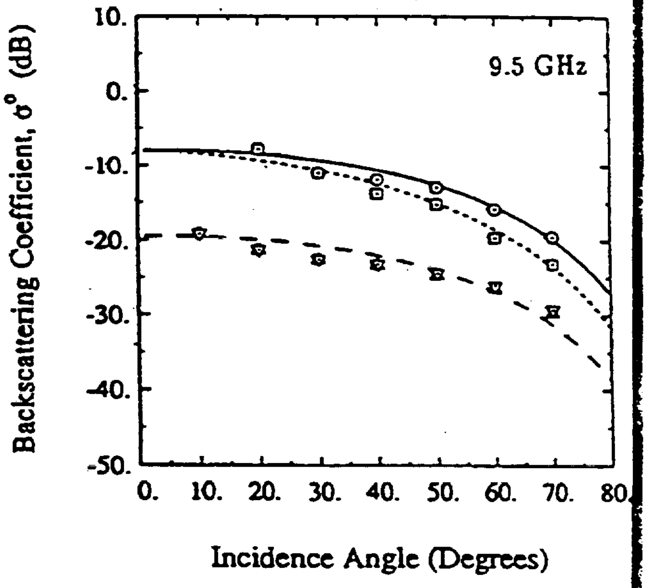
1.5 GHz



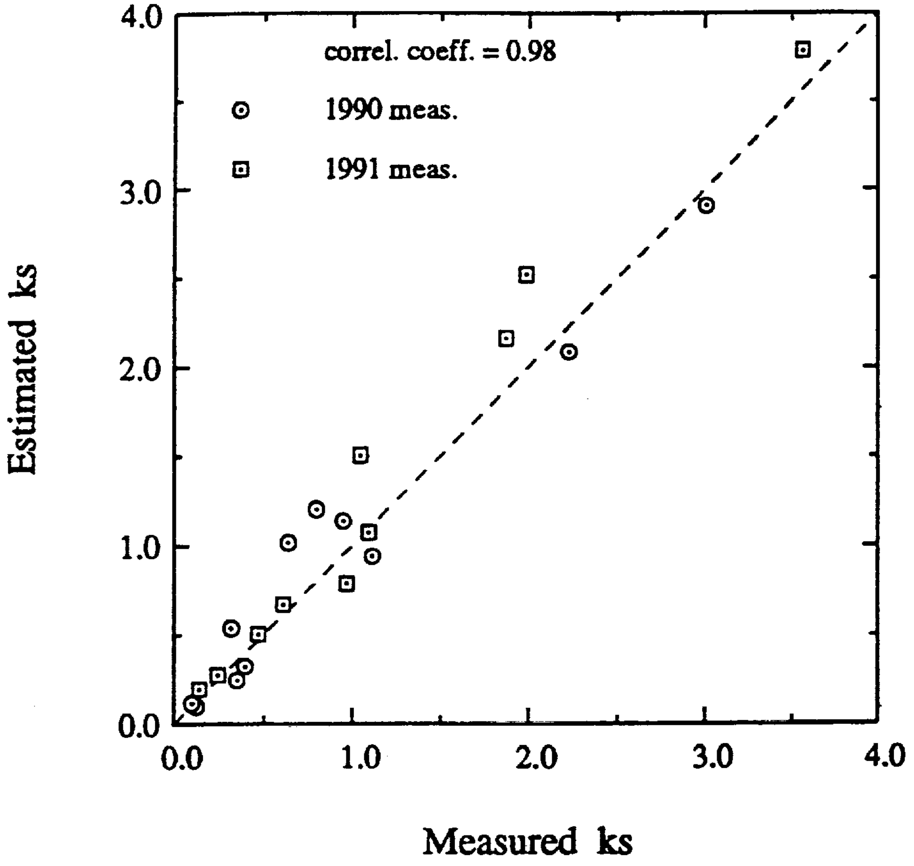
4.75 GHz



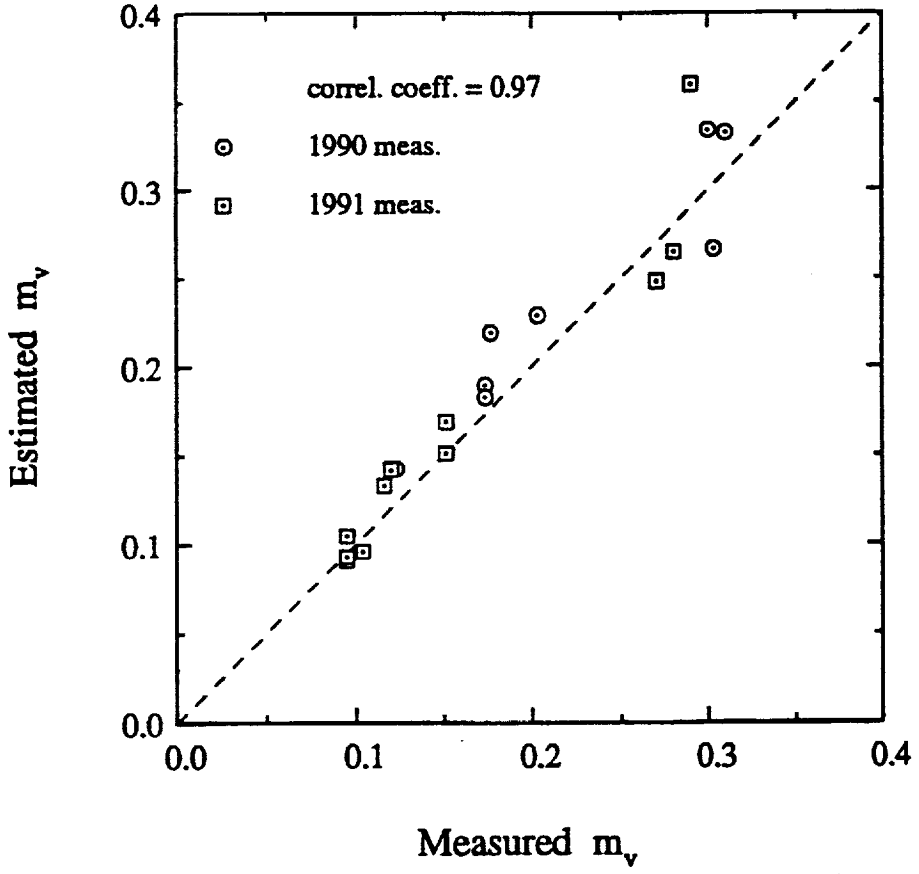
9.5 GHz



MOD-3



rms height



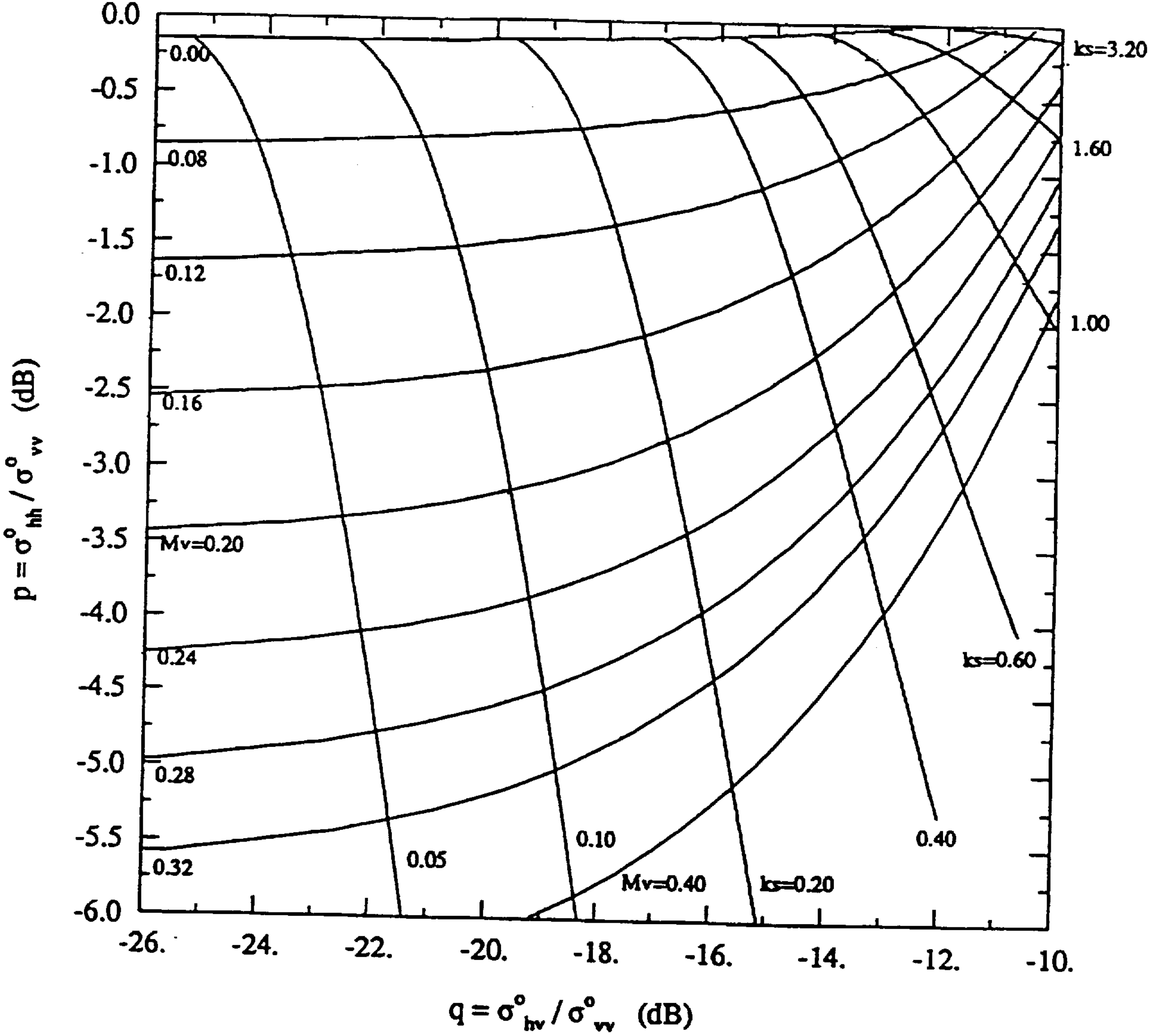
soil moisture

Inversion Algorithm

If radar measures σ^0_{vv}, σ^0_{hh}, and σ^0_{hv} at a given frequency and angle, both s and m_v can be determined from the ratios:

$$p = \sigma^0_{hh} / \sigma^0_{vv}$$
$$q = \sigma^0_{hv} / \sigma^0_{vv}$$

p-q Diagram (1.25 GHz, 40°)

