Observing canopy demography of a tropical moist forest with spectral unmixing of hyperspectral images: a model of HyspIRI science application

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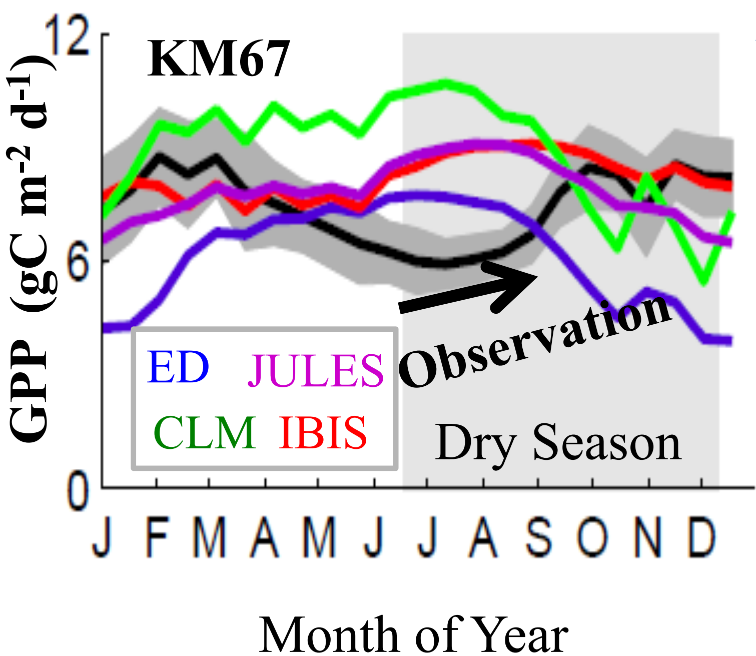
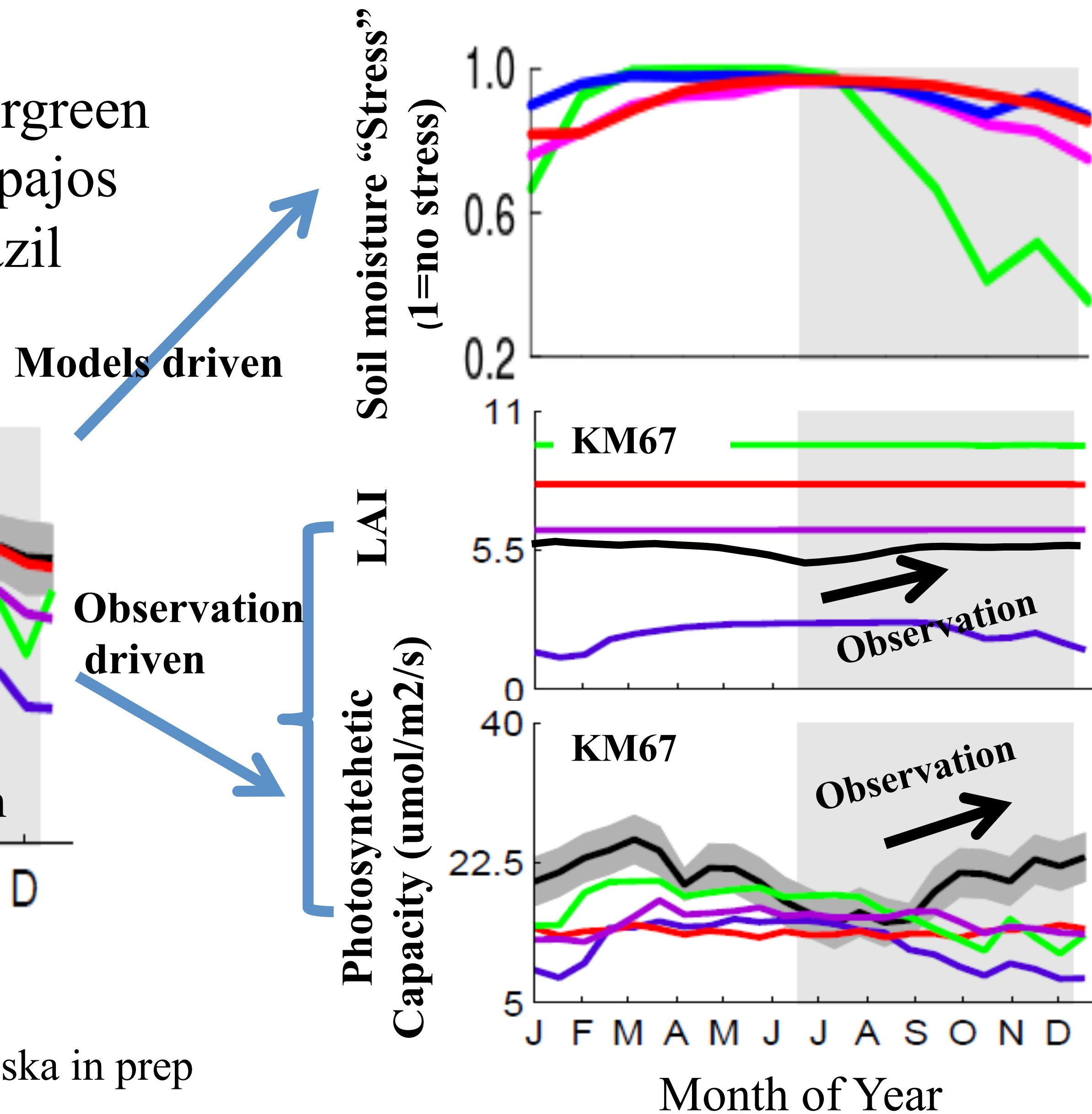
*: Corresponding Authors

Motivating Question: What controls photosynthesis seasonality in tropical evergreen forests?

Example: study of an evergreen tropical moist forest, Tapajos KM67 forest site, Brazil

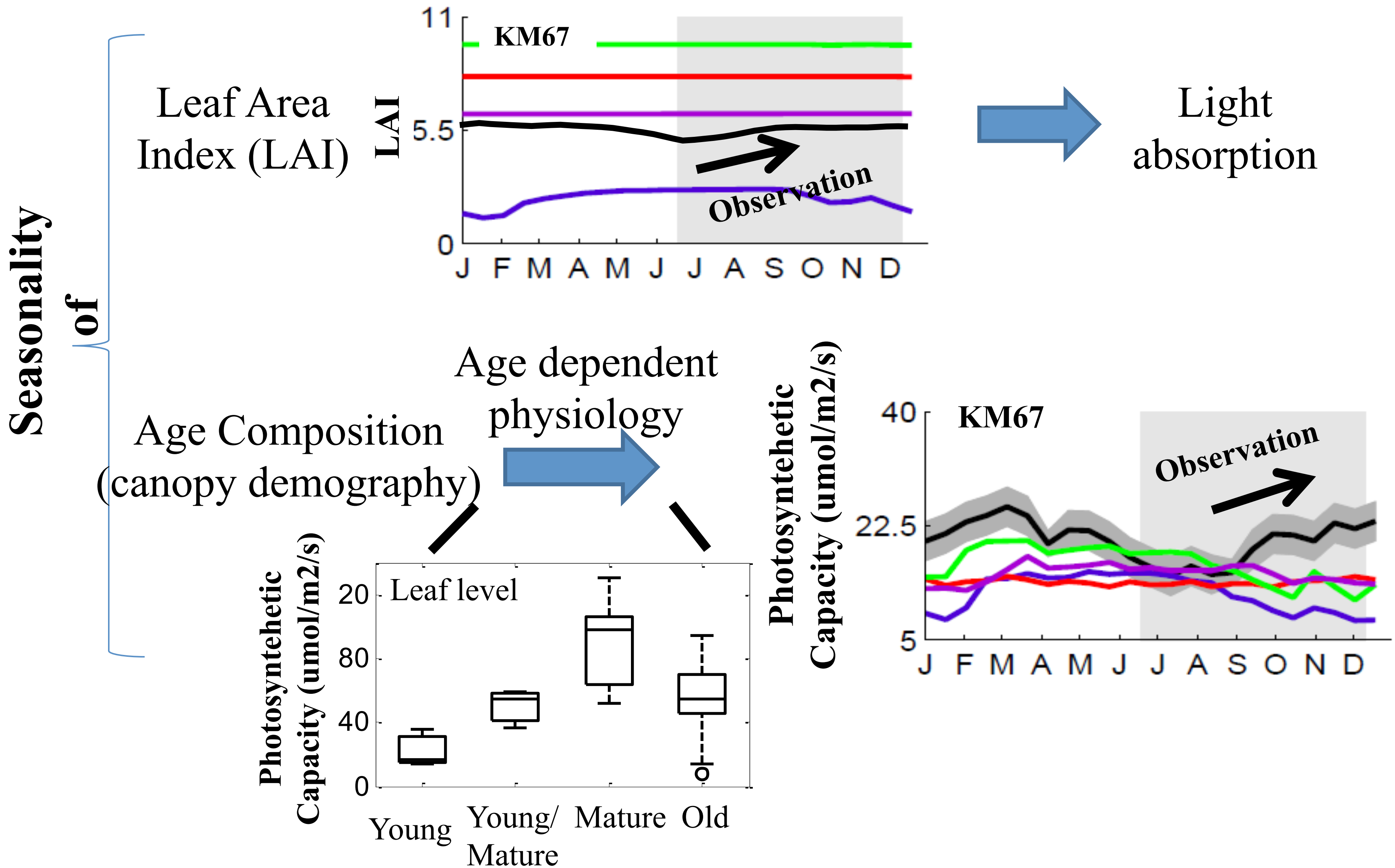




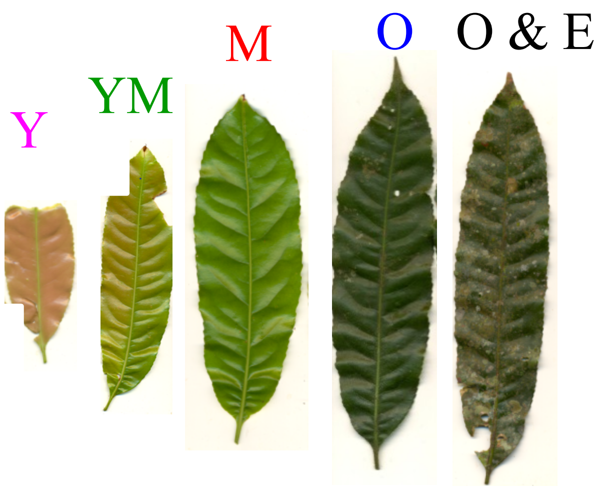
Levine, Restrepo-Coupe, and Saleska in prep

Phenology matters for tropical photosynthesis!

Two aspects of phenology:



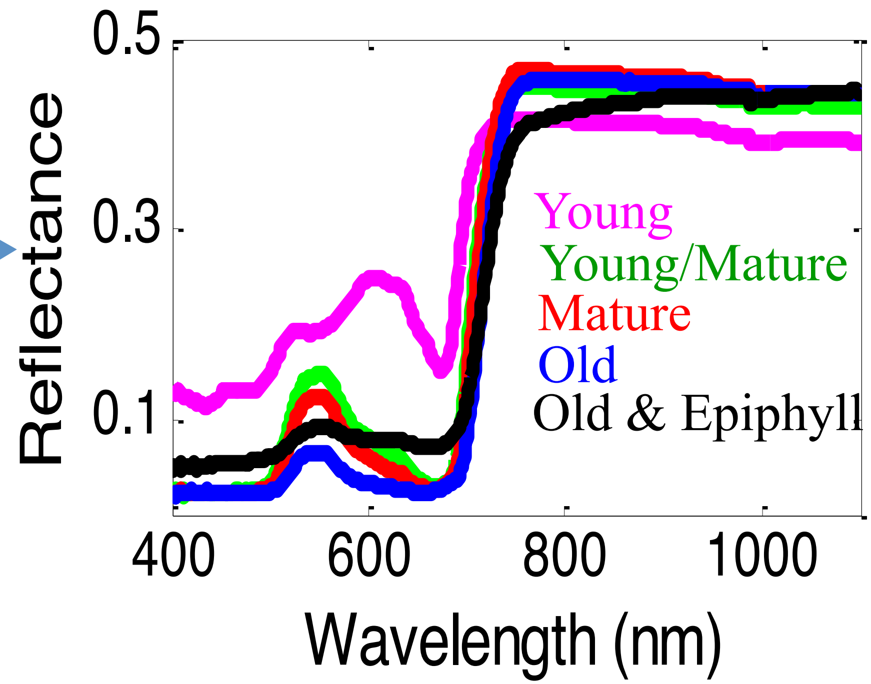
Age dependent hyperspectra



1-m Branch Sample from *Uxi Lista*, on 08/24/2012

Leaf level hyperspectra

(via a handheld ASD)



This pattern is consistent with Roberts et al. (1998), suggesting a feasible way to link leaf level hyperspectra to leaf aging process

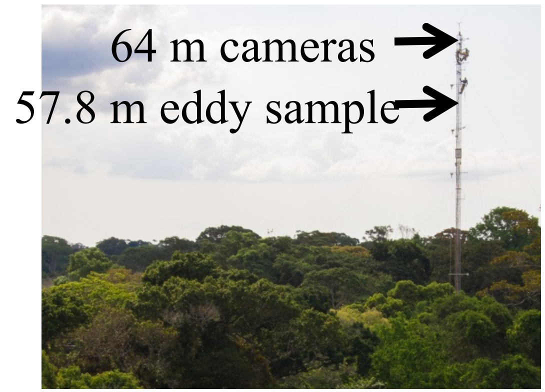
However, canopies are more complex than individual leaf spectra taken under optimal conditions.

