CANOPY SMALL SCALE VARIABILITY FROM HYSPIRI FOR ECOLOGICAL APPLICATIONS

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Second HyspIRI NASA Decadal Survey Mission Science Workshop
Pasadena, CA, August 11-13, 2009

INTRODUCTION

➢Canopy spectral invariant phenomenon

- ***Leaf albedo spectra and two wavelength independent parameters, recollision and escape probabilities, fully determine the spectral response of a vegetation canopy with non-reflecting background to incident solar radiation***

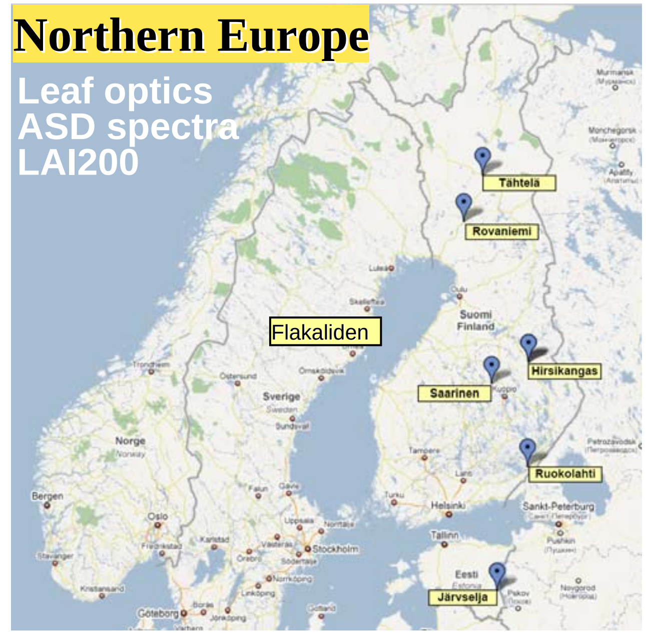
➢Physics

- ***Although the scattering and absorption processes are different at different wavelengths, the interaction probabilities for photons in vegetation media are determined by the structure of the canopy rather than photon frequency or the optics of the canopy (Huang et al., Canopy spectral invariants for remote sensing and model applications," Remote Sens. Environ., 106, pp. 106-122, 2007).***

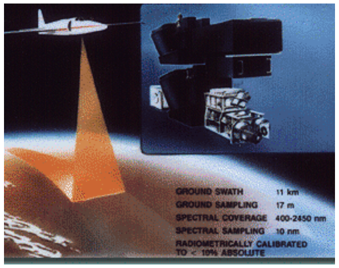
➢Mathematics

- ***property of the exact solution of the radiative transfer equation (Knyazikhin et al., Canopy spectral invariants: a new concept in remote sensing of vegetation, International Conference on Mathematics, Computational Methods & Reactor Physics (M&C 2009), Saratoga Springs, New York, May 3-7, 2009, on CD-ROM, American Nuclear Society, LaGrange Park, IL 2009).***

SITES AND DATA USED

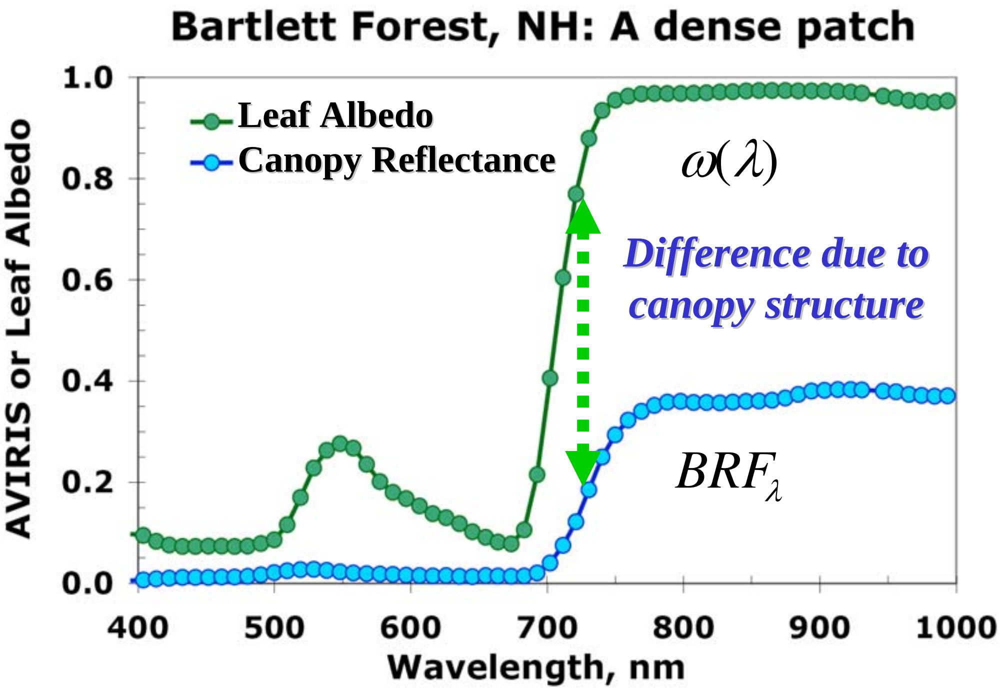


SPECTRAL INVARIANT PHENOMENON: REFLECTANCE



AVIRIS

Resolution: 17 m
Spectral bands: 224
Range: 400-2500 nm
Sp. resolution: 5-12 nm



LI-1800-12
Integrating Sphere

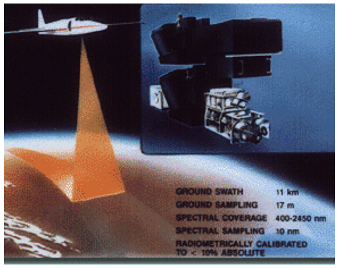
Range: 400-1000 nm
Sp. Resolution: 1nm

LI-1800-12
Integrating Sphere

AVIRIS

Airborne
Visible/**I**nfra**R**ed
Imaging
Spectrometer

SPECTRAL INVARIANT PHENOMENON: REFLECTANCE



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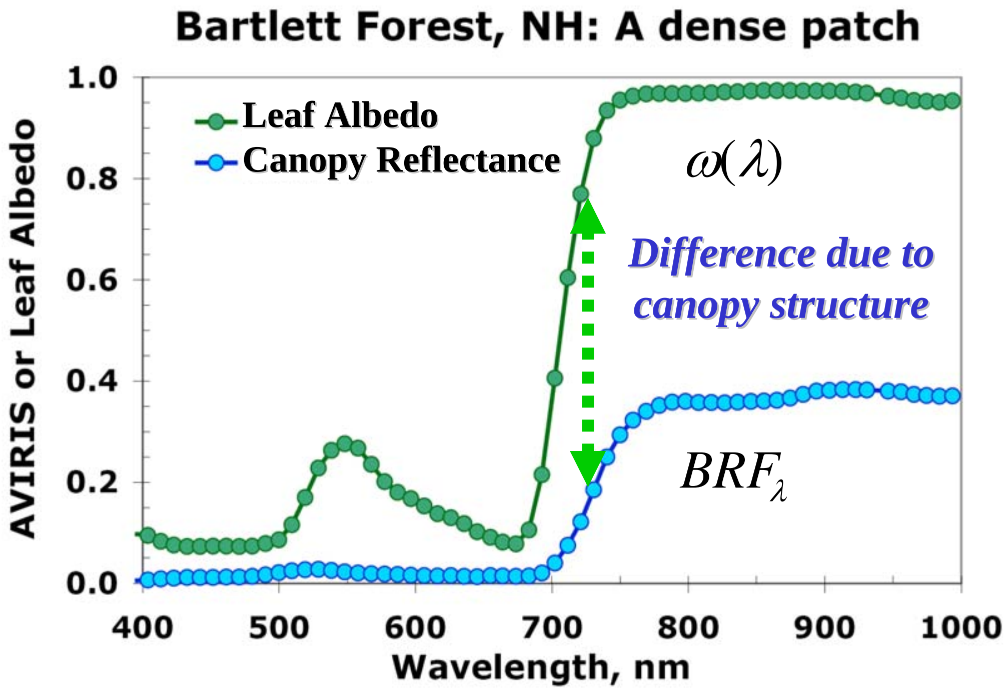

