Assessing sub-pixel vegetation structure from imaging spectroscopy data via simulation

Wei Yao, Martin van Leeuwen, Paul Romanczyk, Dave Kelbe, Mingming Wang, Scott Brown, Adam Goodenough, and Jan van Aardt

Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology

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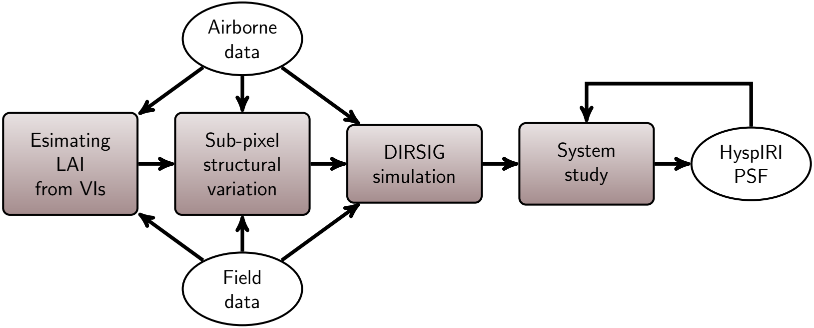
Outline

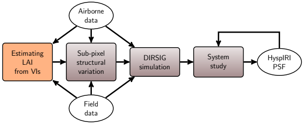
1. Introduction
   - Project outline and objectives
   - DIRSIG
2. Methods
   - Study area
   - Airborne and field data
   - Building virtual scenes
   - DIRSIG simulation
3. Results
   - Estimating LAI from VIs
   - Simulating AVIRIS & HyspIRI data
   - Assessing sub-pixel vegetation structure
4. Conclusions/Outlook

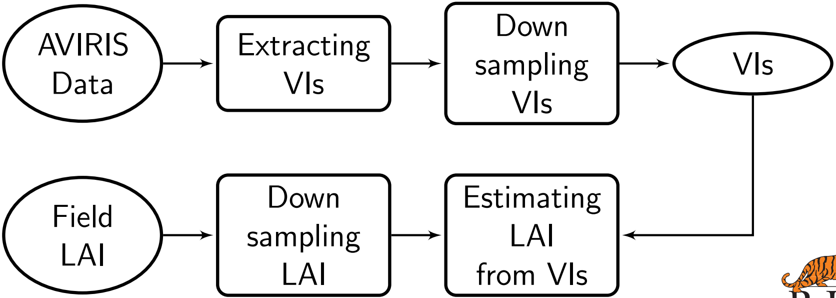
Introduction
Project outline and objectives



Introduction
Project outline and objectives

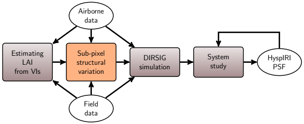
Stage 1: Estimating LAI from VIs

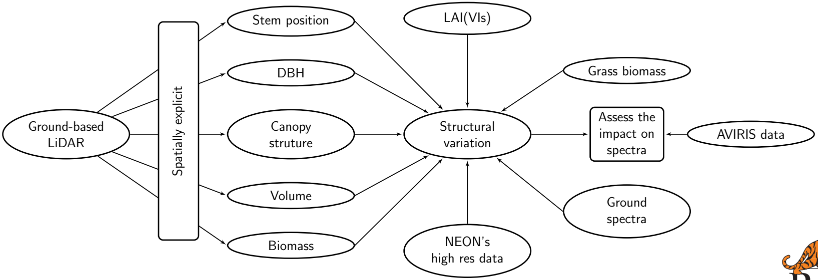




Introduction
Project outline and objectives

Stage 2: Sub-pixel structural variation

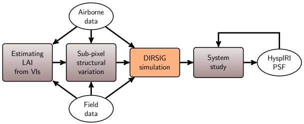


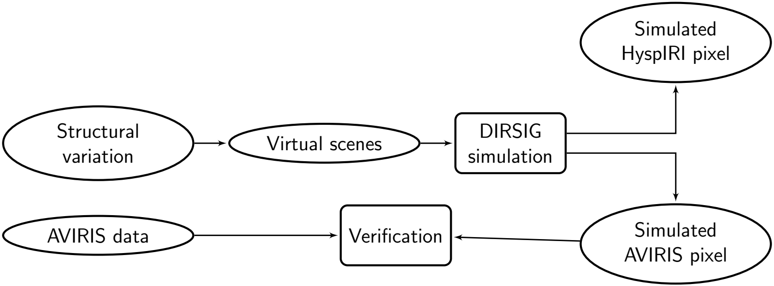


Introduction

Project outline and objectives

Stage 3: DIRSIG simulation



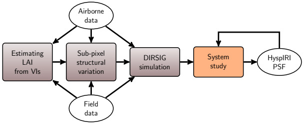


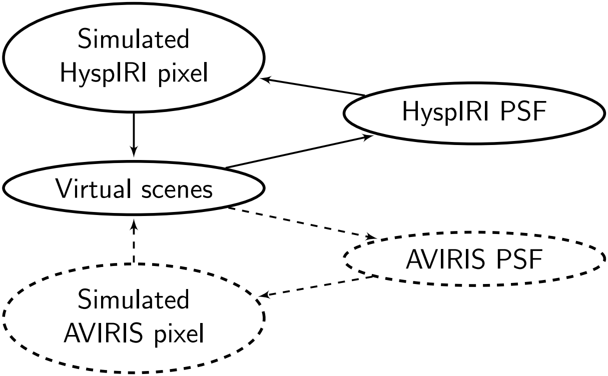
DIRSIG: The Digital Imaging and Remote Sensing Image Generation