This study, we aim to propose a new conceptual approach for demography modeling at canopy level, based on canopy level spectral reflectance

Study Site

Tapajos National Forest, the KM67 eddy covariance tower site (near Santarem, Brazil)

Tropical evergreen moist forest with ~5 month dry season



Eddy Covariance

Data available from 01/2002 to 01/2006, and 08/2008-12/2012

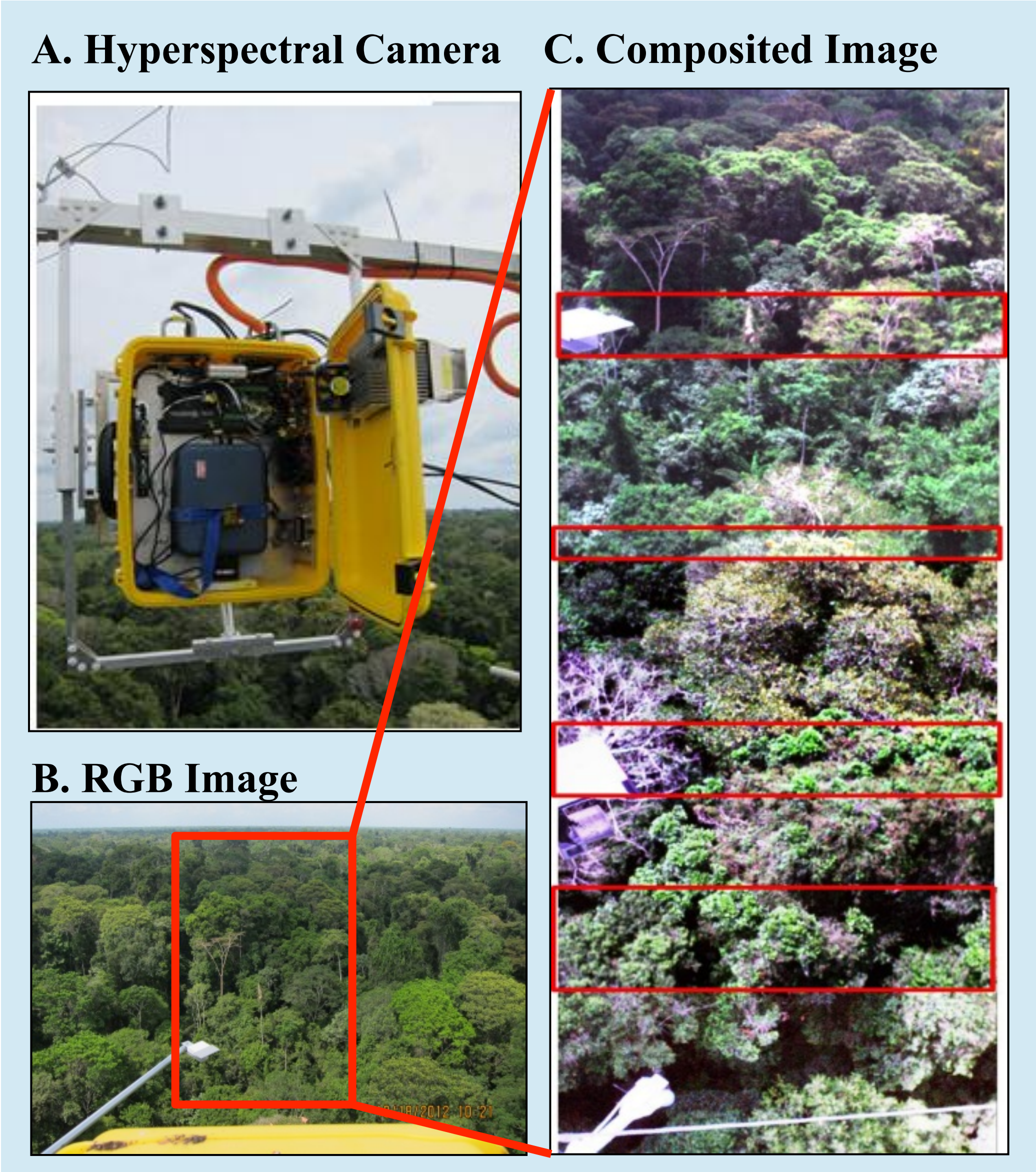
Hyperspectral Vegetation Imaging System (HVIS)

Equipped by Surface Optics Corporation (SOC) 710 camera

Materials: Hyperspectral Vegetation Imaging System

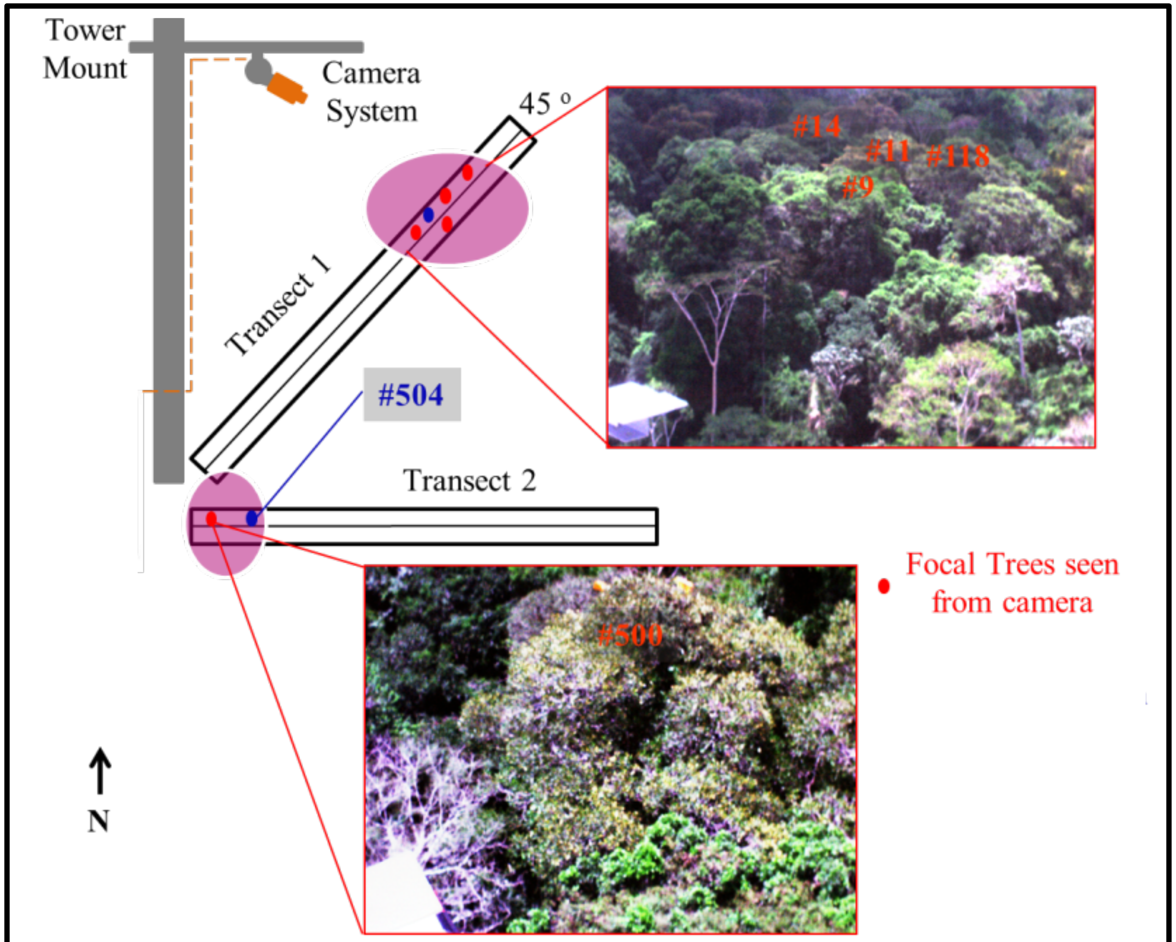
Key parameters:
* Spectral resolution: ~4nm, 128 bands from 385nm to 1050 nm
* Field of view: 36×27 degree
* Temporal resolution: image/10 minutes, from 6 am to 6 pm
* Data available: Jul-Dec, 2012
* Image dimension: 520*696 pixels

Other parameters:
* The camera system was programed to adjust their view angles from nadir view to very oblique view (75^{o}) every 10 minutes, and repeated every hour



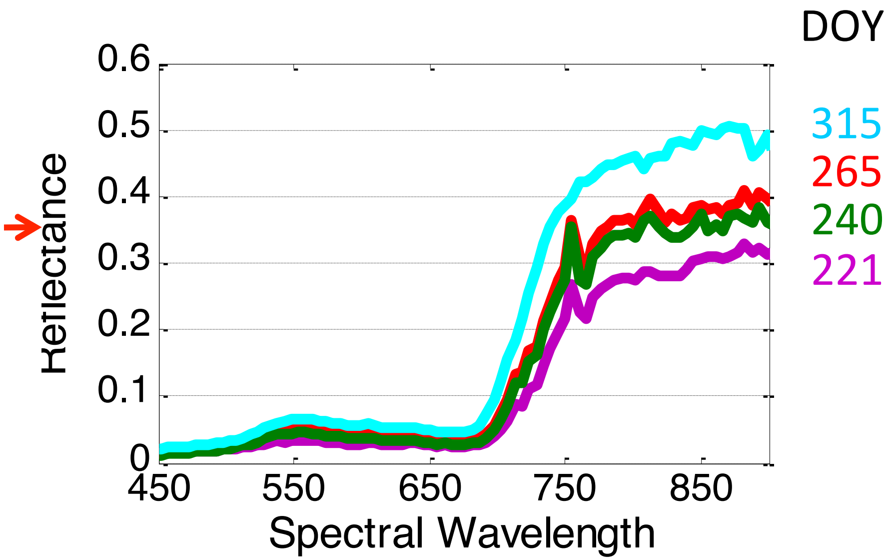
Materials: 2012 Fall Phenology Campaign

* 6 focal trees+14 understory trees were selected; * **canopy demography survey** were conducted for 1-m branches in the early, middle, and late of dry season



Canopy Demography Modeling

Step1 : Acquire canopy hyperspectral reflectance from hyperspectral camera images



Tree #9, fully illuminated leaves, average reflectance for 10*10 pixels; the images selected were under sunny sky condition; all images selected for this analysis between 11 am-12pm local time

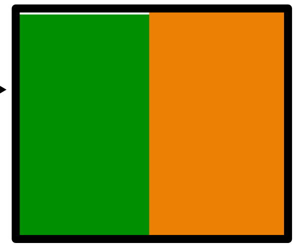
Canopy Demography Modeling

Step2 : Spectral Unmixing Method

Previous Studies
(e.g. Asner and Lobell, 2000, RSE)

One Image Pixel

Vegetation Percentage: f_V



Soil Percentage: f_S

$$R_{\text{composited}} = f_V * R_V + f_S * R_S$$

Composited Reflectance

Pure Vegetation Reflectance

Pure Soil Reflectance

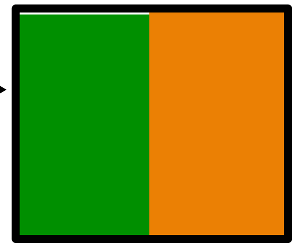
Canopy Demography Modeling

Step2 : Spectral Unmixing Method

This Study

One Image Pixel

Mature Leaves Percentage: f_{M}



Old Leaves Percentage: f_{O}

$$R_{\mathrm{camera}} = f_{\mathrm{M}} * R_{\mathrm{M}} + f_{\mathrm{O}} * R_{\mathrm{O}}$$

