# Investigating the impact of spatially-explicit sub-pixel structural variation on the assessment of vegetation structure from imaging spectroscopy data:
# II Simulation approach

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# What is “simulation approach” and why

Consider HyspIRI is a system $H\{\}$. The inputs related to sub-pixel vegetation structural variation include:

- species of trees: $t(x, y)$
- density of the forest: $d(x, y)$
- position and distribution of trees: $p(x, y)$
- height of trees: $h(x, y)$
- crown size: $c(x, y)$
- $\cdots$

and the output is the spectrum:

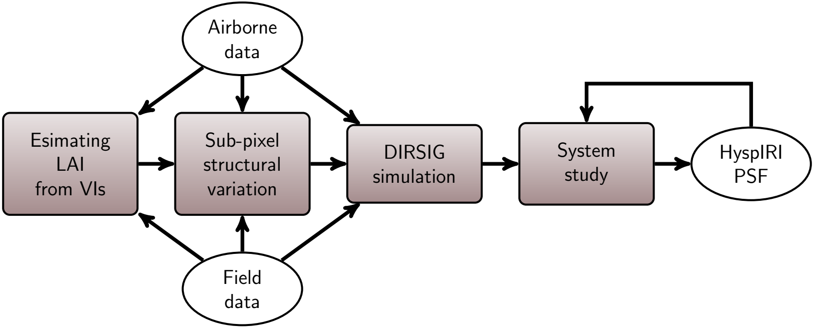
$$s(x, y) = H\{t(x, y), d(x, y), p(x, y), h(x, y), c(x, y), \cdots\}$$

