Spectral-structural interactions at fine-scales

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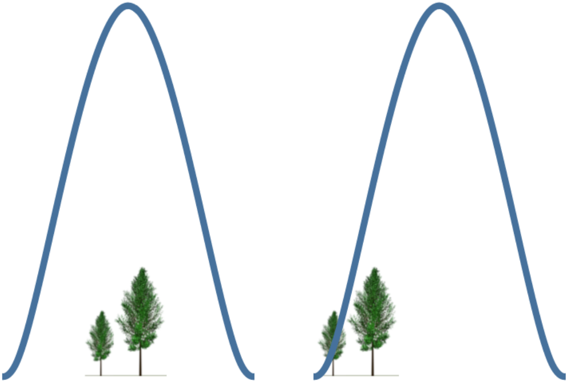
Outline

1. Introduction
   - Project outline and objectives
   - DIRSIG
2. Methods
   - Study area
   - Airborne and field data
   - Building virtual scenes
   - DIRSIG simulation
3. Results
   - Simulation results
4. Conclusions/Outlook
   - Future work

Introduction
Project outline and objectives

Assessing the impact of sub-pixel vegetation structure on imaging spectroscopy



Introduction
Project outline and objectives

How large is a 60 $\times$ 60 m pixel?

Photograph courtesy of Howard Bruce Campbell (AirplaneHome.com)

Introduction
Project outline and objectives

- *Objective 1*: Assess how leaf area index (LAI) affects the spectral response on a per-pixel basis.
  - Determine a stable and valid LAI measuring protocol which could be used to collect ground truth data;
  - Evaluate a range of vegetation indices (VIs), extracted from narrow-band imaging spectroscopy data, to estimate LAI; and
  - Assess the scalability of selected narrow-band VIs from 20 m AVIRIS to 60 m HyspIRI data sets.

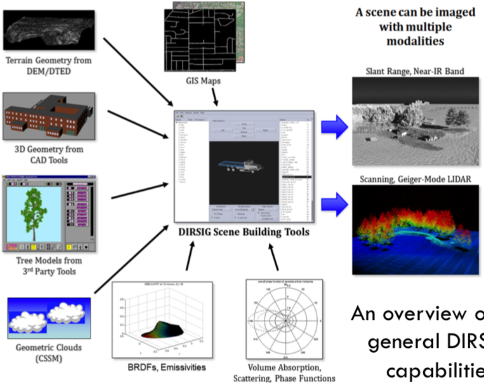
Introduction
Project outline and objectives

- *Objective 2*: Assess how sub-pixel variations in tree canopy height, forest cover, forest clustering, and other forest inventory variables affect the spectral response on a per-pixel basis.
- *Objective 3*: Evaluate how the sub-pixel structural variation interacts with the HyspIRI systems response characteristics, most notably in terms of the point spread function (PSF).

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

Methods
Study area

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

1. San Joaquin Experimental Range (SJER, core site)
2. Soaproot Saddle (SOAP, relocatable site)

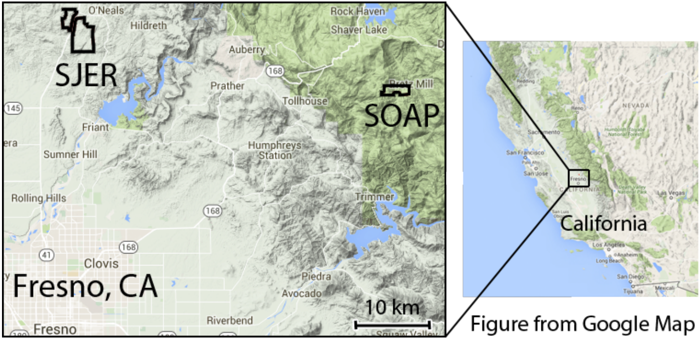


Figure from Google Map

Methods
Field collection

1. San Joaquin Experimental Range:
   - Field data collected in 12 AOP plots during June 9 - 14, 2013

plot 36

plot 116

AOP: Airborne Observation Platform

Methods
Field collection

2. Soaproot Saddle:
   - Field data collected in 8 AOP plots during June 16 - 20, 2013

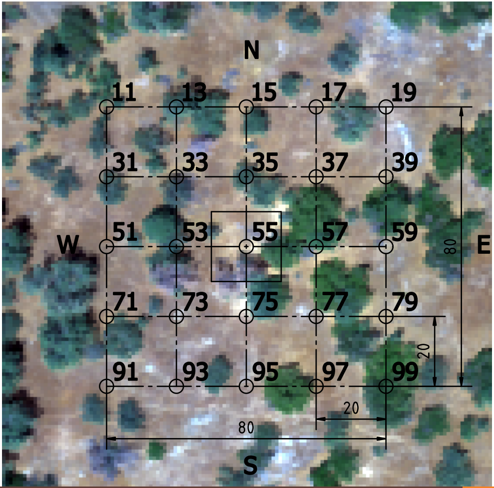
Plot 43

Plot 299

AOP: Airborne Observation Platform

Methods

Field collection



Measurements at each spot within 80 m × 80 m plot:

1. LAI (AccuPAR LP-80)
2. Terrestrial laser scanning (SICK LMS-151)
3. Spectra (SVC HR-1024i)
4. Hemispherical photos
5. GPS position

