Towards a verdict on the influence of sub-pixel vegetation variation on global ecosystem assessment via imaging spectroscopy

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October 19 2017

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   - Assessing pixel-level forest density
   - Assessing sub-pixel tree position
   - Assessing sub-pixel forest clustering
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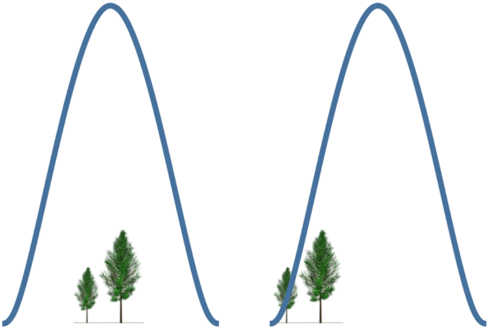
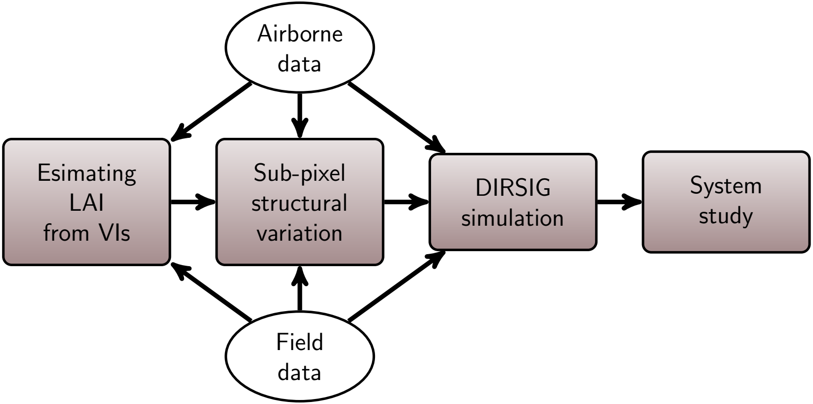
Assessing the impact of sub-pixel vegetation structure on imaging spectroscopy



- *Objective 1.* Assess how variation in 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-C to 60(30) m HyspIRI data sets.

- *Objective 2.* Assess how sub-pixel variations in tree canopy height, forest density, forest clustering, and other forest inventory variables affect the spectral response, or pixel-level radiance in this case, on a per-pixel basis.
- *Objective 3.* Evaluate how the sub-pixel structural variation interacts with the HyspIRI system's response characteristics, most notably in terms of the point spread function (PSF).

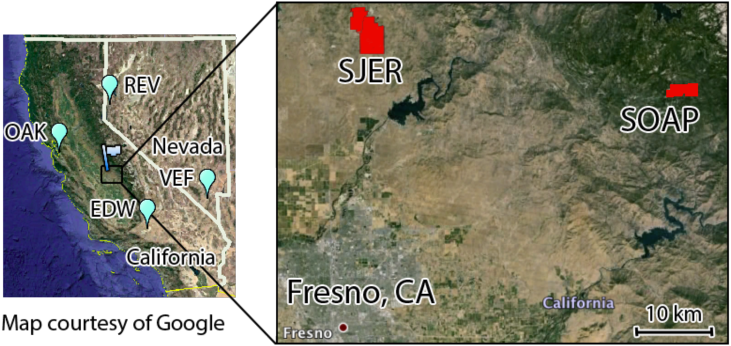

Airborne data
Esimating LAI from VIs
Sub-pixel structural variation
DIRSIG simulation
System study
Field data

Outline

2. Methods
   - Study area
   - Airborne and field data
   - Building virtual scenes
   - Simulate AVIRIS-C using DIRSIG

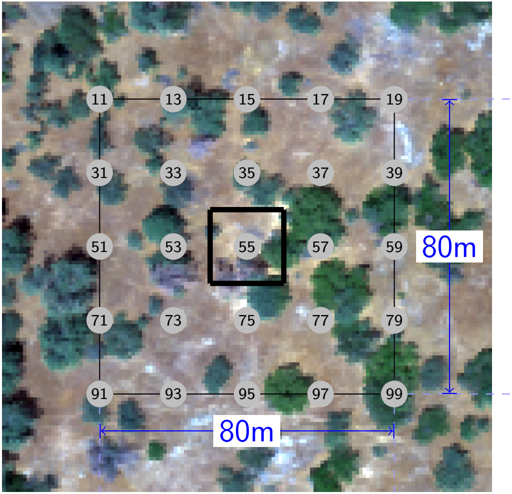
The National Ecological Observatory Network (NEON), Pacific Southwest Domain (D17)

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



Map courtesy of Google

Extend NEON's 20 × 20m site



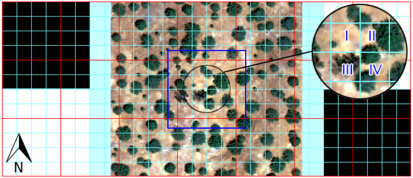
- LAI (AccuPAR LP-80)
- Ground-based lidar (SICK LMS-151, RITTL)
- Spectra (SVC HR-1024i)
- Hemispherical photos

Airborne data were collected by

1. NASA's "classic" Airborne Visible Near-Infrared Imaging Spectrometer (AVIRIS-C) during HyspIRI preparatory airborne campaign, summer 2013 & fall 2014.,
2. NEON's high-resolution imaging spectrometer (NIS) in summer 2013, and
3. NEON's small-footprint waveform-recording LIDAR in summer 2013.