# 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

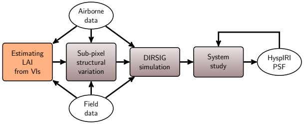
## Project outline and objectives

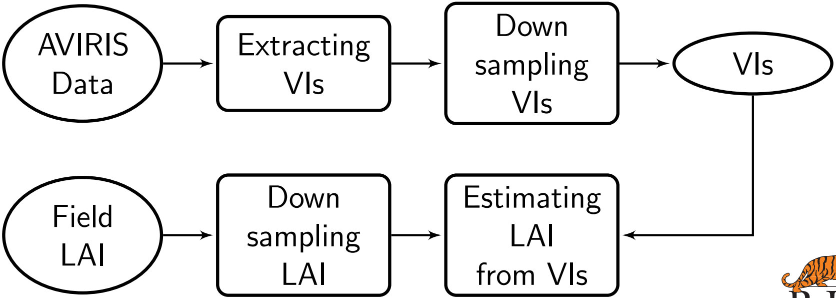


# Introduction

## Project outline and objectives

Stage 1: Estimating LAI from VIs

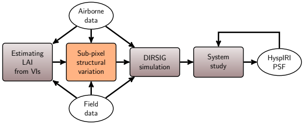


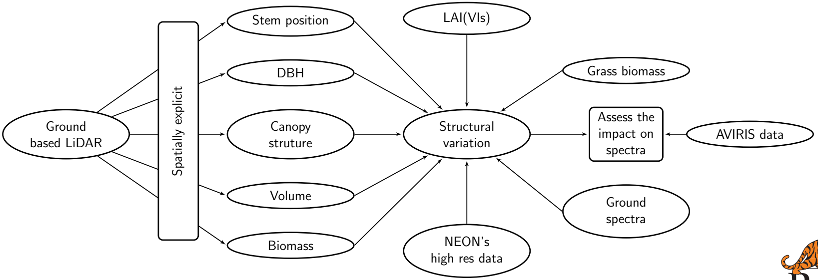



# Introduction

## Project outline and objectives

Stage 2: Sub-pixel structural variation

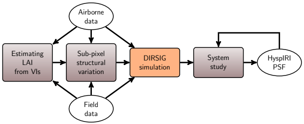


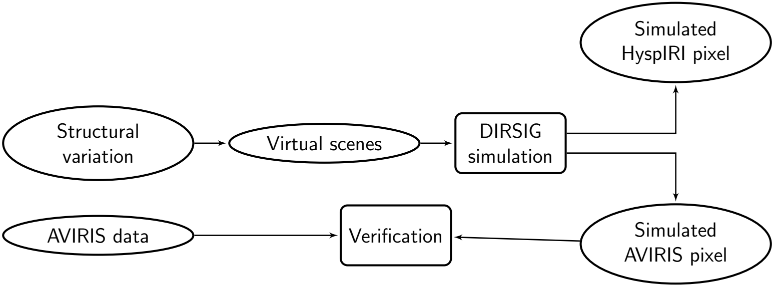



# Introduction

## Project outline and objectives

Stage 3: DIRSIG simulation



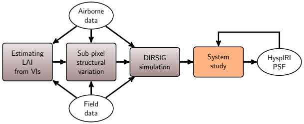



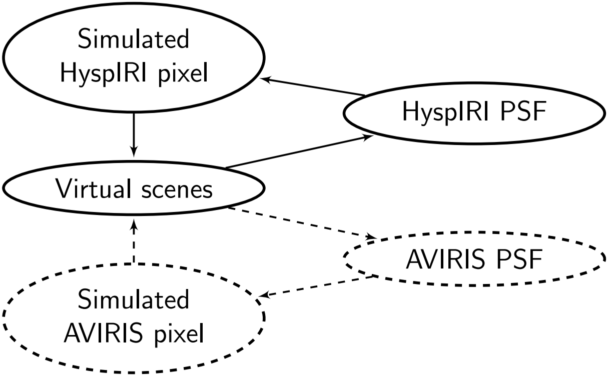

DIRSIG: The Digital Imaging and Remote Sensing Image Generation

# Introduction

## Project outline and objectives

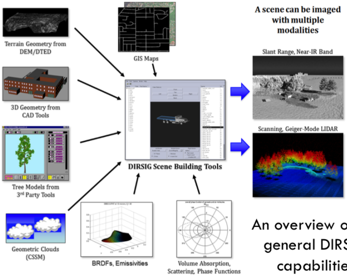
### Stage 4: System study



# Introduction
## DIRSIG simulation - overview

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



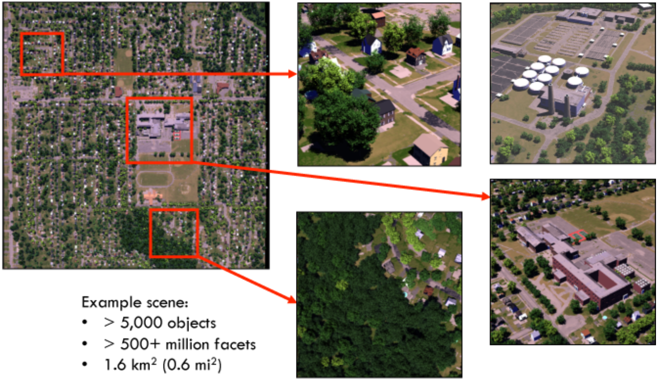

An overview of the general DIRSIG capabilities

http://dirsig.org

- Image Modalities
  Visible through thermal infrared
  (0.4 - 20.0 $\mu m$)
  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

# Introduction

## DIRSIG simulation - overview



Example scene:

- > 5,000 objects
- > 500+ million facets
- 1.6 $km^2$ (0.6 $mi^2$)

# 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)

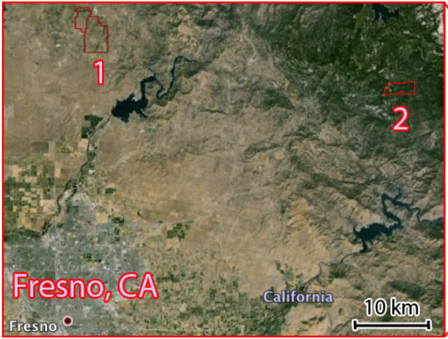




Figure from Google Earth

# 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

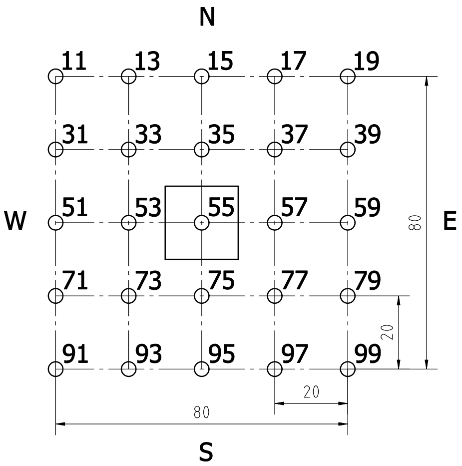
2. Soaproot Saddle:
   - June 16 - 20, 2013: 8 AOP sites (43, 63, 95, 143, 299, 331, 555, 1611)
   - Oct 8 - 10, 2014: 3 AOP sites (43, 143, 299)

Site 43

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:

- June 12, 2013: f130612t01r09 (San Joaquin)
- June 12, 2013: f130612t01r07 (Soaproot)

NEON's spectrometer data collected in the same time:

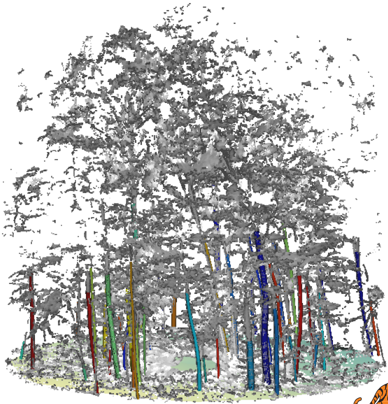
- June 13, 2013: NIS1_20130613_xxxxxx_atmcor.h5 (San Joaquin)
- June 12, 2013: NIS1_20130612_xxxxxx_atmcor.h5 (Soaproot)

