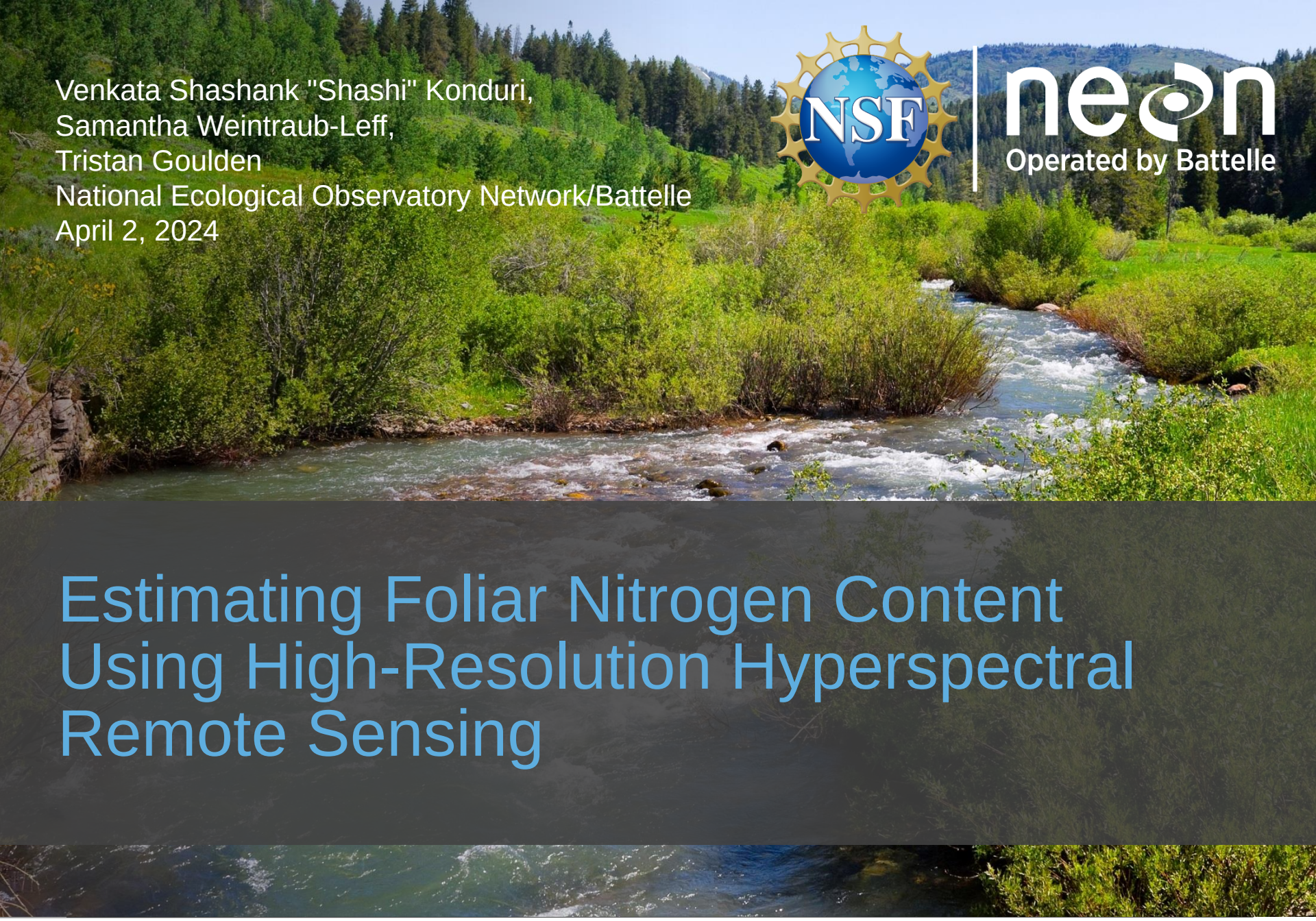

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Samantha Weintraub-Leff,
Tristan Goulden
National Ecological Observatory Network/Battelle
April 2, 2024

Estimating Foliar Nitrogen Content Using High-Resolution Hyperspectral Remote Sensing