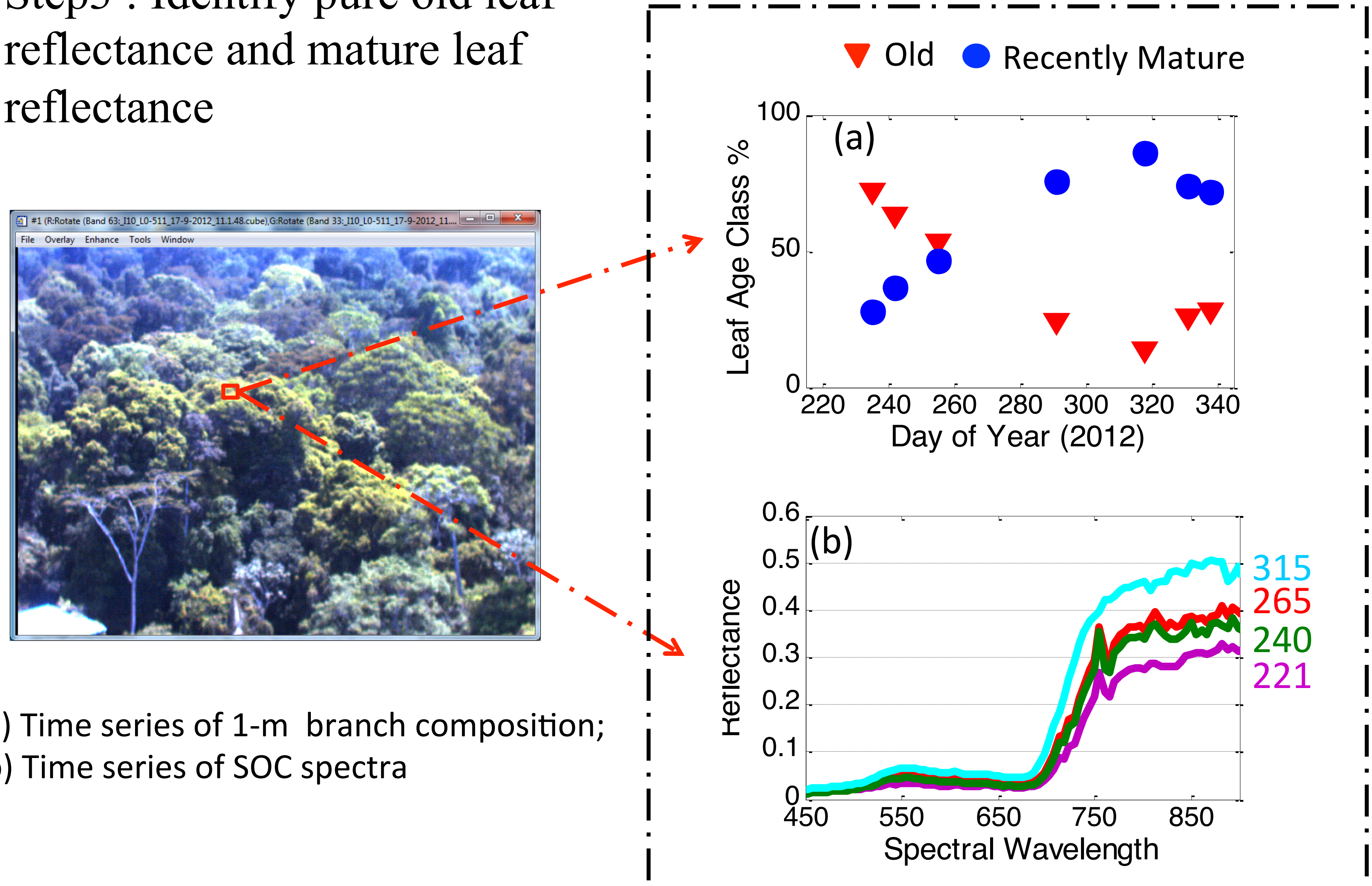
Camera observed Reflectance

Pure Mature Reflectance

Pure Old Reflectance

Canopy Demography Modeling

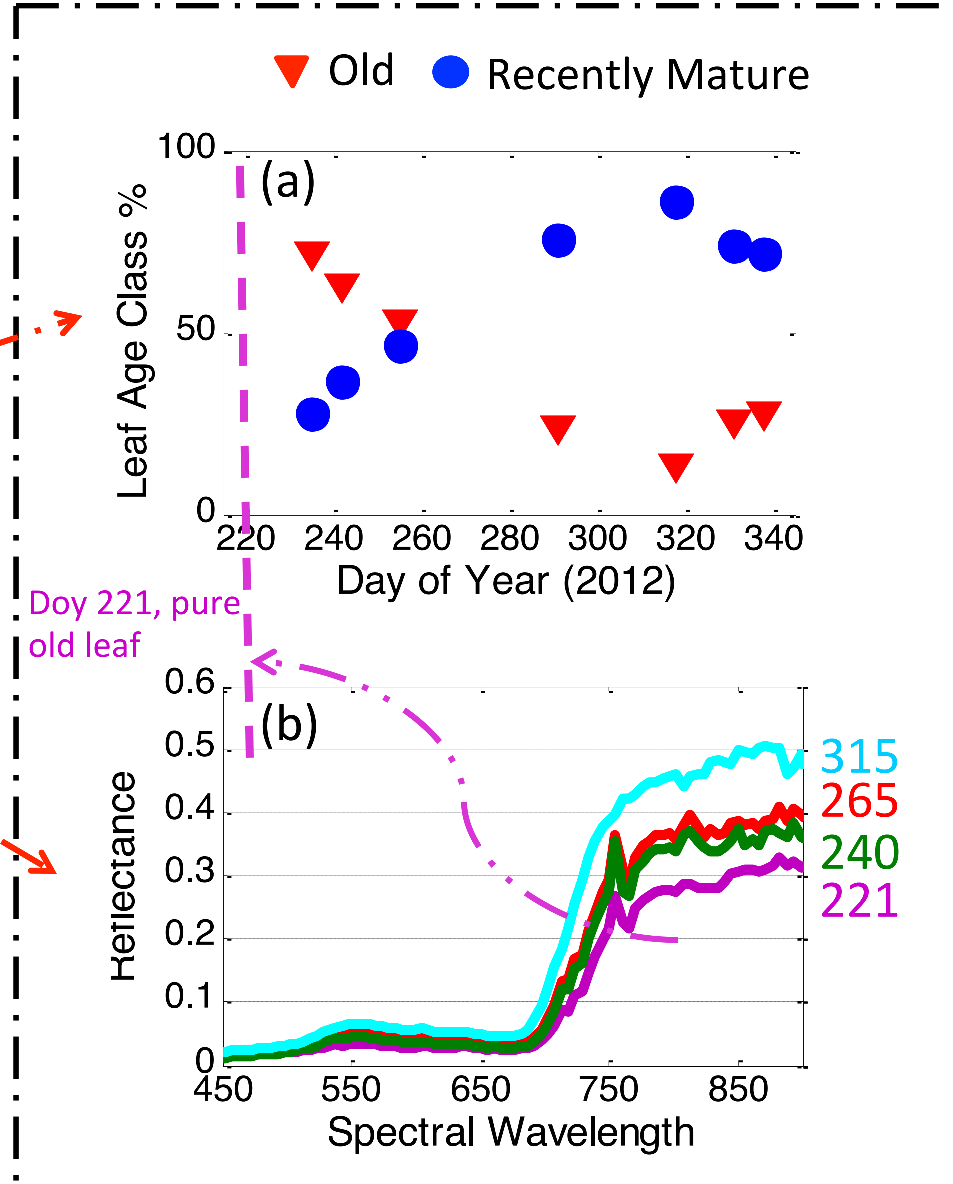
Step3 : Identify pure old leaf reflectance and mature leaf reflectance



(a) Time series of 1-m branch composition;
(b) Time series of SOC spectra

Canopy Demography Modeling

Step3 : Identify pure old leaf reflectance and mature leaf reflectance



(a) Time series of 1-m branch composition;
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Canopy Demography Modeling

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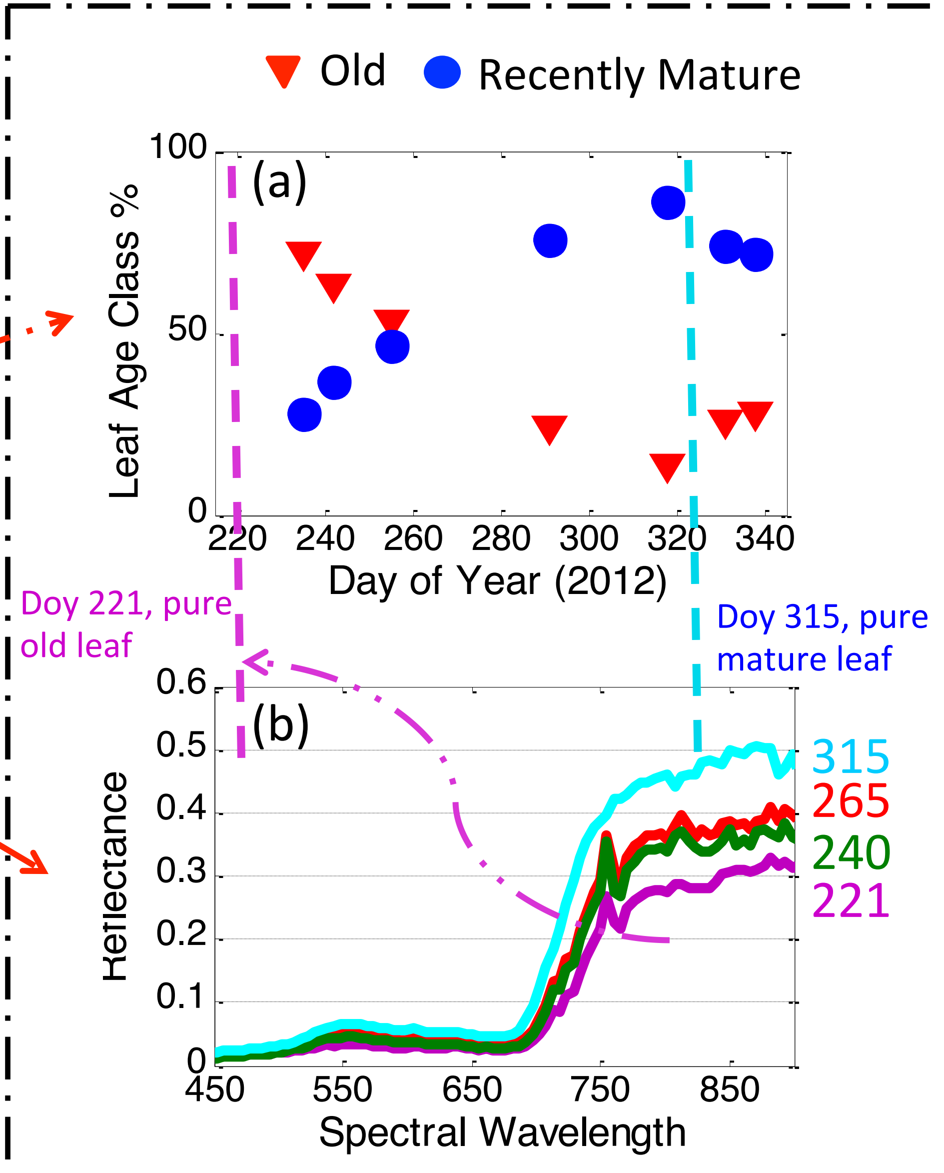

(a) Time series of 1-m branch composition;
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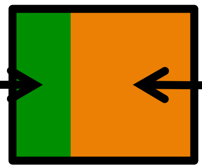
Canopy Demography Modeling