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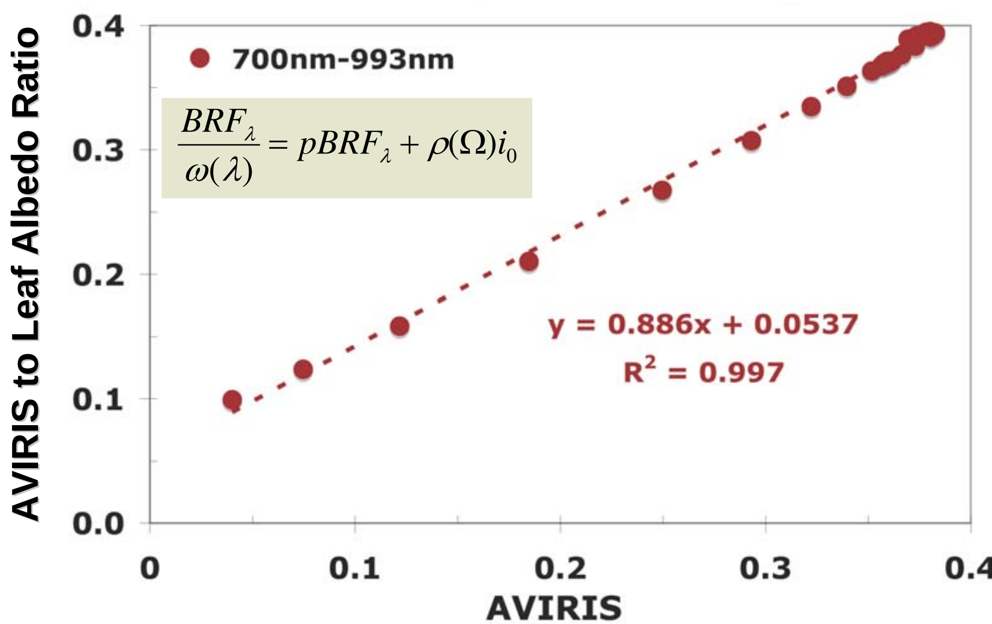
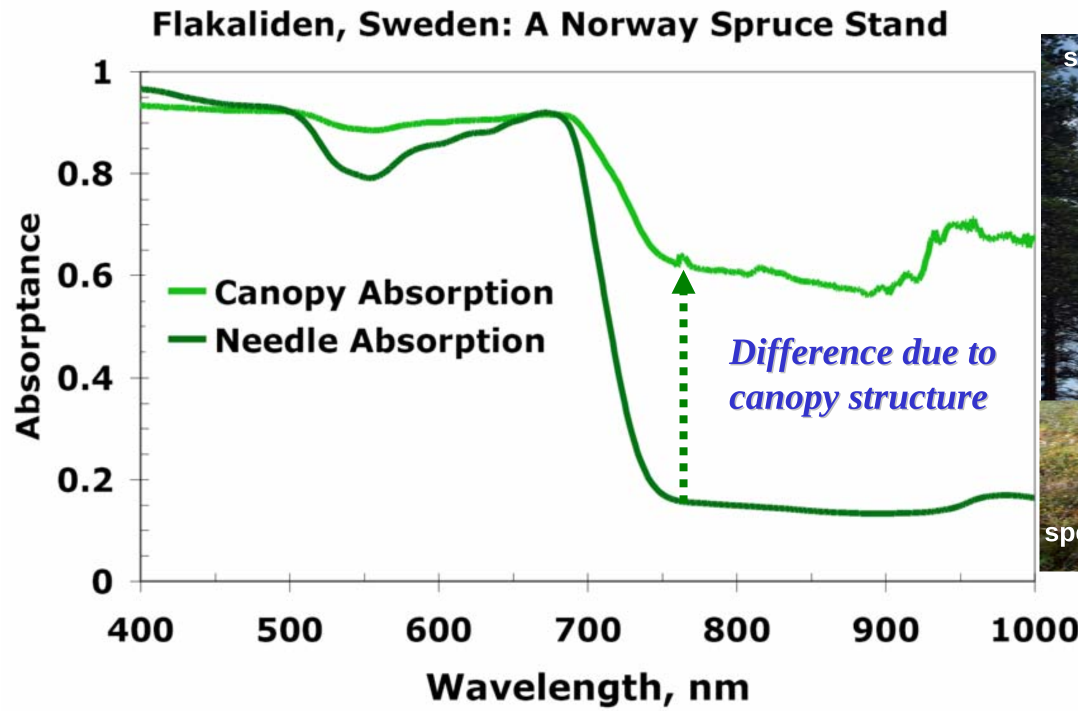
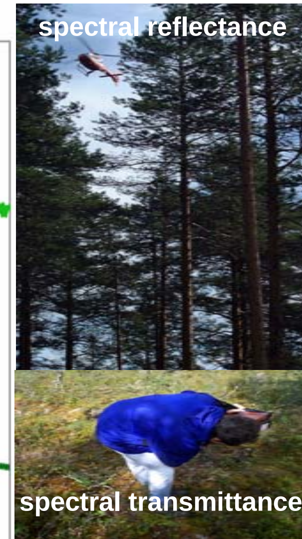
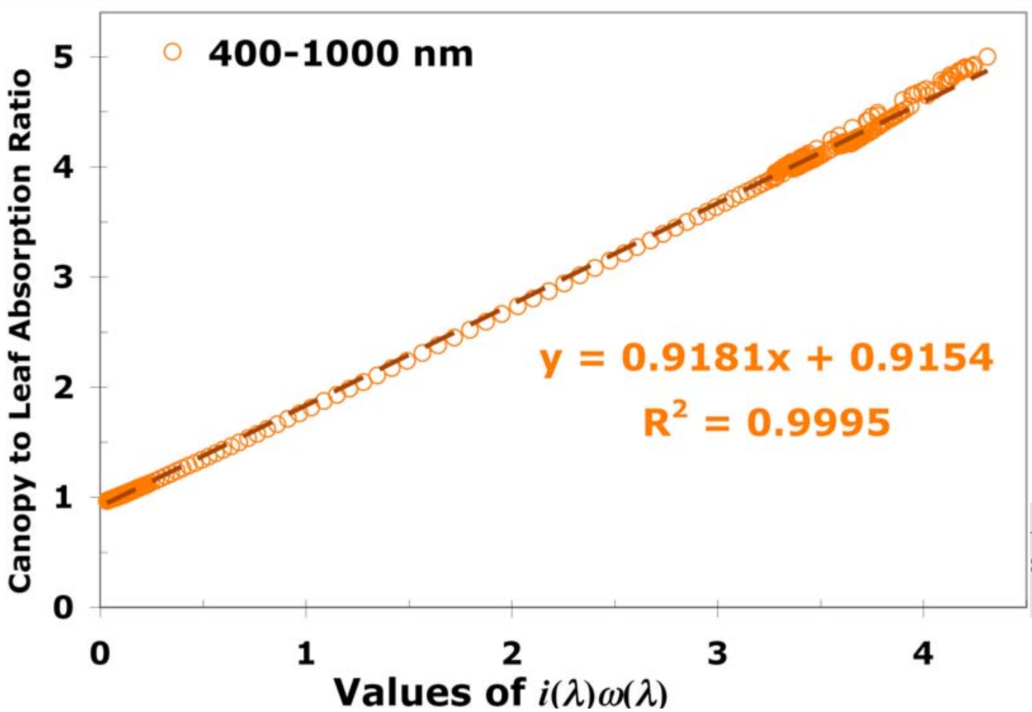


Canopy spectral BRF is determined by leaf albedo and wavelength independent recollision (slope) and escape (intercept) probabilities

SPECTRAL INVARIANT PHENOMENON: ABSORPTION







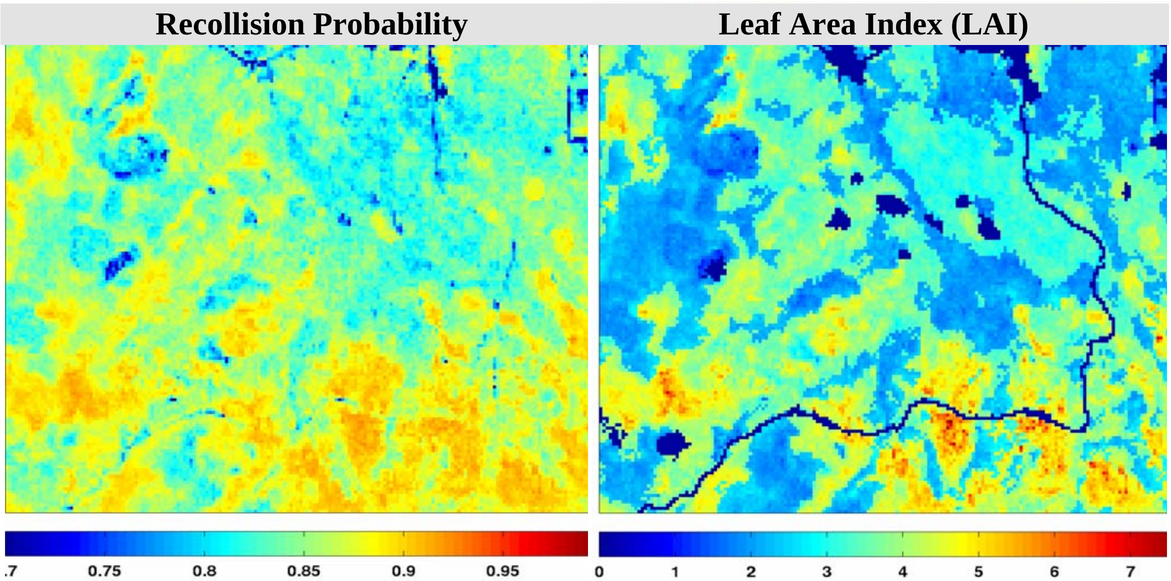
Canopy spectral absorptance is determined by leaf albedo and wavelength independent and wavelength independent recollision probability (slope) and canopy interceptance (intercept).

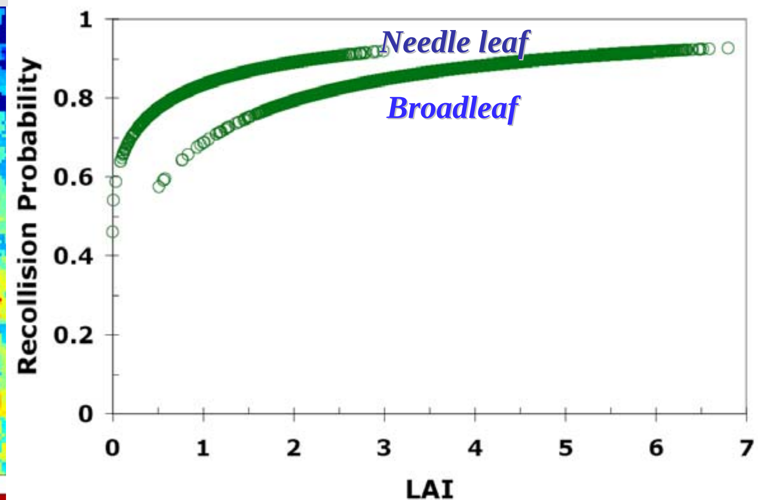
From Huang et al., Canopy spectral invariants for remote sensing and model applications, *Remote Sens. Environ.*, 106, 106-122 (2007).