Introduction

Project outline and objectives

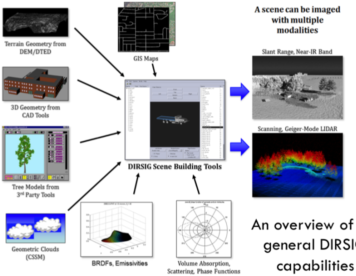
Stage 4: System study





Introduction
DIRSIG simulation - overview

DIRSIG = Digital Imaging and Remote Sensing Image Generation Model
Under development for 20+ years at Rochester Institute of Technology



An overview of the general DIRSIG capabilities

http://dirsig.org

- Image Modalities
  Visible through thermal infrared
  (0.4 - 20.0 μm)
  Passive sensing
  Active Laser sensing
  Active RF sensing
- Instruments
  Single pixel, 1D arrays and 2D arrays.
  Filter, diffraction/refraction, or
  interferogram-based photon collection
- Platforms
  Ground, air or space on static or moving
  platforms

Methods
Study area

The National Ecological Observatory Network (NEON), Pacific Southwest Domain (D17)

1. San Joaquin Experiment Range (Core site)
2. Soaproot Saddle (Relocatable site)

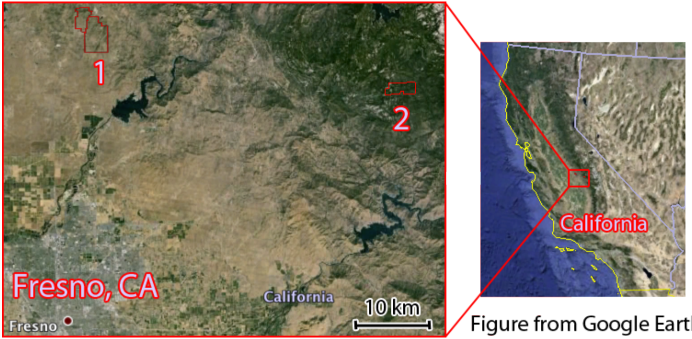


Figure from Google Earth

Methods
Field collection

1. San Joaquin Experiment Range:
   - June 9 - 14, 2013: 12 AOP sites (4, 8, 36, 112, 116, 361, 824, 952)
   - Oct 5 - 7, 2014: 3 AOP sites (36, 116, 824)

Site 36

Site 116

AOP: Airborne Observation Platform

Methods
Field collection

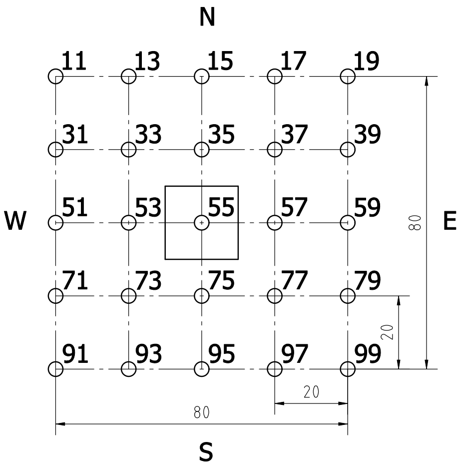
2. Soaproot Saddle:
   - June 16 - 20, 2013: 8 AOP sites (43, 63, 95, 143, 299, 331, 555, 1611)
   - Oct 8 - 10, 2014: 3 AOP sites (43, 143, 299)

Site 143

Site 299

AOP: Airborne Observation Platform

Methods
Field collection



Measurements at each spot within $80 \times 80m$ site:

1. LAI (AccuPAR LP-80)
2. Ground-based lidar (SICK LMS-151, RITTL)
3. Spectra (SVC HR-1024i)
4. Hemispherical photos
5. GPS position

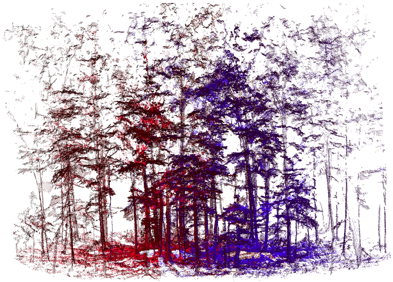
Methods
Airborne collection

- AVIRIS data collected during HyspIRI preparatory airborne campaign, summer 2013 & fall 2014.
- NEON imaging spectrometer (NIS) & LiDAR data collected in summer 2013.