Methods
Airborne collection

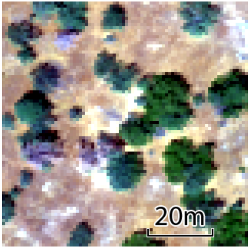
Airborne data were collected by

1. NASA's "classic" Airborne Visible Near-Infrared Imaging Spectrometer (AVIRIS-C),
2. NEON's high-resolution imaging spectrometer (NIS), and
3. NEON's small-footprint waveform-recording LiDAR

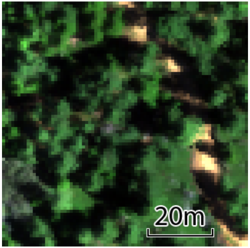
①: http://aviris.jpl.nasa.gov
②③: http://data.neoninc.org

Methods
Building virtual scenes

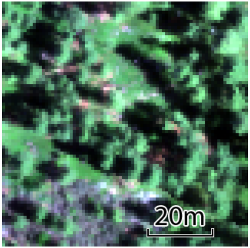
Three plots were selected to build virtual scene



Plot 116



Plot 299

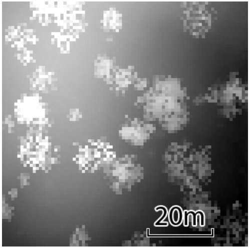


Plot 143

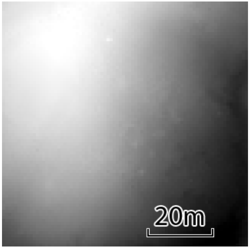
Methods

Building virtual scenes

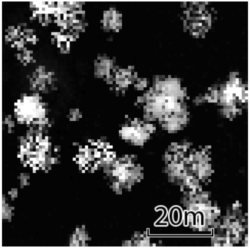
NEON's LiDAR products



DSM



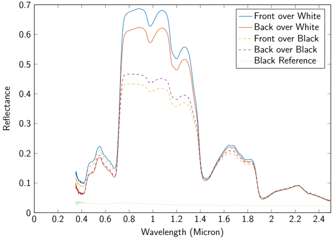
DTM

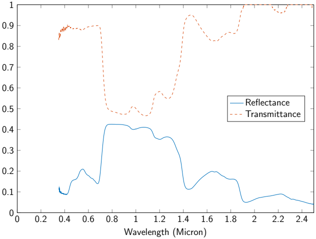


DHM

Methods
Building virtual scenes

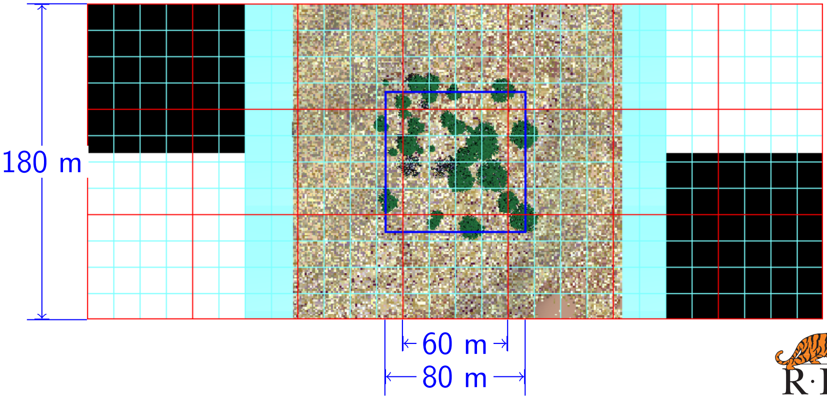
Leaf spectral samples





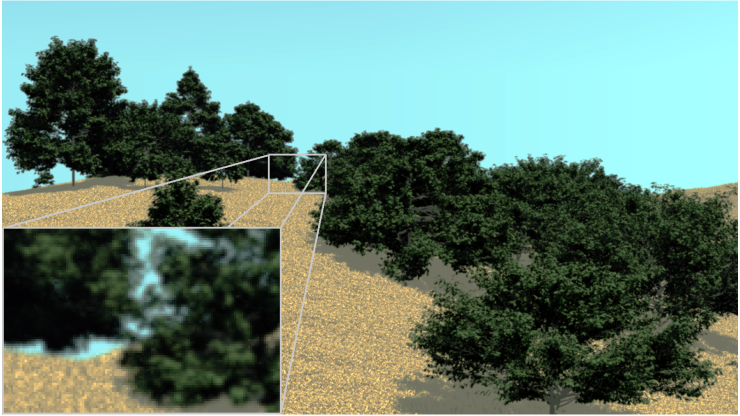
Methods
Building virtual scenes

Virtual scene layout



Methods
Building virtual scenes

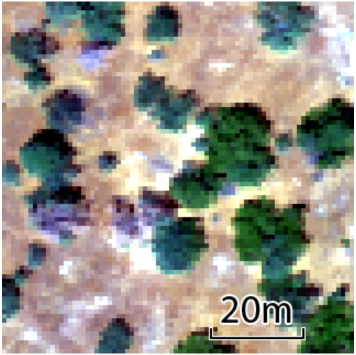
The side view of plot 116 scene



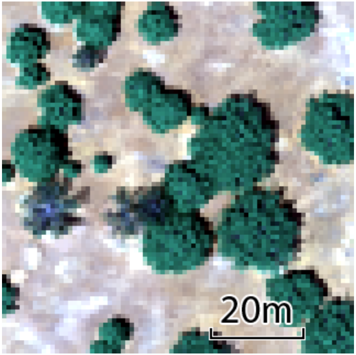
Methods

Simulate AVIRIS data

Verify the plot 116 scene by simulating NEON's high-resolution spectrometer (NIS)