This material is based upon work supported by NSF's National Ecological Observatory Network, which is a major facility fully funded by the National Science Foundation and managed by Battelle

Overview

- NEON observatory and Airborne Observation Platform (AOP)
- Updates to AOP data products
- Sampling protocols for AOP and foliar chemistry
- Foliar trait modeling workflow and assumptions
- Preliminary results
- Next steps

Overview of NEON and Airborne Observation Platform (AOP)

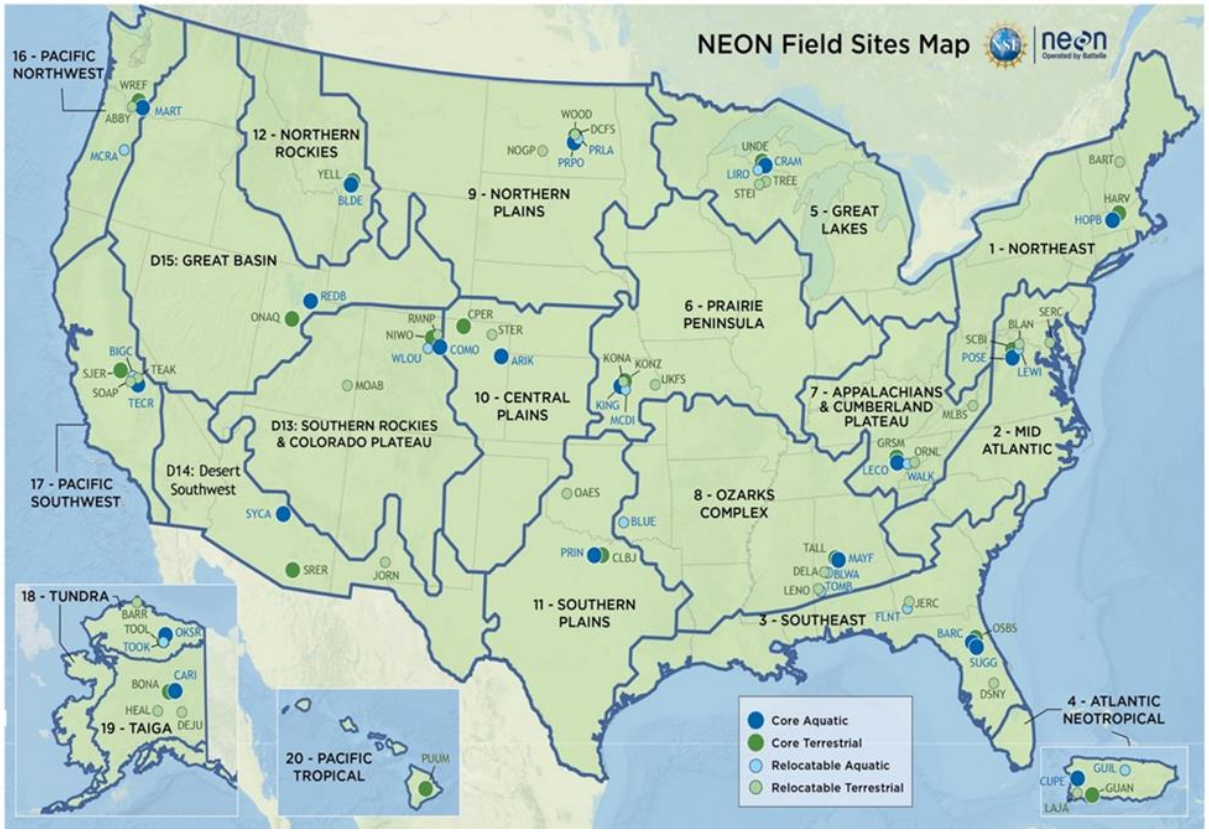
NEON Observatory

81
Field Sites
(47 Terrestrial
34 Aquatic)

20
Eco-Domains
Across the 48 contiguous states, Alaska, Hawaii, and Puerto Rico

30
Years Planned Operations
(Began 24May, 2019)

>180
Data Products
(Albedo, Leaf Area Index, CO_2 Flux, CH_4 Concentration, etc)