Methods

Register multiple Terrestrial Laser Scanner (TLS) scans and extract stem map from TLS data

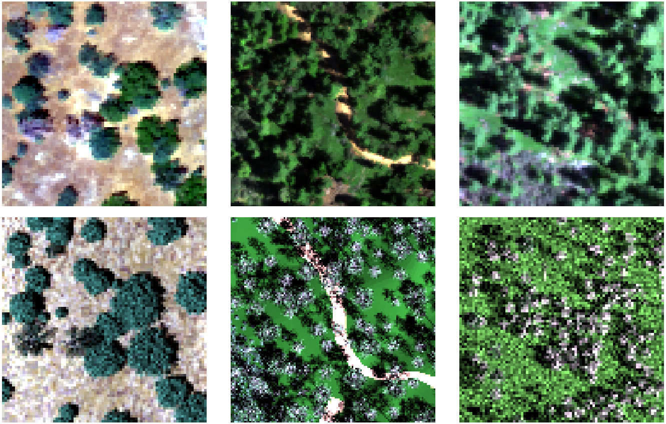
- Algorithm:
  Extract coordinates of trunk-ground intersection as tie-points for registration
  Rank potential correspondence sets using geometric constraints
  Use RANSAC to query candidate point set matches
- Features:
  No markers are placed in the scene
  No initial pose estimation is required



By Dave Kelbe, PhD student

Methods

Simulate NEON's high-resolution spectrometer data



NIS data

DIRSIG data

Site 116 Site 299 Site 143

Methods

Simulate HyspIRI

DIRSIG key settings

- Height = 600km
- GSD = 60m
- 224 bands, 380 - 2500nm, 10nm FWHM
- Use MODTRAN to simulate atmospheric radiative transfer

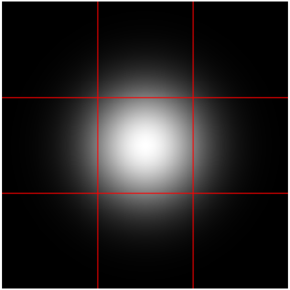
MODTRAN key settings:

- Enable multiple scattering (IMULT = +1)
- Mid-latitude summer model (MODEL = 2)
- RURAL extinction (IHAZE = 1)

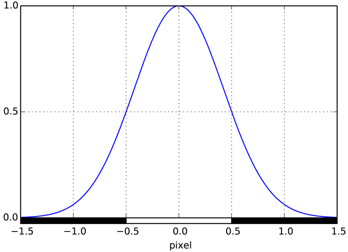
Methods

Simulate HyspIRI

Point spread function (PSF)
2-D Gaussian Function, FWHM = pixel size (60m GSD)



2-D Gaussian kernel

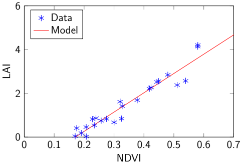


Profile of the kernel

Results
Estimating LAI from VIs

Simulated forest LAI vs NDVI

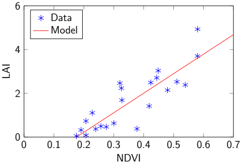
5 m transect spacing



$$LAI = 8.826 \cdot NDVI - 1.506$$

$$R^2 = 0.92$$

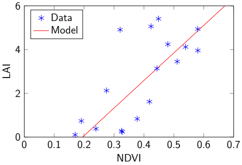
10 m transect spacing



$$LAI = 8.928 \cdot NDVI - 1.566$$

$$R^2 = 0.77$$

15 m transect spacing



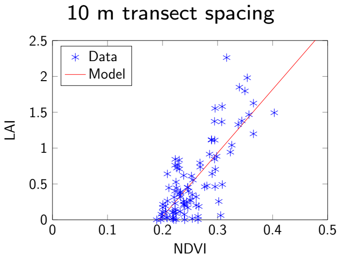
$$LAI = 12.61 \cdot NDVI - 2.457$$

$$R^2 = 0.66$$

Forest LAI can be measured along multiple transects.

Results
Estimating LAI from VIs

Measured forest LAI vs NDVI



$$\mathrm{LAI} = 8.858 \cdot \mathrm{NDVI} - 1.725$$

$$R^2 = 0.61$$

Regression model from simulated data:

$$\mathrm{LAI} = 8.928 \cdot \mathrm{NDVI} - 1.566$$

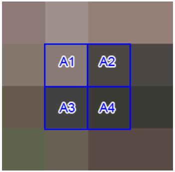
$$R^2 = 0.77$$

Forest LAI can be measure along multiple transects.

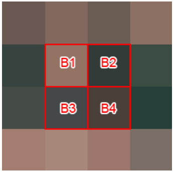
Methods
Simulating AVIRIS data

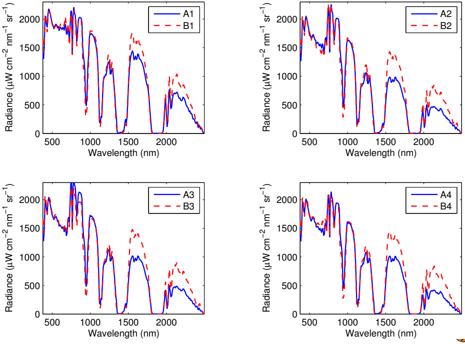
Verify the model using site 116 scene

AVIRIS data



Simulated data

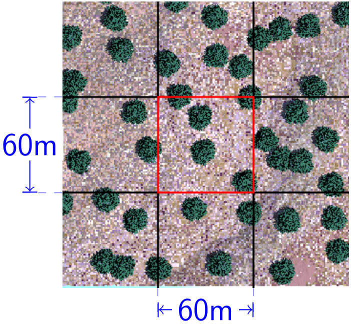




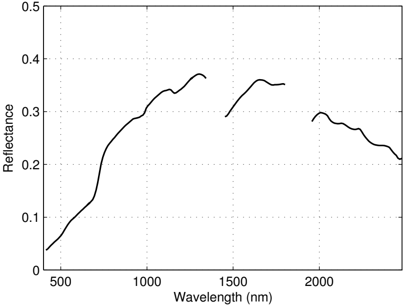
Results

Assessing sub-pixel vegetation structure

Density of the "forest"