Step3 : Identify pure old leaf reflectance and mature leaf reflectance

One Image Pixel

Mature Leaves Percentage: f_M



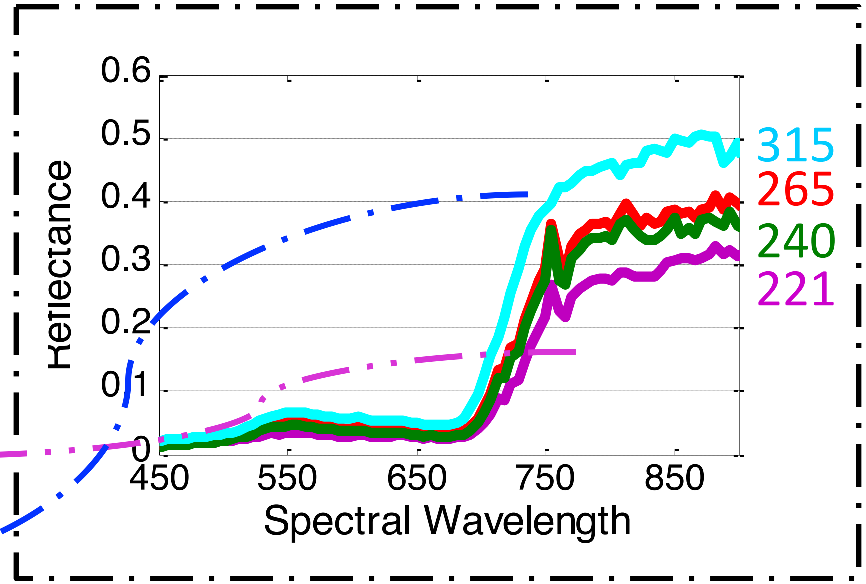
Old Leaves Percentage: f_O

$$R_{camera} = f_M * R_M + f_O * R_O$$

Camera observed Reflectance

Pure Mature Reflectance

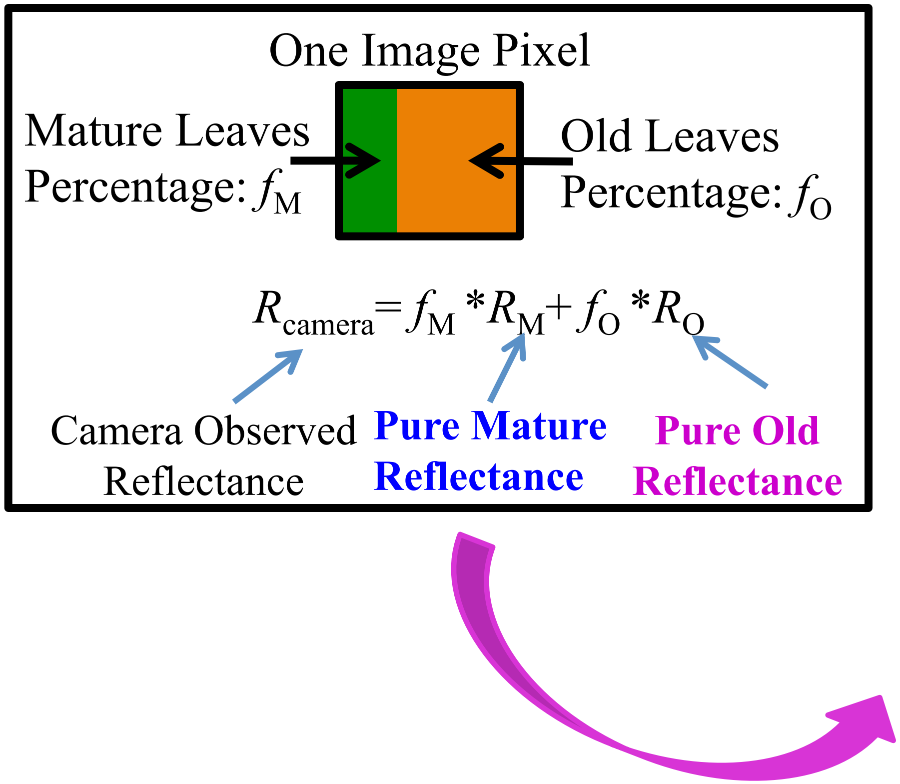
Pure Old Reflectance



*All the channels from 450 nm-900 nm were used for spectral unmixing

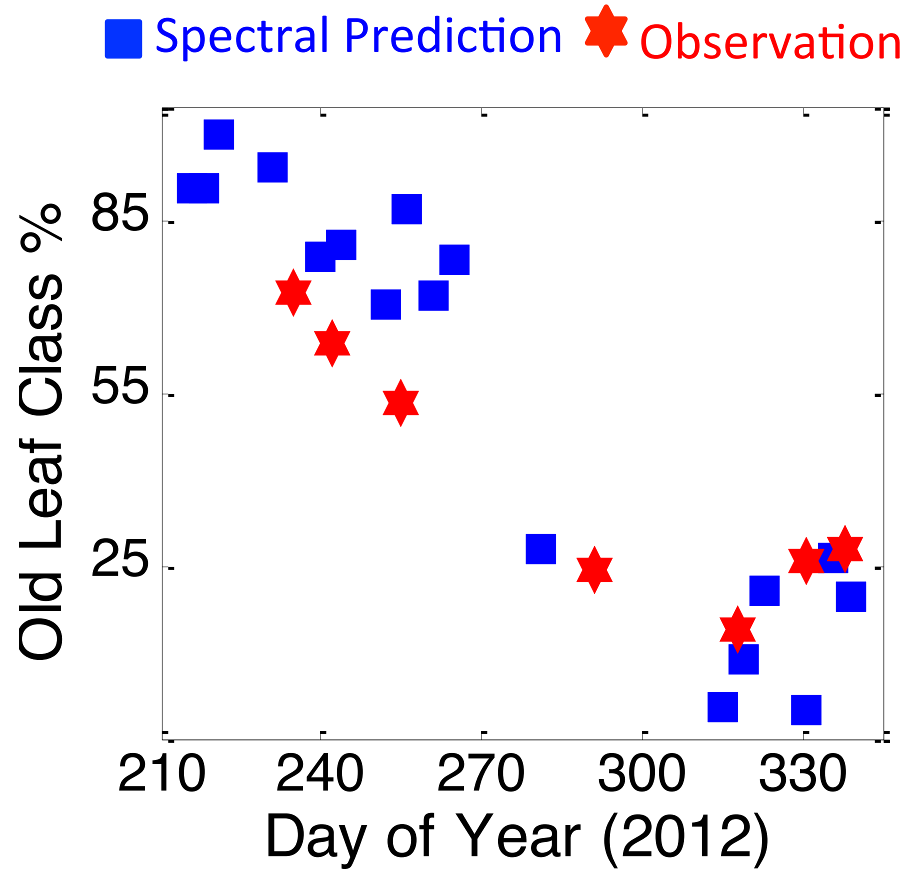
Canopy Demography Modeling

Step4 : prediction of the seasonality of canopy demography



Model Inversion

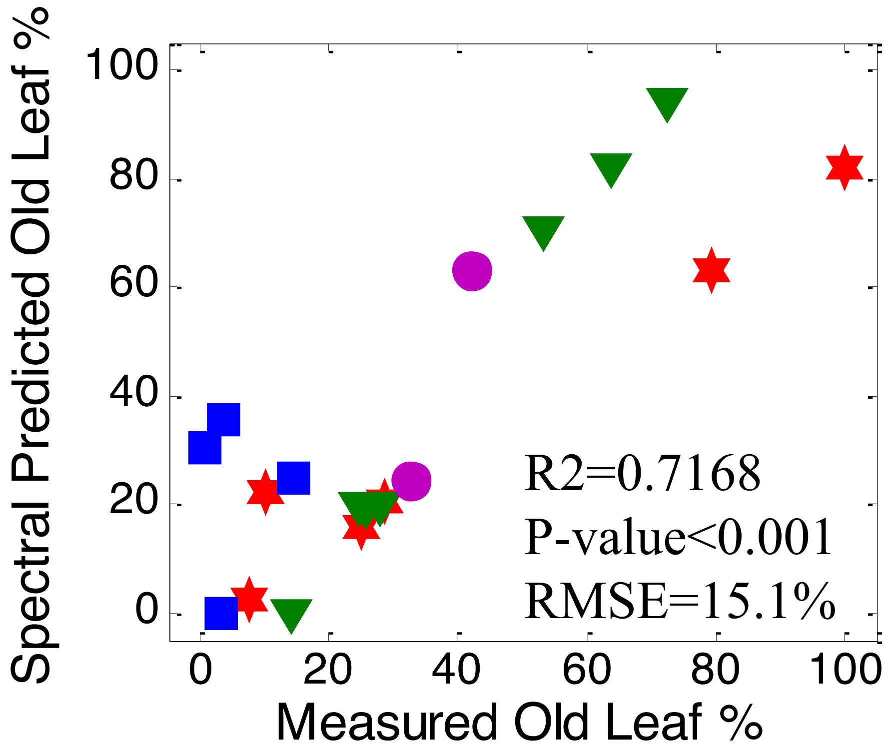
Example species: *Erisma uncinatum*, Vochysiaceae



Canopy Demography Modeling

Step4 : prediction of the seasonality of canopy demography

Four dominant tree species in KM67 forest site



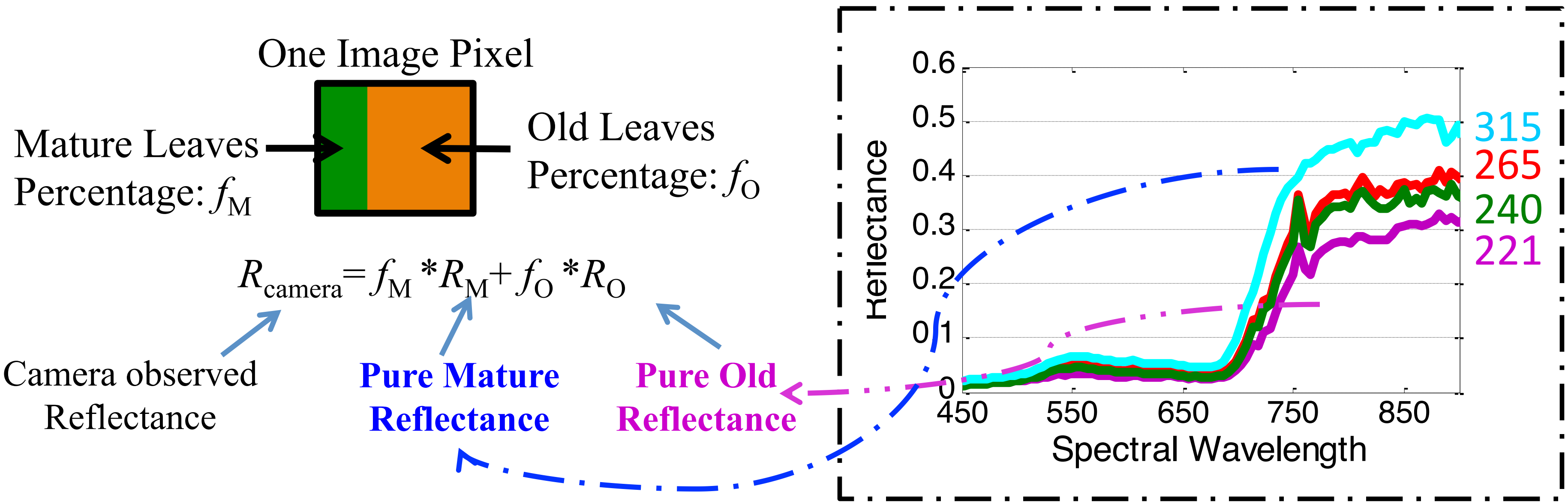
Species Name	**Family**
Tachigali eriopetala	Leguminosae-Caesalp
Erisma uncinatum Warm.	Vochysiaceae
Manilkara huberi	Sapotaceae
Ocotea sp.	Lauraceae

Canopy Demography Modeling

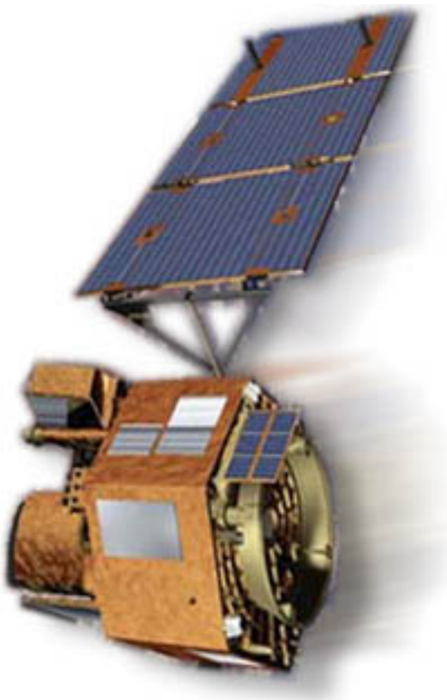
*All the channels from 450 nm-900 nm were used for spectral unmixing

* The spectra unmixing result is dominated by the variation in NIR reflectance

* This result is very similar like that proposed by Doughty and Goulden (2008), who tried to link NIR absorbance to model leaf age



Hyperion: a model to test application to HyspIRI



Key Parameters:

(1) Launch date: 11/21/2000

(2) Spectral resolution: 224 bands from 400 nm to 2500 nm

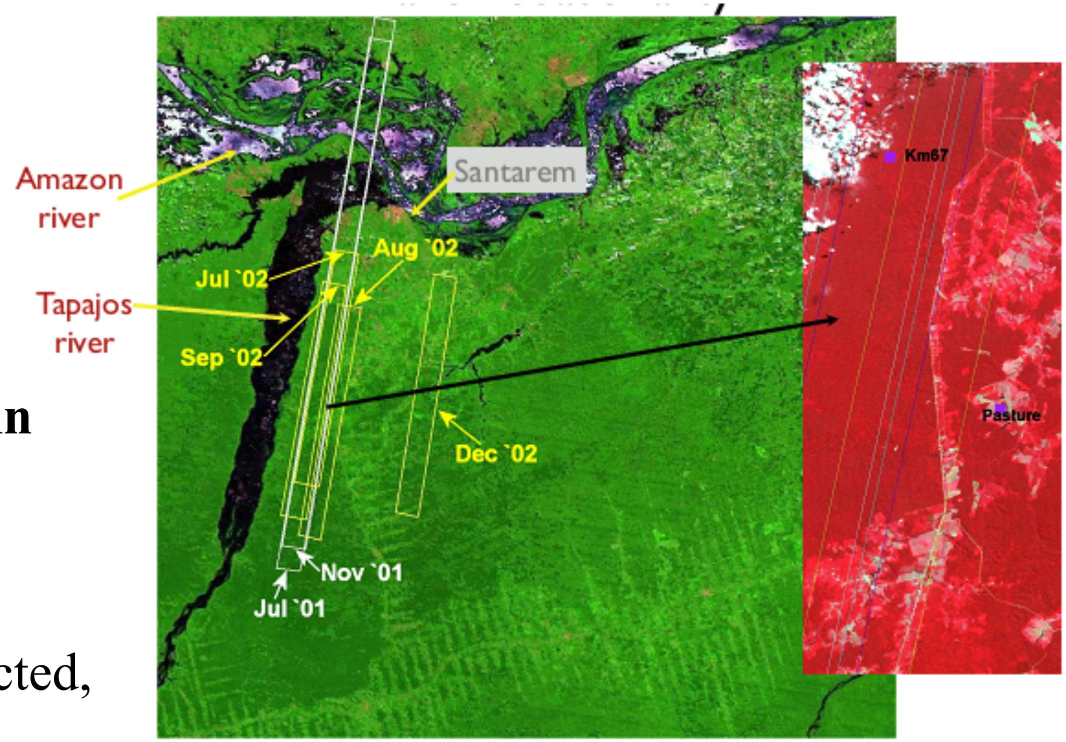
(3) Temporal resolution: 16-day frequencies

(4) Spatial resolution: 30 m pixels, and 8-10 km wide imagery

Earth Observing-1 Hyperion

HyspIRI Mission Study

Hyperion: a model to test application to HyspIRI

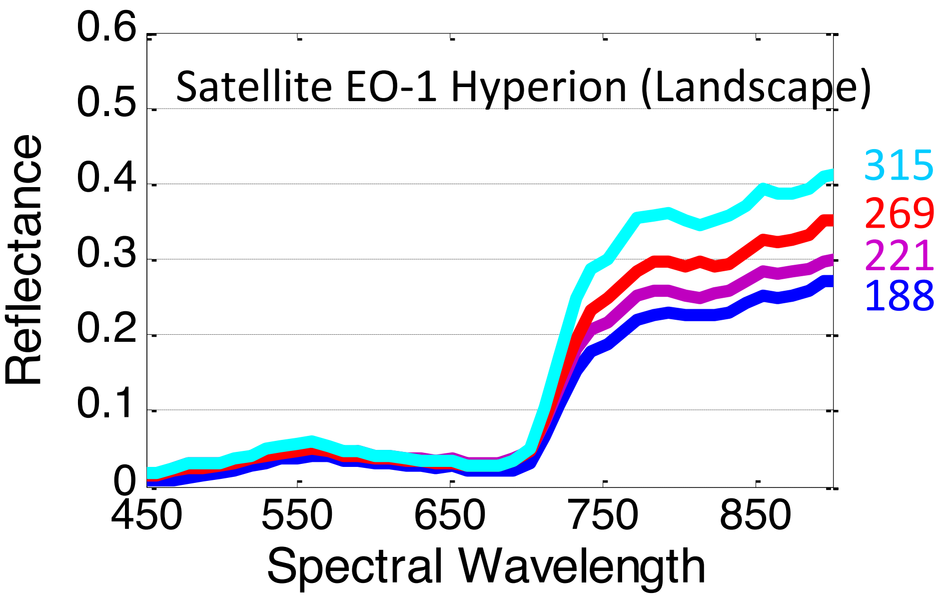


EO-1 Hyperion in TNF-KM67 site in 2001, 2002

(1) 25*25 pixels (~1 km*1km)

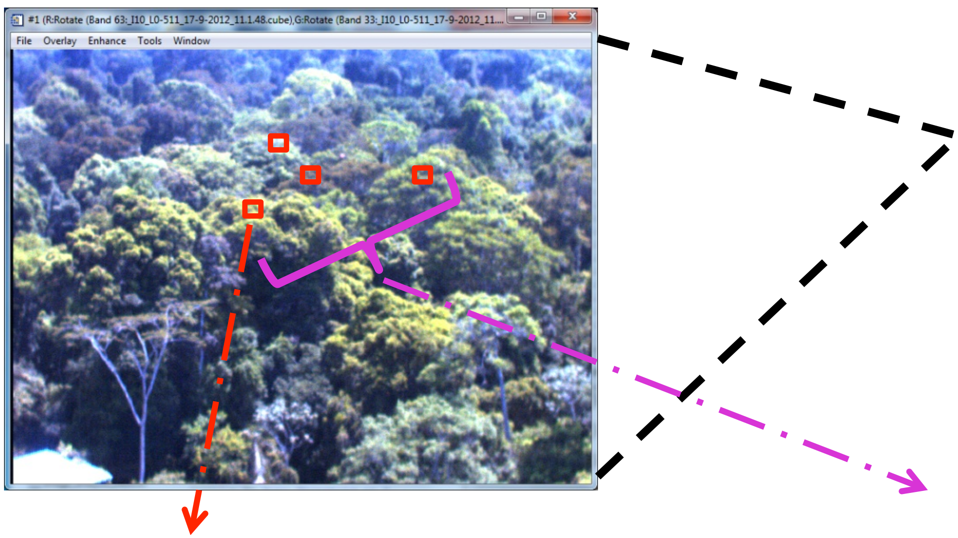
(2) The data were radiometrically-calibrated, atmospherically corrected, and converted from radiance to apparent surface reflectance

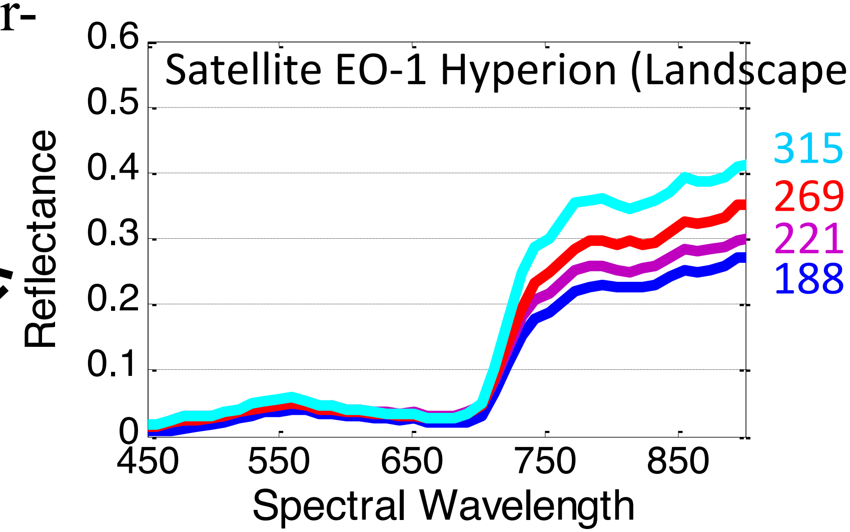
(3) Solar Zenith Angle: 39° in early dry season (July) to 34° in late dry season (December)

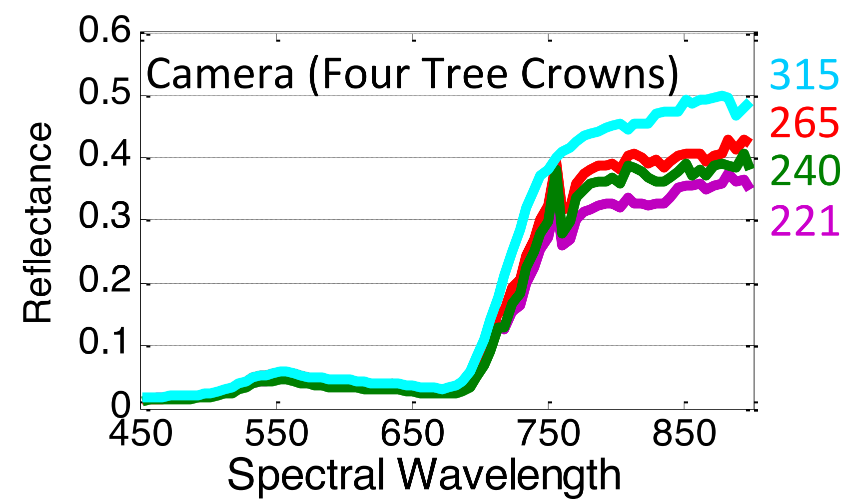


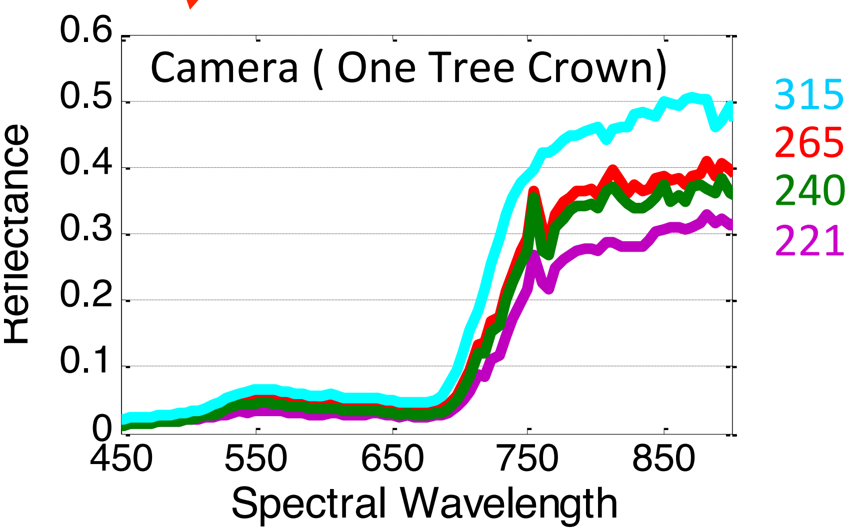
Hyperion: a model to test application to HyspIRI

Hyperspectra comparison between near-surface remote sensing and satellite







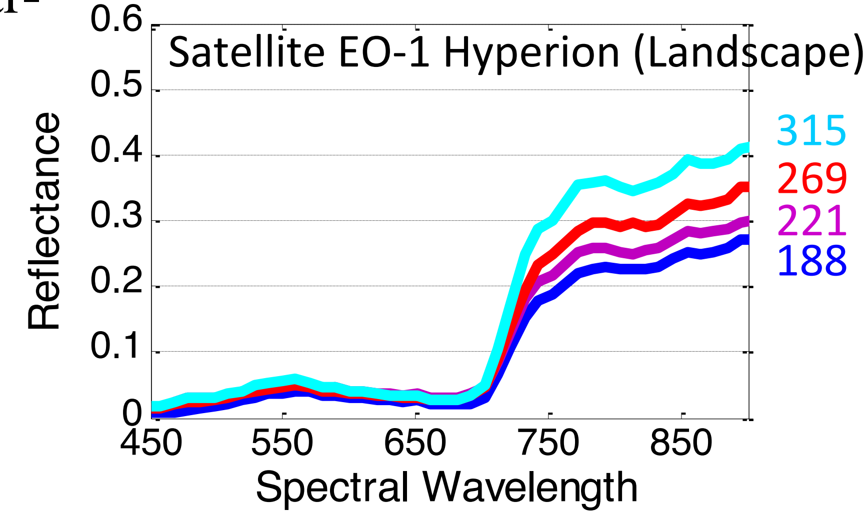


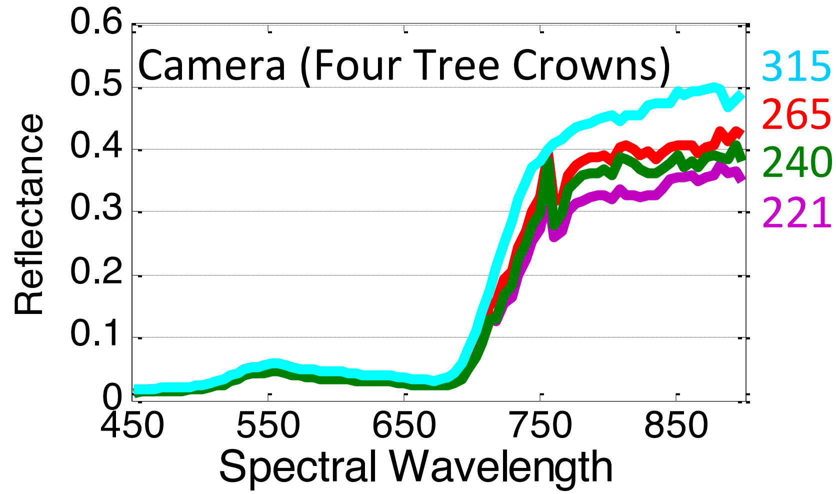
Hyperion: a model to test application to HyspIRI

Hyperspectra comparison between near-surface remote sensing and satellite

*View Angle: ~70 degree (Camera);
~nadir (EO-1 Hyperion)