# Methods

## Extract stem map from Terrestrial Laser Scanner (TLS) data

- Method:
  Model tree stems using iterative cylinder-following approach
- Results:
  Detailed structural modeling
  Tree Location $R^2 = 0.99$
  Stem Density $R^2 = 0.86$ for visible stems
  Tree Diameter $R^2 = 0.80$

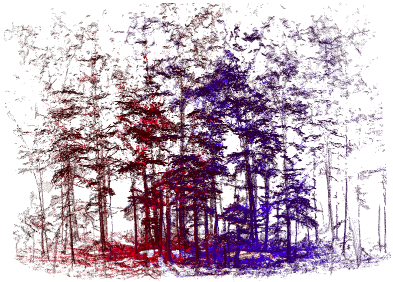
By Dave Kelbe, PhD student



# Methods

## Register multiple TLS scans

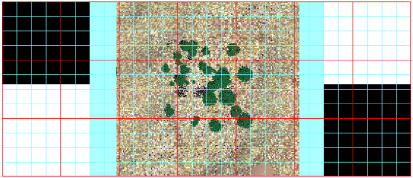
- Algorithm:
  Extract coordinates of trunk-ground intersection as tie-points for registration
  Rank potential correspondence sets using geometric constraints
  Use RANSAC to query candidate point set matches
- Features:
  No markers are placed in the scene
  No initial pose estimation is required



By Dave Kelbe, PhD student

# Methods
## Building virtual scenes

### Virtual scene layout

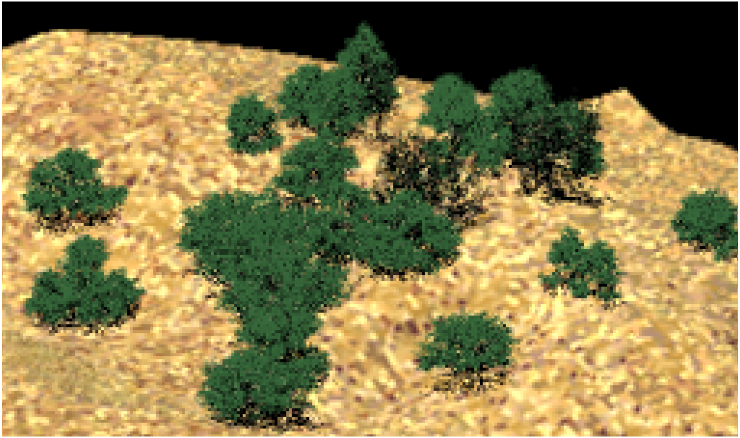


- Terrain size: 180 × 180 meters, which corresponds to 3 × 3 HyspIRI pixels (60m GSD, red grid), or 12 × 12 AVIRIS pixels (15m GSD, cyan grid)
- Elevation is derived from the airborne lidar data

- 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
## Building virtual scenes

The side view of site 116 scene

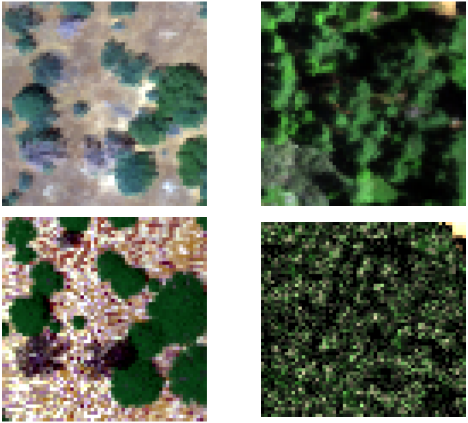


# Methods

## Simulate NEON's high-resolution spectrometer data

NEON's spectrometer data

Simulated data



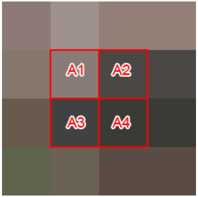
Site 116 Site 299

# Methods

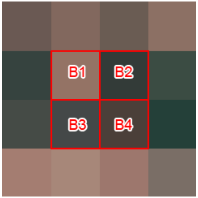
## Simulate AVIRIS data

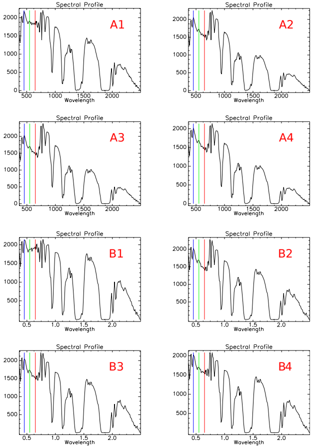
Verify the model by the Site 116 scene

AVIRIS data




Simulated data



# Methods

## Simulate HyspIRI

DIRSIG key settings

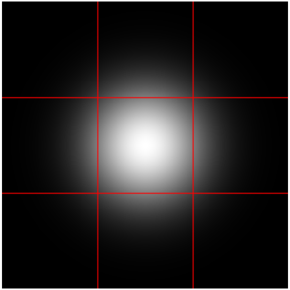
- Height = 600km
- GSD = 60m
- 224 bands, 380 - 2500nm, 10nm FWHM
- Use MODTRAN to simulate atmospheric radiative transfer