RECOLLISION PROBABILITY AND LEAF AREA INDEX

Bartlett Forest, NH

Airborne Visible/InfraRed Imaging Spectrometer (AVIRS) data, August 2003





$pLe = S_0 e,\ \ p \ge 0,\ e \ge 0,\ \ \omega(\lambda)\equiv 1$

Leaf Area Index: one-sided green leaf area per unit ground area

The recollision probability combined with the Leaf Area Index has the potential to discriminate between broadleaf and coniferous canopies

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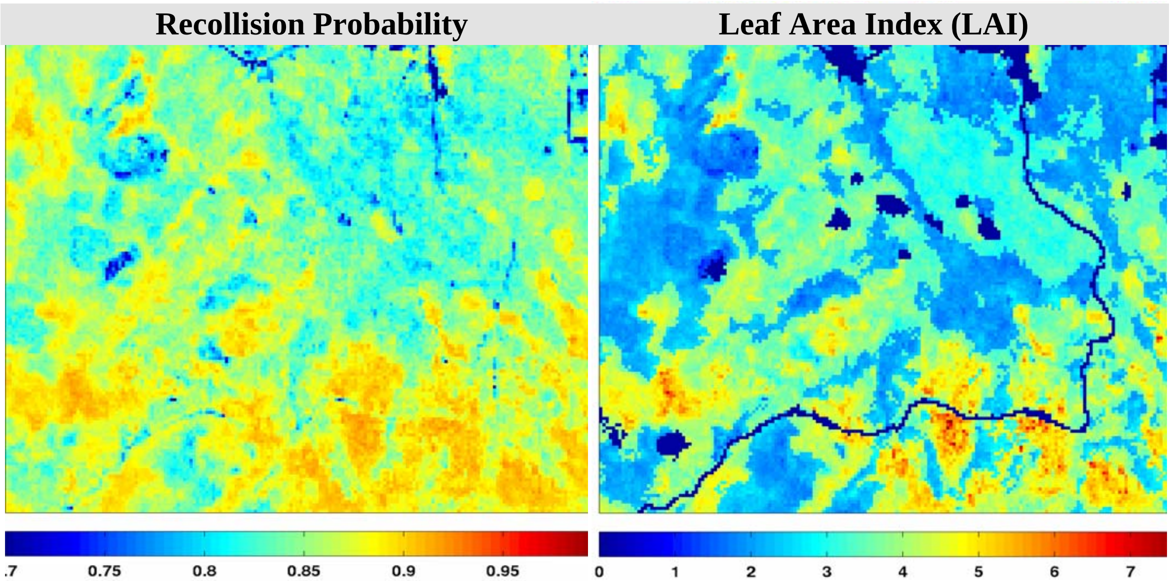

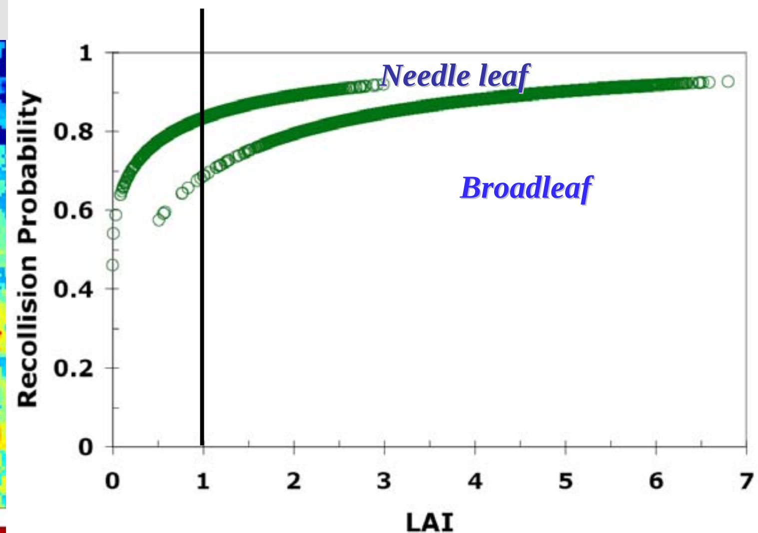

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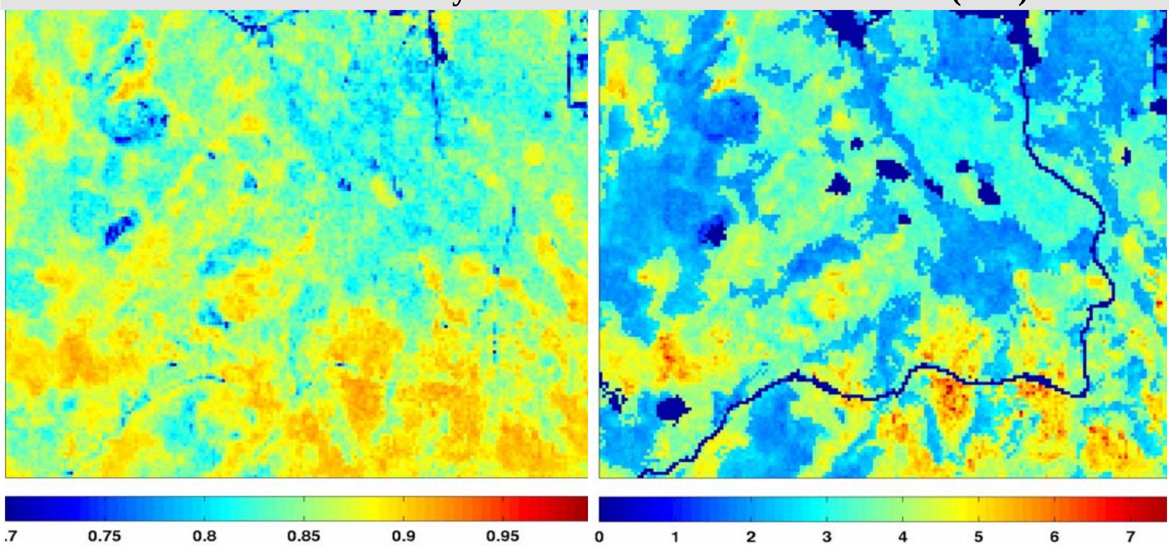
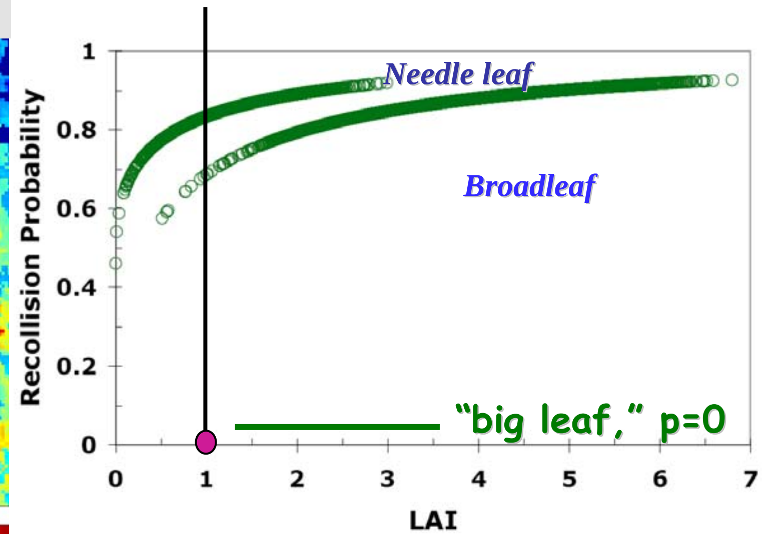
Recollision Probability | **Leaf Area Index (LAI)**





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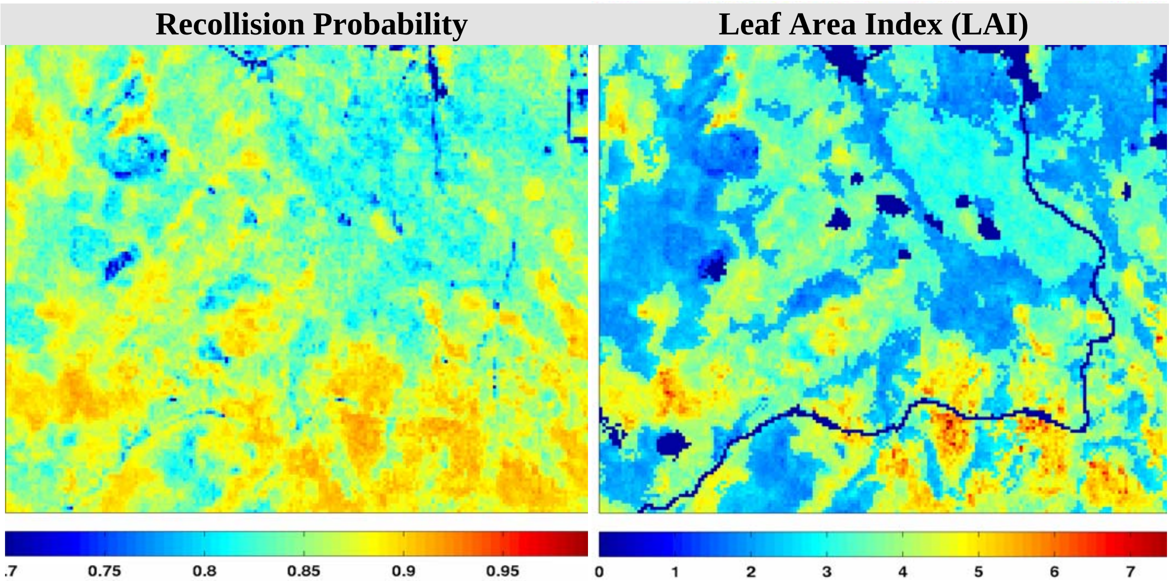