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

Virtual scene layout

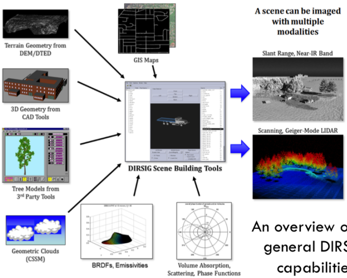


- Terrain size: 180 × 180 meters, which corresponds to 3 × 3 HyspIRI pixels (60m GSD, red grid), or 12 × 12 AVIRIS pixels (15m GSD, cyan grid)
- Elevation is derived from the airborne lidar data

- The center 80 × 80 meters area corresponds to the actual vegetation structure of our study area
- 3D tree models are generated by OnyxTREE
- The reflectance spectra of leaf, bark, grass, soil, rock are measured by RIT field team and NEON AOP team
- Two black panels and two white panels are placed at the corners and used as reference objects for empirical line method (ELM) atmospheric compensation

Methods
DIRSIG simulation - overview

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

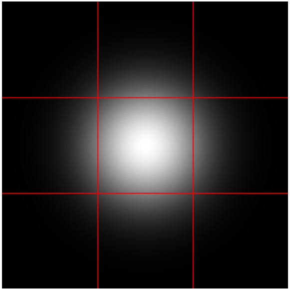


An overview of the general DIRSIG capabilities

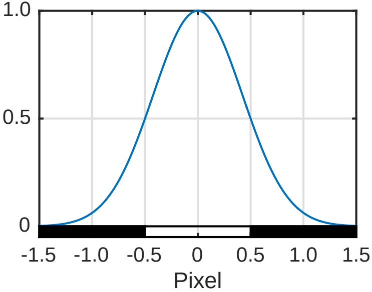
http://dirsig.org

- 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

Point spread function (PSF)
2-D Gaussian Function, FWHM = pixel size (18m GSD)

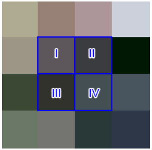


2-D Gaussian kernel

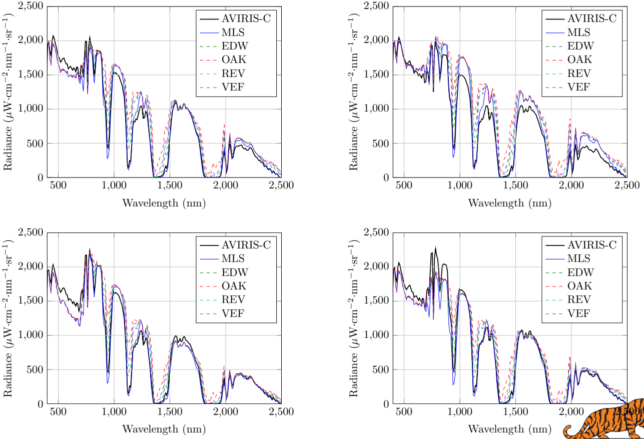


Profile of the kernel

Verify the model using SJER 116 scene



AVIRIS-C data

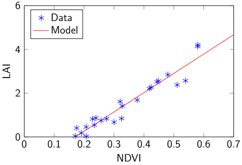


Outline

3. Simulating the impact of structural variation
   - Assessing pixel-level LAI
   - Assessing pixel-level forest density
   - Assessing sub-pixel tree position
   - Assessing sub-pixel forest clustering

Simulated forest LAI vs NDVI

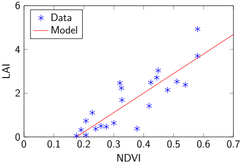
5 m transect spacing



$LAI = 8.826 \cdot NDVI - 1.506$

$R^2 = 0.92$

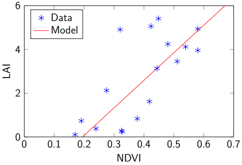
10 m transect spacing



$LAI = 8.928 \cdot NDVI - 1.566$

$R^2 = 0.77$

15 m transect spacing

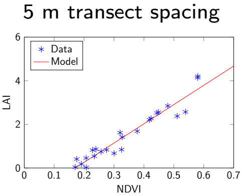


$LAI = 12.61 \cdot NDVI - 2.457$

$R^2 = 0.66$

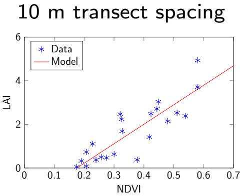
The LAI of forest can be measured along multiple transects.

Simulated forest LAI vs NDVI



LAI $= 8.826 \cdot$ NDVI - 1.506

$R^2 = 0.92$



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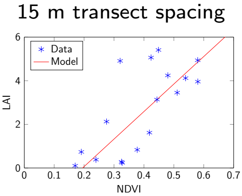


LAI $= 12.61 \cdot$ NDVI - 2.457

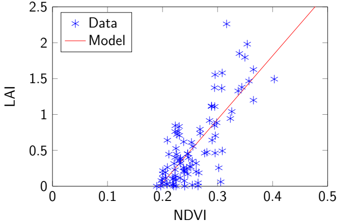
$R^2 = 0.66$

The LAI of forest can be measured along multiple transects.

Simulating PAR sensor and LAI assessment
Validate the protocol by field and airborne data

Measured forest LAI vs NDVI

10 m transect spacing



LAI = 8.858 · NDVI - 1.725

$R^2 = 0.61$

Regression model from simulated data:

LAI = 8.928 · NDVI - 1.566

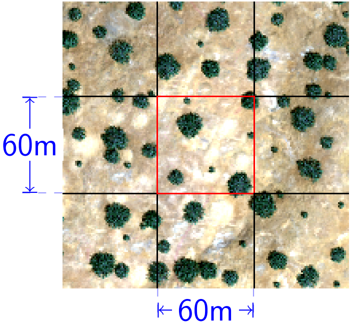
$R^2 = 0.77$

The LAI of forest can be measured along multiple transects.