MODTRAN key settings:

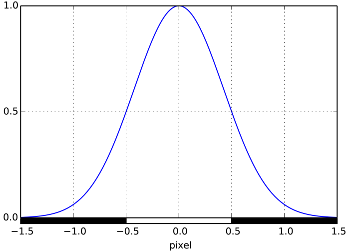
- Enable multiple scattering (IMULT = +1)
- Mid-latitude summer model (MODEL = 2)
- RURAL extinction (IHAZE = 1)

# Methods
## Simulate HyspIRI

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



2-D Gaussian kernel




Profile of the kernel

# Methods

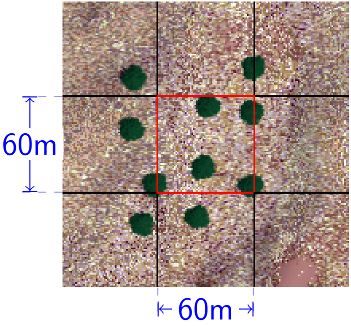
## Simulate HyspIRI

Generate multiple simulated HyspIRI data sets of different:

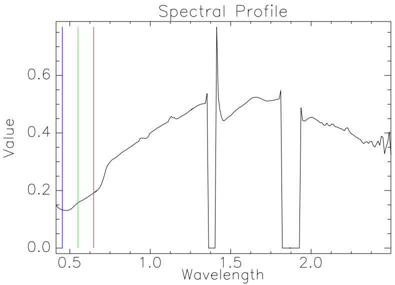
- density of the "forest"
- position and distribution of trees
- height of trees
- crown size
- species of trees.

# Results
## Simulation results

Density of the "forest"



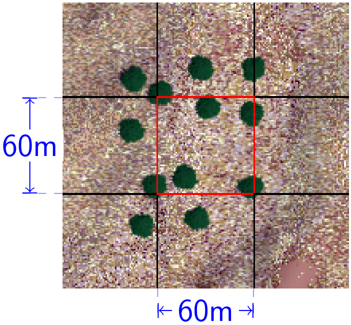

Density = 0.1



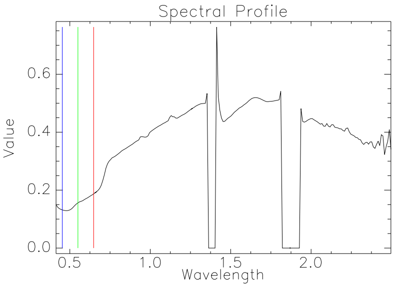

Spectrum of the center pixel

# Results
## Simulation results

Density of the "forest"



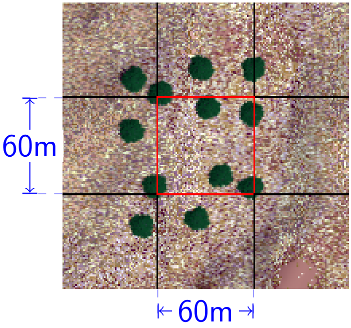

Density = 0.2



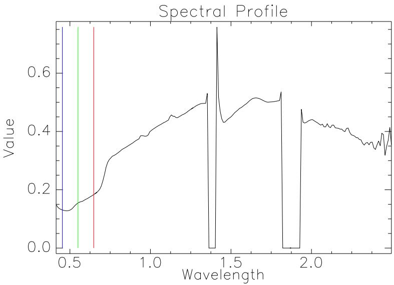

Spectrum of the center pixel

# Results
## Simulation results

Density of the "forest"



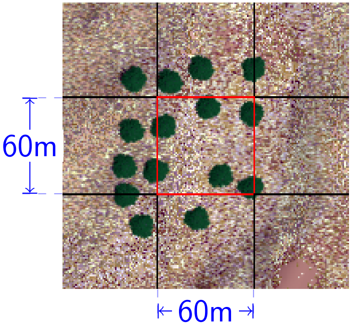

Density = 0.3



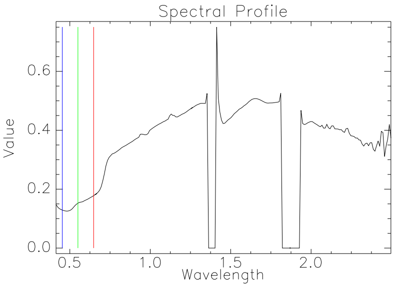

Spectrum of the center pixel

# Results
## Simulation results

Density of the “forest”