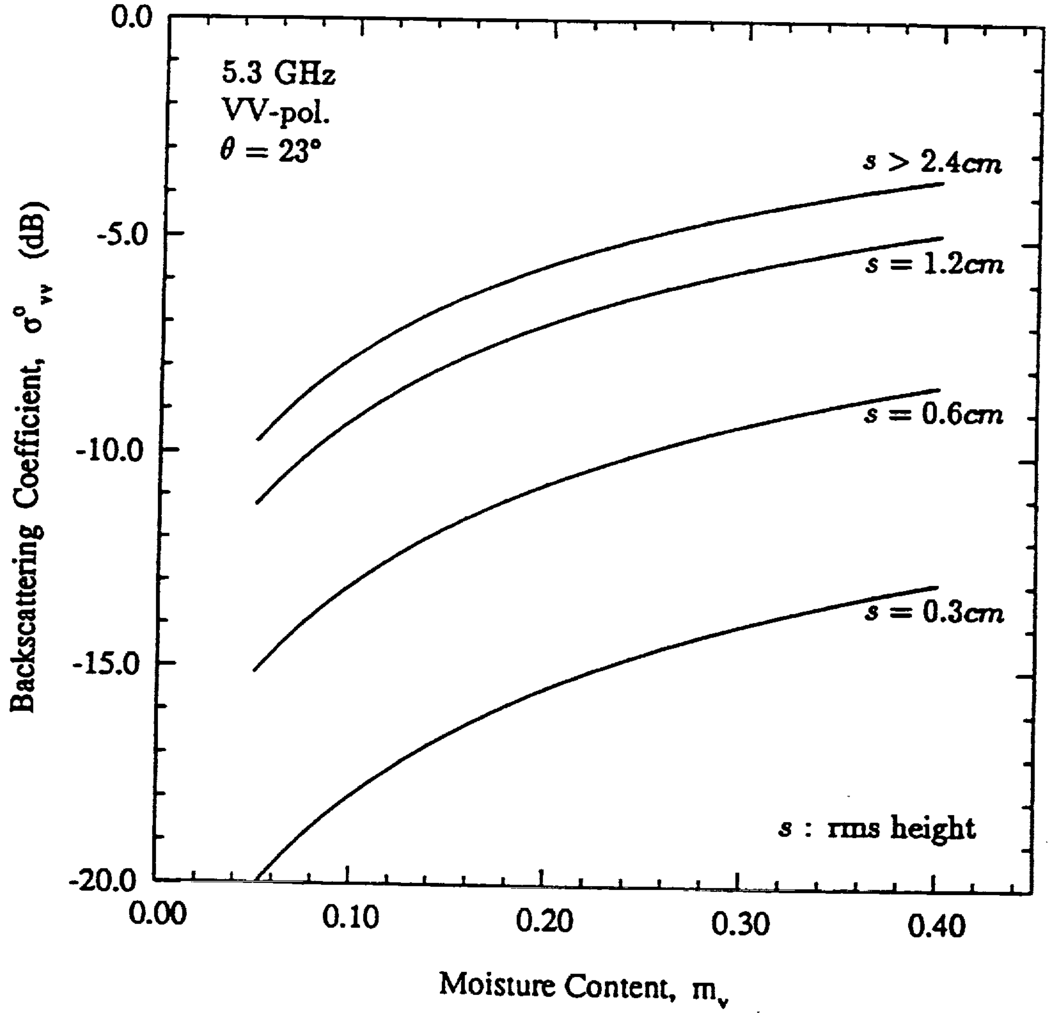


Note: $p(\text{dB}) = 10\log\left(\sigma^0_{hh} / \sigma^0_{vv}\right) = \sigma^0_{hh}(\text{dB}) - \sigma^0_{vv}(\text{dB})$

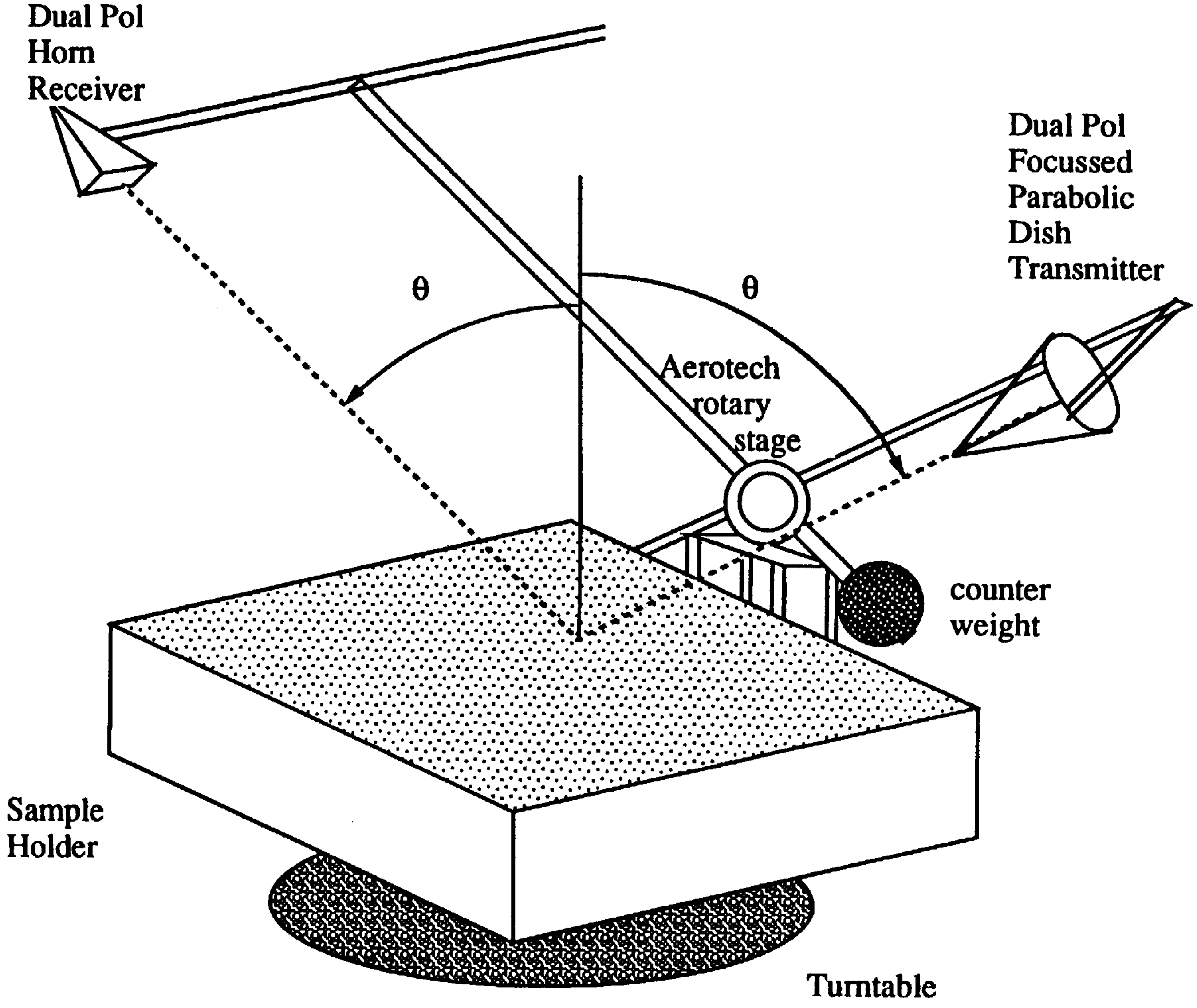
$q(\text{dB}) = \sigma^0_{hv}(\text{dB}) - \sigma^0_{vv}(\text{dB})$.