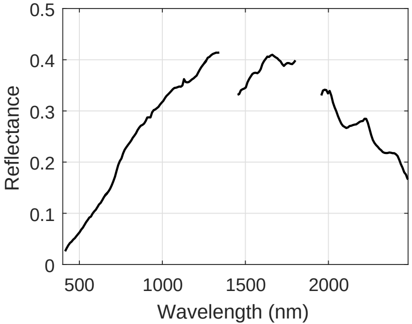
Simulating the impact of structural variation

Assessing forest density

Density of the "forest"



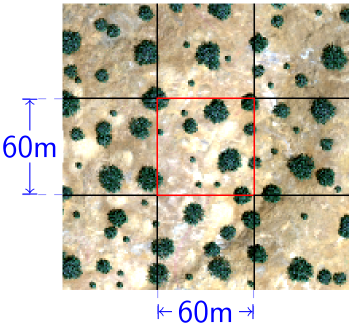
CC = 0.12



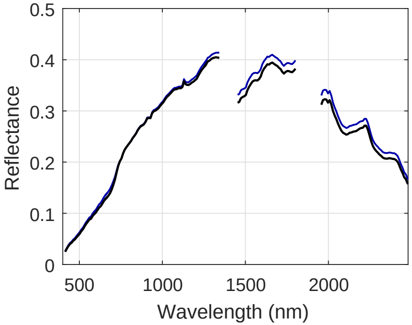
Spectrum of the center pixel

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

Density of the "forest"



CC = 0.14



Spectrum of the center pixel

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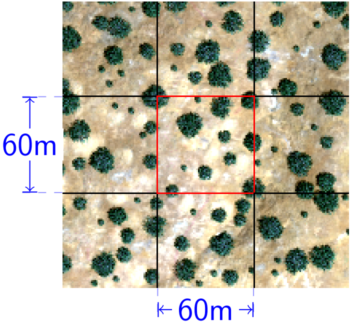
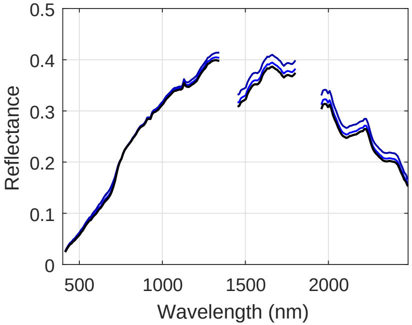
Density of the "forest"



CC = 0.17



Spectrum of the center pixel

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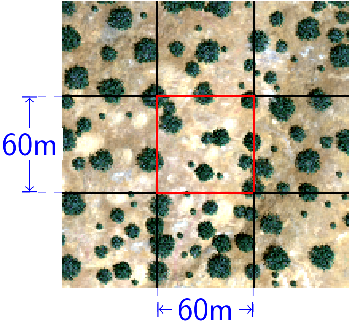
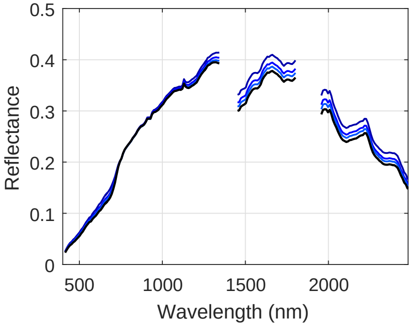
Density of the "forest"



CC = 0.20



Spectrum of the center pixel

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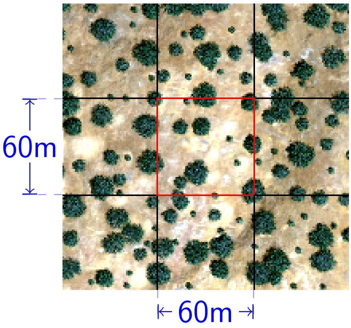
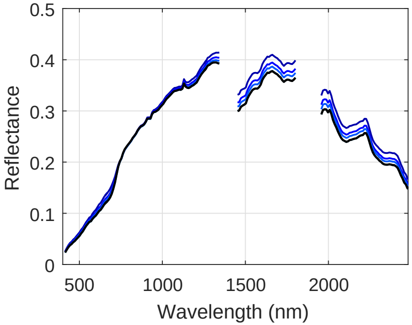
Density of the "forest"



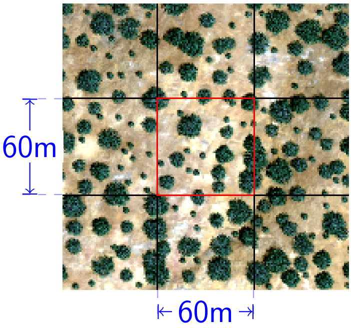
$CC = 0.21$



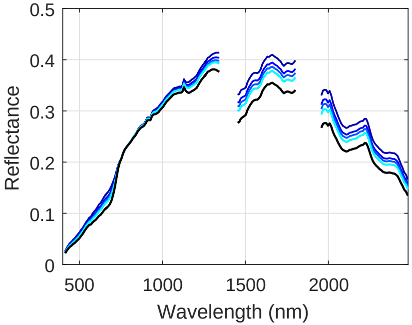
Spectrum of the center pixel

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

Density of the “forest”



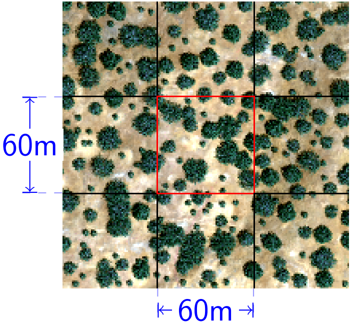
CC = 0.27



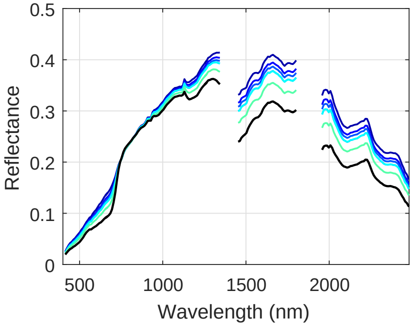
Spectrum of the center pixel

Density of the “forest” is quantified by tree canopy cover (CC), the proportion of land area covered by tree crowns.