NIS data



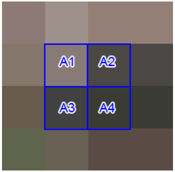
DIRSIG simulation results

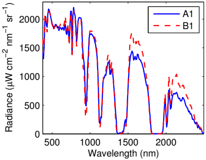
Methods

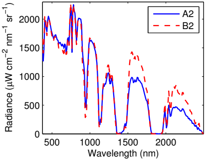
Simulate AVIRIS data

Verify the model by the plot 116 scene

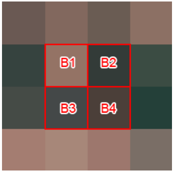
AVIRIS data

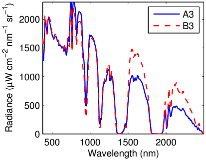


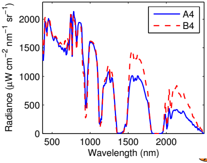




Simulated data







Methods

Simulate HyspIRI

DIRSIG key settings

- Height $= 600$km
- GSD $= 60$m
- 224 bands, 380 - 2500nm, 10nm FWHM
- Date & time: 2013-06-12T19:00:00 (UTC)
- Use MODTRAN to simulate atmospheric radiative transfer

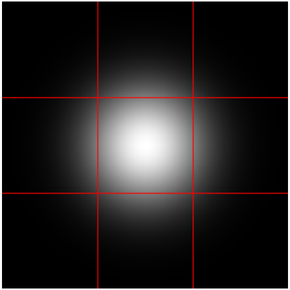
MODTRAN key settings:

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

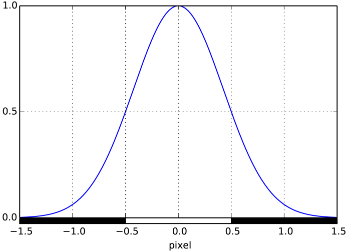
Methods

Simulate HyspIRI

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



2-D Gaussian kernel



Profile of the kernel

Methods

Simulate HyspIRI

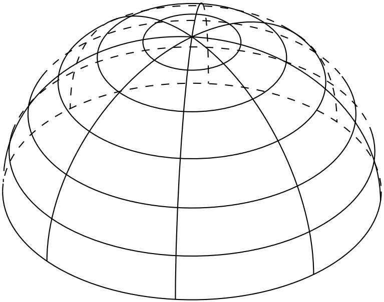
Generate multiple simulated HyspIRI data sets of different:

- Leaf area index (LAI)
- Canopy cover
- Position and distribution of trees
- Tree clustering

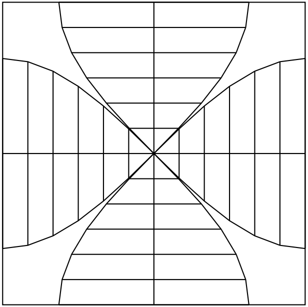
Methods

Simulate PAR/LAI sensor

Project a hemisphere onto a plane for data collection and analysis



Hemisphere



Plane

Methods

Simulate PAR/LAI sensor

DIRSIG key settings:

- Data-driven detector model
- Master detector array: 350×350
- Secondary detector array: 100×100 (for sun disk)
- Use MODTRAN to simulate atmospheric radiative transfer

MODTRAN key settings:

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

Above-canopy PAR

06/12/2013, 07:00-17:00

Methods

Simulate PAR/LAI sensor

Below-canopy PAR

Real Image

DIRSIG Simulation

Methods
Simulate PAR/LAI sensor

Below-canopy PAR

Real Image

DIRSIG Simulation

Methods

Simulate PAR/LAI sensor

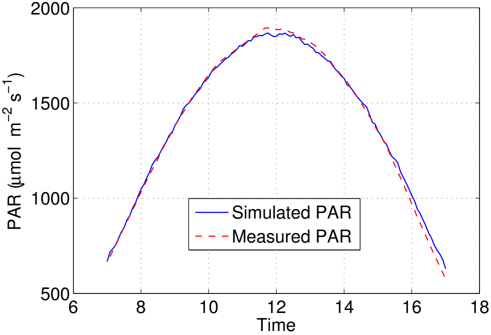
Below-canopy PAR

Real Image

DIRSIG Simulation

Results
Simulation results

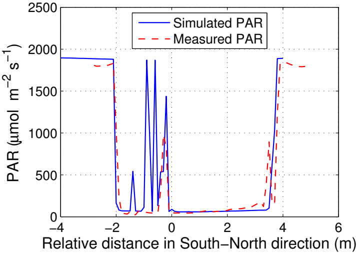
Above-canopy PAR



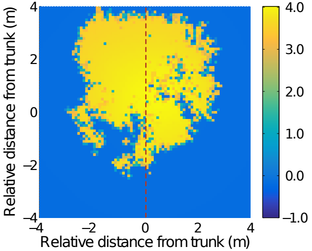
06/12/2013, 07:00-17:00

Results
Simulation results

Below-canopy PAR and LAI of single canopy



Simulated PAR under a canopy

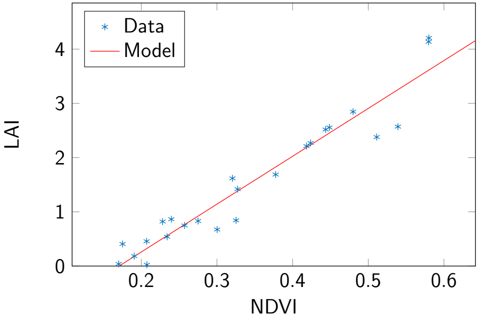


LAI calculated from simulated PAR

The LAI of a single canopy can be measured along a transect

Results
Simulation results

Sparse forest LAI



$$LAI = 8.826 \cdot NDVI - 1.506$$
$$R^2 = 0.92$$

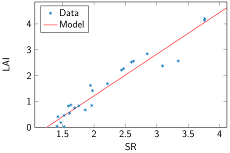
The LAI of forest can be measured along multiple transects.