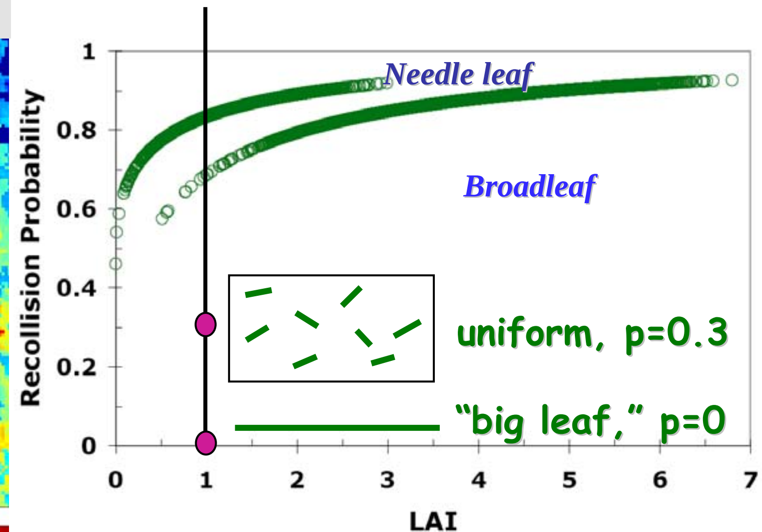

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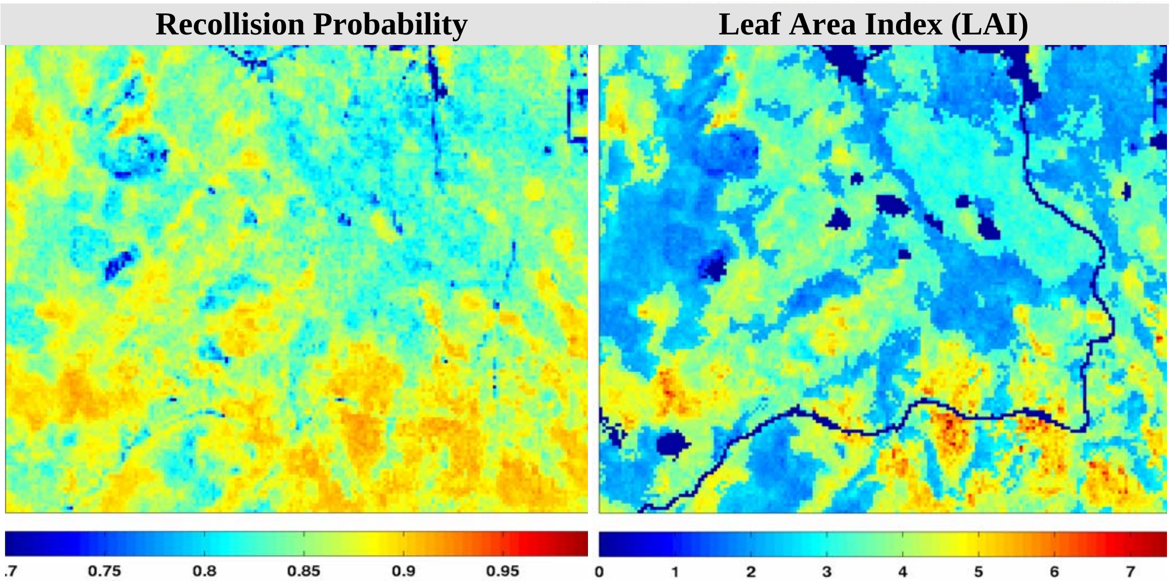

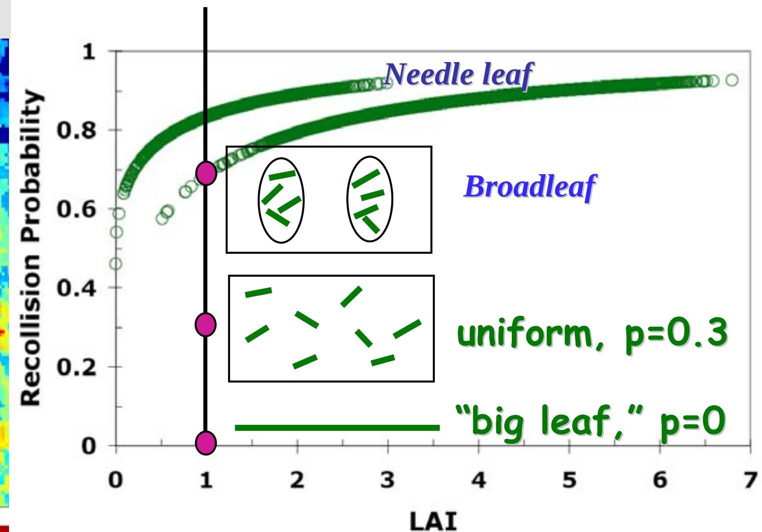

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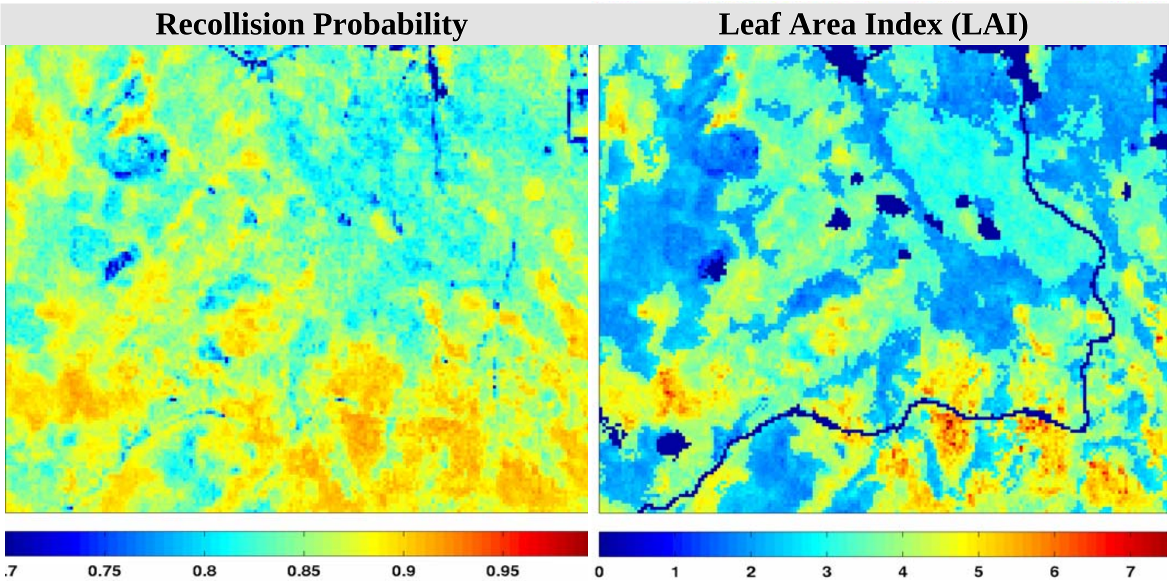

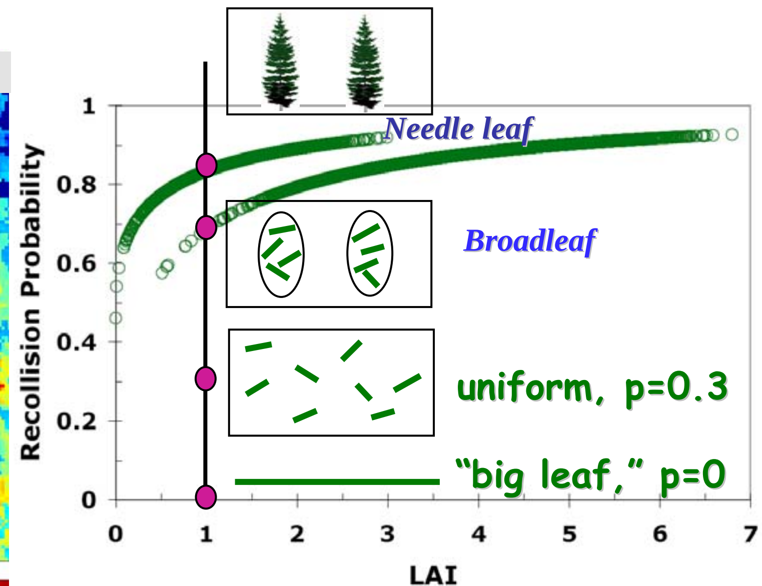

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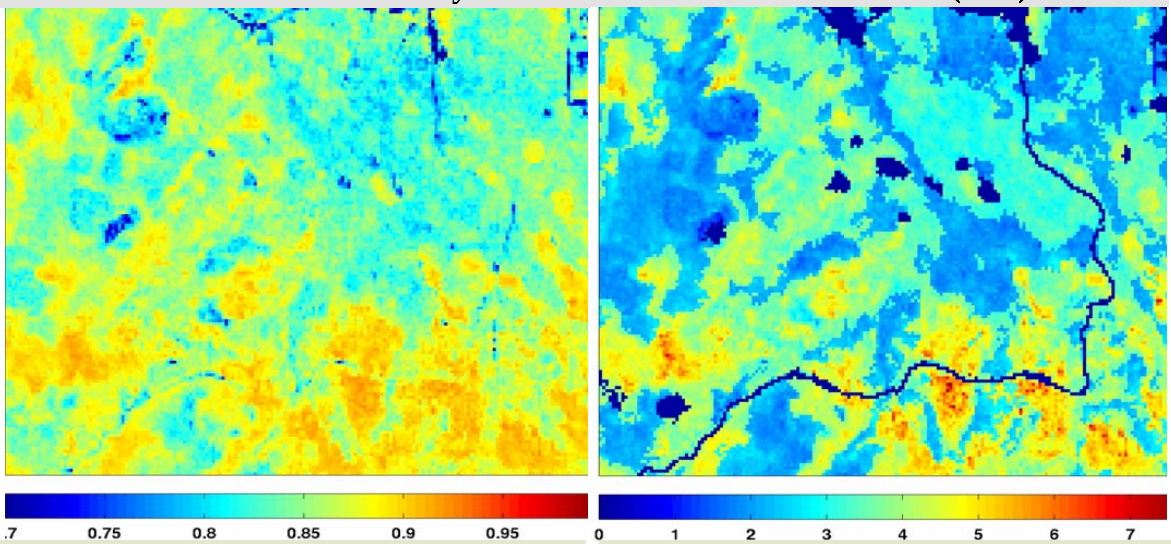