d = 0.20



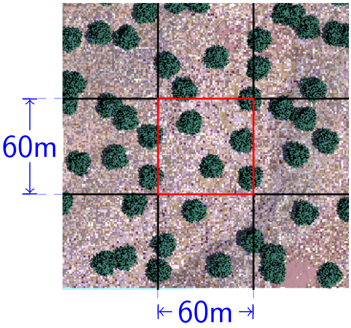
Spectrum of the center pixel

Density of the "forest" is quantified by tree canopy cover (d), the proportion of land area covered by tree crowns.

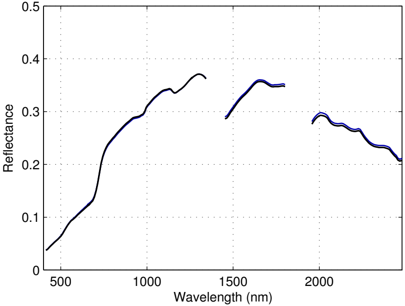
Results

Assessing sub-pixel vegetation structure

Density of the “forest”



$d = 0.22$



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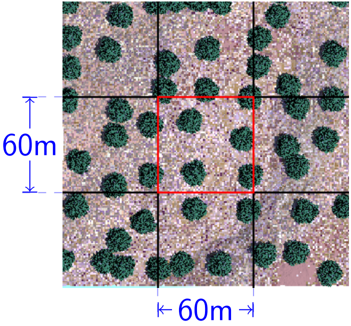
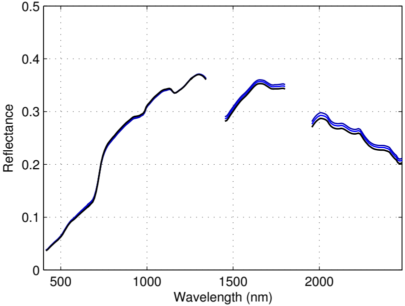


$d = 0.24$



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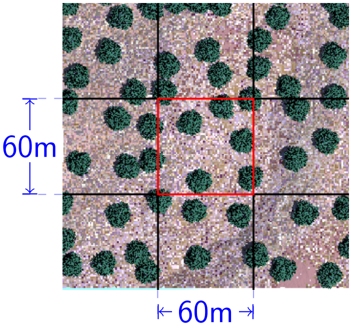
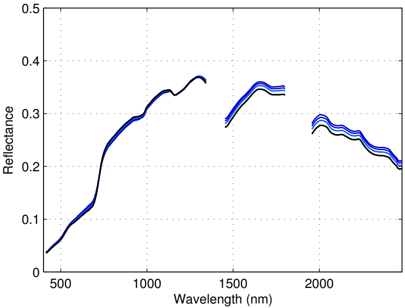
Assessing sub-pixel vegetation structure

Density of the "forest"



$d = 0.25$



Spectrum of the center pixel

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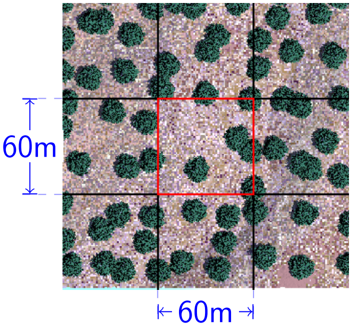
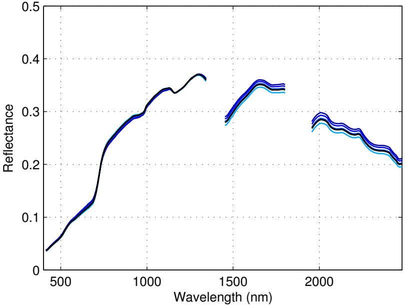
Results

Assessing sub-pixel vegetation structure

Density of the “forest”



$d = 0.30$



Spectrum of the center pixel

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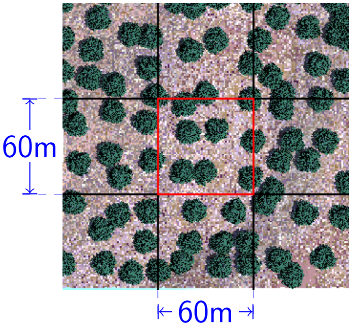
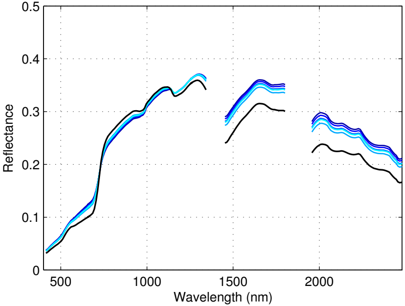
Results

Assessing sub-pixel vegetation structure

Density of the “forest”