- LAI was estimated from simulated PAR measurements of a virtual PAR sensor in DIRSIG
- Normalized Difference Vegetation Index (NDVI) was extracted from simulated imaging spectroscopy data

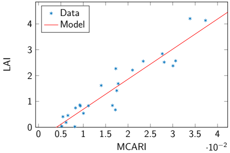
Results

Simulation results

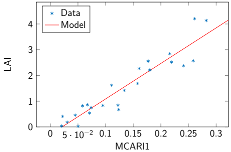
Sparse forest LAI: other vegetation indices



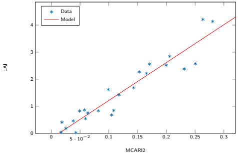
$$LAI = 1.612 \times SR - 2.007$$
$$R^2 = 0.929$$



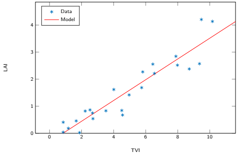
$$LAI = 116.435 \times MCARI - 0.468$$
$$R^2 = 0.891$$



$$LAI = 13.795 \times MCARI1 - 0.292$$
$$R^2 = 0.890$$



$$LAI = 14.003 \times MCARI2 - 0.187$$
$$R^2 = 0.911$$



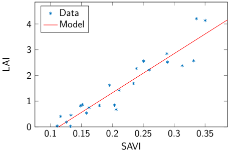
$$LAI = 0.384 \times TVI - 0.323$$
$$R^2 = 0.889$$

Haboudane, D., *et. al.* "*Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture.*" Remote sensing of environment 90, no. 3 (2004): 337-352.

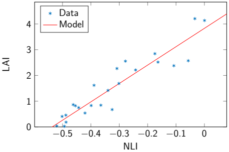
Results

Simulation results

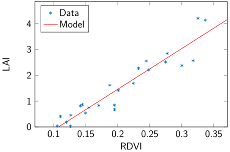
Sparse forest LAI: other vegetation indices



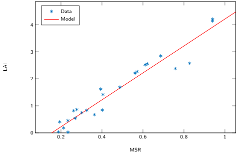
$$LAI = 15.221 \times SAVI - 1.718$$
$$R^2 = 0.895$$



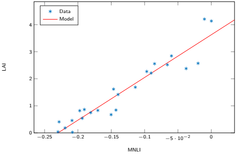
$$LAI = 7.139 \times NLI + 3.829$$
$$R^2 = 0.879$$



$$LAI = 15.767 \times RDVI - 1.693$$
$$R^2 = 0.902$$



$$LAI = 4.982 \times MSR - 0.772$$
$$R^2 = 0.936$$



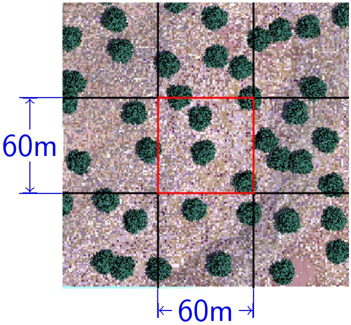
$$LAI = 15.786 \times MNLI + 3.627$$
$$R^2 = 0.914$$

Gong, P., *et. al.* "*Estimation of forest leaf area index using vegetation indices derived from Hyperion hyperspectral data.*" Geosci. Remote Sens. IEEE Trans. On 41, (2003): 1355-1362.

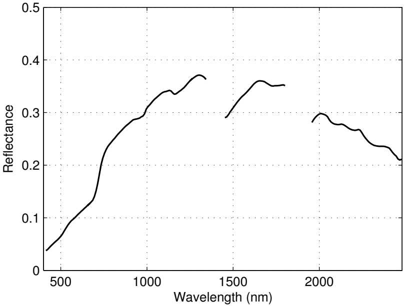
R·I·T

Results
Simulation results

Canopy cover (CC)



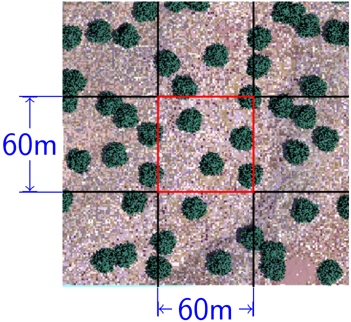
CC = 0.20



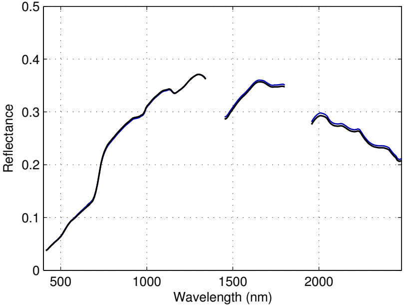
Spectrum of the center pixel

Results
Simulation results

Canopy cover (CC)