ERS-1 SAR Response

$\theta = 23°$
vv Polarization

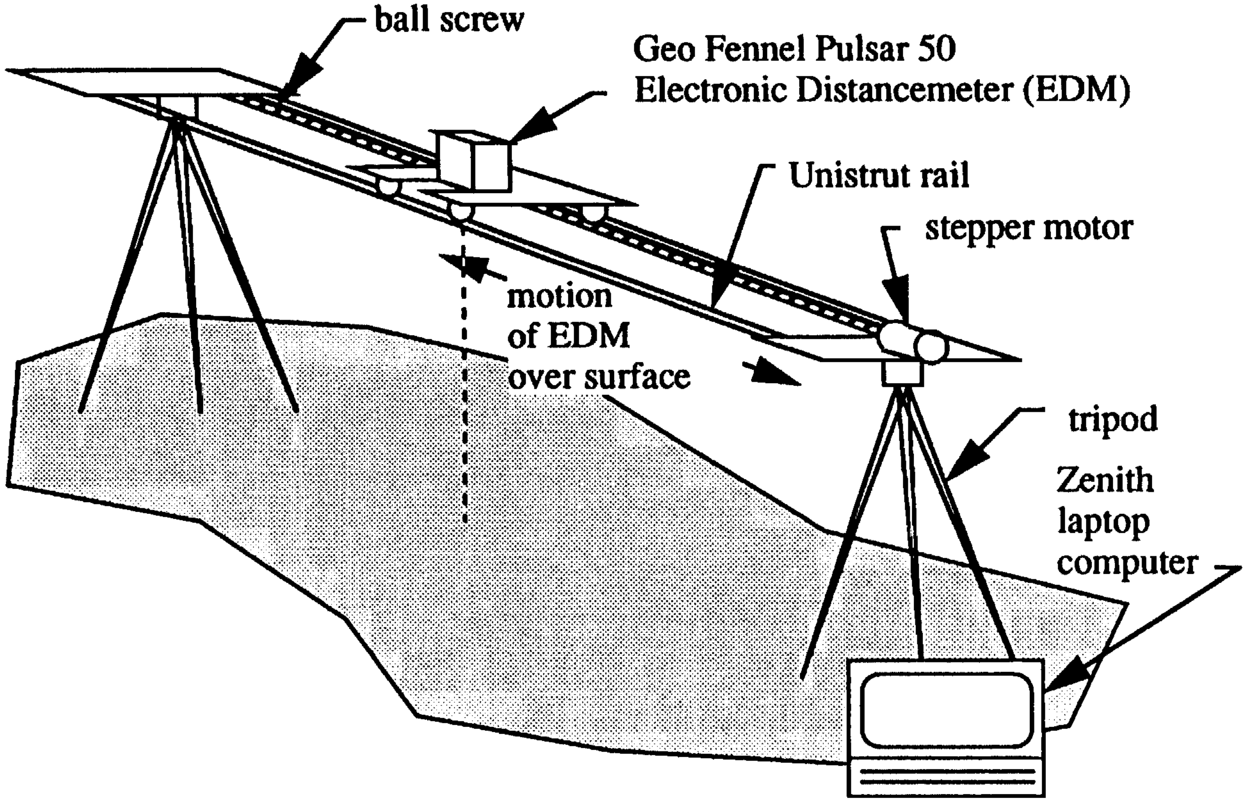


RADIATION LABORATORY



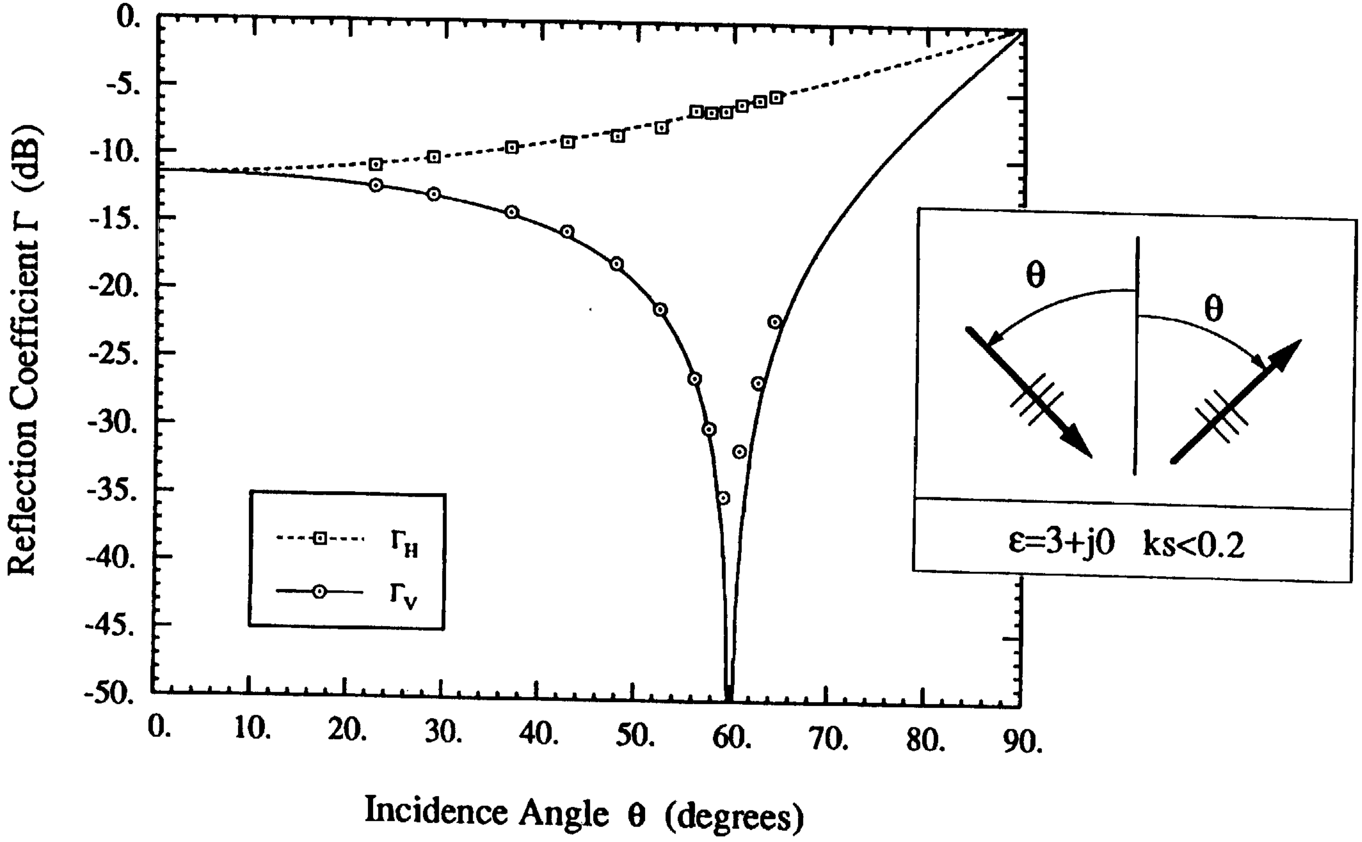
Bistatic Facility

RADIATION LABORATORY



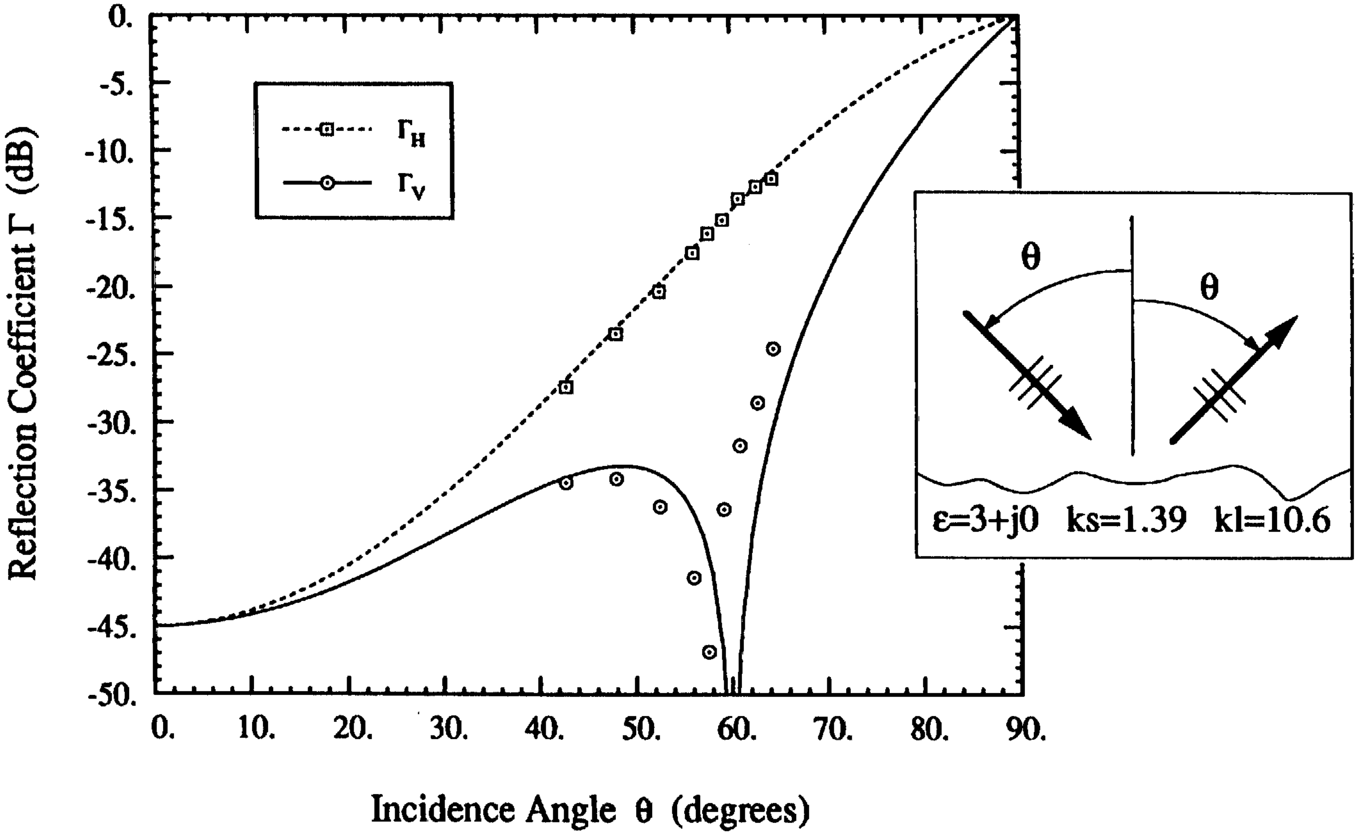
Laser Profiler

Coherent Reflectivity

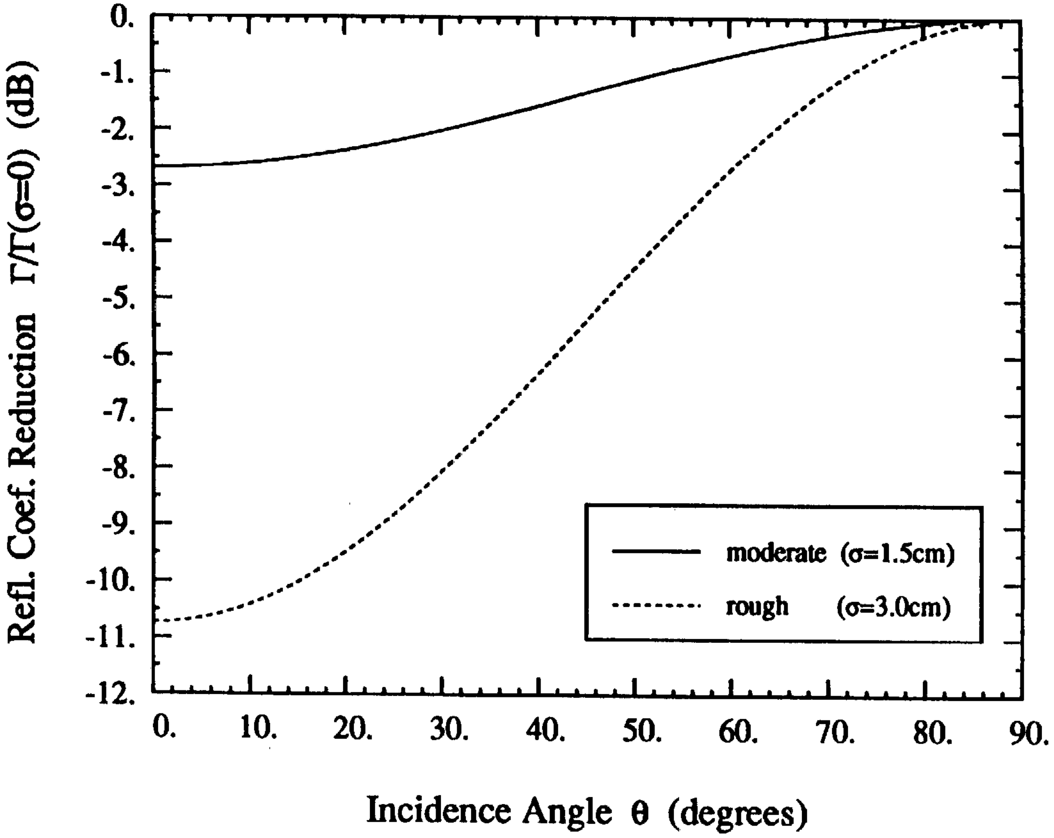


RADIATION LABORATORY

Coherent Reflectivity



Reduction of Reflectivity by Surface Roughness at L-band



RADAR RESPONSE TO VEGETATION

- OBJECTIVES
  - To Discriminate/Classify Vegetation Classes
  - To Estimate Biomass
  - To Estimate LAI
  - To Estimate Soil Moisture
  - To Monitor Changes (deforestation, growth, stress, etc.)
  - Other

- VEGETATION CANOPY
  - Structure: (1) Macro (tree or plant scale): Tree height, density, ground cover
    (2) Micro (wavelength scale): Leaves, branches
  - Dielectric Properties
  - Ground Cover (soil, debris, undergrowth, etc.)

- TOOLS
  - Wavelength
  - Polarizations
  - Phase Statistics
  - Incidence Angle
  - Time

- APPROACH
  - Theory
  - Observations
    - Lab
    - Field
    - Air SAR
    - Satellite

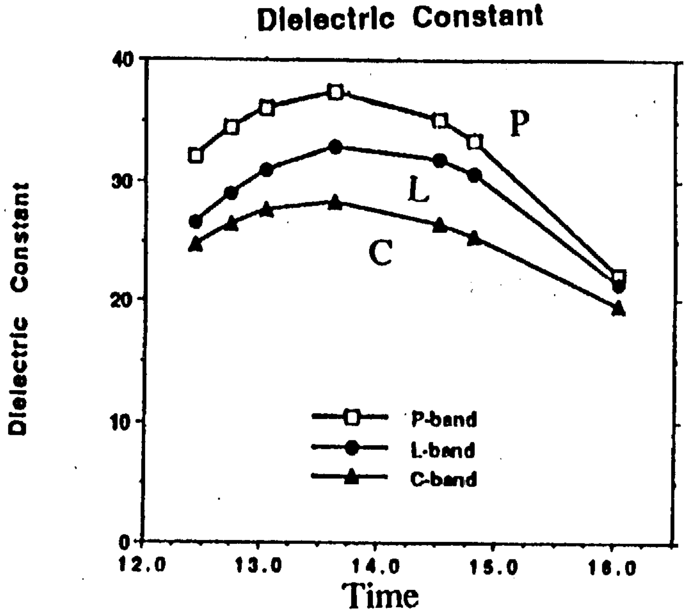
DIURNAL VARIATION IN σ^0

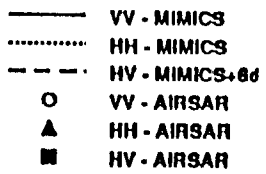
Humid Temperate Forest Loblolly Pines at Duke Forest