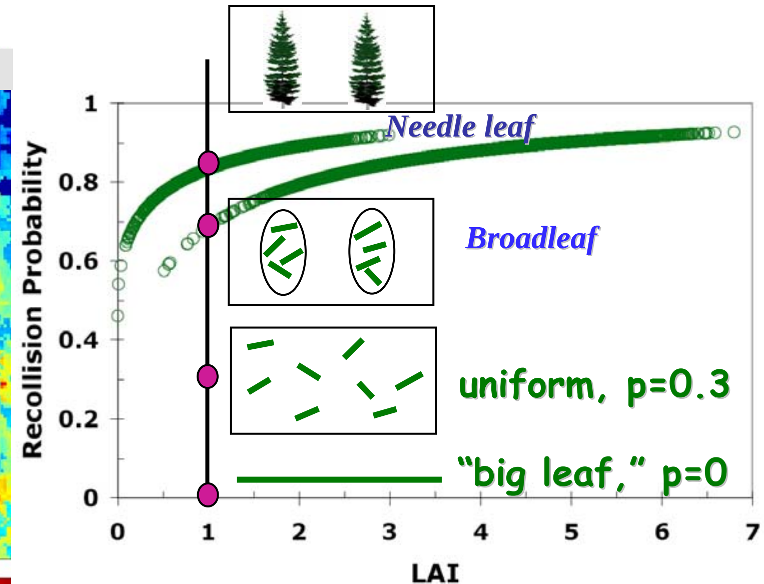

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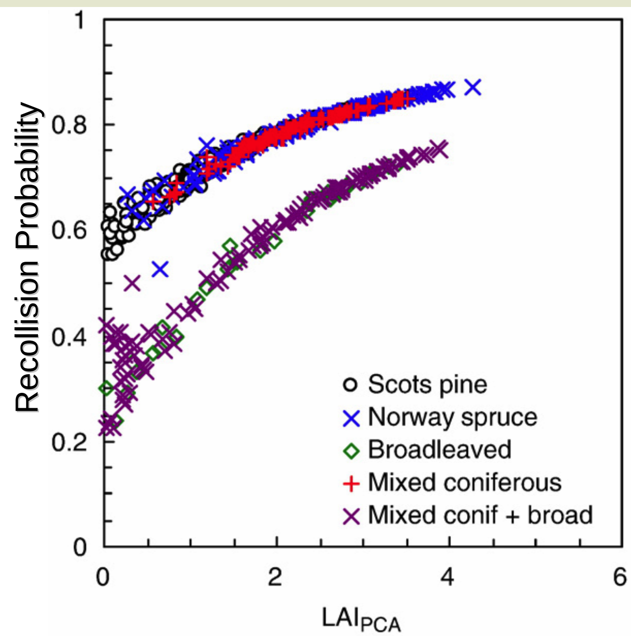
Leaf Area Index: one-sided green leaf area per unit ground area

Rautiainen et al. derived similar relationships using forest inventory data from 1032 forest plots in Finland



From Rautiainen et al., On the relationship of canopy LAI and photon recollision probability in boreal forests, *Remote Sens. Environ*, **113**, pp. 458-461 (2008).

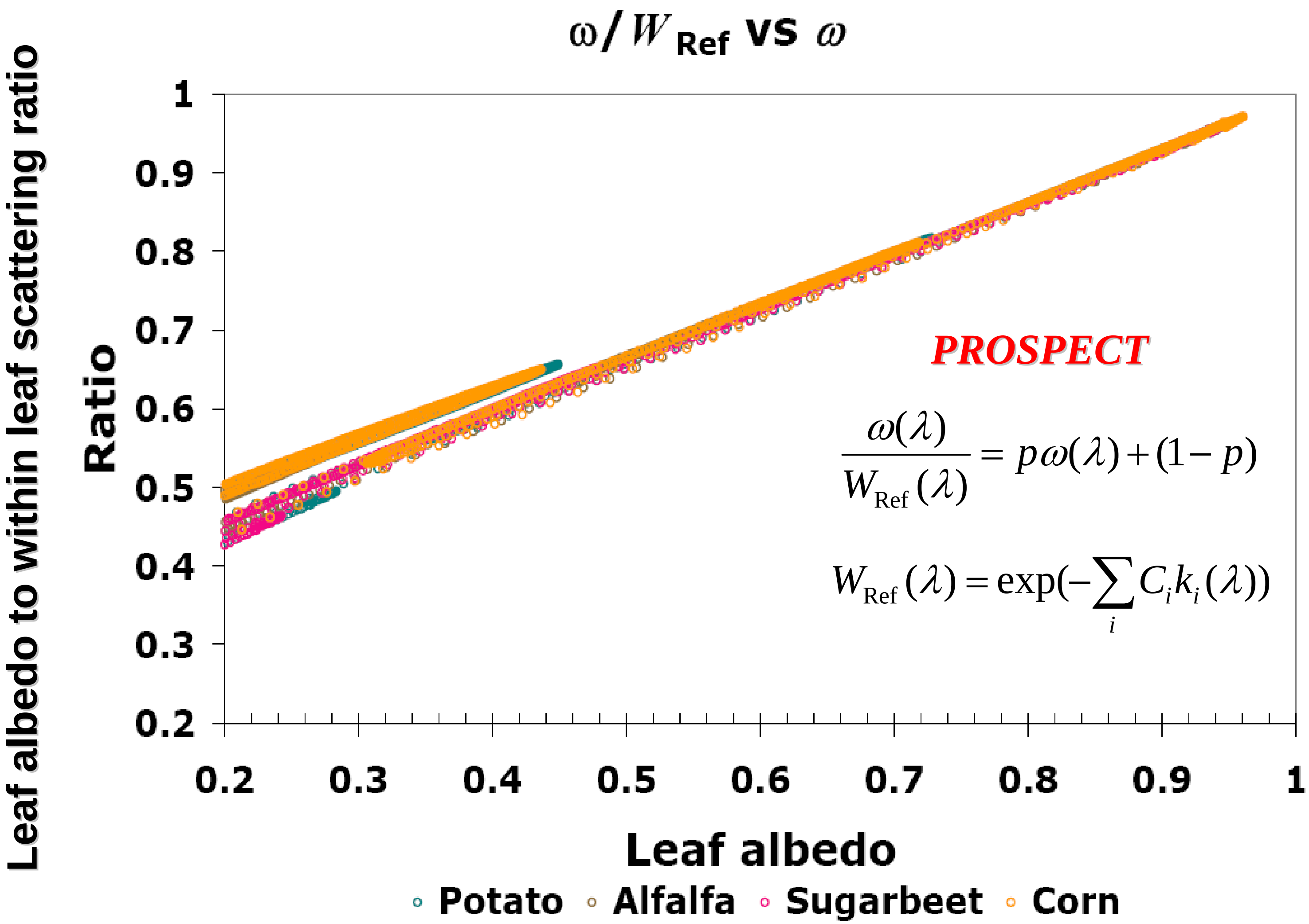
LEAF ALBEDO

- ***The canopy spectral invariant approach requires the use of the leaf albedo spectrum which is NOT always available in interpretation of spectral data***
- ***The question then arises whether or not the lack of this information would make the approach inapplicable***

$$BRF_\lambda = \omega_\lambda \frac{R}{1 - p\omega_\lambda} \qquad \frac{\Delta BRF_\lambda}{BRF_\lambda} = \frac{\Delta\omega_\lambda}{\omega_\lambda} \frac{1}{1 - p\omega_\lambda}$$

PROSPECT MODEL FOLLOWS SPECTRAL INVARIANT RELATIONSHIPS

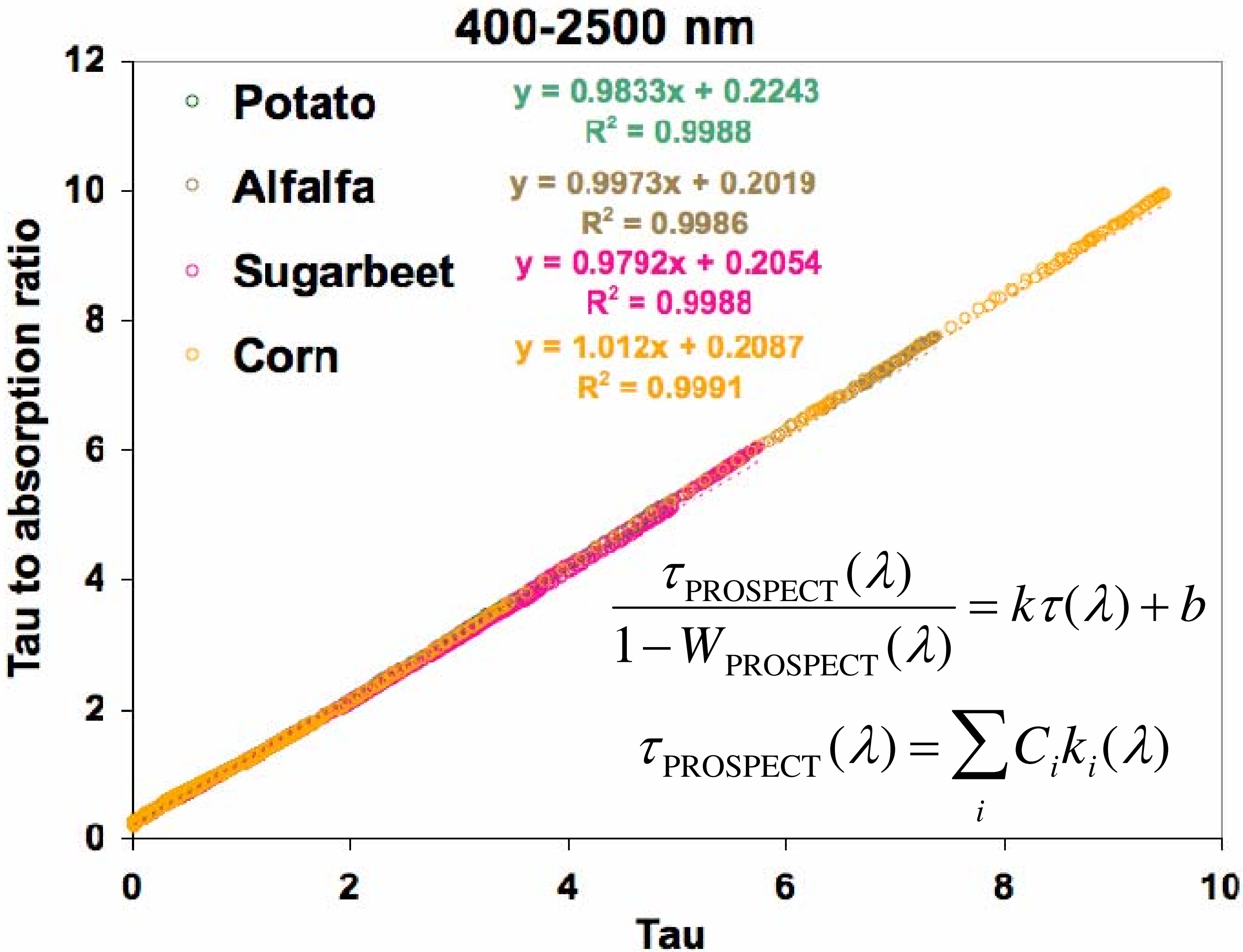
Lewis, P. and M. Disney (2007), Spectral invariants and scattering across multiple scales from within-leaf to canopy, Remote Sensing of Environment, 109, 196-206



It is possible to express both the canopy- and leaf-level single scattering albedo as a function of canopy spectral invariants