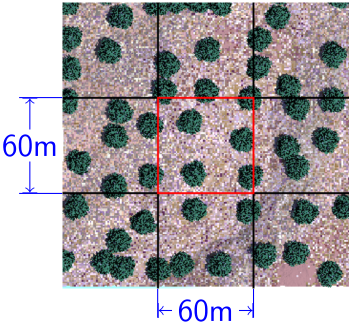
CC = 0.22



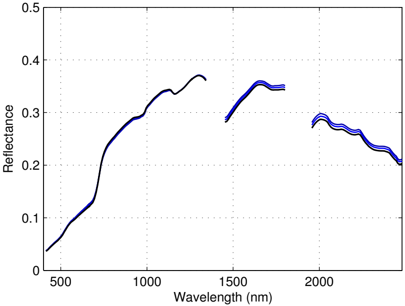
Spectrum of the center pixel

Results
Simulation results

Canopy cover (CC)



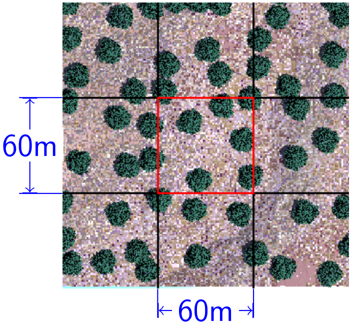
CC = 0.24



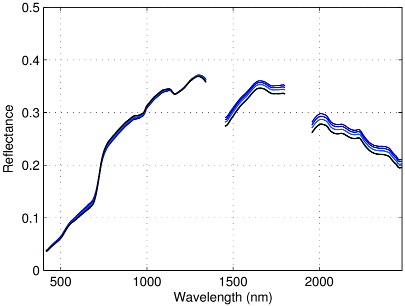
Spectrum of the center pixel

Results
Simulation results

Canopy cover (CC)



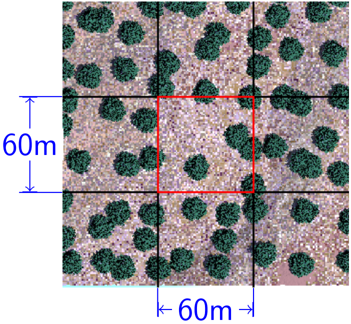
CC = 0.25



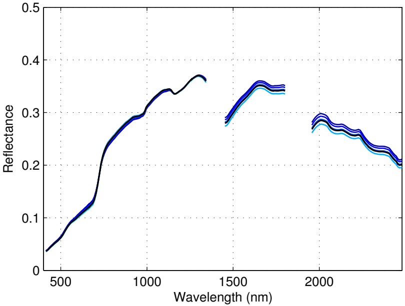
Spectrum of the center pixel

Results
Simulation results

Canopy cover (CC)



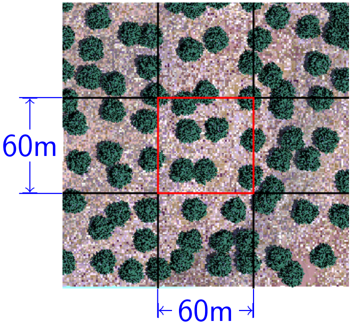
CC = 0.30



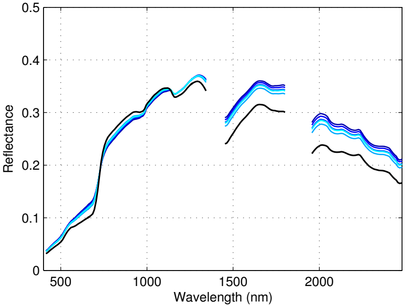
Spectrum of the center pixel

Results
Simulation results

Canopy cover (CC)



CC = 0.36

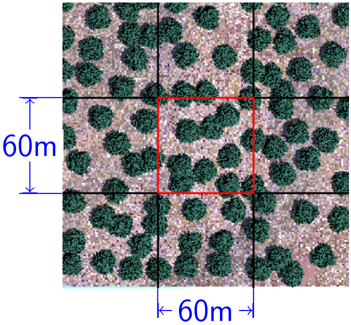


Spectrum of the center pixel

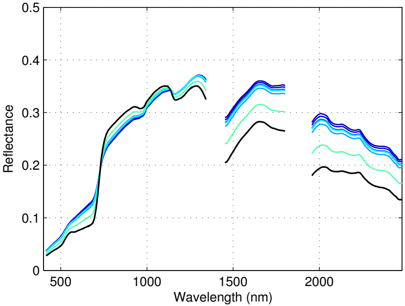
Results

Simulation results

Canopy cover (CC)



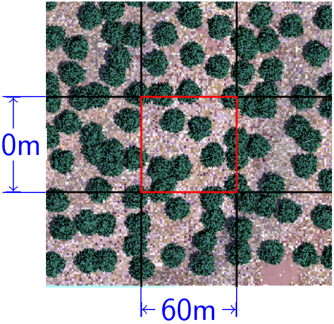
CC = 0.40



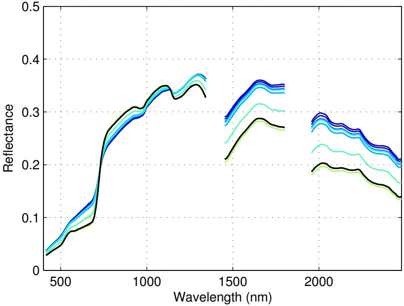
Spectrum of the center pixel

Results
Simulation results

Canopy cover (CC)