$d = 0.36$



Spectrum of the center pixel

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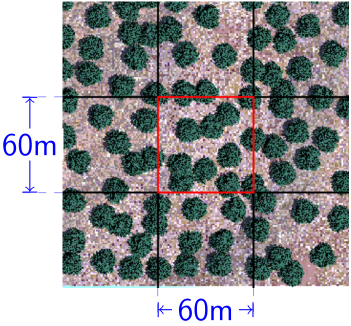
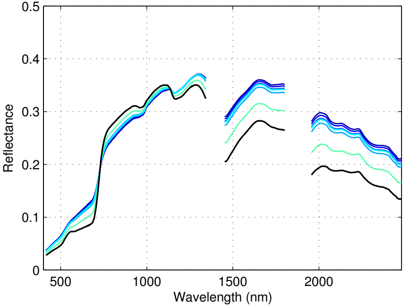
Results
Assessing sub-pixel vegetation structure

Density of the "forest"



$d = 0.40$



Spectrum of the center pixel

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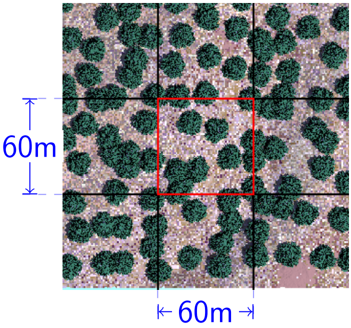
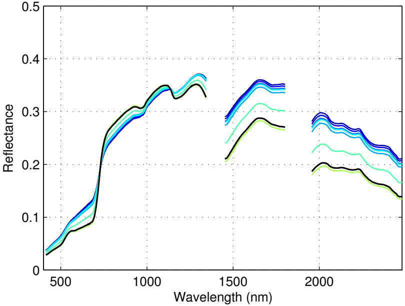
Results

Assessing sub-pixel vegetation structure

Density of the “forest”





$d = 0.43$

Spectrum of the center pixel

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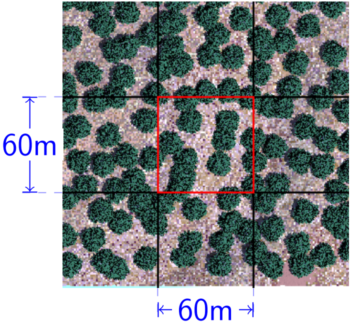
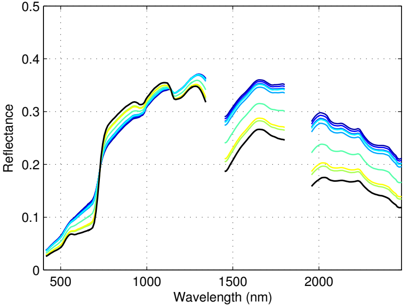
Results

Assessing sub-pixel vegetation structure

Density of the "forest"



$d = 0.50$



Spectrum of the center pixel

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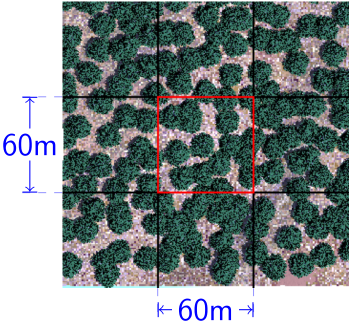
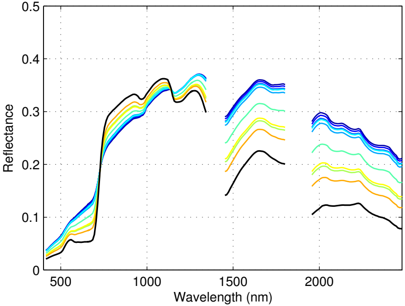
Results

Assessing sub-pixel vegetation structure

Density of the “forest”



d = 0.61



Spectrum of the center pixel

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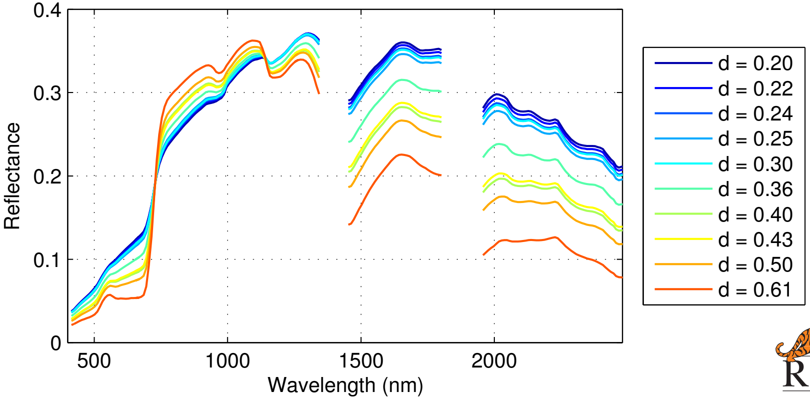
Results

Assessing sub-pixel vegetation structure

Density of the “forest”



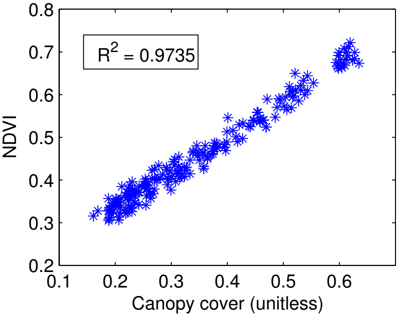
Results

NDVI vs density

- Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

- "Forest" density
  Tree canopy cover refers to the proportion of land area covered by tree crowns (m^2/m^2).