LEAF ABSORPTION FOLLOWS SPECTRAL INVARIANT RELATIONSHIPS

Latorre et al., (2009), Monitoring crops with CHRIS/PROBA, Remote Sensing of Environment (in preparation)

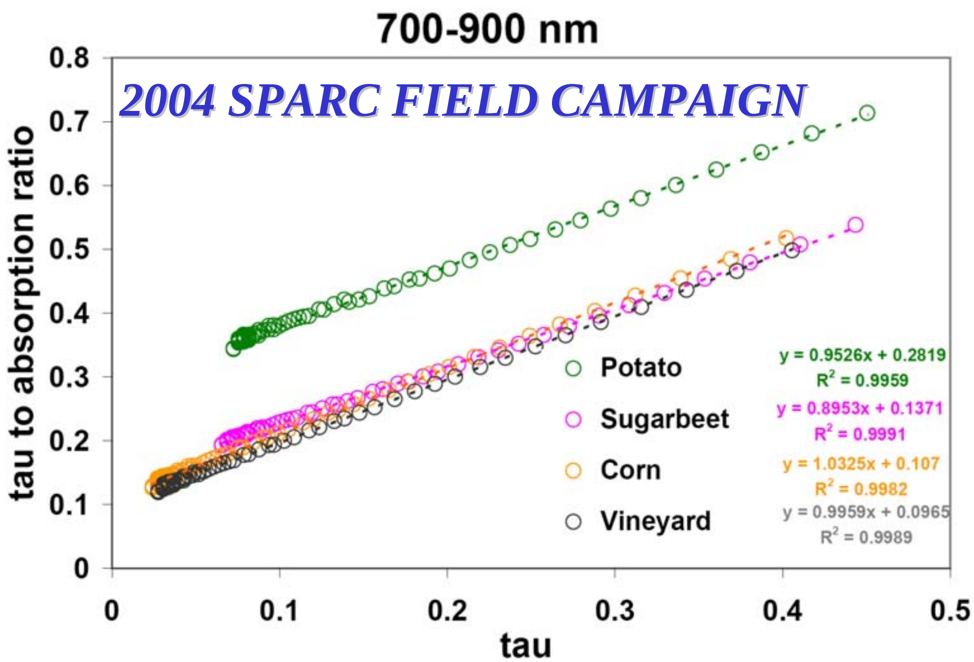


$$\frac{\tau_{\mathrm{PROSPECT}}(\lambda)}{1-W_{\mathrm{PROSPECT}}(\lambda)} = k\tau(\lambda)+b$$

$$\tau_{\mathrm{PROSPECT}}(\lambda) = \sum_i C_i k_i(\lambda)$$

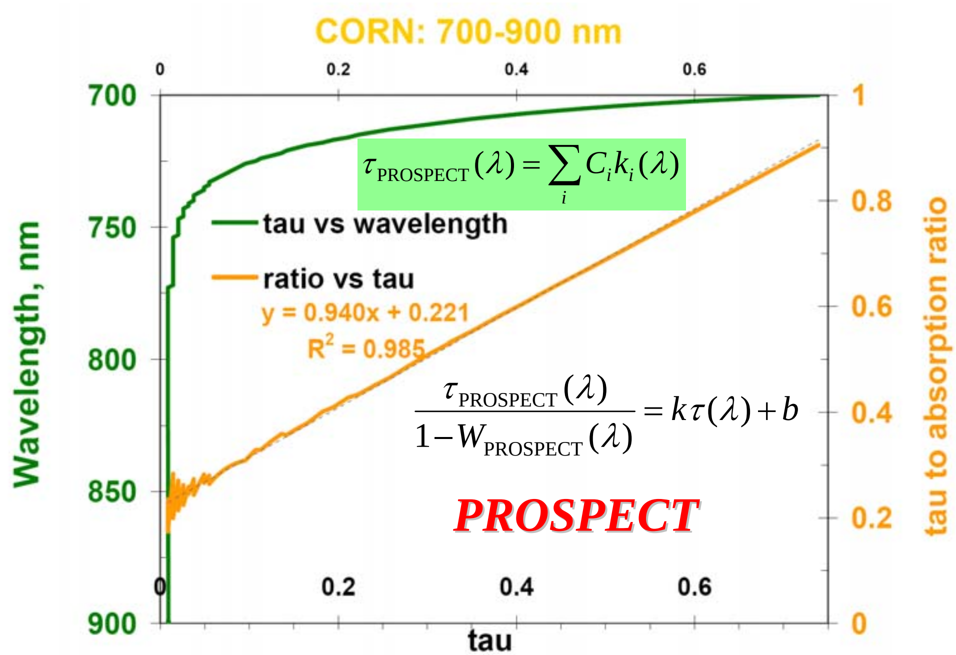
PROSPECT <u>INPUT</u> (C_i) AND <u>OUTPUT</u> (W) ARE RELATED VIA SPECTRAL INVARIANT RELATIONSHIPS

FIELD DATA SUPPORT *PROSPECT* PREDICTIONS



$$\tau(\lambda) = \sum_i C_i k_i(\lambda)$$

$$\frac{\tau(\lambda)}{1 - W(\lambda)} = k\tau(\lambda) + b$$



The spectral invariants provide a framework through which structural information can be maintained in a self-consistent manner across multiple scales from leaf- to canopy-level scattering

RETRIEVING LEAF PHYSIOLOGY AND CANOPY STRUCTURE

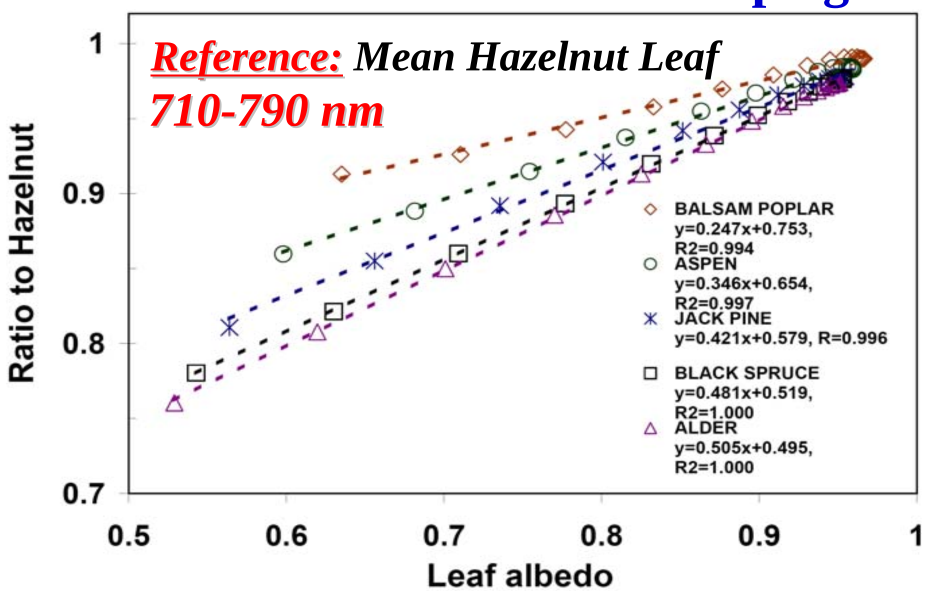
- ***"… without knowledge of either canopy structure [p], or the leaf biochemical constituents, independent retrieval of either from total scattering measurements <u>is not possible</u>" (Lewis&Disney,RSE, 109, p. 205)***

- ***However their finding suggests the existence of a reference leaf albedo, i.e., a given leaf albedo is related to the reference via spectral invariant relationship within a certain spectral interval***

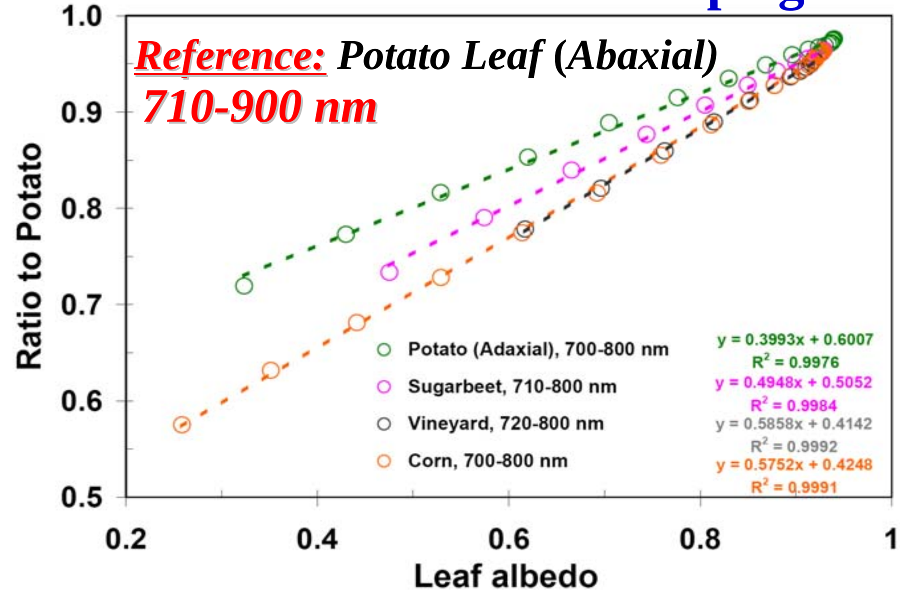
FIELD DATA SUPPORT THE HYPOTHESIS ABOUT REFERENCE ALBEDO

Spectral invariant relationship: $$\frac{\omega_\lambda}{\omega_{\text{reference},\lambda}} = p\omega_\lambda + (1-p)$$

1994 BOREAS Field Campaign



2004 SPARC field Campaign



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Spectral invariant relationship:

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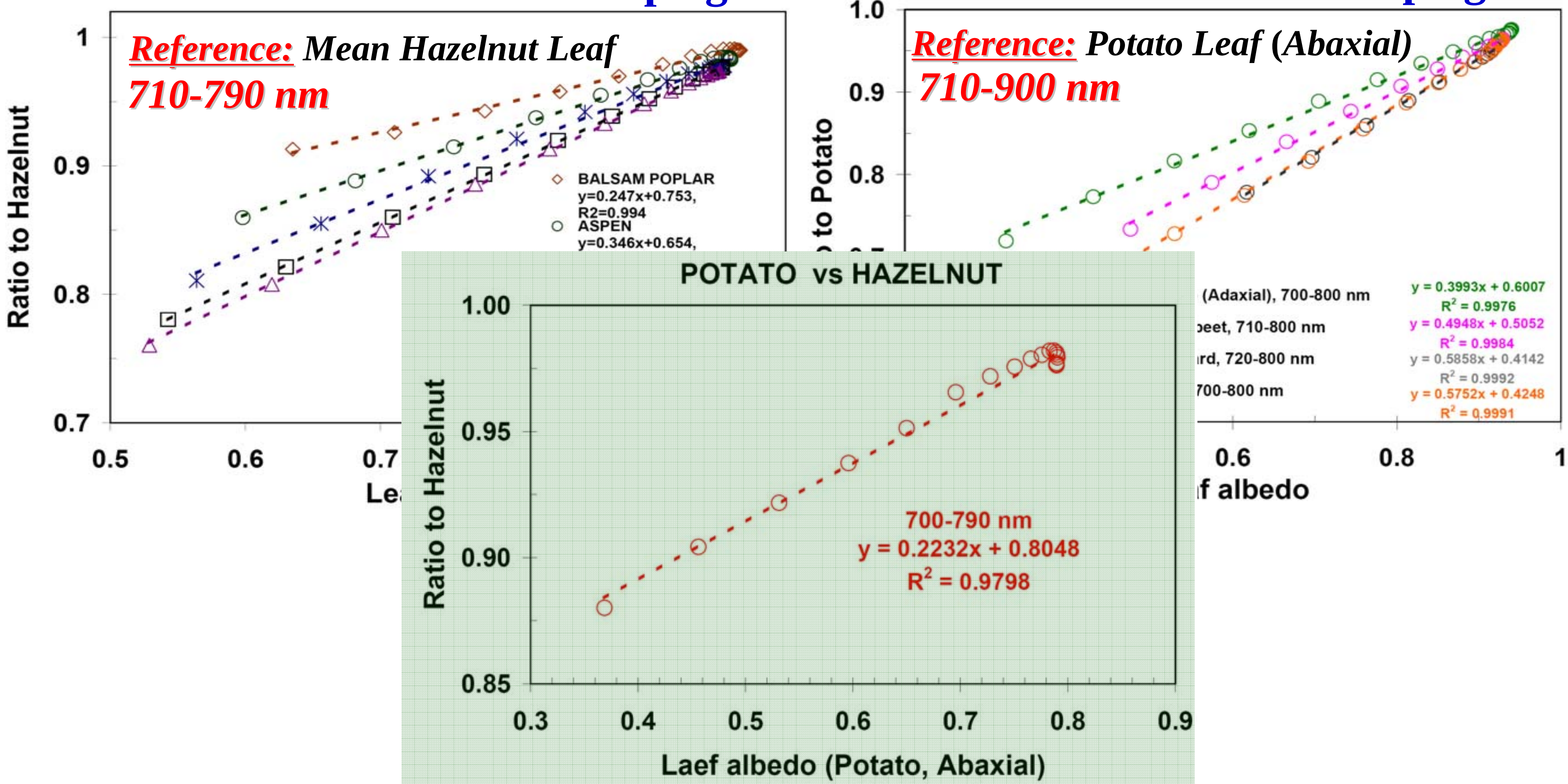
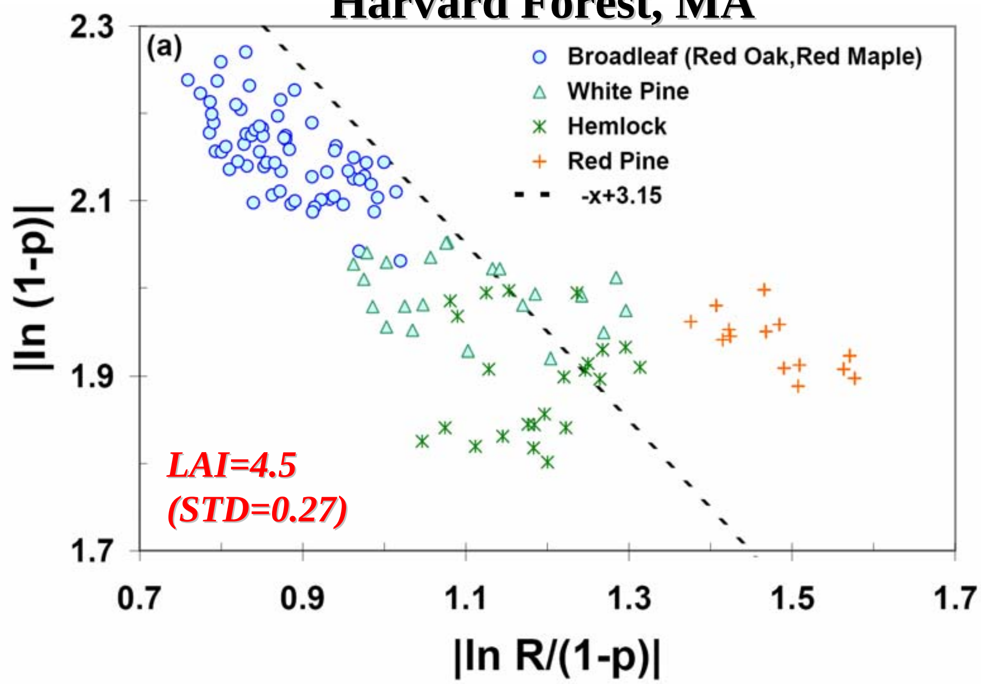
1994 BOREAS Field Campaign | **2004 SPARC field Campaign**



Hazelnut from Canada can be transformed into Spanish Potato!

SPECTRAL INVARIANT SPACE FROM AVIRIS DATA

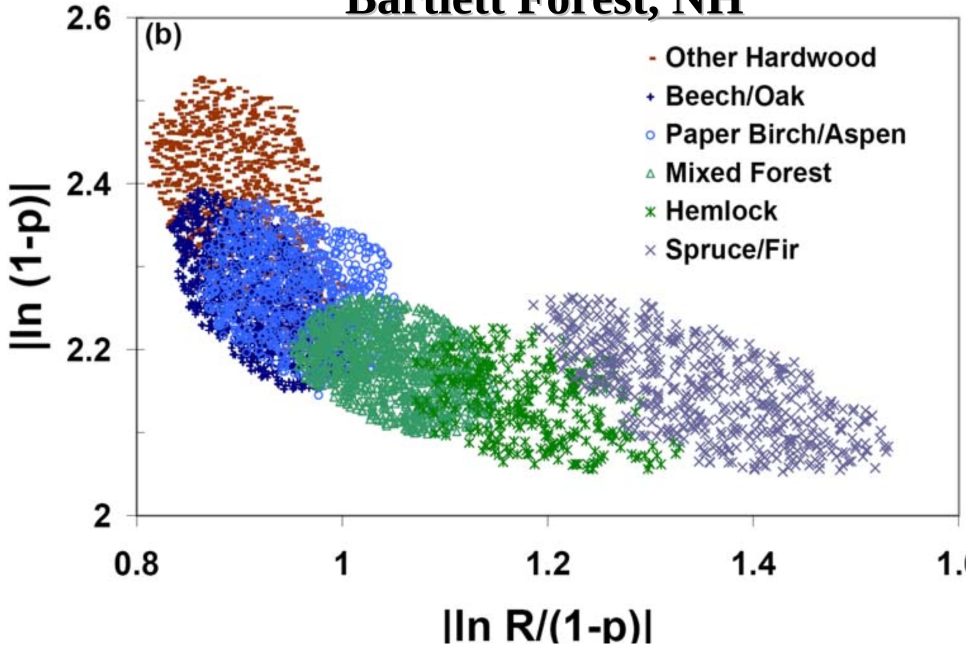
Harvard Forest, MA



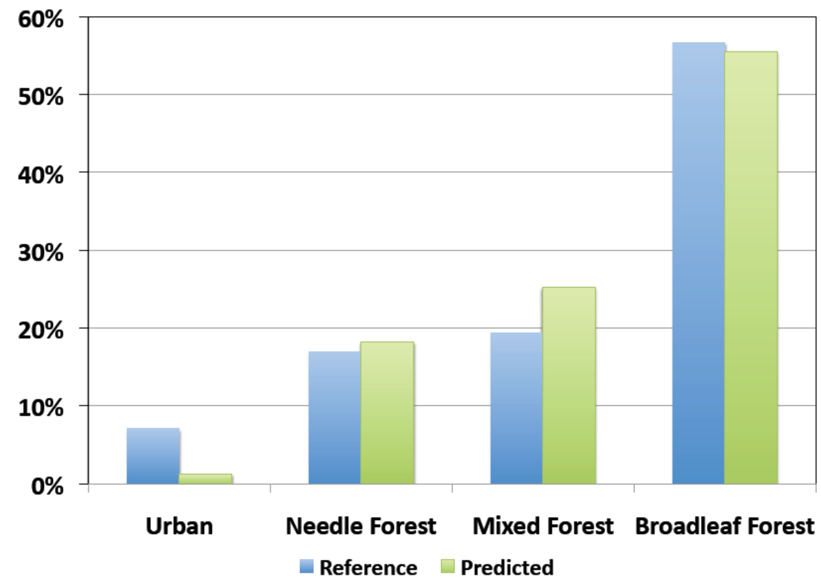
Location of points in the spectral invariant space depend on properties of canopy structure at both micro- (e.g., leaf vs. shoot) and macroscale (e.g., stand and tree geometry).

Spectrally invariant parameters convey information needed to discriminate between forest types.