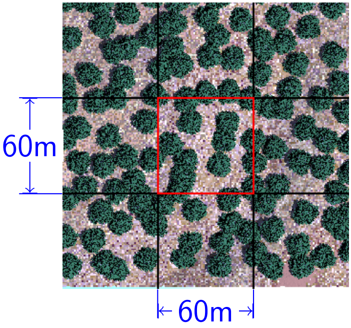
CC = 0.43



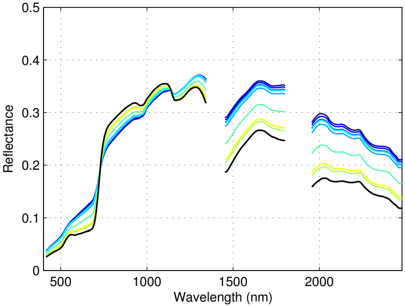
Spectrum of the center pixel

Results
Simulation results

Canopy cover (CC)



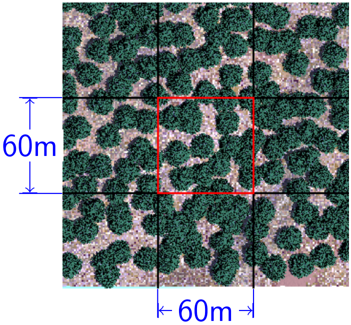
CC = 0.50



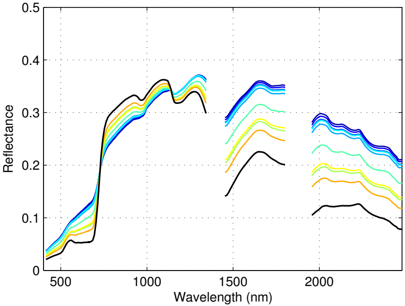
Spectrum of the center pixel

Results
Simulation results

Canopy cover (CC)



CC = 0.61

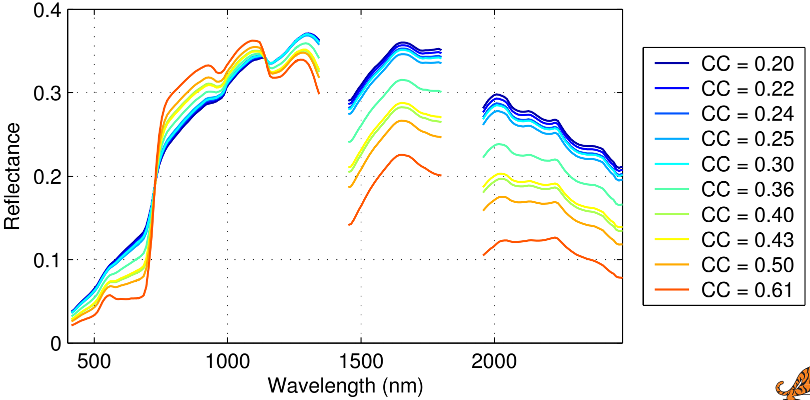


Spectrum of the center pixel

Results

Simulation results

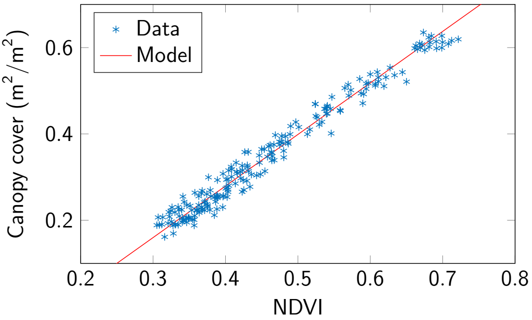
Canopy cover (CC)



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

Results
Simulation results

Canopy cover (CC)



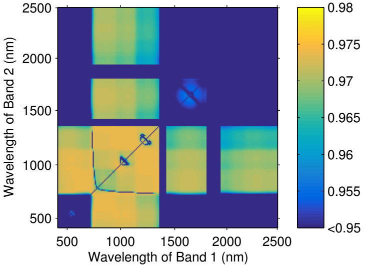
$$CC = 1.163 \cdot NDVI - 0.184$$
$$R^2 = 0.97$$

Results

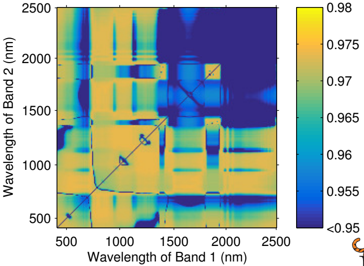
Narrow band vegetation indices (VIs) to characterize the canopy cover

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

R^2 value of regression models



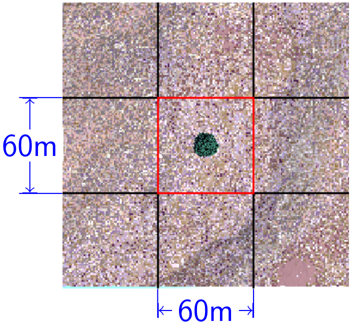
Reflectance VI



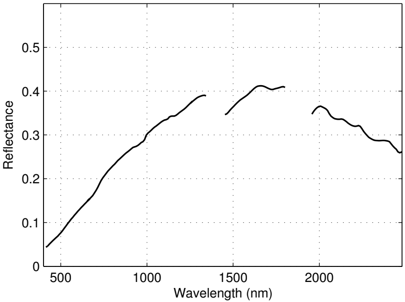
Radiance VI

Results
Simulation results

Tree position



Tree at (0, 0)