*Spectra Contribution:
(1) Limited number of tree crowns, and illuminated leaves (Camera);
(2) More species diversity, sunny and shade leaves, branches, soils (EO-1 Hyperion)





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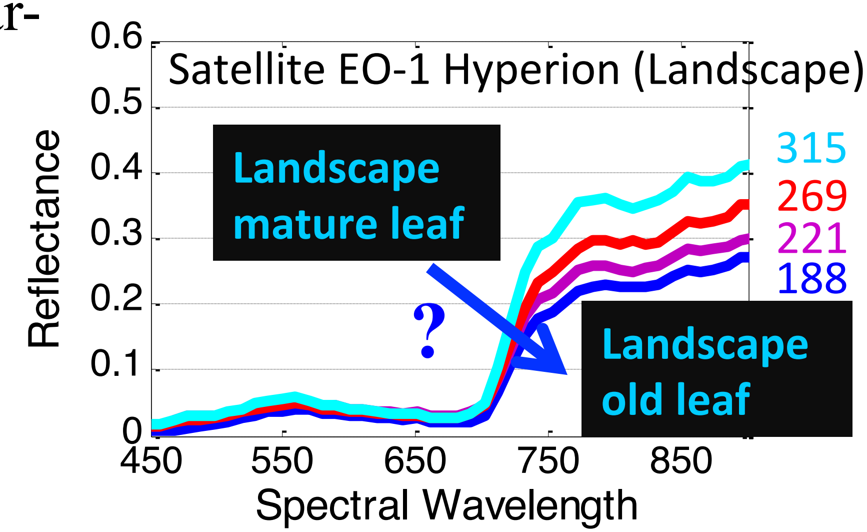

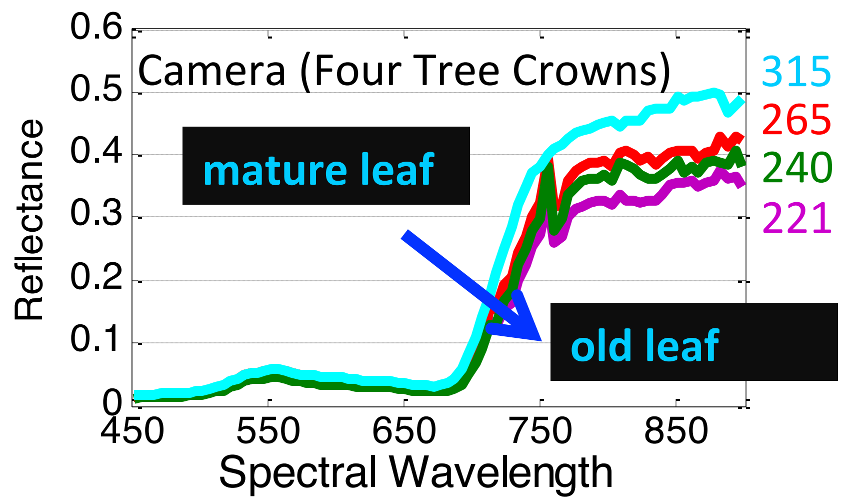

Hyperion: a model to test application to HyspIRI

Applying spectra unmixing approach to landscape, or even Amazonian basin

(1) More species in one site

(2) More near-surface remote sensing studies (tower based or airborne based)

(3) More field campaigns

(Oxford University)

Tambopata Reserve, Peru

French Guiana

Manaus K34 site
(INPA and University of Arizona)

Tapajos K67 site
(University of Arizona)

✦ ▲ Demography Campaign

✦ Hyperspectral Camera

Summary

1. Canopy demography seasonality is important for plant phenology and tropical forest metabolism

2. Spectral unmxing approach was attempted for the first time here for extracting canopy demographic composition based on canopy spectral reflectance acquired by a tower mounted imaging system.

3. Time-series of canopy spectra (via tower mounted camera system) showed similar trend as that from Hyperion. This suggests the former can be a model system for the study of Hyperion and HyspIRI, while the later can expand the spatial scale of the former measurements.

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Kleber Silva Campos (UFOPA)
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Ty Taylor (UofA)
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Max Li (University of Arizona)
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Raimundo Cosme Oliveiera (UFOPA)
Steve Bissell (US)

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NASA Terrestrial Ecology Program

Photo Credit: Neill Prohaska

Amazon-PIRE
PARTNERSHIP FOR INTERNATIONAL RESEARCH AND EDUCATION IN
Amazon Climate Interactions

Hyperion: a model to test application to HyspIRI

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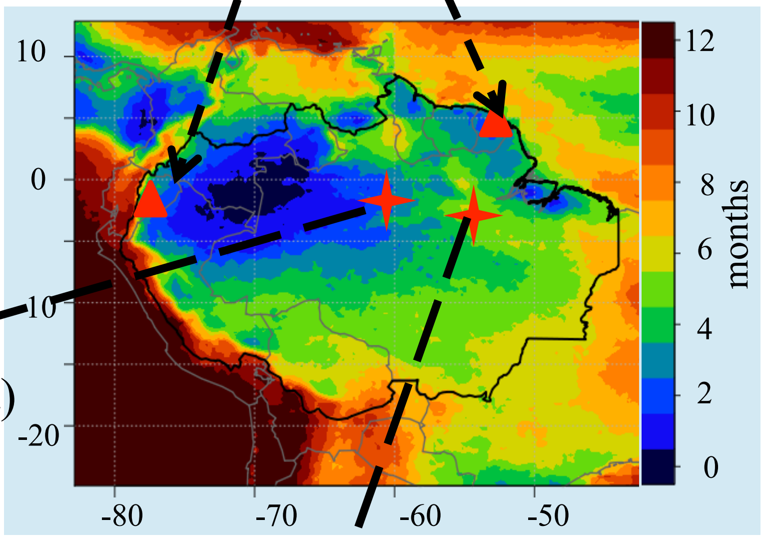


Demography Campaign

Hyperspectral Camera

Future Work

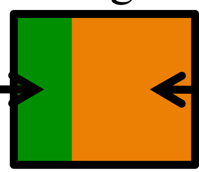
1. Improve Methodology

(1) Give more weight on the spectral reflectance at visible light region

(2) Develop a 2or 3 band "canopy demography index"