While ε* of trunks are found to vary by 30%,

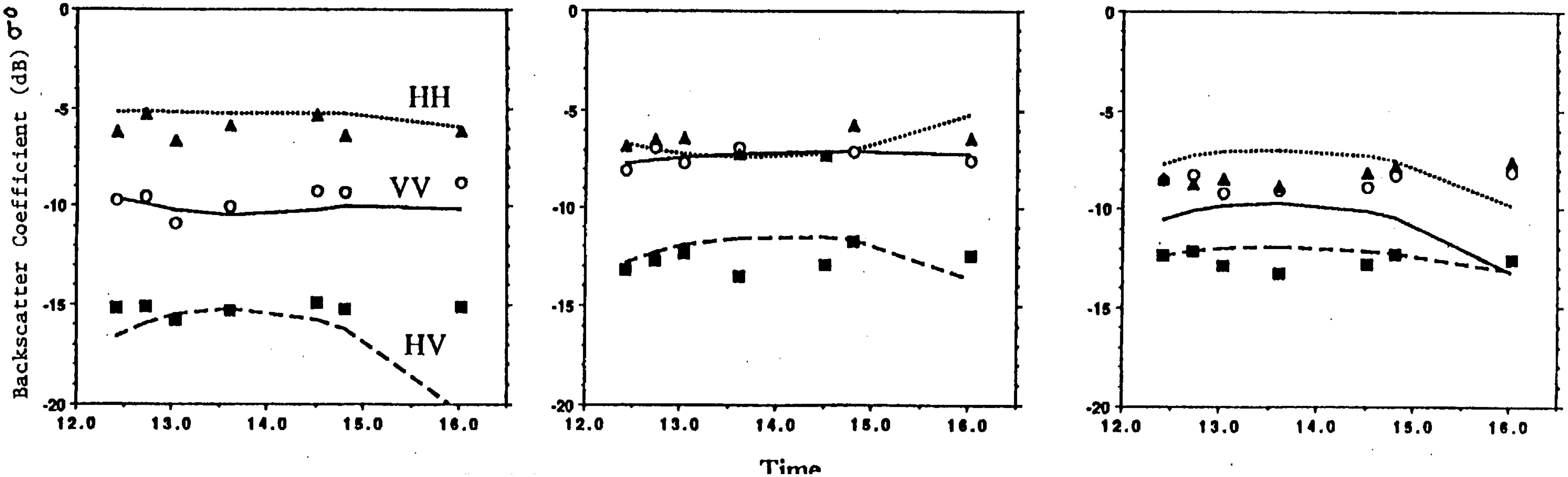
σ^0 varies by only ≈ 1dB

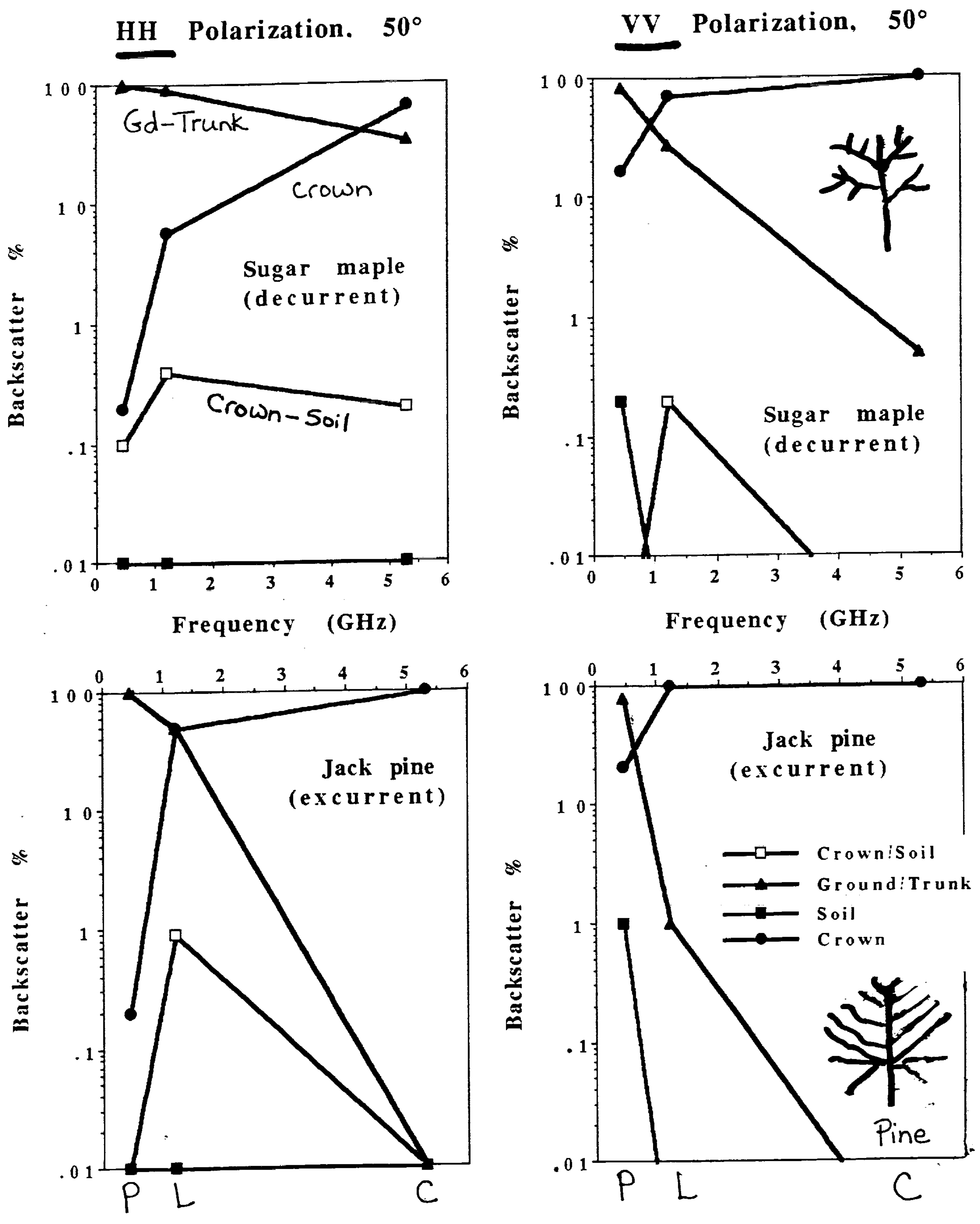
Calibration accuracy is 1dB

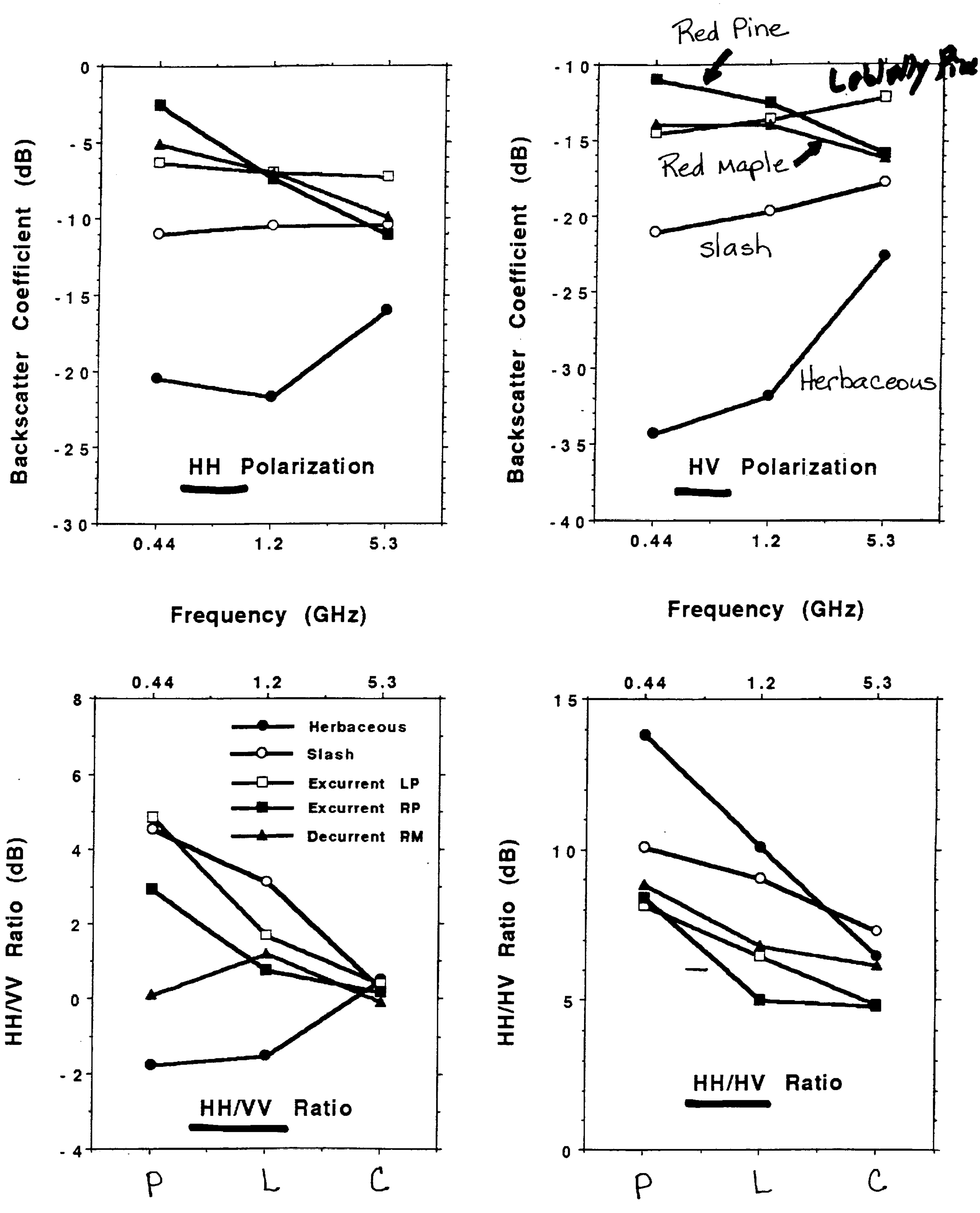




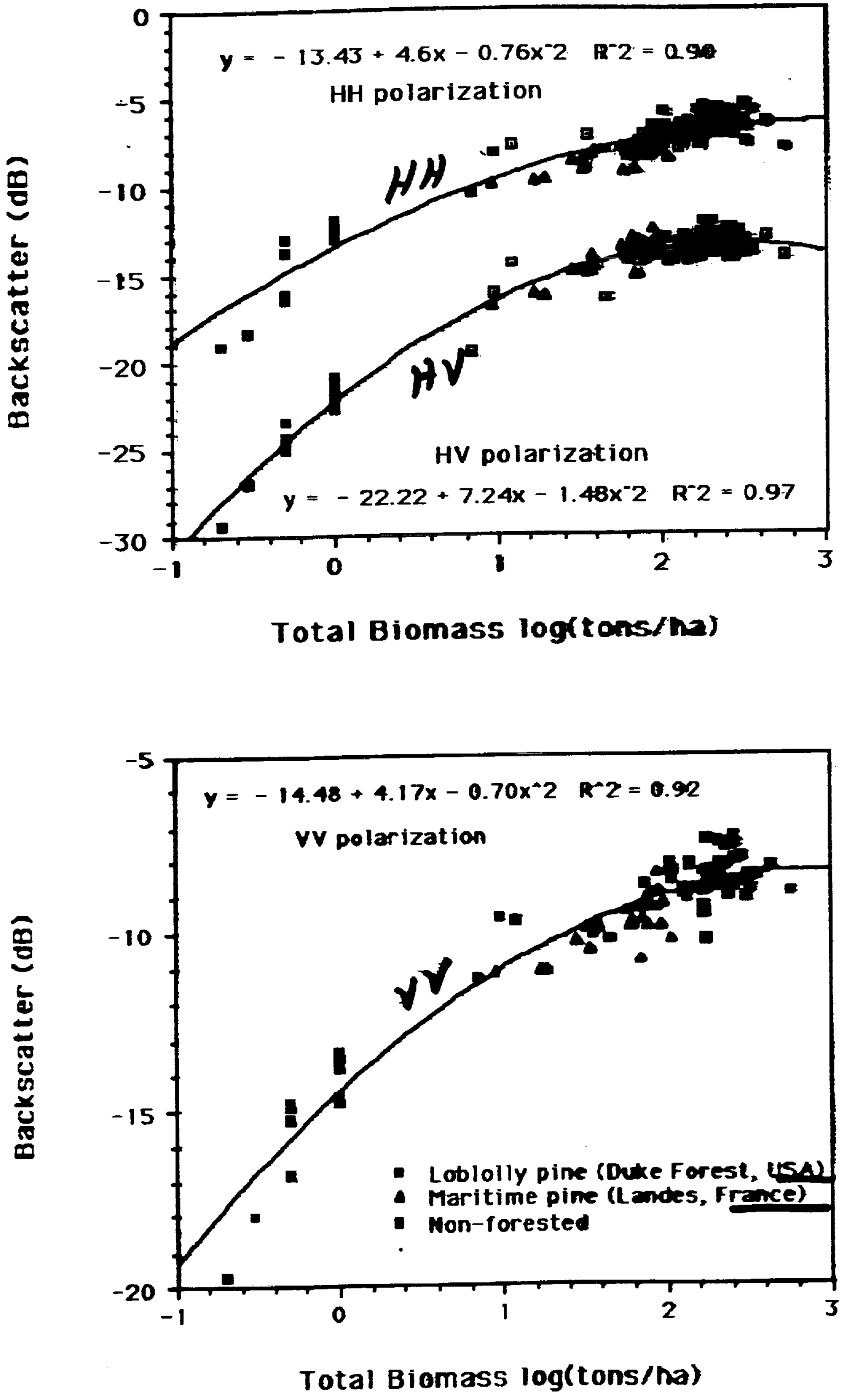
P-Band L-Band C-Band

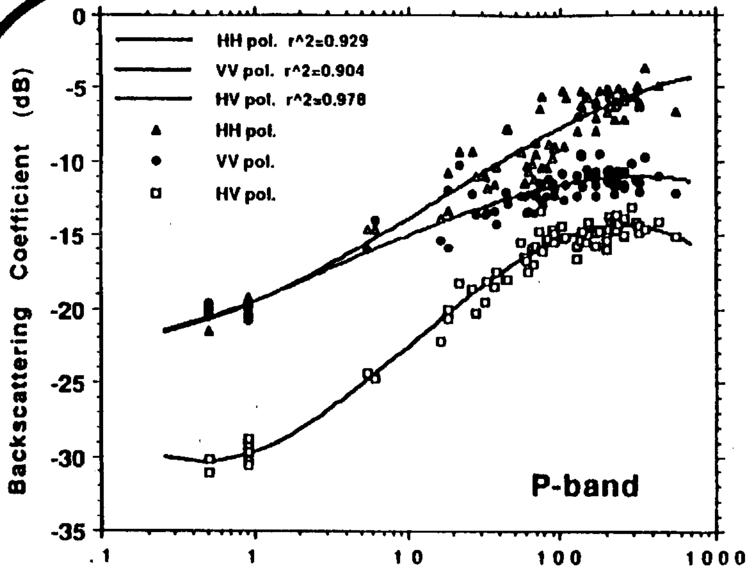


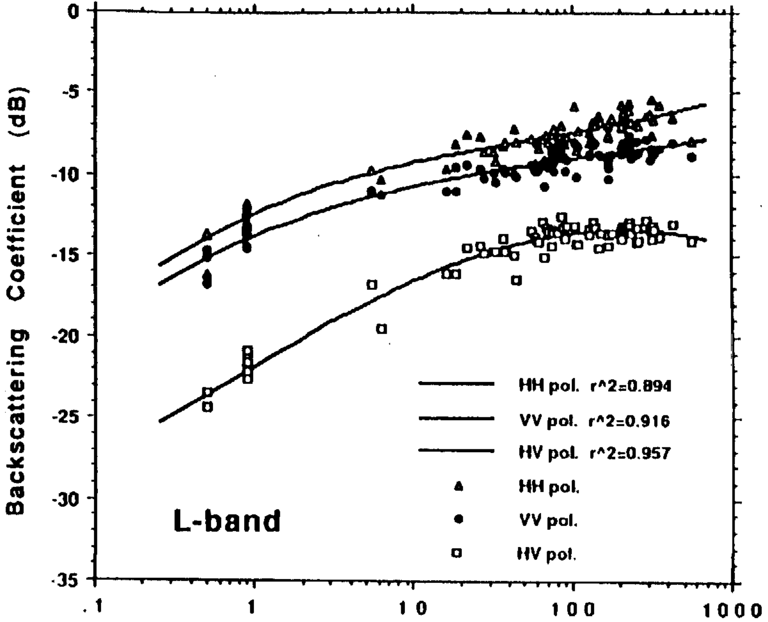

HH Polarization. 50°
VV Polarization. 50°
Backscatter %
Frequency (GHz)
100
10
1
.1
.01
0
1
2
3
4
5
6
Gd-Trunk
Crown
Crown-Soil
Sugar maple
(decurrent)
Jack pine
(excurrent)
Crown/Soil
Ground/Trunk
Soil
Crown
Pine
P
L
C

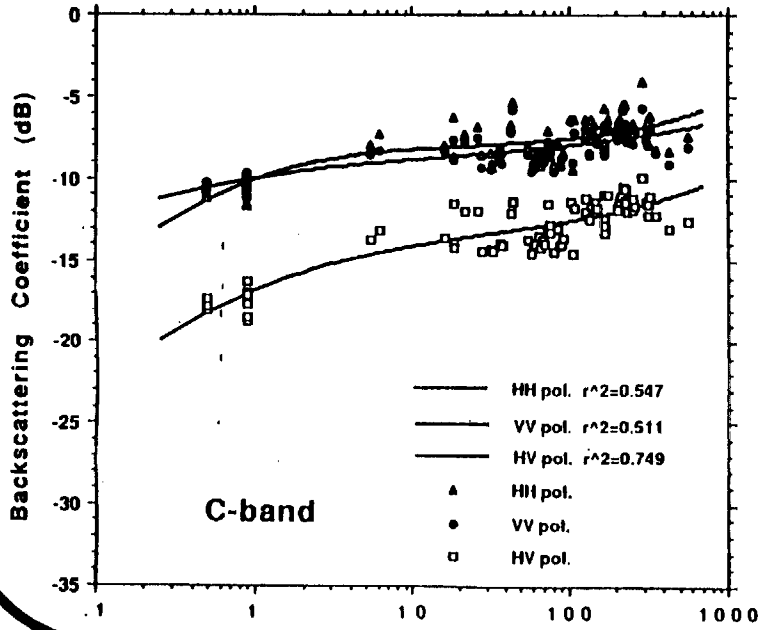

Red Pine
Loblolly Pine
Red Maple
slash
Herbaceous
Backscatter Coefficient (dB)
HH Polarization
HV Polarization
0
- 5
- 1 0
- 1 5
- 2 0
- 2 5
- 3 0
- 3 5
- 4 0
0.44
1.2
5.3
Frequency (GHz)
HH/VV Ratio (dB)
HH/VV Ratio
HH/HV Ratio (dB)
HH/HV Ratio
8
6
4
2
- 2
- 4
1 5
1 0
5
Herbaceous
Slash
Excurrent LP
Excurrent RP
Decurrent RM
P
L
C