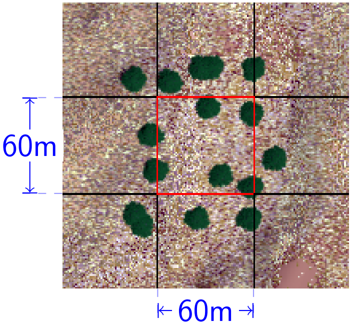

Density = 0.4



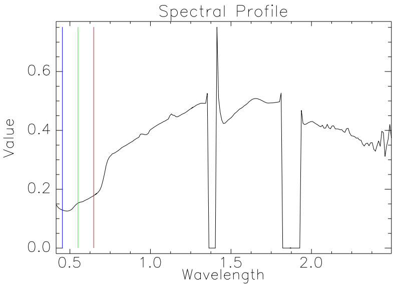

Spectrum of the center pixel

# Results
## Simulation results

Density of the "forest"



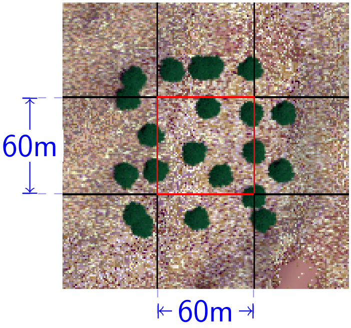

Density = 0.5



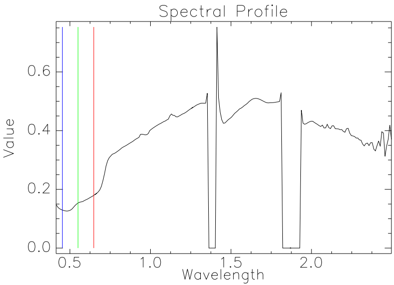

Spectrum of the center pixel

# Results
## Simulation results

Density of the “forest”



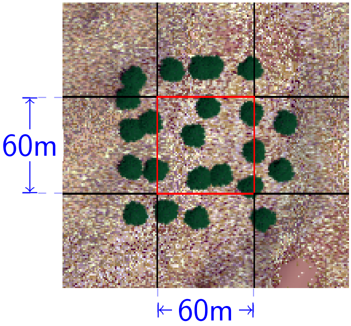

Density = 0.6



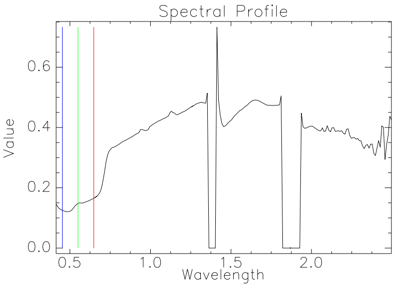

Spectrum of the center pixel

# Results
## Simulation results

Density of the "forest"



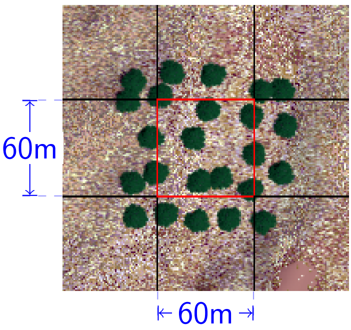

Density = 0.7



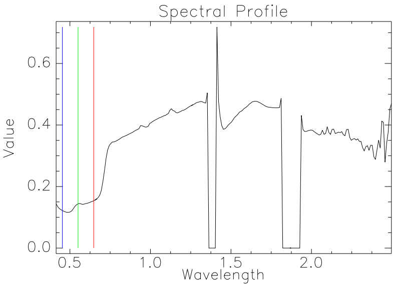

Spectrum of the center pixel

# Results
## Simulation results

Density of the "forest"




Density = 0.8

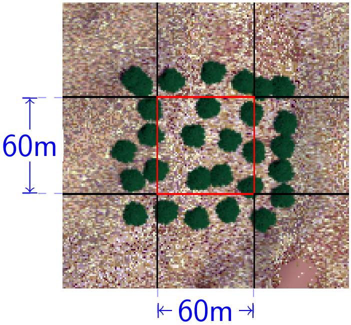



Spectrum of the center pixel

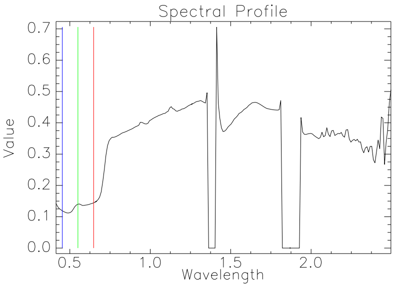
# Results

## Simulation results

Density of the “forest”