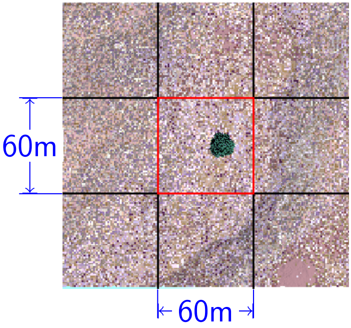


Spectrum of the center pixel

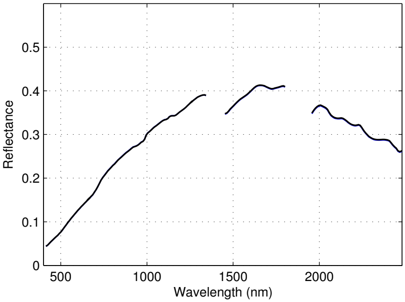
Results

Simulation results

Tree position



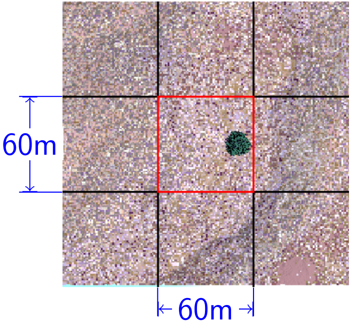
Tree at (10, 0)



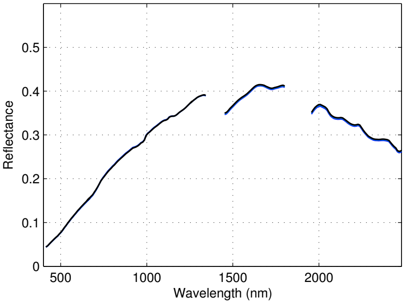
Spectrum of the center pixel

Results
Simulation results

Tree position



Tree at (20, 0)

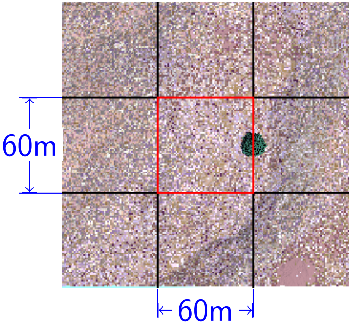


Spectrum of the center pixel

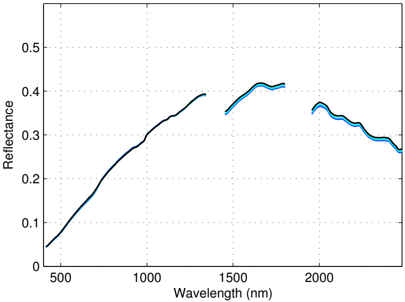
Results

Simulation results

Tree position



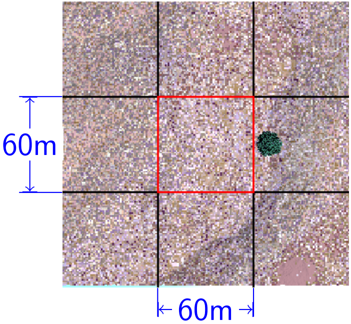
Tree at (30, 0)



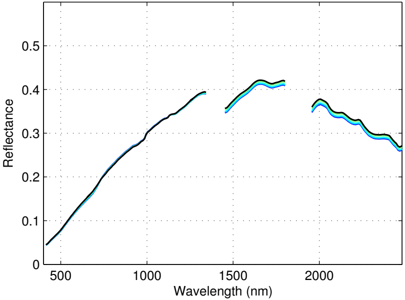
Spectrum of the center pixel

Results
Simulation results

Tree position



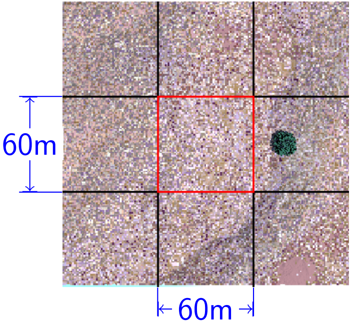
Tree at (40, 0)



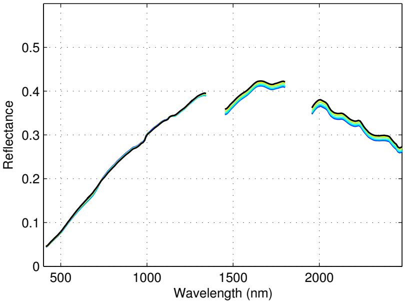
Spectrum of the center pixel

Results
Simulation results

Tree position



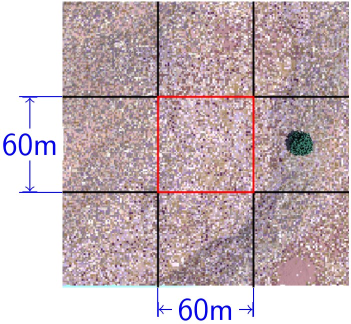
Tree at (50, 0)



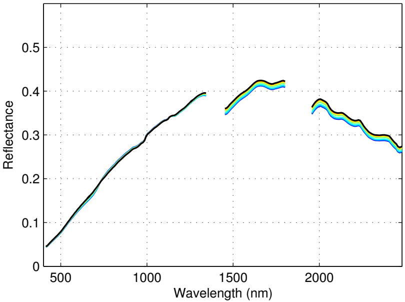
Spectrum of the center pixel

Results
Simulation results

Tree position



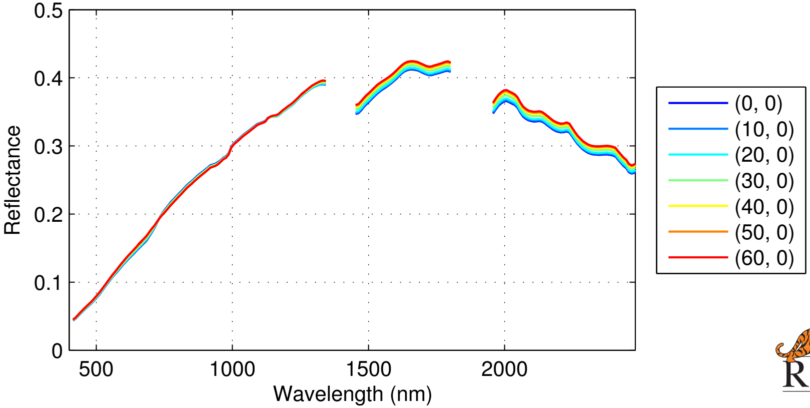
Tree at (60, 0)