Calibrated AIRSAR Response at L-Band to Standing Forest Biomass

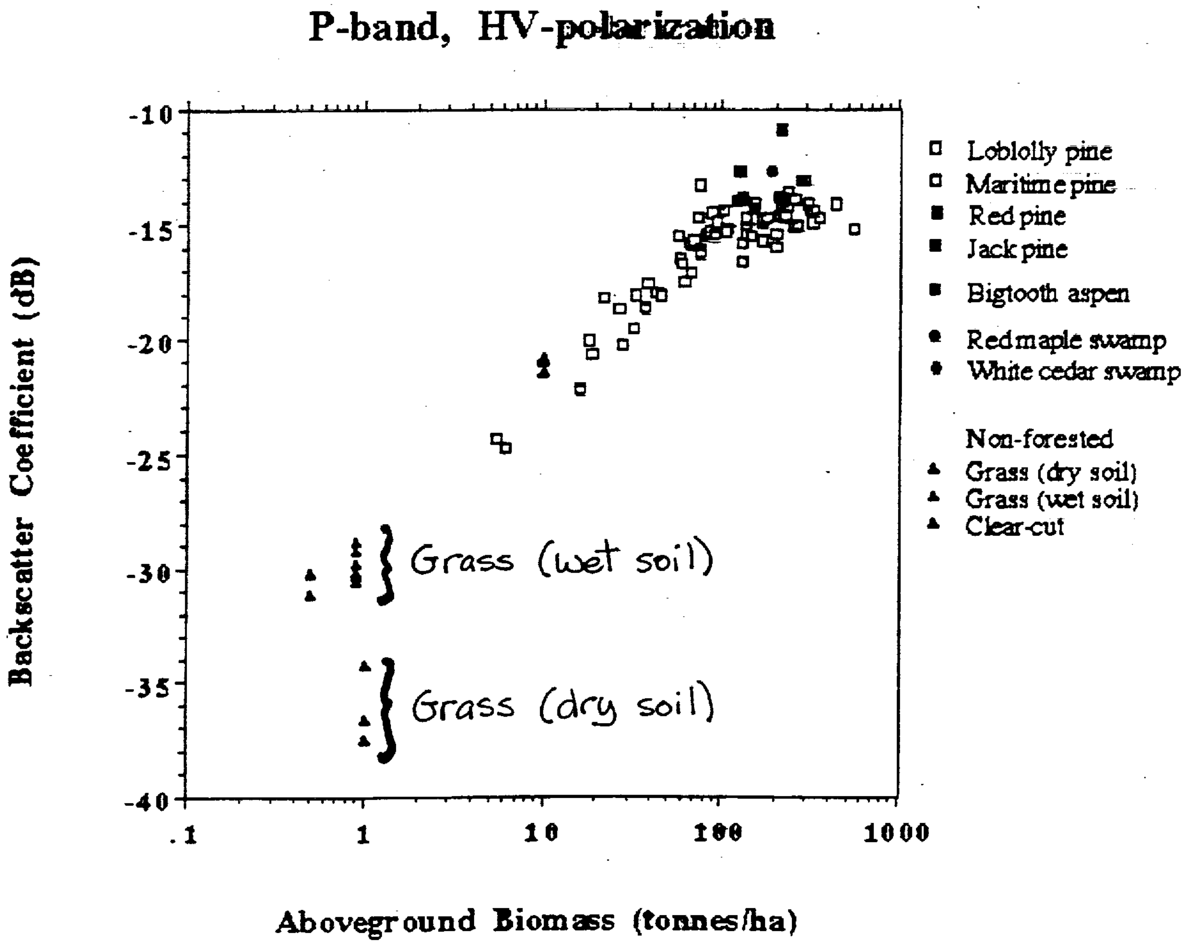




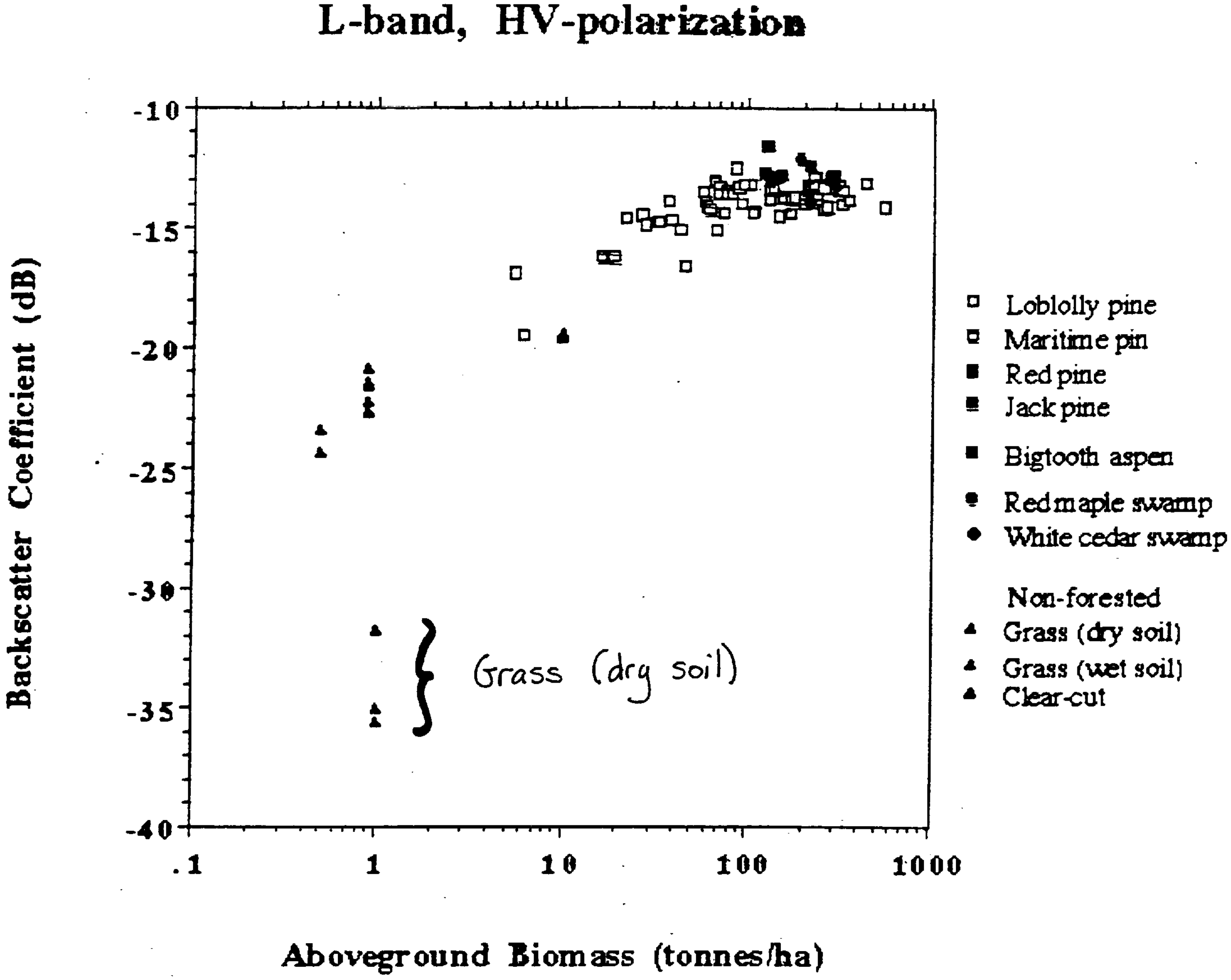




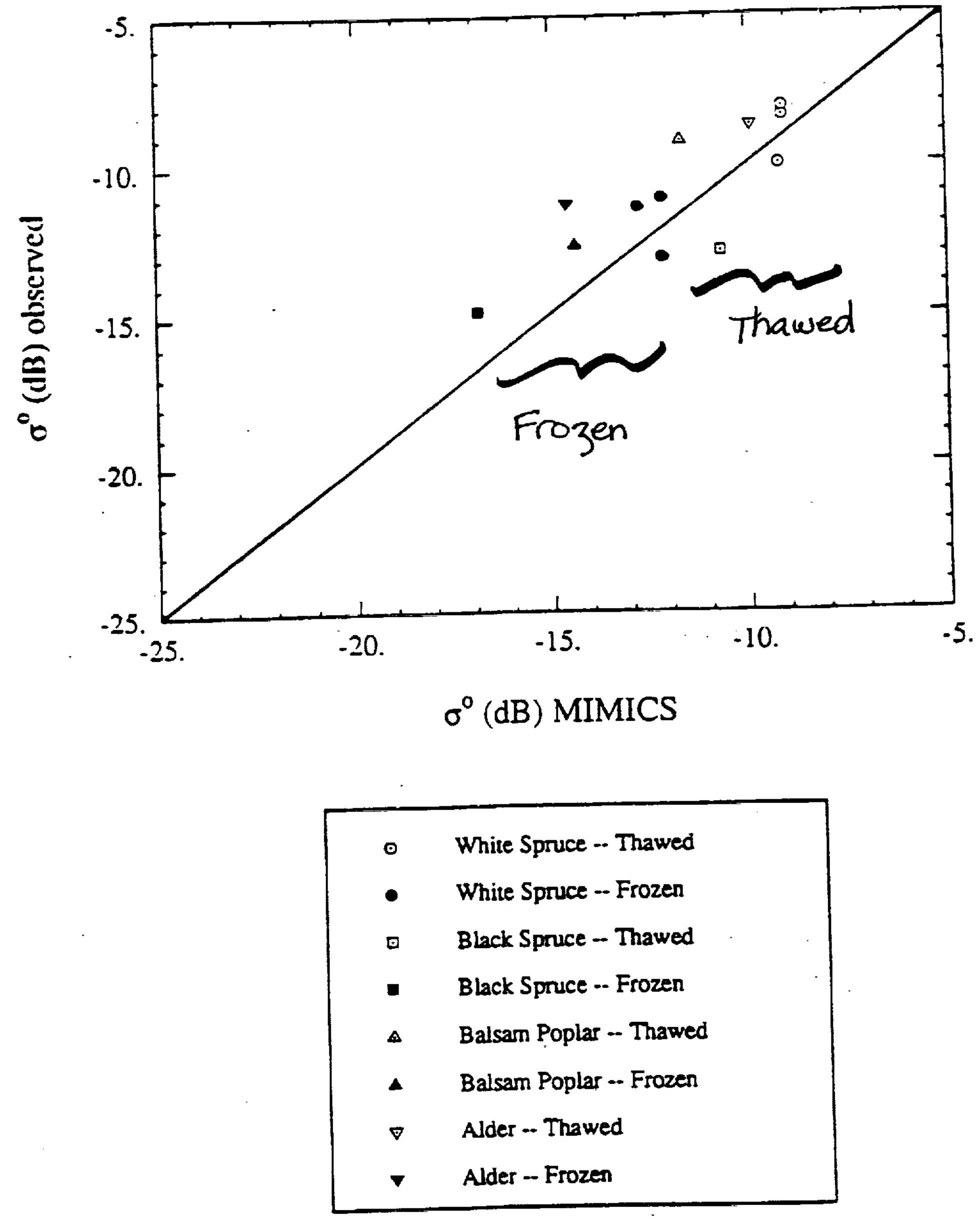
Backscatter From Loblolly and Maritime Pines


P-band, HV-polarization

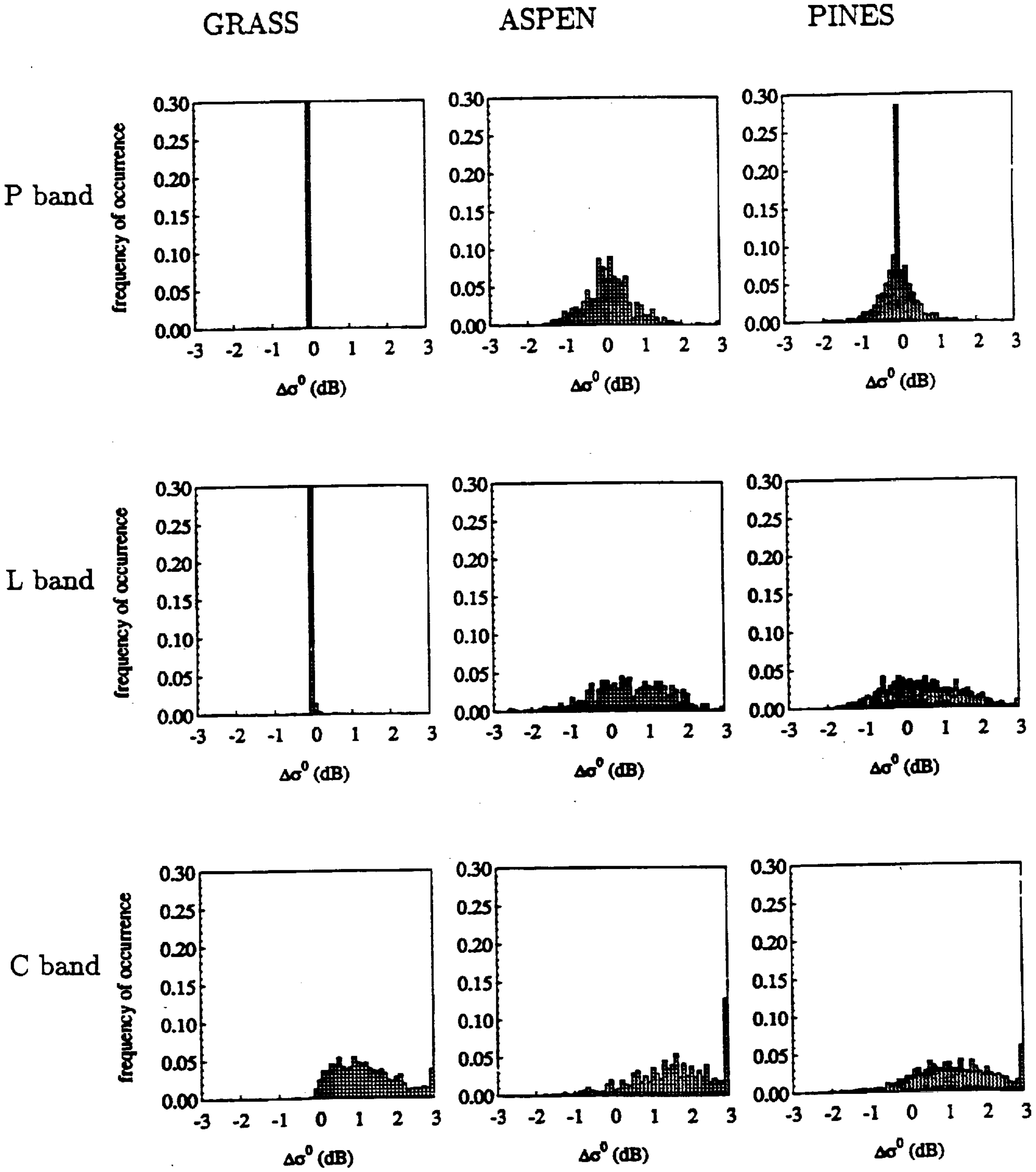
Duke Forest
Michigan Forests
Landes "

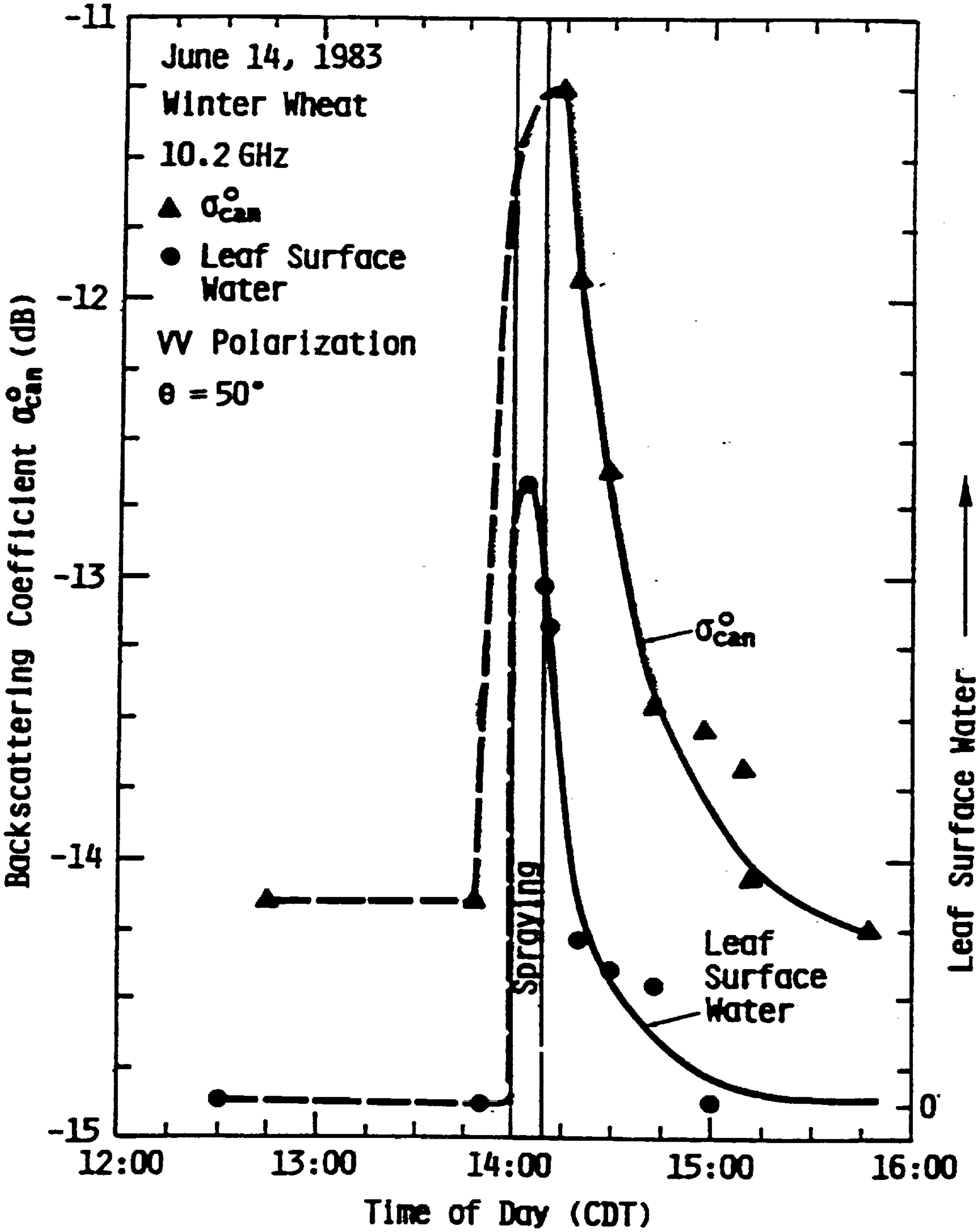

L-band, HV-polarization
-10
-15
-20
-25
-30
-35
-40
Backscatter Coefficient (dB)
.1
1
10
100
1000
Aboveground Biomass (tonnes/ha)
Loblolly pine
Maritime pin
Red pine
Jack pine
Bigtooth aspen
Red maple swamp
White cedar swamp
Non-forested
Grass (dry soil)
Grass (wet soil)
Clear-cut
Grass (dry soil)

6. L-BAND SAR OBSERVATIONS IN ALASKA



Pellston $\Delta\sigma^0$, July 8 – July 10, HH-polarization




June 14, 1983
Winter Wheat
10.2 GHz
▲ σ^o_{can}
● Leaf Surface Water
VV Polarization
$\theta = 50°$
Spraying
σ^o_{can}
Leaf Surface Water
-11
-12
-13
-14
-15
12:00
13:00
14:00
15:00
16:00
Time of Day (CDT)
Backscattering Coefficient σ^o_{can} (dB)
Leaf Surface Water
0

ERS-1 RESULTS

- **Class Statistics**
- **Observation *versus* Theory (MIMICS)**
- **Biomass Response (Deciduous and Coniferous)**
- **Seasonal Variation (LAI)**
  - **Deciduous**
  - **Coniferous**