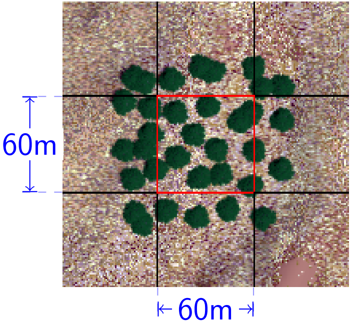

Density = 0.9



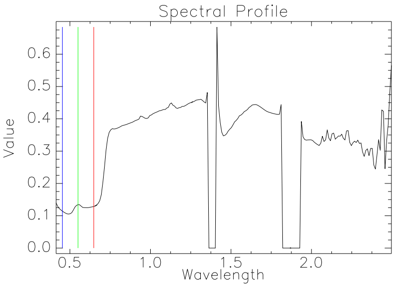

Spectrum of the center pixel

# Results
## Simulation results

Density of the “forest”



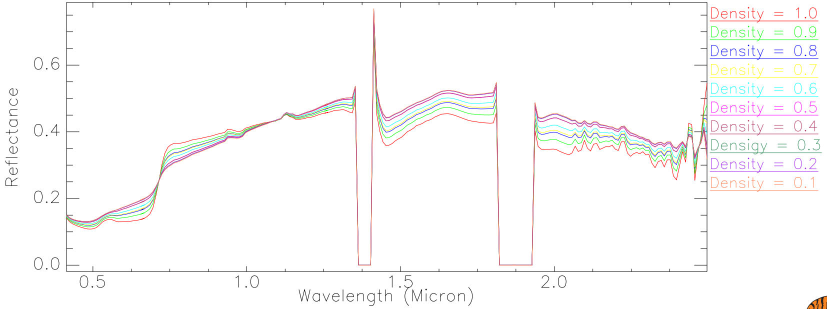

Density = 1




Spectrum of the center pixel

# Results
## Simulation results

Density of the “forest”



# Results

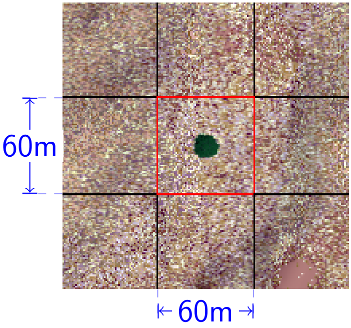
## Update of field work

Site 43 (Jun 17, 2013)

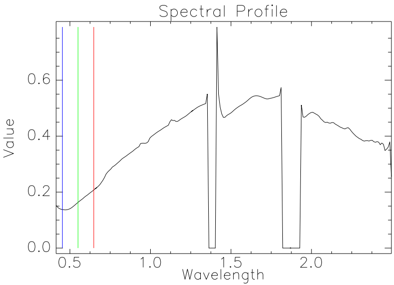
Site 43 (Oct 9, 2014)

# Results
## Simulation results

Position of tree



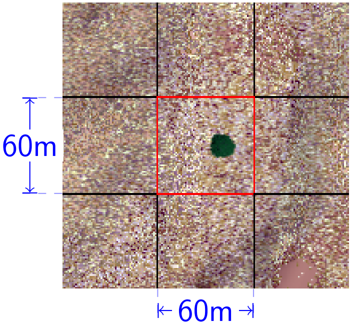

Tree at (0, 0)



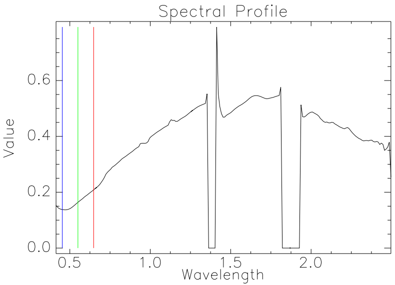

Spectrum of the center pixel

# Results
## Simulation results

Position of tree



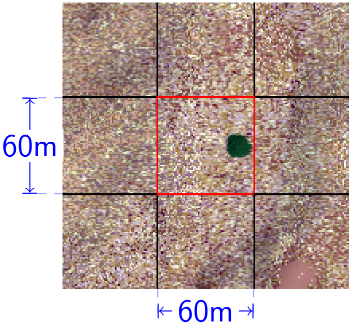

Tree at (10, 0)



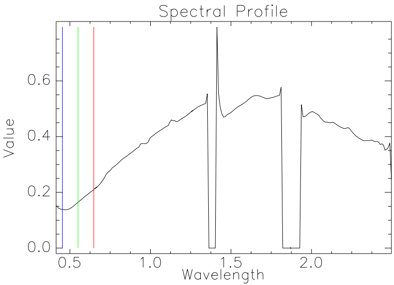

Spectrum of the center pixel

# Results
## Simulation results

Position of tree



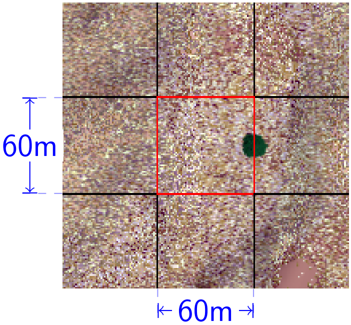

Tree at (20, 0)