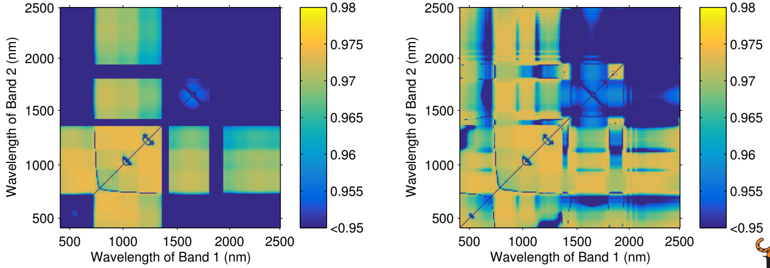


Results

Narrow band vegetation indices (VIs) to characterize the forest density

$$VI = \frac{Band1 - Band2}{Band1 + Band2}$$

R^2 value of regression models

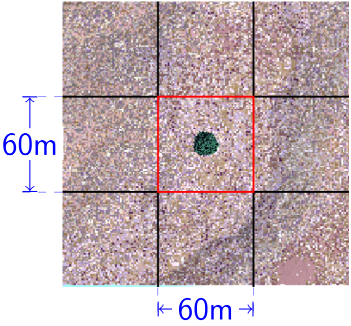


Reflectance VI   Radiance VI

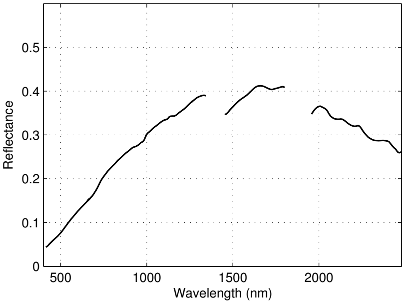
Results

Assessing sub-pixel vegetation structure

Tree position



Tree at (0, 0)

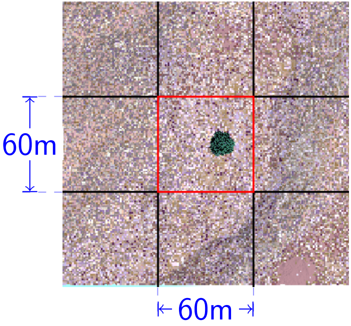


Spectrum of the center pixel

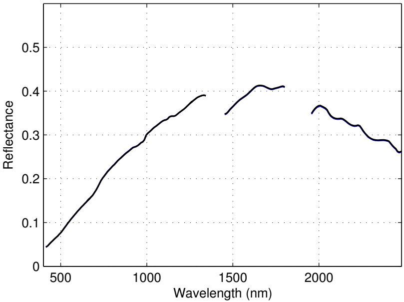
Results

Assessing sub-pixel vegetation structure

Tree position



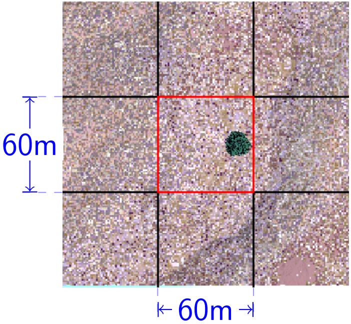
Tree at (10, 0)



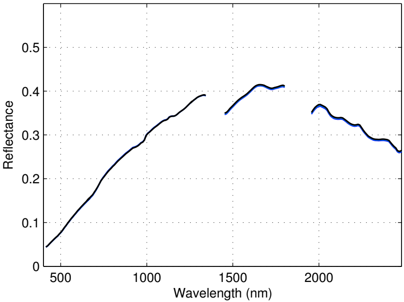
Spectrum of the center pixel

Results
Assessing sub-pixel vegetation structure

Tree position



Tree at (20, 0)

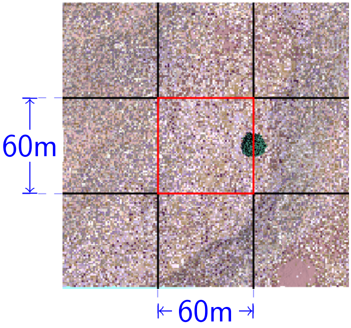


Spectrum of the center pixel

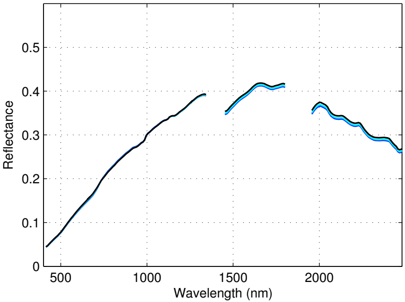
Results

Assessing sub-pixel vegetation structure

Tree position



Tree at (30, 0)