The University of Michigan

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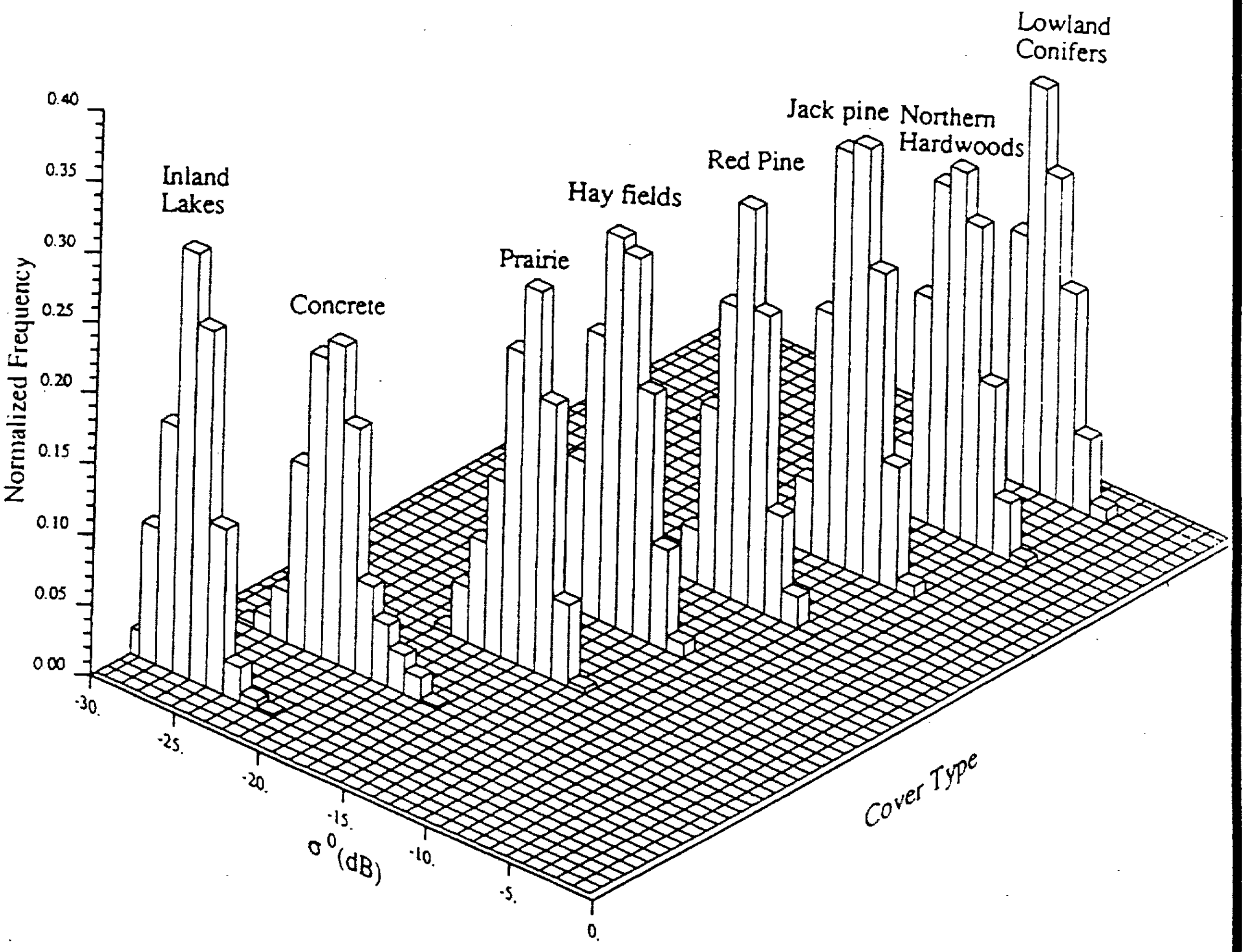
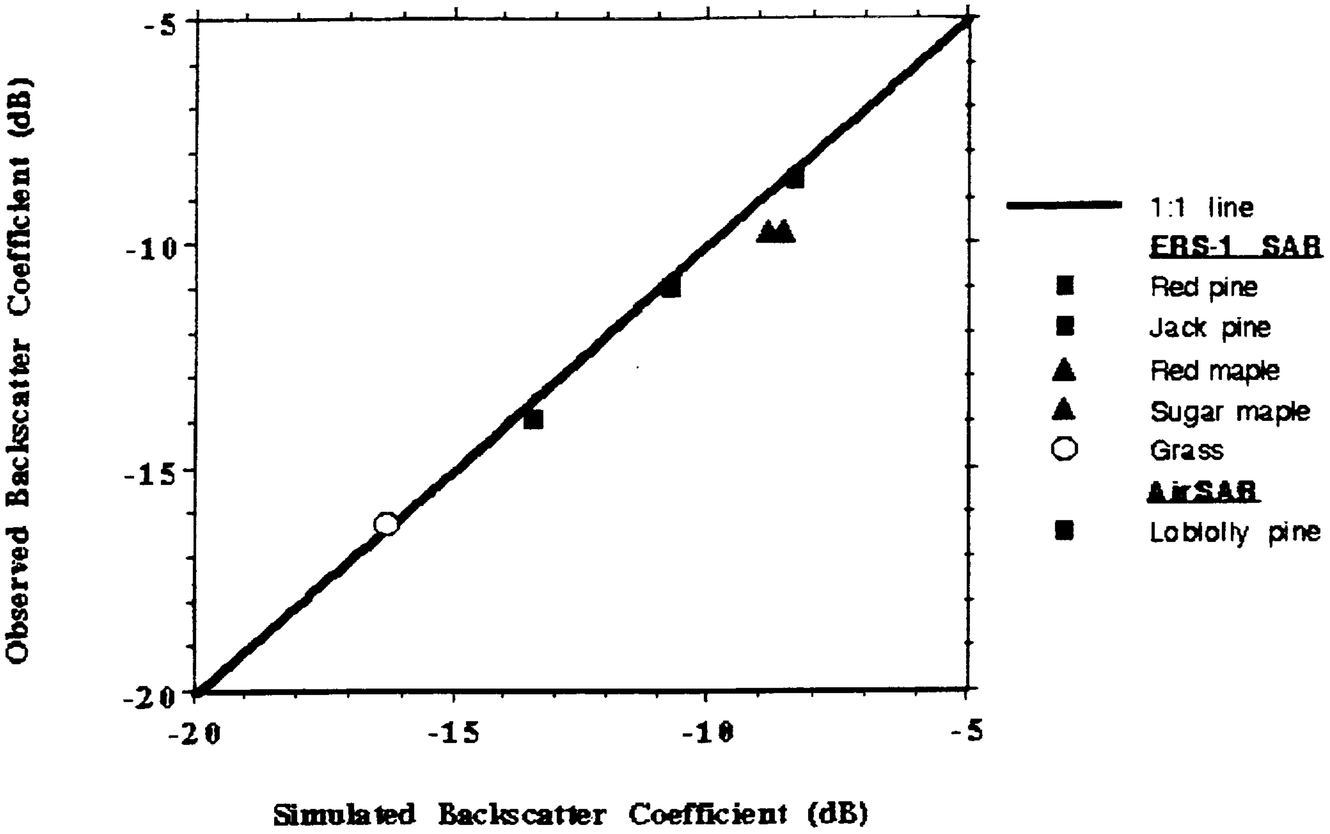
ERS-1 Class Statistics for 3x3 Pixel Averages

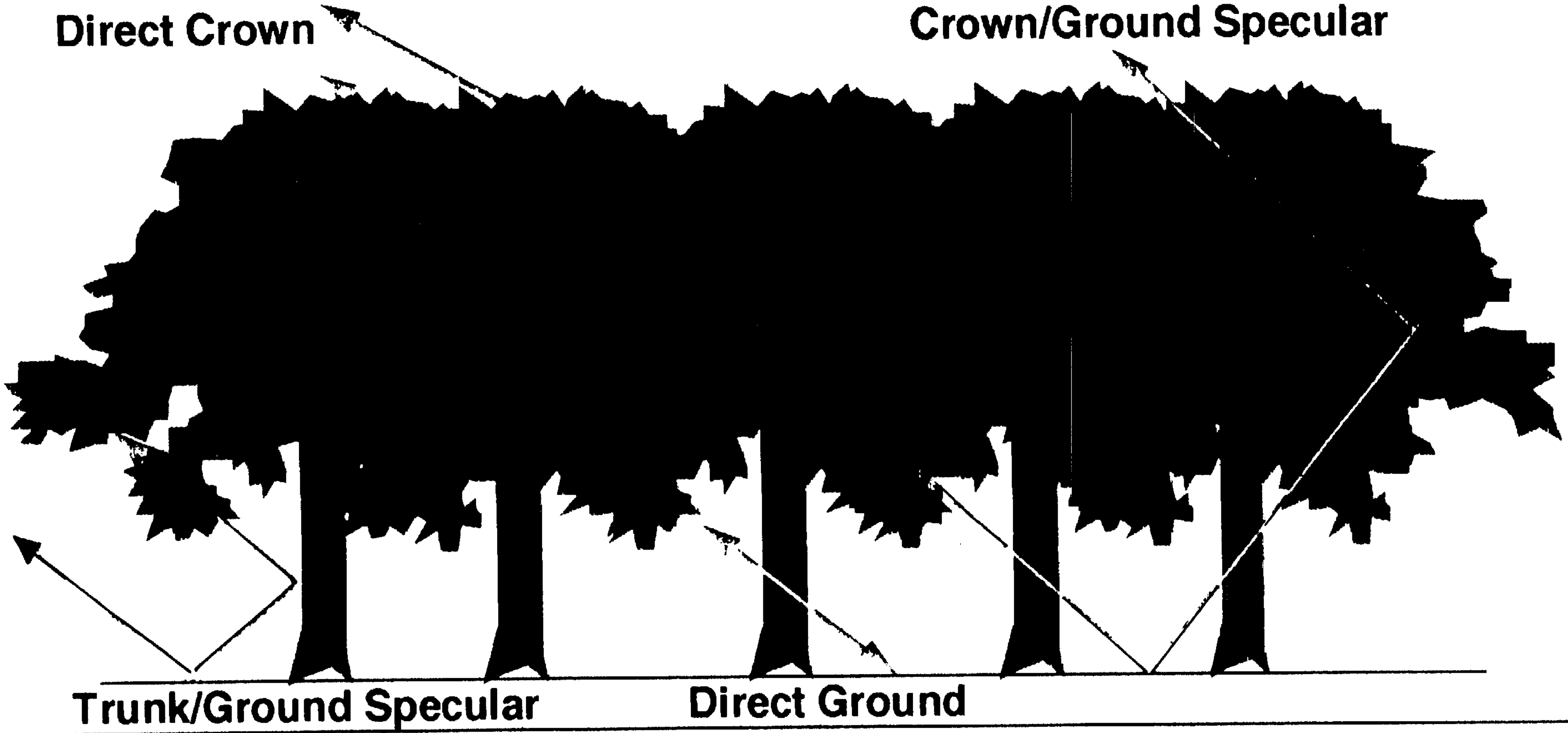


Comparison of SAR Observations with MIMICS Simulations
C-band, VV-polarization



ERS-1 Backscatter Modeled by MIMICS for Northern Michigan Forests in August 1991

Dominant Mechanisms in Radar Backscattering by Forests



Dominant Specie	Percent of Total Return				
	Crown	Crown/Ground	Trunk/Ground	Ground	σ° (dB)
Red maple	95.5	0.3	4.3	-	-8.6
Sugar maple	96.4	0.4	3.2	-	-8.9
Jack pine	100	-	-	-	-10.7
Red Pine	41.3	10.4	48.1	.2	-13.4
grass	0.03	0.2	-	99.8	-14.4