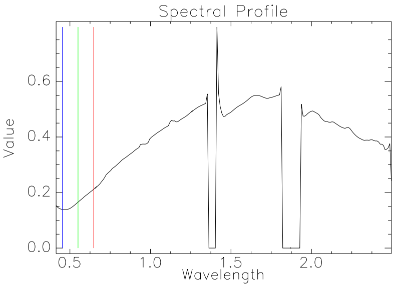

Spectrum of the center pixel

# Results
## Simulation results

Position of tree



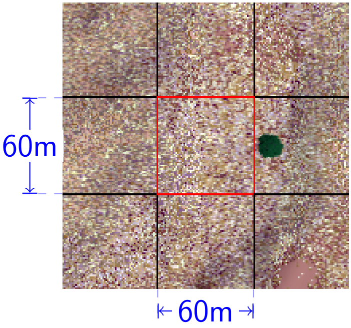

Tree at (30, 0)



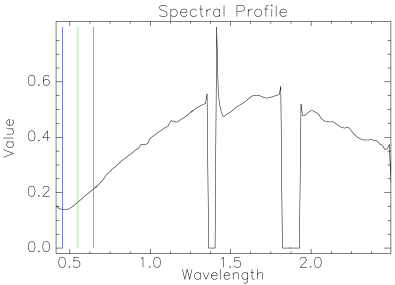

Spectrum of the center pixel

# Results
## Simulation results

Position of tree




Tree at (40, 0)

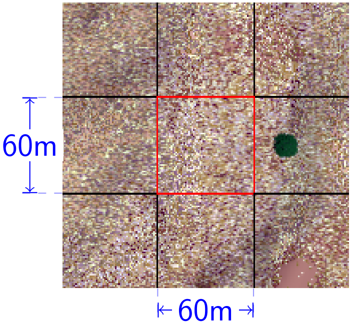



Spectrum of the center pixel

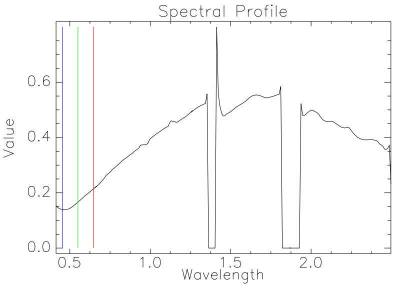
# Results

## Simulation results

Position of tree



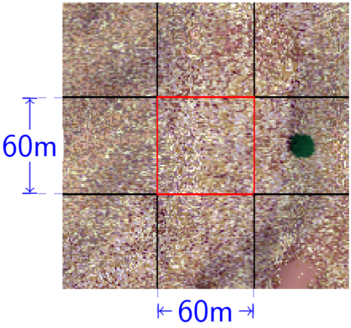

Tree at (50, 0)



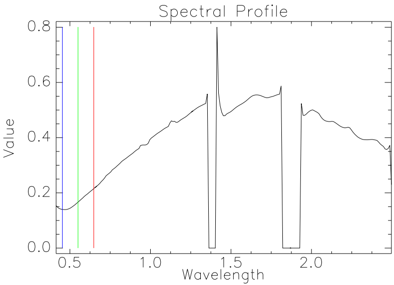

Spectrum of the center pixel

# Results
## Simulation results

Position of tree



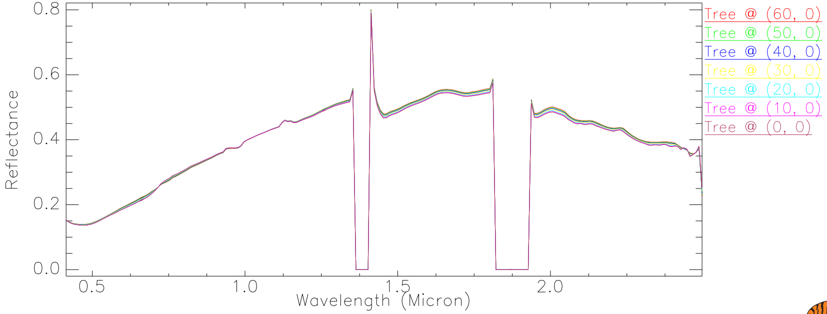

Tree at (60, 0)