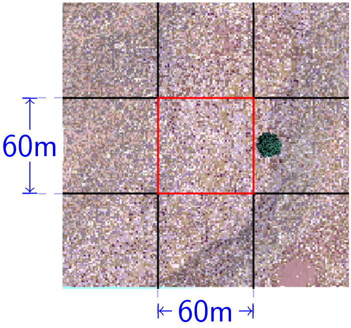


Spectrum of the center pixel

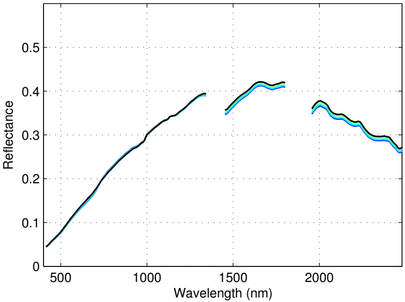
Results

Assessing sub-pixel vegetation structure

Tree position



Tree at (40, 0)

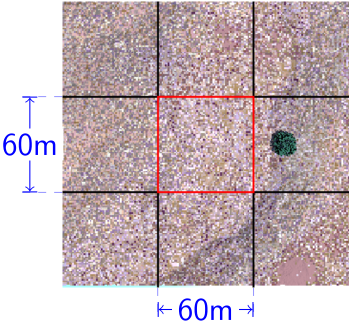


Spectrum of the center pixel

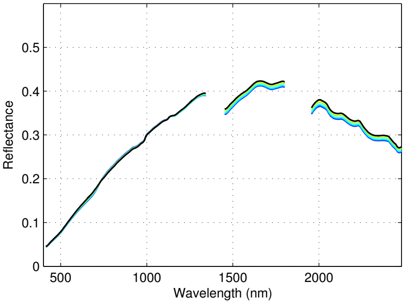
Results

Assessing sub-pixel vegetation structure

Tree position



Tree at (50, 0)

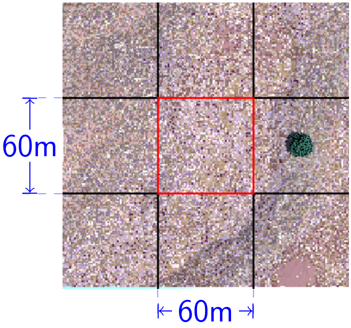


Spectrum of the center pixel

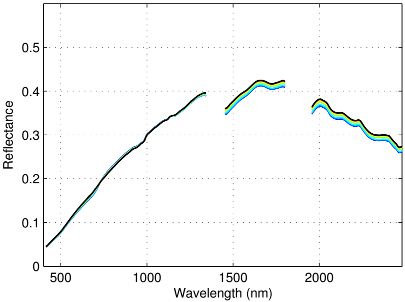
Results

Assessing sub-pixel vegetation structure

Tree position



Tree at (60, 0)