Density of the “forest”



CC = 0.31

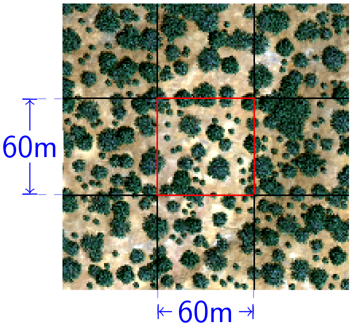


Spectrum of the center pixel

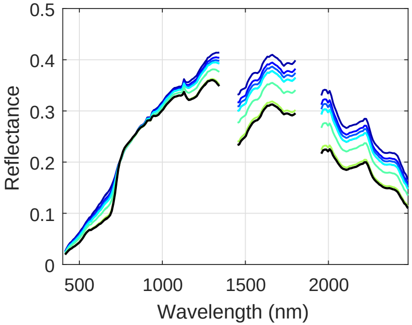
Density of the “forest” is quantified by tree canopy cover (CC), the proportion of land area covered by tree crowns.

Simulating the impact of structural variation
Assessing forest density

Density of the "forest"



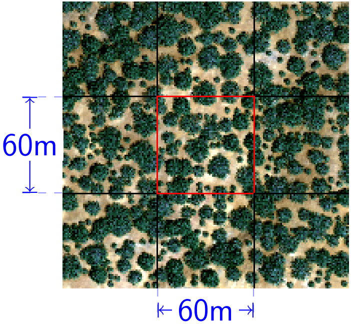
CC = 0.38



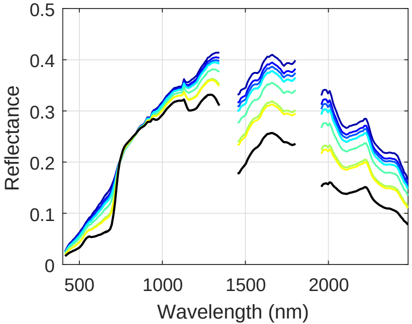
Spectrum of the center pixel

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

Density of the "forest"



$CC = 0.51$



Spectrum of the center pixel

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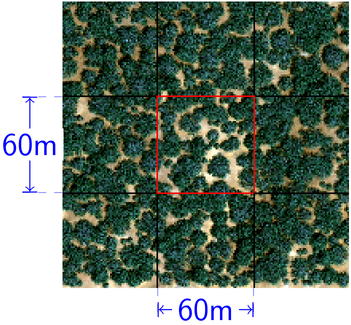
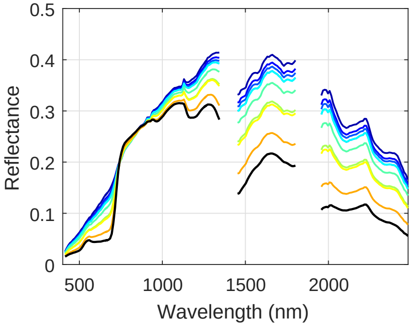
Density of the “forest”



CC = 0.66



Spectrum of the center pixel

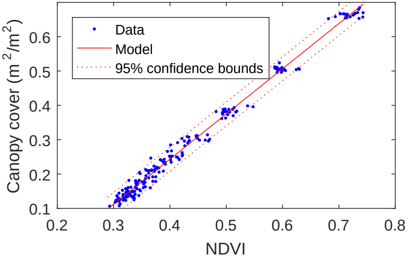
Density of the “forest” is quantified by tree canopy cover (CC), the proportion of land area covered by tree crowns.

NDVI vs. density

- Normalized Difference Vegetation Index (NDVI)

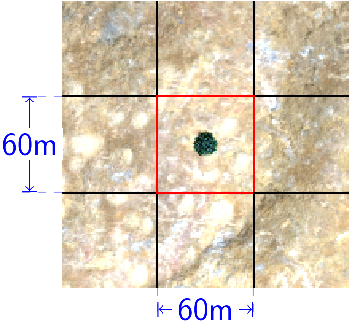
$$NDVI = \frac{NIR - Red}{NIR + Red}$$

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

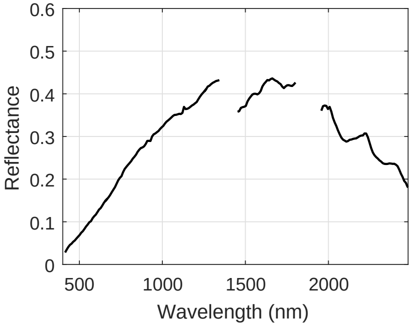


$$R^2 = 0.989$$
$$RMSE = 0.0175(\mathrm{m}^2/\mathrm{m}^2)$$

Tree position

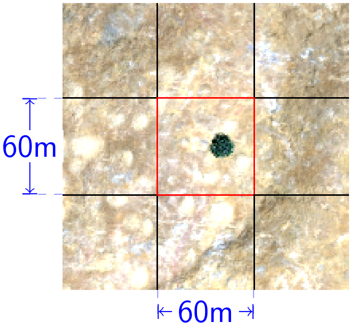


Tree at (0, 0)