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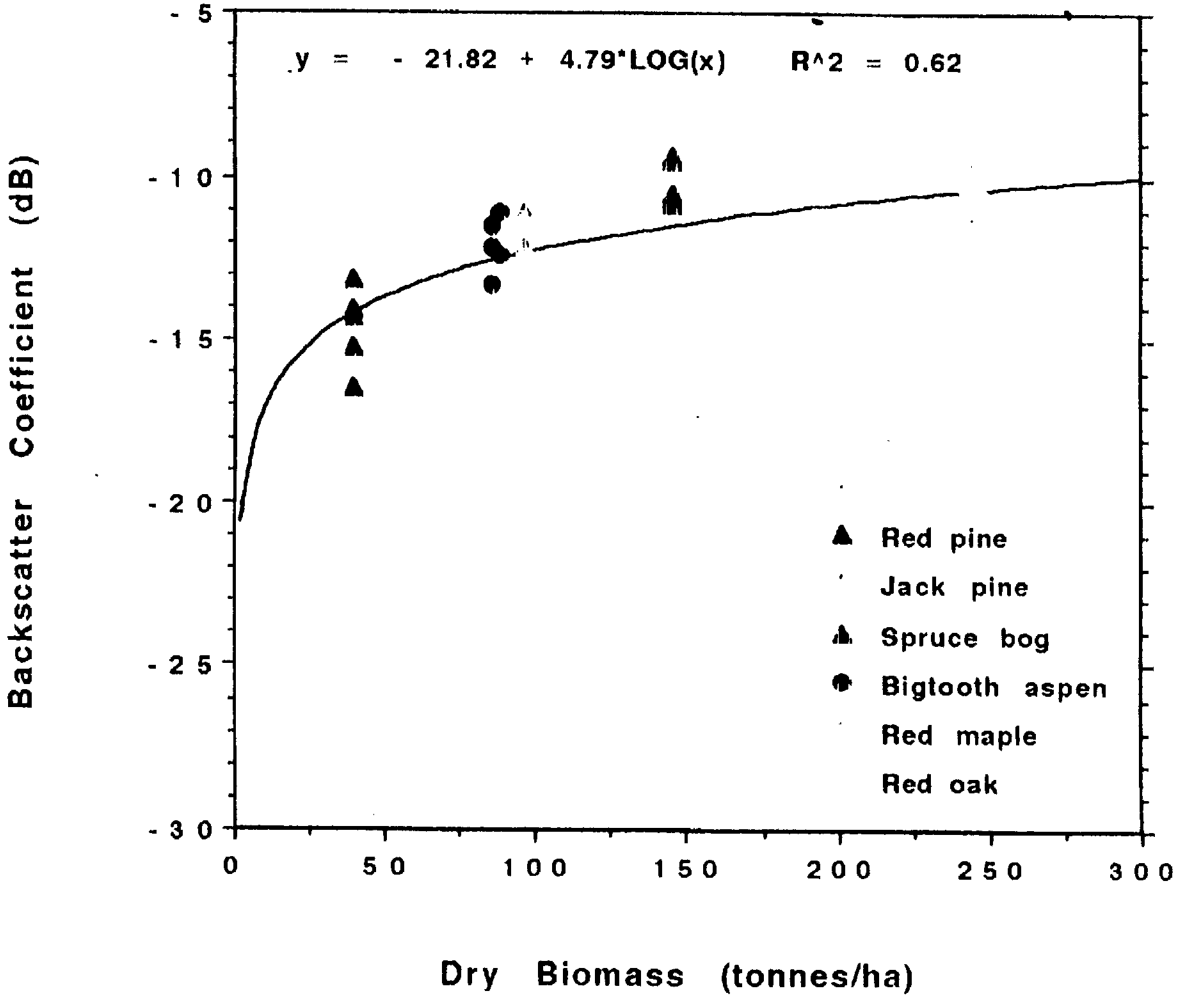
Dependence Upon Above Ground Forest Biomass



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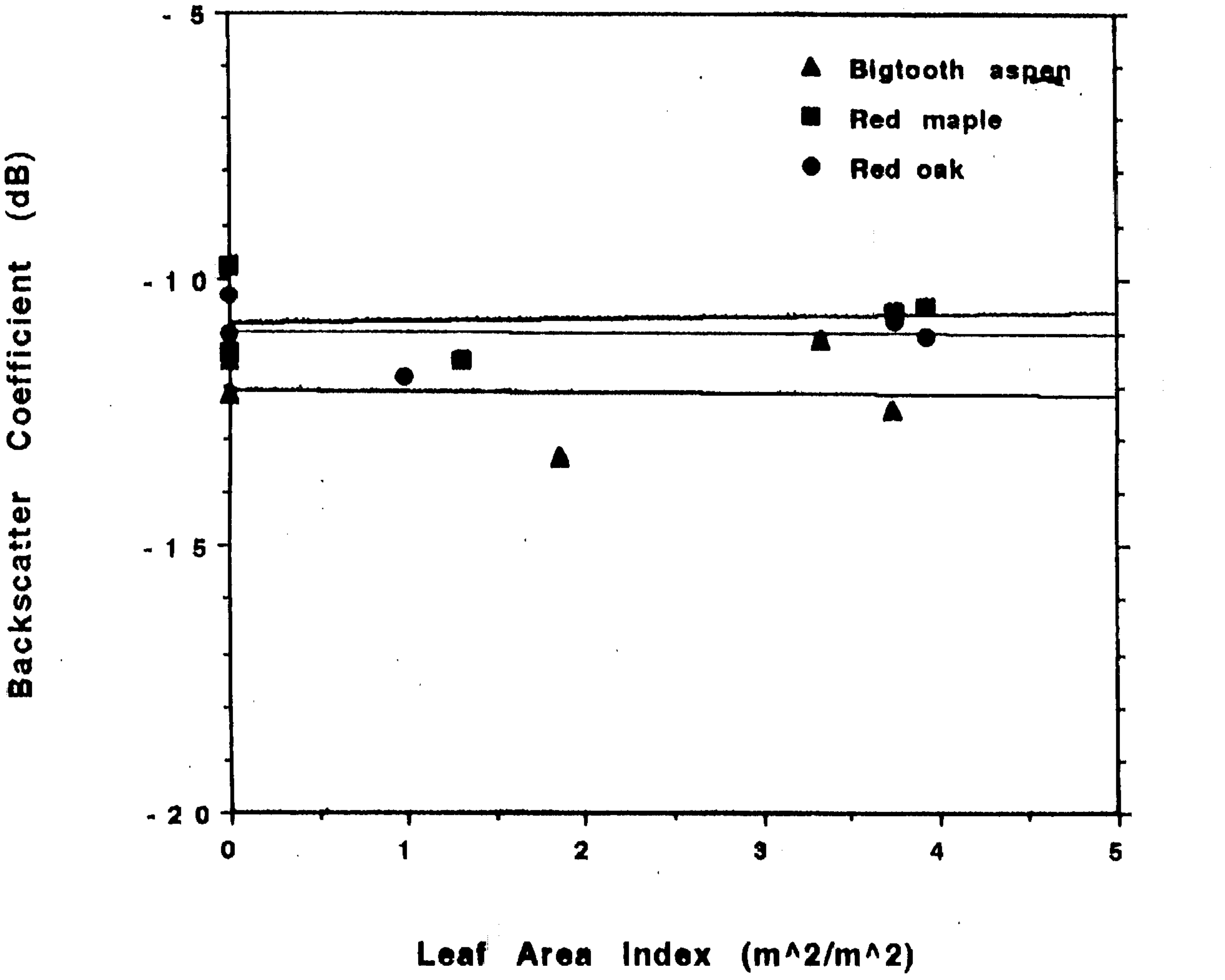
Backscatter vs. LAI for Deciduous Forests



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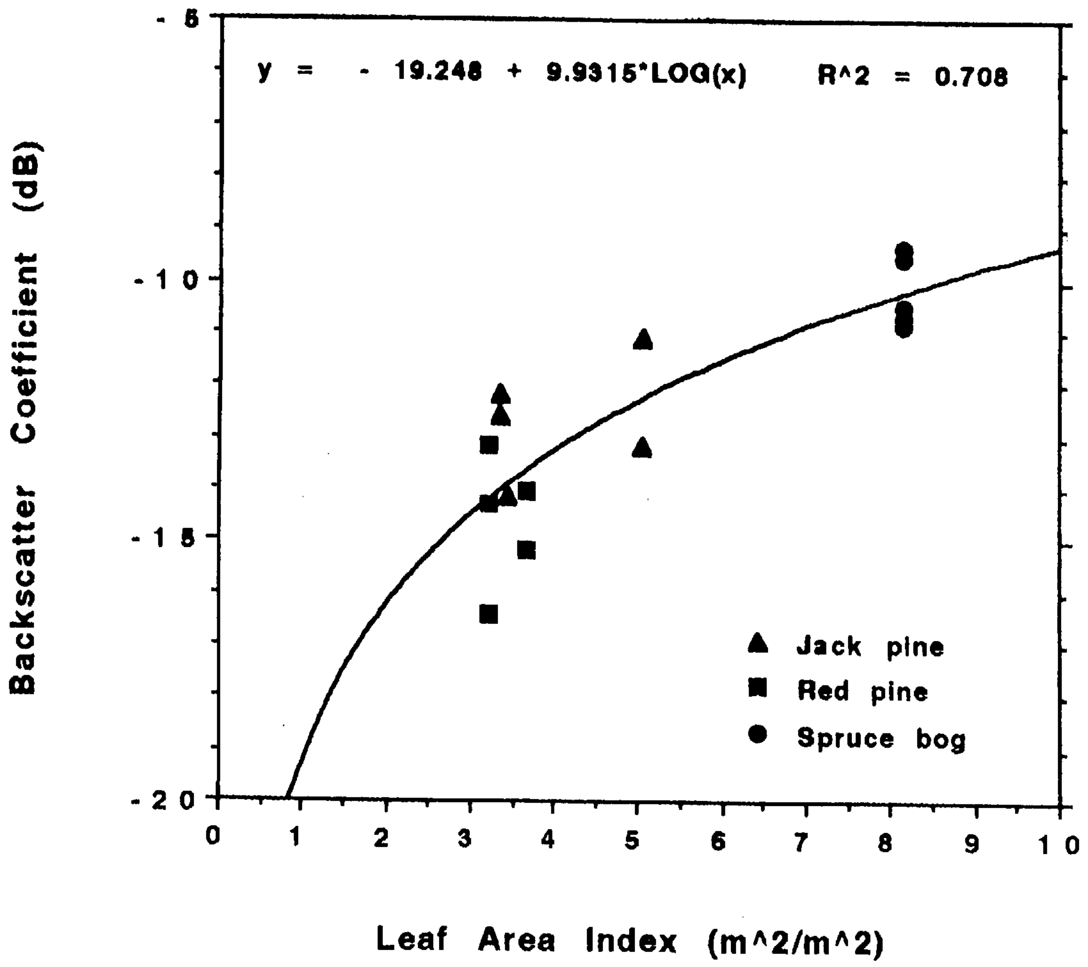
Backscatter vs. LAI for Closed-Canopy Conifer Forests



CONCLUSIONS & RECOMMENDATIONS

I. SURFACE SCATTERING

Status

1. Retrieval of Soil Moisture and Surface Roughness
    - L-Band Quad-Pol for bare soil
    - P-Band Quad-Pol: extends to agricultural crops

Field tested,
Some AirSAR
Verification

2. Effects of Organic Debris
    - Extinction depends on size / λ
      At P and L-Bands, only trunks and large branches are significant

Demonstrated
in lab

II. VEGETATION SCATTERING

MIMICS,
AirSar,
ERS-1

1. In general σ° = f (biomass, structure)
2. Extinction by crown layer increases with frequency
3. Scattering by foliage and small branches:
    - negligible at P and L Bands
    - dominates at C and X Bands
4. Scattering by trunks and large branches:
    - dominates at P and L Bands

CONCLUSIONS & RECOMMENDATIONS

- Even P-Band is insensitive to high biomass forests (Pacific NW ≅ 500 tons/ha)

6. Innundation under Forest Cover

   L-Band HH

   SIR-B
   AirSAR
   Verified

7. Effects of Intercepted Precipitation

   - negligible at P Band
   - ≅ 1 dB increase or decrease at L-Band
   - ≅ 2 dB increase at C-Band

   AirSAR,
   Scattering
   Verified

8. Freezing of Vegetation Leads to

   Significant changes in σ° at all Bands

   AirSAR,
   MIMICS
   Verified

9. Deforestation Readily Detectable at

   P and L-Band

   SIR-B,
   AirSAR

10. LAI Foliar Biomass Estimation

    C-Band Quad or X-Band

    MIMICS,
    Field,
    AirSAR

11. Multi-Date Observations: Very Powerful Tool

    - Requires good Relative Calibration (Stability) ≅ ± 1 dB
    - Requires good Absolute Calibration ≅ ± 1 dB