Spectrum of the center pixel

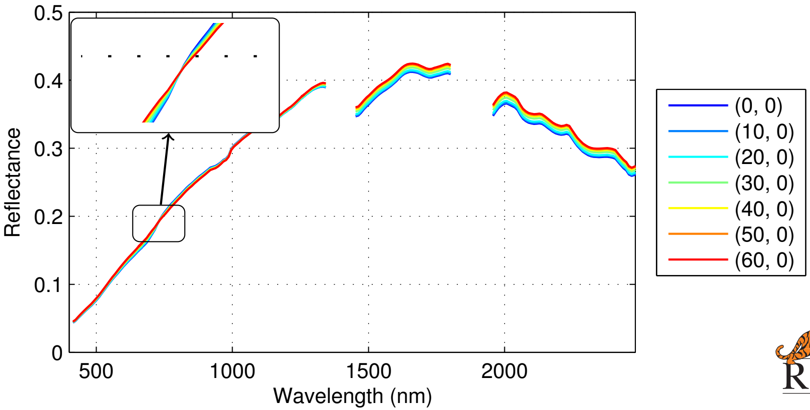
Results
Simulation results

Tree position



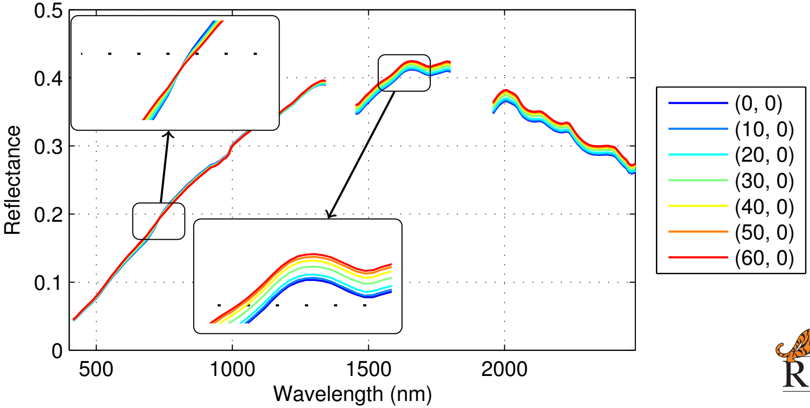
Results
Simulation results

Tree position



Results
Simulation results

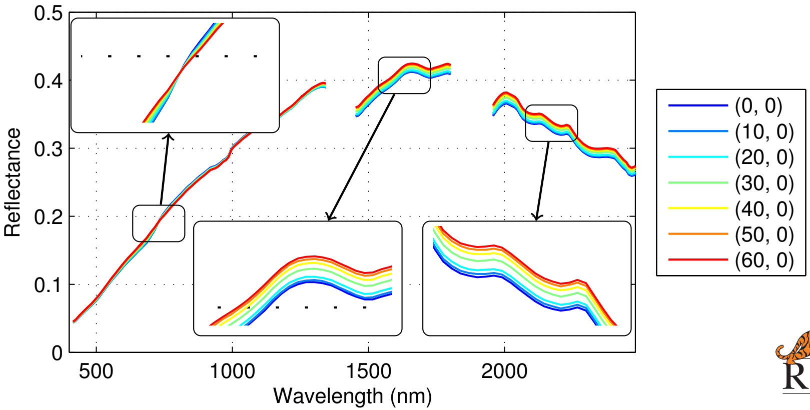
Tree position



Results

Simulation results

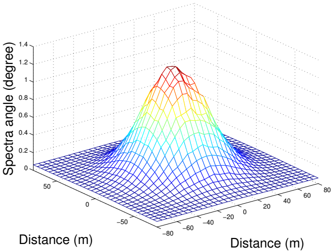
Tree position

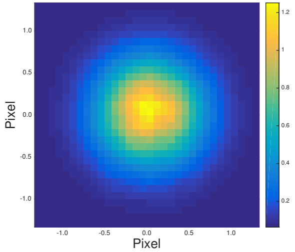


Results
Simulation results

Tree position: spectral angle

$$\theta(x, y) = \cos^{-1}\left[\frac{\mathbf{x}(x, y) \cdot \mathbf{x}_0}{\|\mathbf{x}(x, y)\| \cdot \|\mathbf{x}_0\|}\right]$$





Conclusions/Outlook

Conclusions

Results indicate:

1. HyspIRI is sensitive to forest density in the blue and red spectral regions due to pigment concentration changes, as well as the SWIR region due to water content variation.
2. The effect of tree position is determined by the system's PSF.
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. Increase the number of simulations to assess other sub-pixel vegetation structural variables:
    - tree clustering
    - crown size
2. Quantify the simulation results:
    - employ statistical methods (wavelength pair-wise comparison, derivative analyses) to analyze simulation results
3. Investigate LiDAR-based approaches for calibration of HyspIRI structural estimates

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