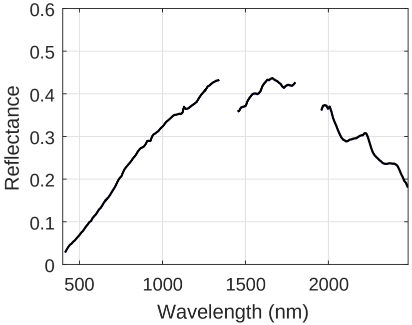


Spectrum of the center pixel

Tree position

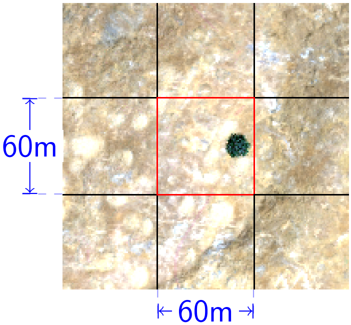


Tree at (10, 0)

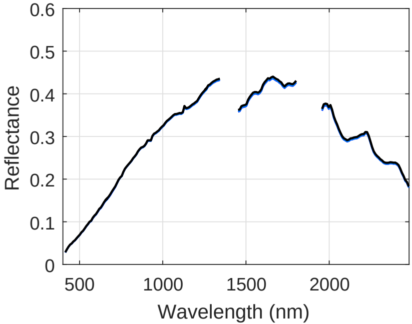


Spectrum of the center pixel

Tree position

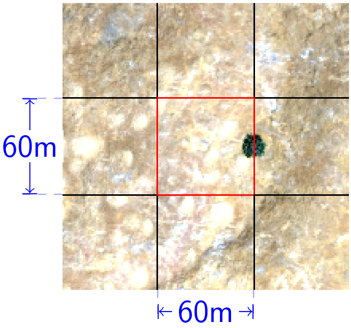


Tree at (20, 0)

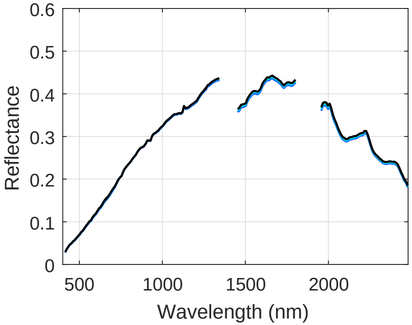


Spectrum of the center pixel

Tree position



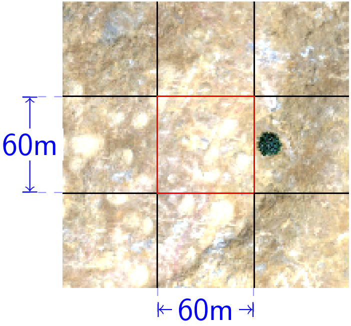
Tree at (30, 0)



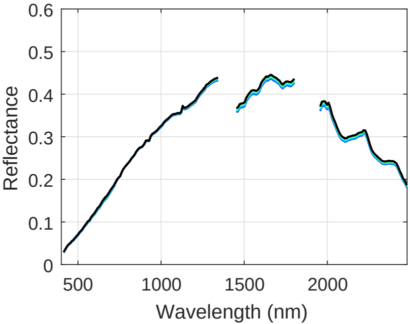
Spectrum of the center pixel

Simulating the impact of structural variation
Assessing tree position

Tree position

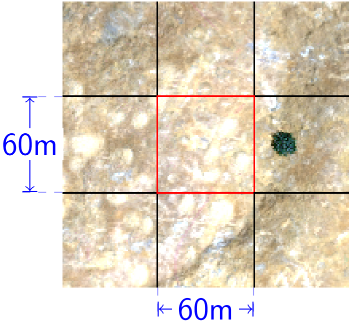


Tree at (40, 0)

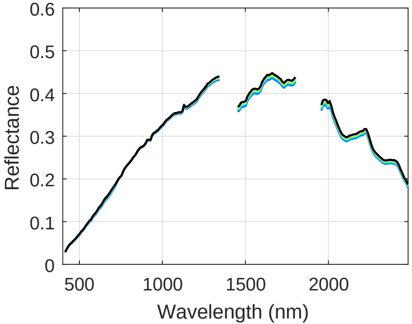


Spectrum of the center pixel

Tree position

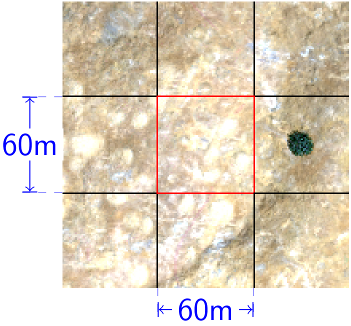


Tree at (50, 0)

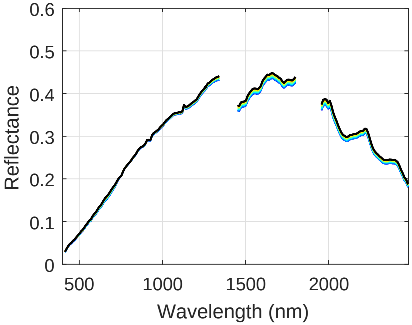


Spectrum of the center pixel

Tree position

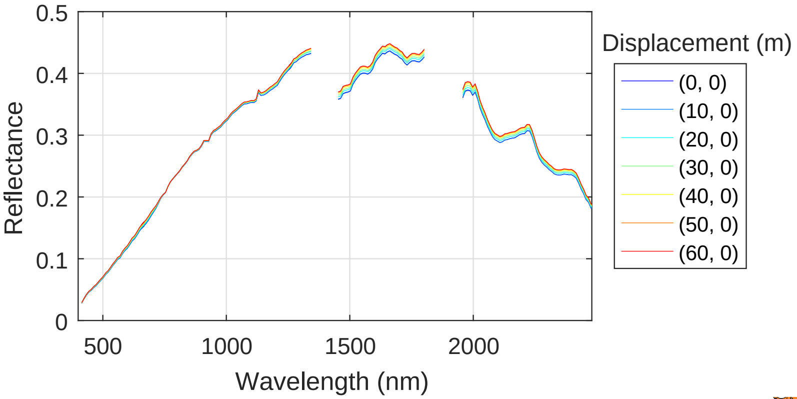


Tree at (60, 0)