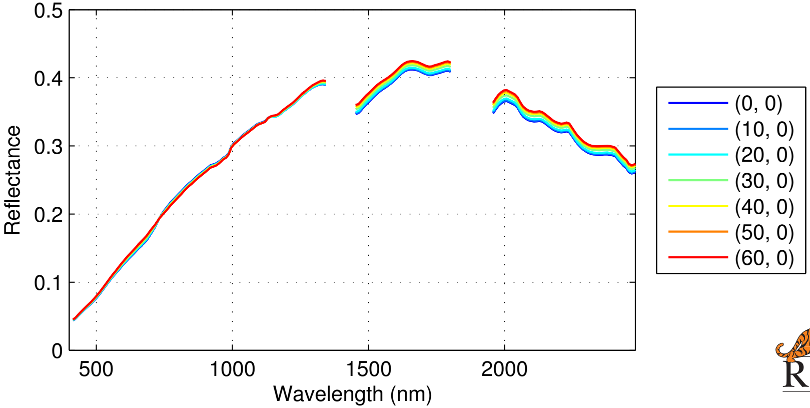


Spectrum of the center pixel

Results

Assessing sub-pixel vegetation structure

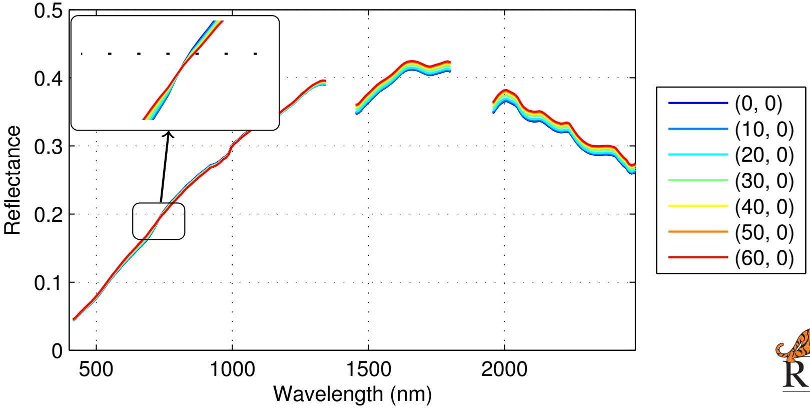
Tree position



Results

Assessing sub-pixel vegetation structure

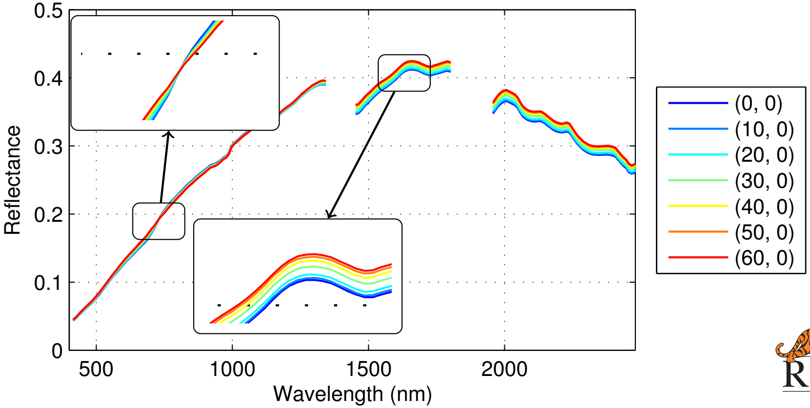
Tree position



Results

Assessing sub-pixel vegetation structure

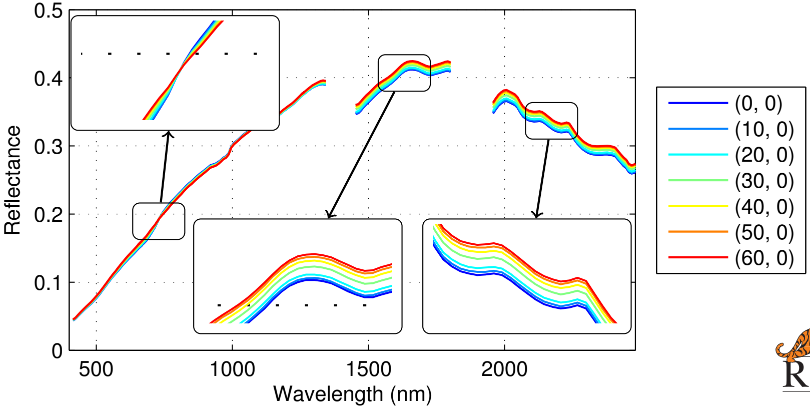
Tree position



Results

Assessing sub-pixel vegetation structure

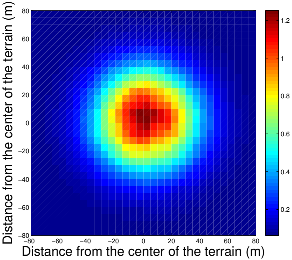
Tree position

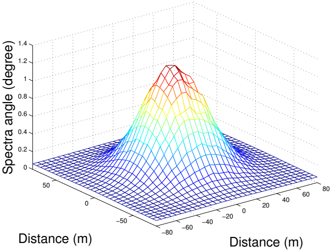


Results

The spectral angle distribution

$$\theta = \cos^{-1}\left[\frac{\mathbf{x_1}\cdot\mathbf{x_2}}{\|\mathbf{x_1}\|\|\mathbf{x_2}\|}\right]$$





Conclusions/Outlook

Conclusions

Results indicate:

1. VIs could be used to estimate forest density from HyspIRI data.
2. The effect of vegetation's position is mainly determined by the PSF of spectrometer.
3. The system's suitability for consistent global vegetation structural assessments could be improved by adapting calibration strategies to account for this variation in sub-pixel structure.

Conclusions/Outlook

Future work

1. Re-run current simulations according to updated VSWIR specification:
   - 30 m GSD
   - new PSF
2. Increase the number of simulations to assess other sub-pixel vegetation structural variables:
   - height of trees
   - crown size
   - forest species
3. Quantify the simulation results.
4. Investigate Lidar-based approaches for calibration of HyspIRI structural estimates.

Conclusions/Outlook

Associated Publications

Refereed journal articles

- Yao, W., van Aardt, J., Romanczyk, P., Kelbe, D., van Leeuwen, M., Brown, S., and Goodenough, G. "Reviewing LAI collection protocol – a simulation study focused on PAR sensor". *Sensors*. In preparation.
- Yao, W., van Aardt, J., Romanczyk, P., Kelbe, D., van Leeuwen, M., Brown, S., and Goodenough, G. "A simulation approach to assessing sub-pixel vegetation structure impacts on imaging spectrometer response". *IEEE Transactions on Geoscience and Remote Sensing*. In preparation.

Conclusions/Outlook

Associated Publications

Conference Proceedings & Posters

- Yao, W., van Aardt, J., Romanczyk, P., Brown, S., Kelbe, D., van Leeuwen, M., and Kerekes, J. (2015b). "Towards robust forest leaf area index assessment using an imaging spectroscopy simulation approach". In: *Proceedings of International Geoscience and Remote Sensing Symposium (IGARSS)*. Milan, Italy. July 26-31, 2015.
- Yao, W., van Aardt, J., Romanczyk, P., Kelbe, D., and van Leeuwen, M. (2015a). "Assessing the Impact of Sub-pixel Vegetation Structure on Imaging Spectroscopy Via Simulation". In: *Proceedings of SPIE. Vol. 9472.* Baltimore, MD, USA, 94721K94721K-7. doi: 10.1117/12.2176992.
- Yao, W., van Aardt, J., Romanczyk, P., Kelbe, D., van Leeuwen, M., and Kampe, T. (2015c). "Constructing Virtual Forest Scenes for Assessment of Sub-pixel Vegetation Structure From Imaging Spectroscopy ". In: *American Geophysical Union (AGU) Fall Meeting.* San Francisco, CA, USA. December 14-18, 2015.

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Wei Yao (wxy3806@rit.edu), PhD student

Jan van Aardt (vanaardt@cis.rit.edu), Adviser

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