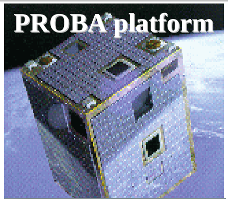
Bartlett Forest, NH



Distribution of forest types at the Bartlett Forest



REMOTE SENSING OF CROPS



CHRIS sensor

Resolution: 20m
Spectral bands: 62
Range: 410-1050 nm
Sp.resolution:5-12 nm
5 nominal angles

Spectral invariant space from PROBA/CHRIS data over the Barrax site, about 20 km from Albacete, Spain

N = 2

Level 1: p_1=0.8

Level 2: $p_{2,1}$=0.18

$$g=\sqrt{(1-0.8)(1-0.18)}=0.41$$

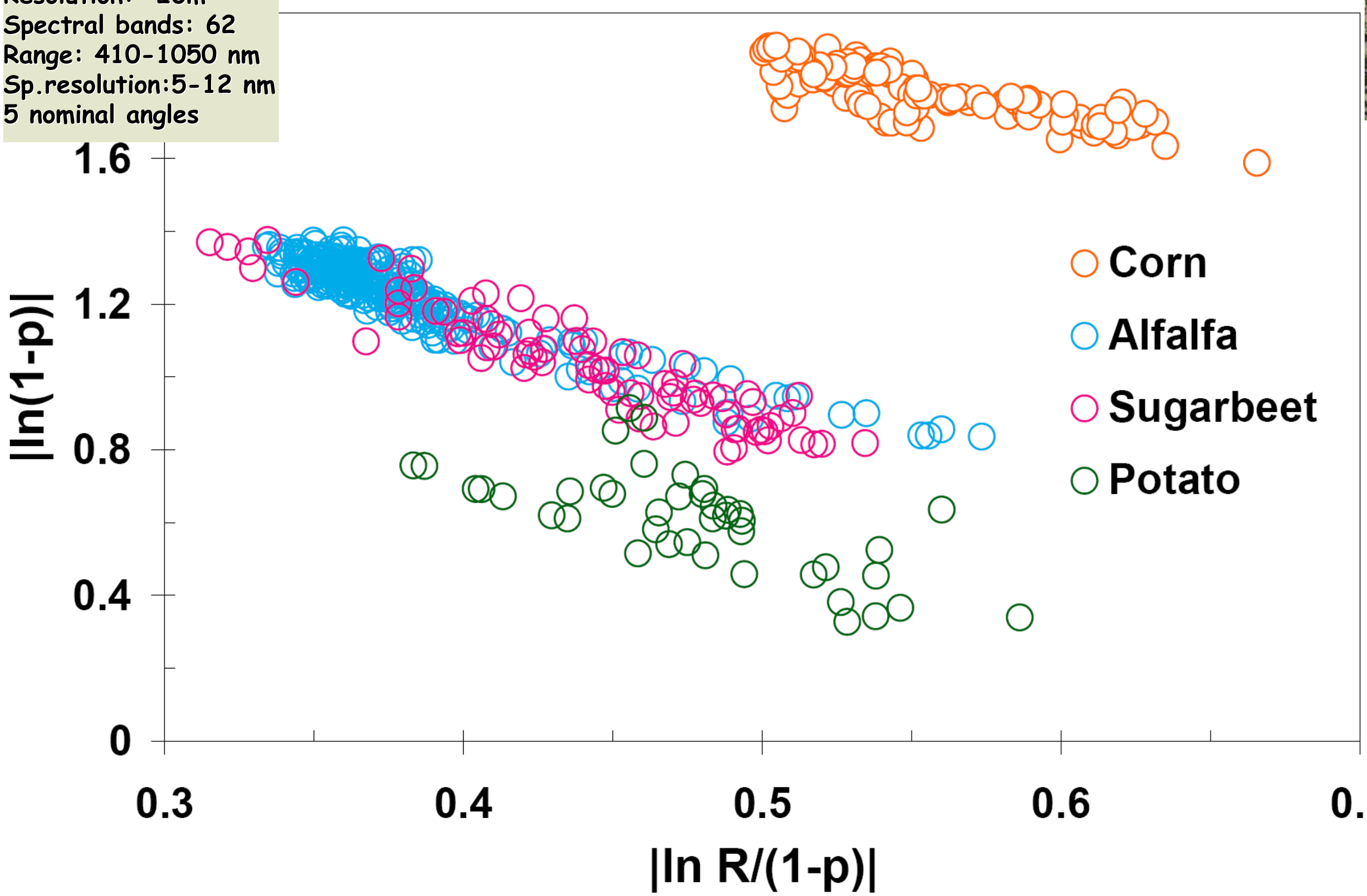
|ln(1-*p*)| =2 |ln 0.41 | = 1.81

N = 2

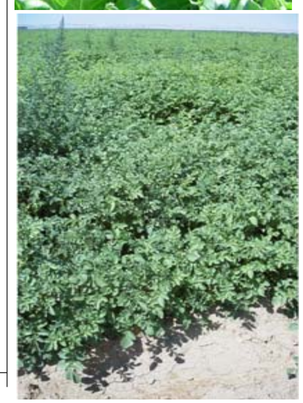
$$g=\sqrt{(1-0.6)(1-0.30)}=0.53$$

|ln(1-*p*)| =2 |ln 0.53 | = 1.27

VZA=0

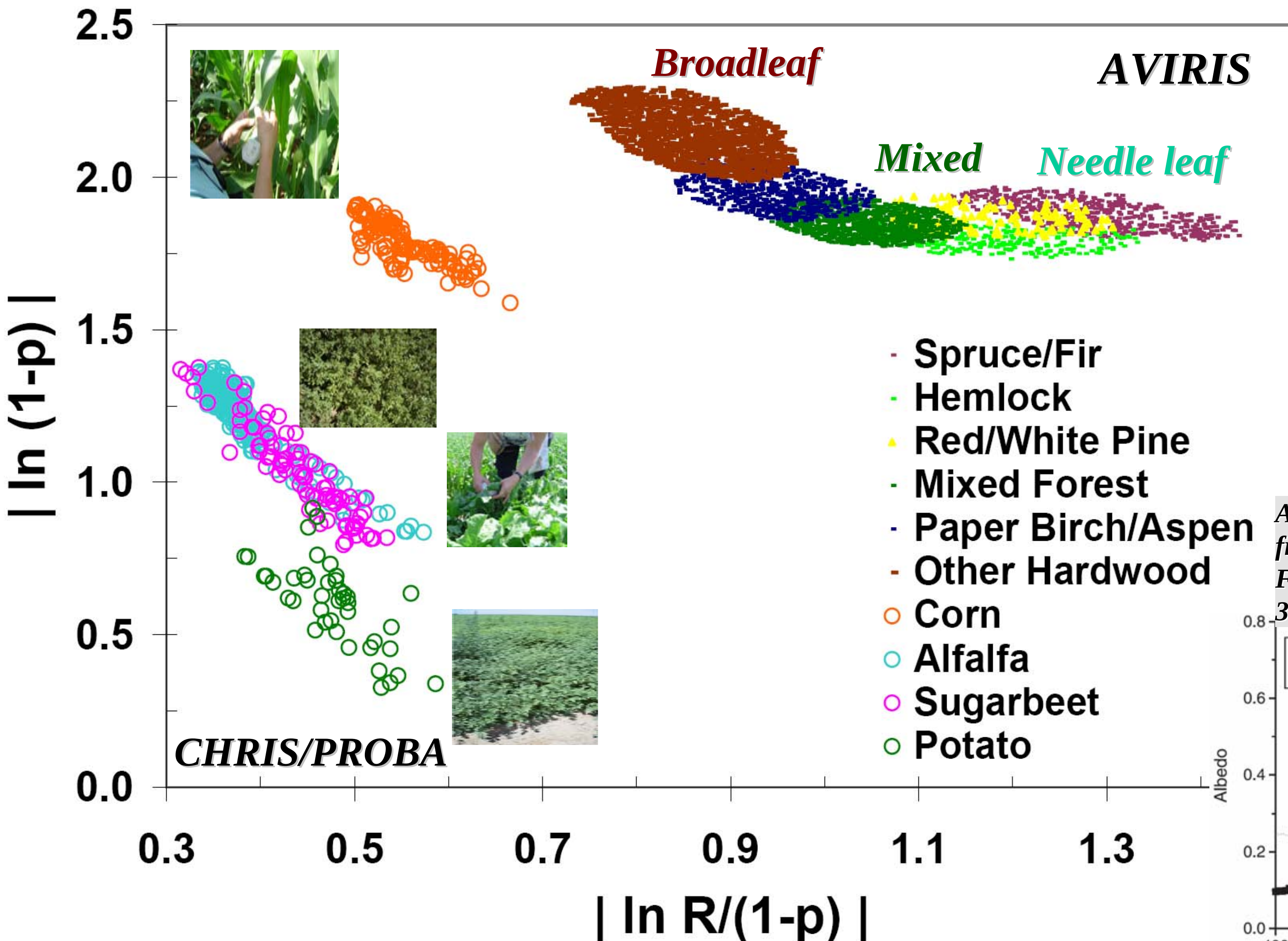


Sugarbeet

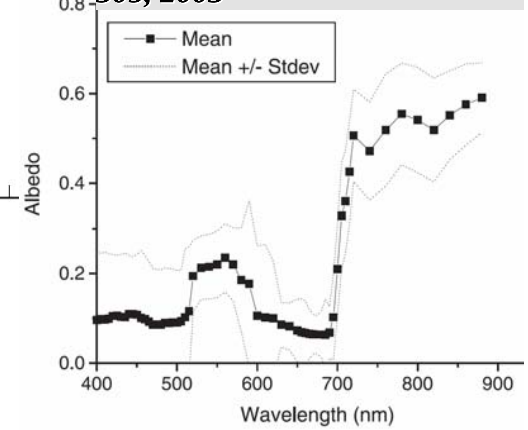


Potato

FORESTS AND CROPS FROM HYPERSPECTRAL DATA



Albedo of a 5-7 cm Scots Pine from a helicopter mounted ASD. From Wang et al., RSE, 85,304-305, 2003



Spectrally invariant parameters convey information needed to discriminate between vegetation types and probably to derive leaf albedo

CONCLUSIONS

- ***Leaf albedo spectra, wavelength independent recollision and escape probabilities <u>fully determine</u> the spectral response of a vegetation canopy with non-reflecting background to incident solar radiation***
- ***Spectral invariants allow for the separation of the structural and radiometric components of the measured and/or modeled signal. The former is a function of canopy structure while the latter is a function of leaf biochemical behavior***
- ***Spectral invariants offer a simple and accurate parameterization for the shortwave radiation block in many global models of climate, hydrology, biogeochemistry, and ecology***
- ***In remote sensing applications, the information content of spectral data can be fully exploited if the wavelength independent variables can be retrieved, for they can be more directly related to structural characteristics of the vegetation canopy***

Some of the above statements are valid if the reference leaf albedo exists. Therefore

the search for models for the reference leaf albedo and understanding the physical reasons for this phenomenon are essential to realize the potential of the hyperspectral remote sensing of vegetated surface