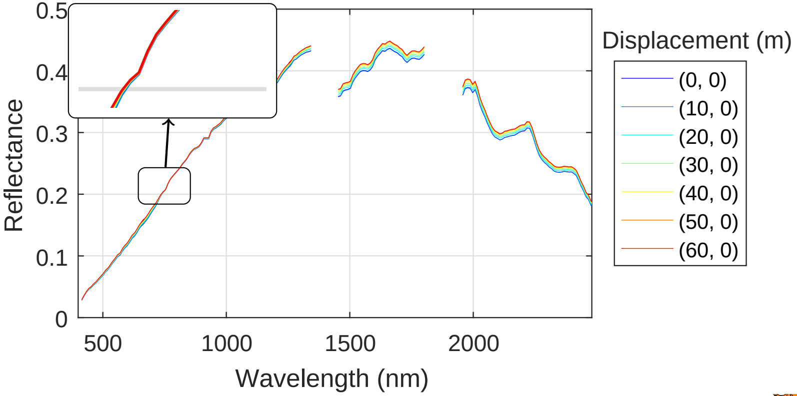


Spectrum of the center pixel

Tree position

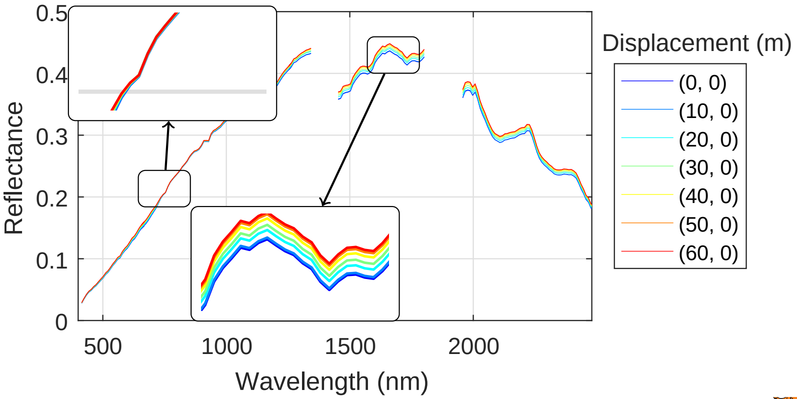


Tree position



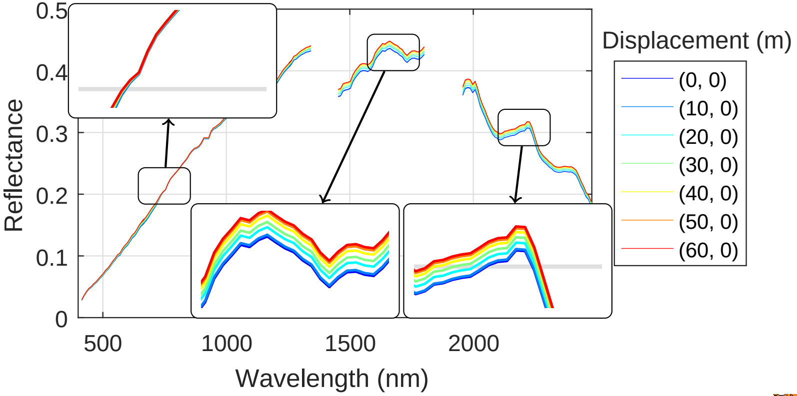
Simulating the impact of structural variation
Assessing tree position

Tree position



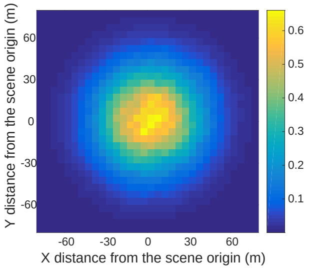
Simulating the impact of structural variation
Assessing tree position