Spectrum of the center pixel

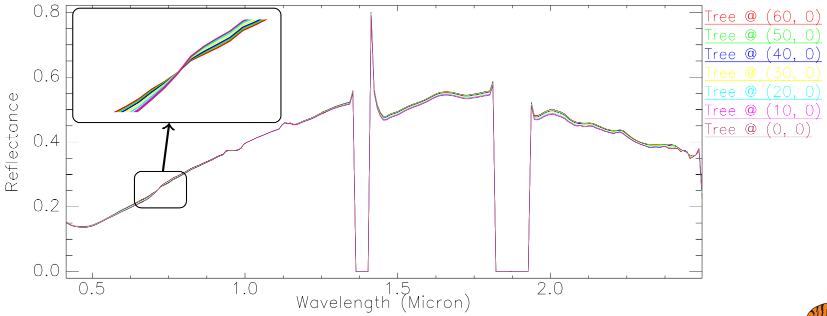
# Results
## Simulation results

### Position of tree



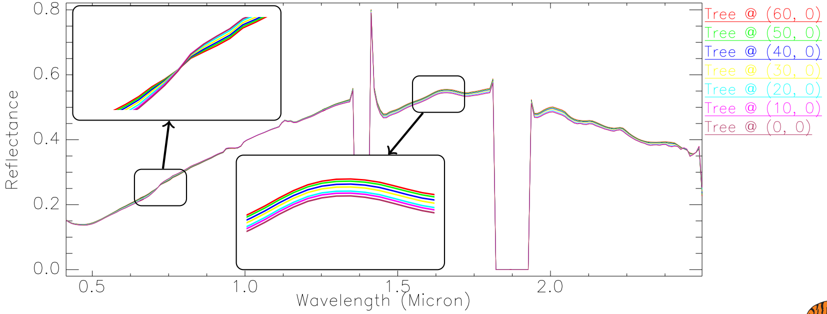
# Results
## Simulation results

Position of tree



# Results
## Simulation results

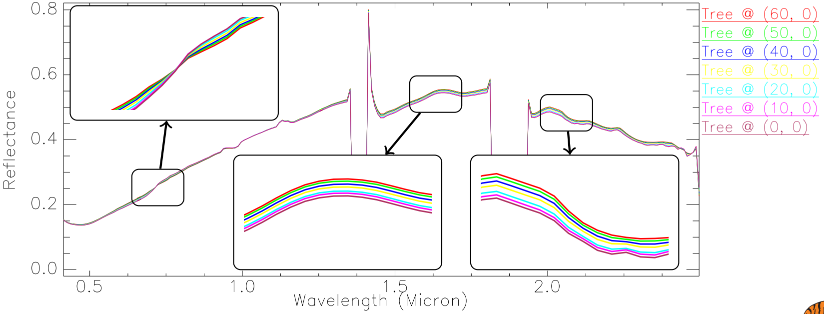
### Position of tree



# Results

## Simulation results

Position of tree



# Conclusions/Outlook

## Conclusions

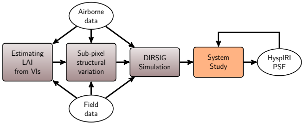
Early results indicate:

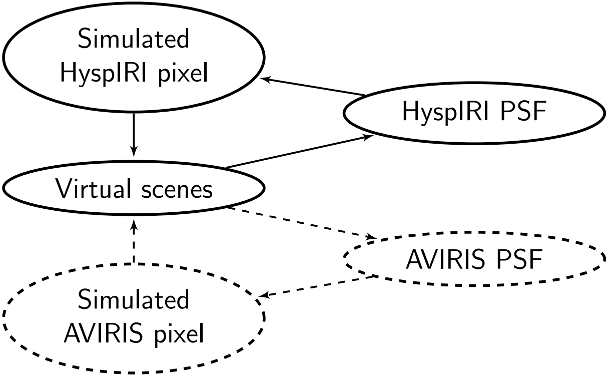
1. HyspIRI is sensitive to forest density in the blue and red spectral regions due to pigment concentration changes, as well as the SWIR region due to water content variation.
2. The system's suitability for consistent global vegetation structural assessments could be improved by adapting calibration strategies to account for this variation in sub-pixel structure.
3. HyspIRI is stable on the sub-pixel position of tree.

# Conclusions/Outlook

## Future work

Stage 4: System Study



# Conclusions/Outlook

## Future work

1. Increase the number of simulations to assess other sub-pixel vegetation structural variables:
    - height of trees
    - crown size
2. Quantify the simulation results:
    - Define narrow band vegetation indices (VIs) to characterize the sub-pixel vegetation structure
    - Employ statistical methods(wavelength pair-wise comparison, derivative analyses) to analyze simulation results
3. Investigate Lidar-based approaches for calibration of HyspIRI structural estimates

# Conclusions/Outlook

## Future work

Review our hypotheses:

1. Fine-scale, within-pixel structural assessments can be used to improve our understanding of HyspIRI-based estimates of leaf area, leaf area index (LAI), and vegetation biomass;
2. From a systems perspective, the spatially explicit within-pixel structural variations are quantifiable when it comes to their impact on the HyspIRI systems response (point spread function);
3. An improved understanding of (1) and (2) will lead to proper calibration of HyspIRI based vegetation structure estimates.

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