One Image Pixel

Mature Leaves Percentage: f_M



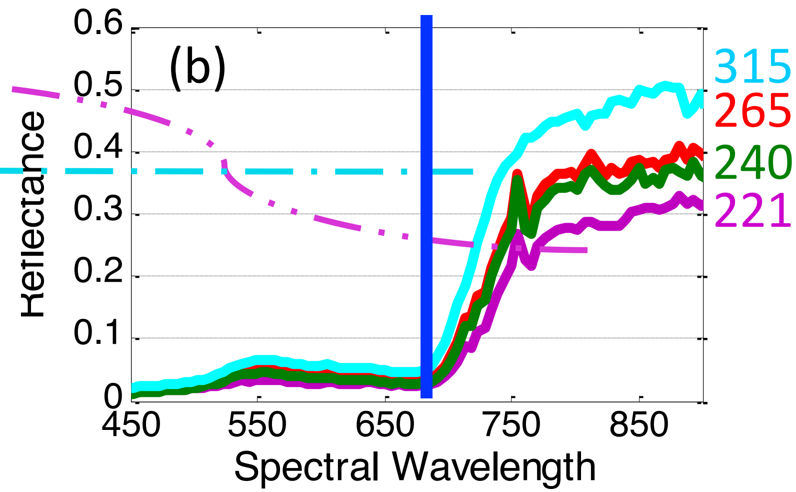
Old Leaves Percentage: f_O

$$R_{camera} = f_M * R_M + f_O * R_O$$

Camera observed Reflectance

Pure Mature Reflectance

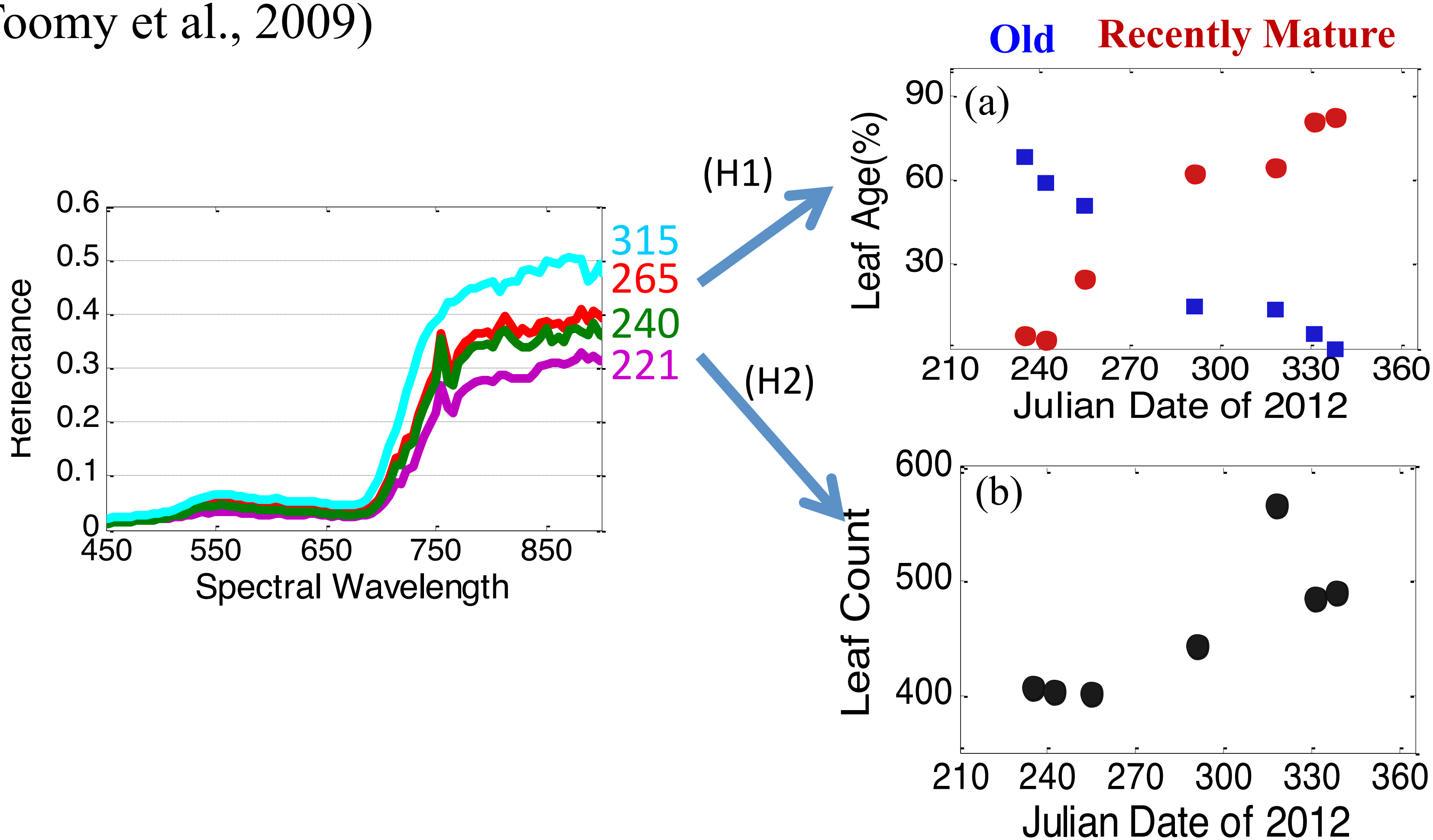
Pure Old Reflectance



Future Work

2. Hypothesis Test

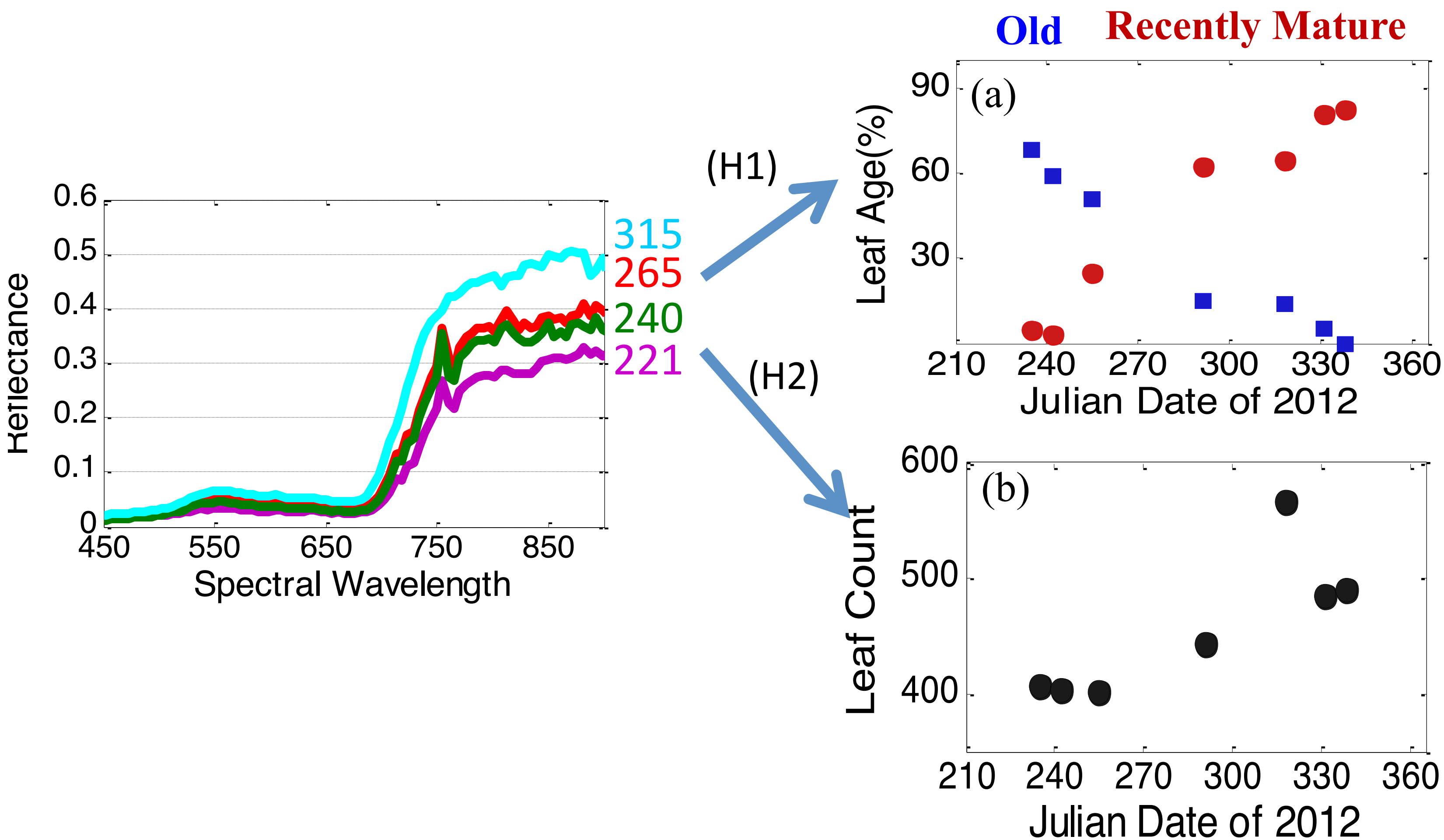
The change of spectra in dry season is driven by the change of (H1) canopy demography and/or (H2) leaf amount, and/or other process (e.g. epiphyll Toomy et al., 2009)



Future Work

2. Hypothesis Test

It will be great to incorporate some processes based model (e.g. Prospect+SAIL) to quantitatively assess these two hypotheses



Materials: 2012 Fall Phenology Campaign

* 6 focal trees+14 understory trees were selected; * samples were collected in the early, middle, and late of dry season (Mid-Aug to Early-Dec)

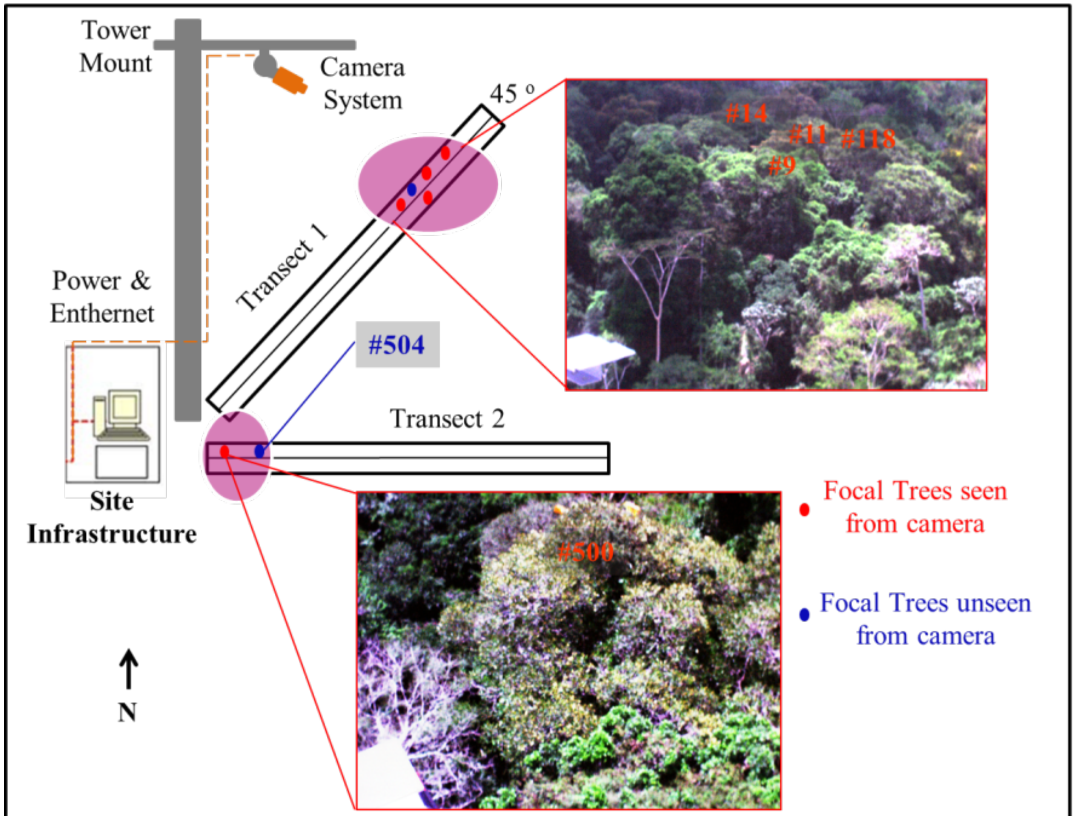
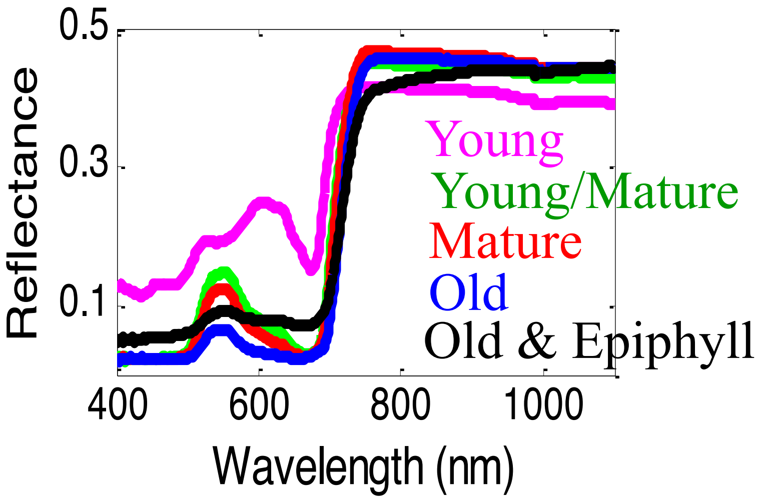


Fig 3. Basic Infrastructure in TNF-KM67 site (Tower Mounted Imaging System & Transect for Tree Survey) & Plant Species Selected for 2012 Field Campaign

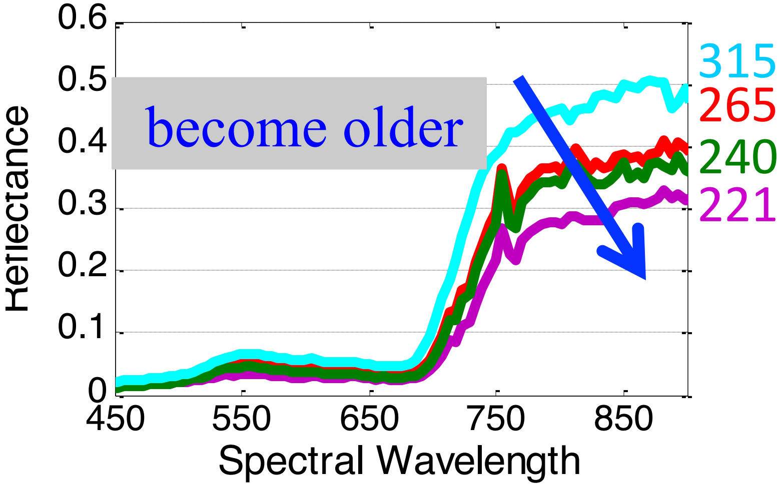
Tree #/ Name	Nome Científico	Família
Tr# 9	*Erisma uncinatum* Warm.	Vochysiaceae
Tr# 11	*Ocotea* sp.	Lauraceae
Tr# 118	*Tachigali eriopetala* (Ducke) L.G.Silva & H.C.Lima	Leguminosae -Caesalp.
Tr# 500	*Manilkara huberi* (Ducke) A.Chev.	Sapotaceae
Tr# 504	*Coussarea paniculata* (Vahl) Standl.	Rubiaceae
Sap Flow Tree	*Chamaecrista scleroxylon* (Ducke) H.S.Irwin & Barneby	Leguminosae -Caesalp.

Leaf Spectra & Canopy Spectra

Leaf level hyperspectra
(via a handheld ASD)



Canopy level hyperspectra
(via tower mounted camera)



Methodology: Reflectance Calculation

$$R_{leaf,\lambda_i} = R_{reference,\lambda_i} * Radiation_{leaf,\lambda_i} / Radiation_{reference,\lambda_i} \quad (1)$$

$$R_{leaf,\lambda_i} = R_{reference,\lambda_i} * DN_{leaf,\lambda_i} / DN_{reference,\lambda_i} \quad (2)$$

Premise from equation (1) to equation (2) is DN linearly scales with radiation for each wavelength (was tested in the lab!!)

R_{leaf,λ_i}: leaf reflectance at wavelength λ_i

$R_{reference,\lambda_i}$: reference reflectance at wavelength λ_i

$Radiation_{leaf,\lambda_i}$: leaf surface radiation at wavelength λ_i

DN_{leaf,λ_i}: camera based digital number at wavelength λ_i

DN_{leaf,λ_i} $DN_{reference,\lambda_i}$

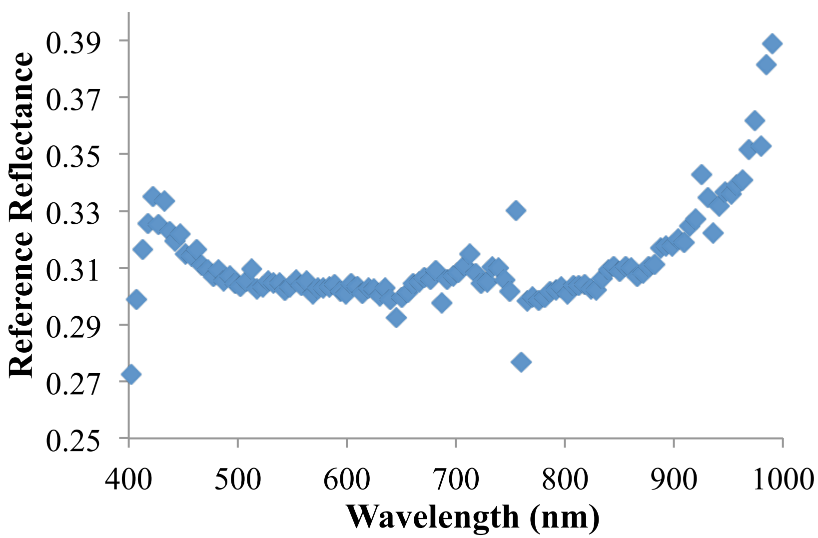
$R_{reference,\lambda_i}$ ←

- Calibrated by an known surface reflectance Spectralon
- Under clear sky condition
- Diurnal pattern for characterizing BRDF of reference plates

Methodology
(Example of $R_{reference,\lambda_i}$)

$$R_{leaf,\lambda_i} = R_{reference,\lambda_i} * Radiation_{leaf,\lambda_i} / Radiation_{reference,\lambda_i} \quad (1)$$

$$R_{leaf,\lambda_i} = R_{reference,\lambda_i} * DN_{leaf,\lambda_i} / DN_{reference,\lambda_i} \quad (2)$$