Tree position

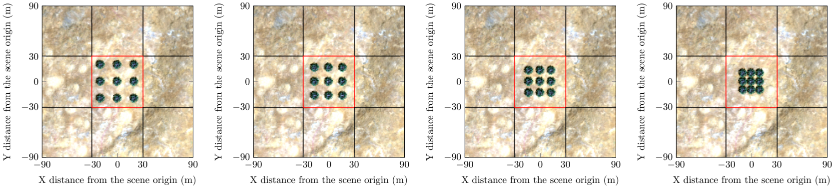


The spectral angle distribution

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

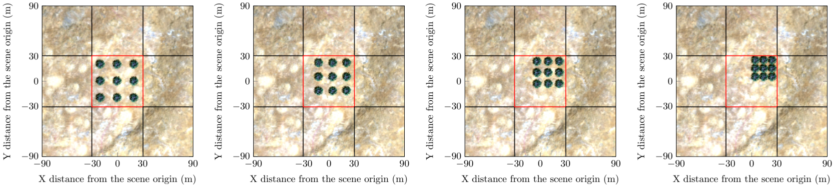


Virtual scene design



Increasingly denser towards the pixel center

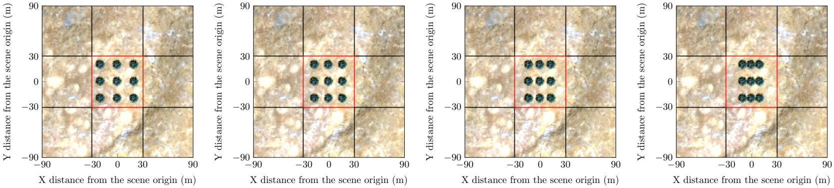
Virtual scene design



Increasingly denser towards the top-right (northeast) pixel corner

Simulating the impact of structural variation
Assessing forest clustering

Virtual scene design

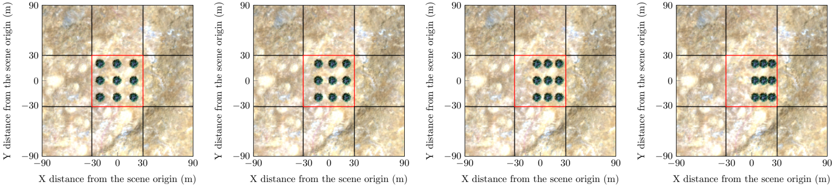


More linearly compact in the vertical direction, towards the pixel center

Simulating the impact of structural variation

Assessing forest clustering

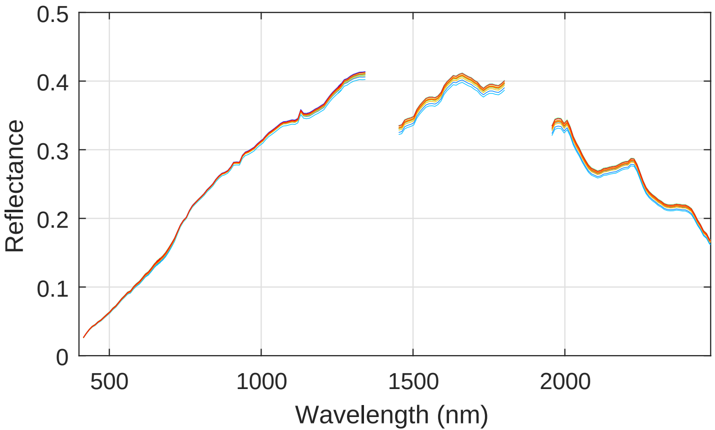
Virtual scene design



More linearly compact in the vertical direction, towards the right (eastern) pixel edge

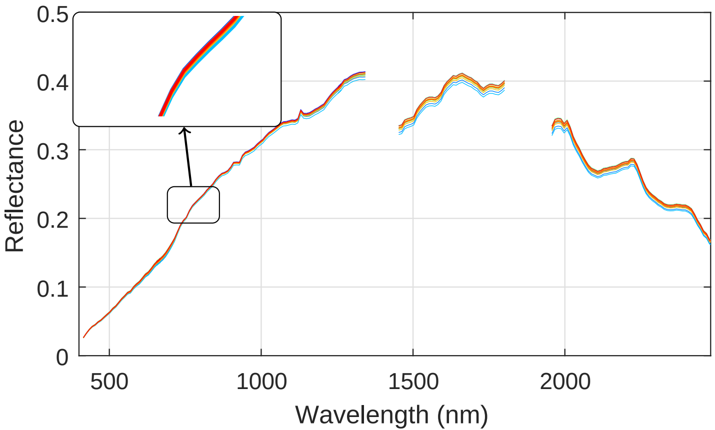
Simulating the impact of structural variation
Assessing forest clustering

Tree position



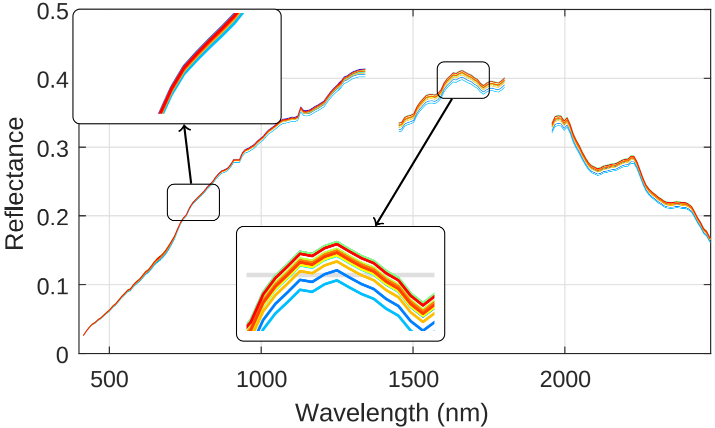
Simulating the impact of structural variation
Assessing forest clustering

Tree position



Simulating the impact of structural variation
Assessing forest clustering

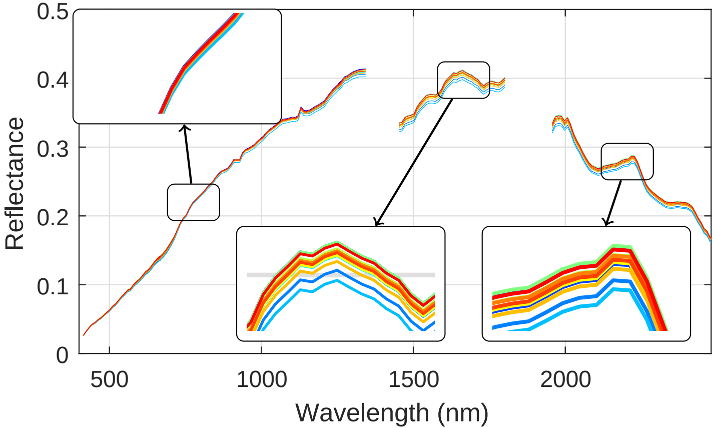
Tree position



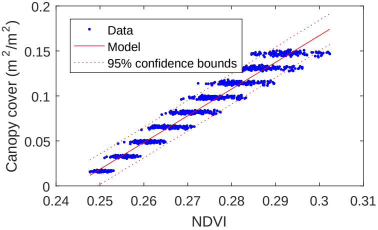
Simulating the impact of structural variation

Assessing forest clustering

Tree position



NDVI vs. Canopy cover



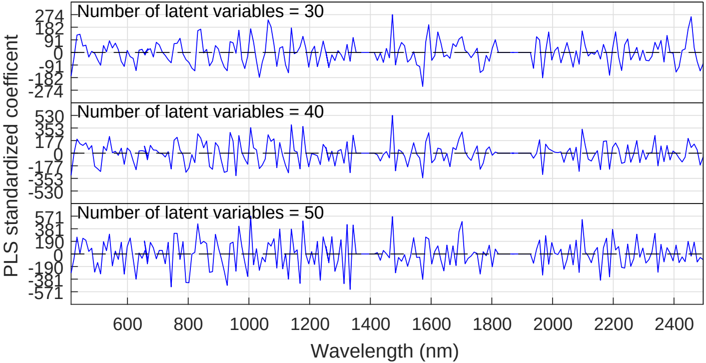
$$R^2 = 0.96$$
$$RMSE = 0.00864(\mathrm{m}^2/\mathrm{m}^2)$$

The results of previous experiment:

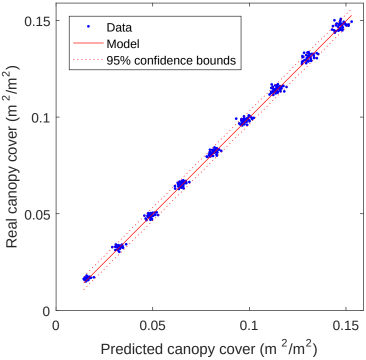
$$R^2 = 0.989$$
$$RMSE = 0.0175(\mathrm{m}^2/\mathrm{m}^2)$$

Partial least-square (PLS) regression approach

- Standardized PLs regression coefficients provided the magnitude and direction of influence of each band



Partial least-square (PLS) regression approach



$$R^2 = 0.99$$
$$RMSE = 0.00171(\mathrm{m}^2/\mathrm{m}^2)$$

The results of NDVI-CC model:

$$R^2 = 0.96$$
$$RMSE = 0.00864(\mathrm{m}^2/\mathrm{m}^2)$$

Outline

4. Conclusions

Conclusions

Results indicate:

1. VIs could be used to estimate sub-pixel forest structural variables, e.g., LAI and forest density, from HyspIRI data.
2. The effect of vegetation's position is mainly determined by the PSF of spectrometer.
3. A more accurate PLS regression model can be used to assess the canopy cover regardless of in-pixel distribution at pixel-level.

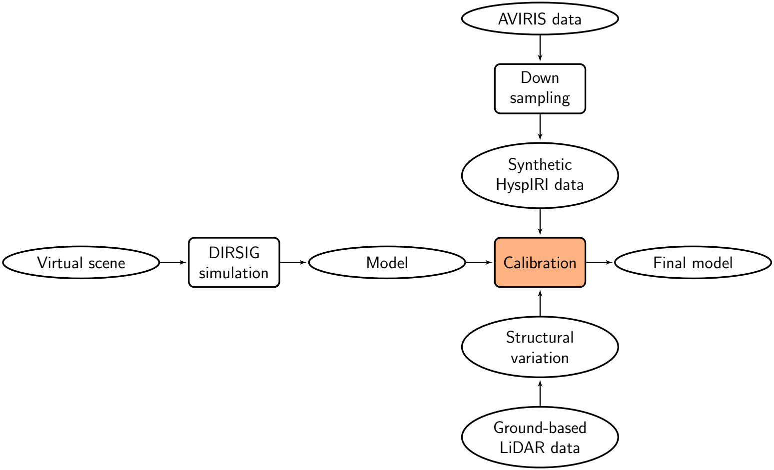
Refereed journal articles

- Wei Yao, David Kelbe, Martin van Leeuwen, Paul Romanczyk, and Jan van Aardt. "Towards an Improved LAI Collection Protocol via Simulated and Field-Based PAR Sensing". In: *Sensors* 16.7 (2016), pp. 1092.
- Wei Yao, Jan van Aardt, David Kelbe, Paul Romanczyk, Scott Brown, and Adam Goodenough. "A simulation approach to assessing sub-pixel vegetation structure effected on global imagery spectroscopy". In: *IEEE Transactions on Geoscience and Remote Sensing* (2017). In preparation.

Conference proceedings & Posters

- Wei Yao, Martin van Leeuwen, Paul Romanczyk, David Kelbe, Mingming Wang, Scott D Brown, Adam A Goodenough, and Jan van Aardt. "Towards an improved understanding of the influence of subpixel vegetation structure on pixel-level spectra: a simulation approach". In: *SPIE Defense+ Security*. International Society for Optics and Photonics. 2016, 98401H.
- Wei Yao, Martin van Leeuwen, Paul Romanczyk, David Kelbe, and Jan van Aardt. "Assessing the impact of sub-pixel vegetation structure on imaging spectroscopy via simulation". In: *SPIE Defense+ Security*. International Society for Optics and Photonics. 2015, 94721K.
- Wei Yao, Martin van Leeuwen, Paul Romanczyk, Dave Kelbe, Scott Brown, John Kerekes, and Jan van Aardt. "Towards robust forest leaf area index assessment using an imaging spectroscopy simulation approach". In: *Geoscience and Remote Sensing Symposium (IGARSS), 2015 IEEE International*. IEEE, 2015, pp. 5403- 5406.
- Wei Yao, Jan van Aardt, Paul Romanczyk, David Kelbe, Martin van Leeuwen, and Thomas Kampe. "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. (Poster)

- Calibration and validation of the experimental results



Acknowledgments

- This material is based upon work supported by the NASA HyspIRI Mission under Grant No. NNX12AQ24G.
- Thanks to NASA JPL and NEON for providing airborne data.

Thanks!

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