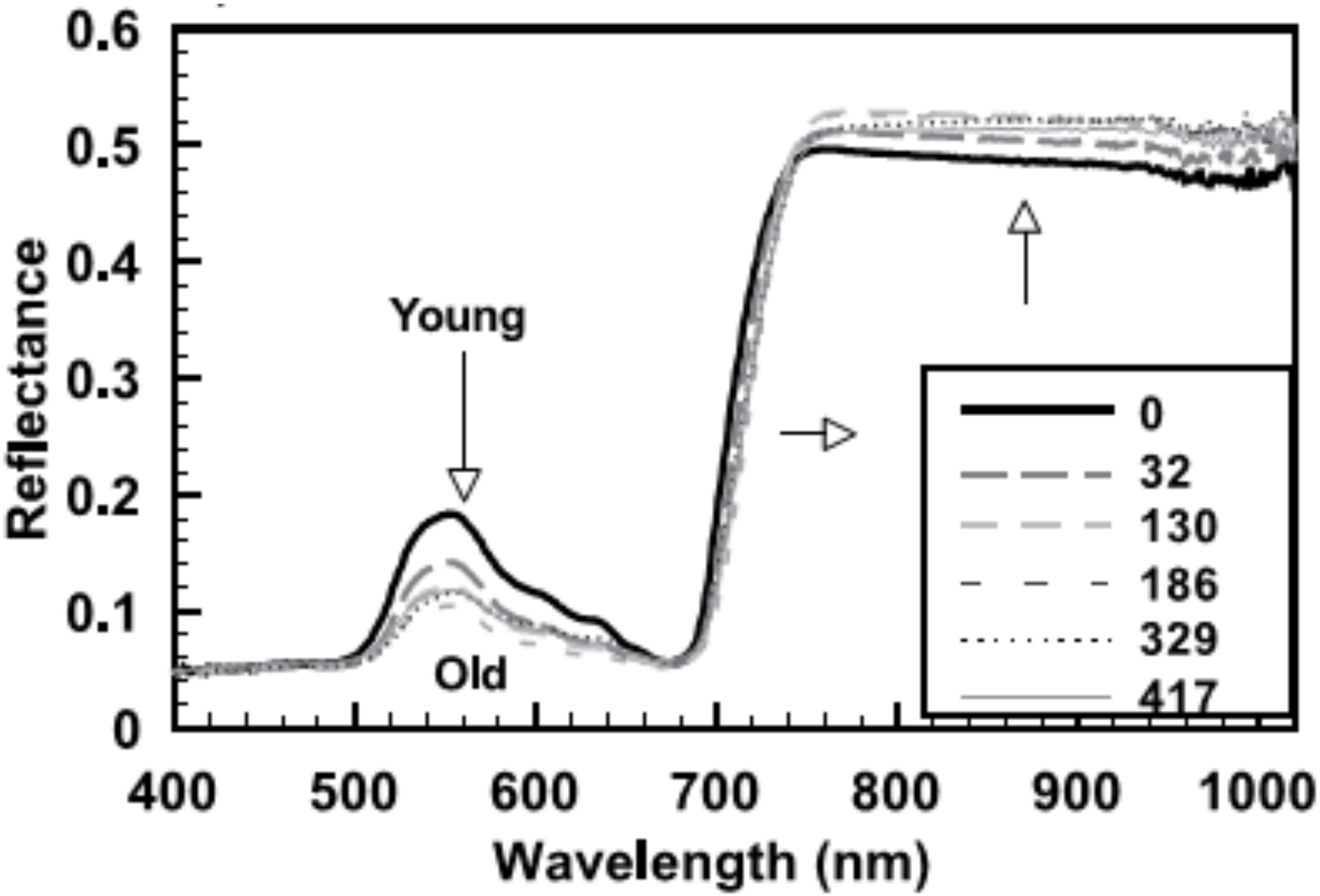


Characterizing diurnal BRDF of Reference Plates at UA campus, clear sky condition

Spectra-Age Model

Example species: *Aldina* (species name), *Fabaceae* (family name)

Temporal changes in spectral reflectance (Roberts et al., 1998)



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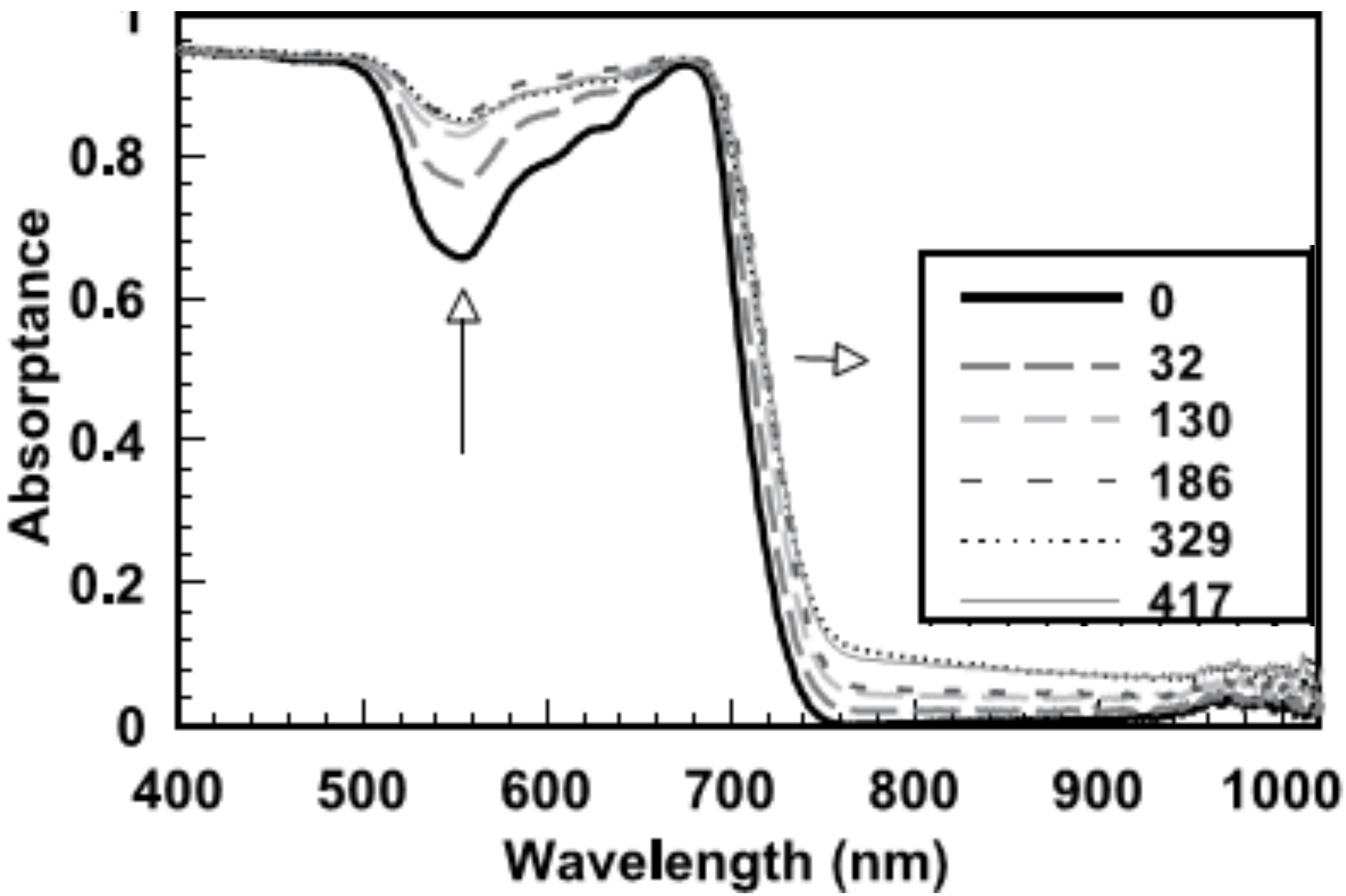

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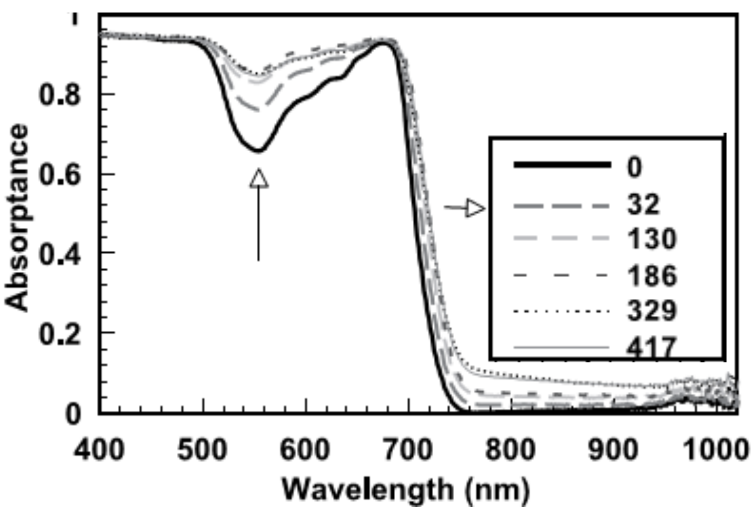
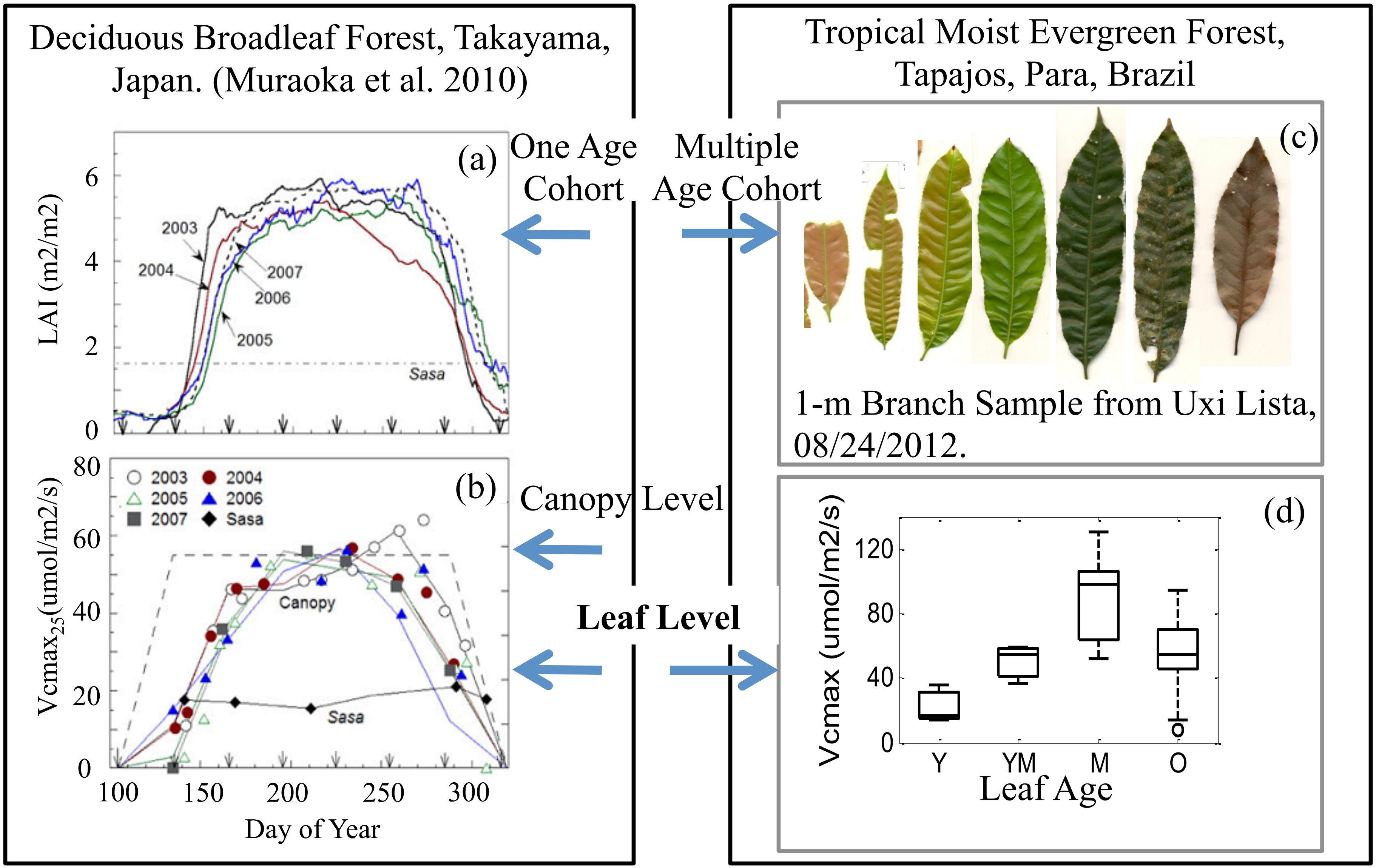


Spectra-Age Model by Doughty and Goulden (2008)

$$NIR_{absorbance} = 0.048 + 0.0027 * (months_{since\ leaf\ flush} - 3)$$

Deciduous Forests & Evergreen Tropical Forests



Materials: Leaf Demography Survey

- Collected one meter branches multiple times throughout the dry season.
- Branches from sun and shade microenvironments within the trees.
- Counted young, mature and old leaves on sampled branches.