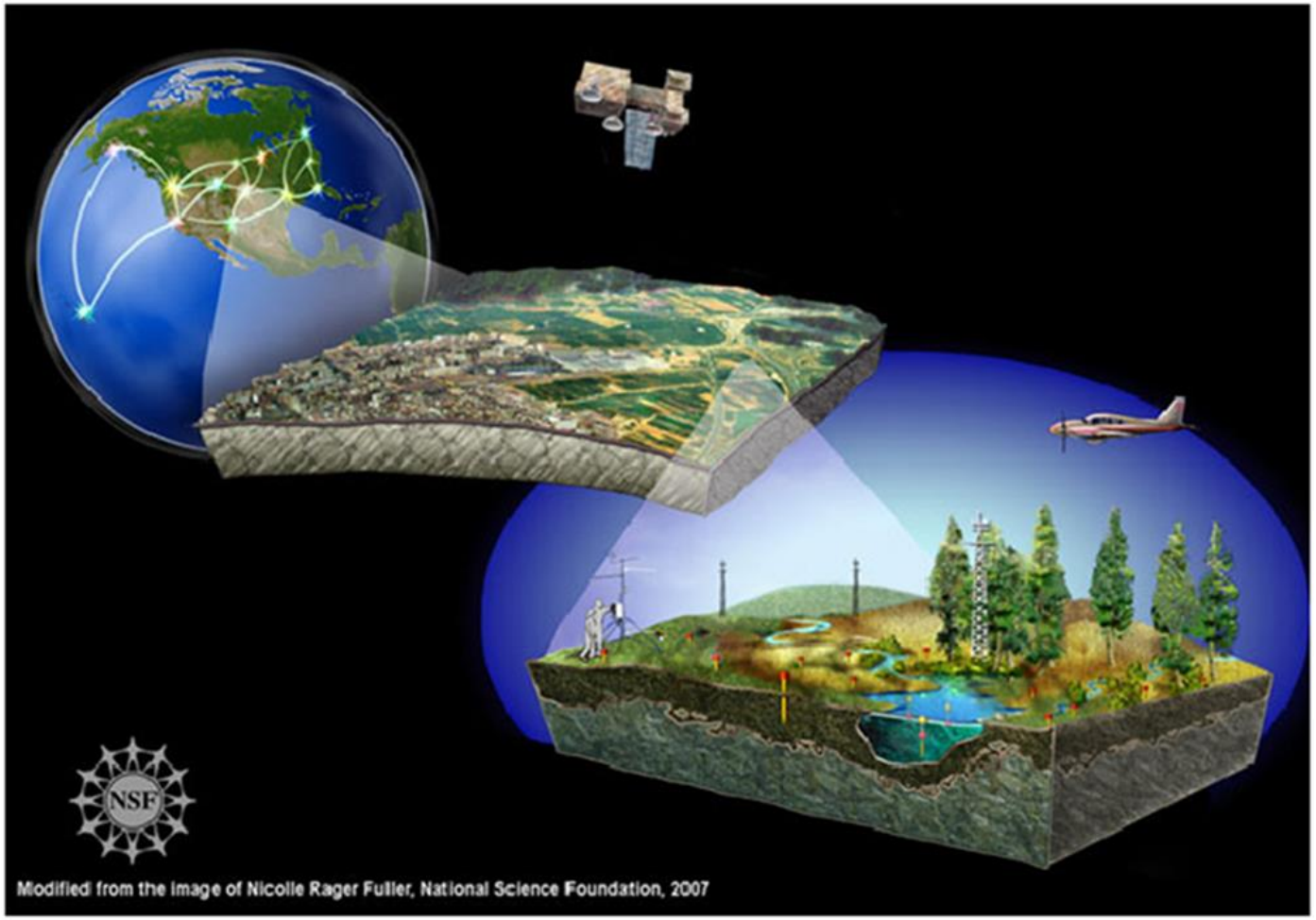


- Free and open data
- Standardized framework
- Data interoperability for integration with other research networks

NEON sampling design

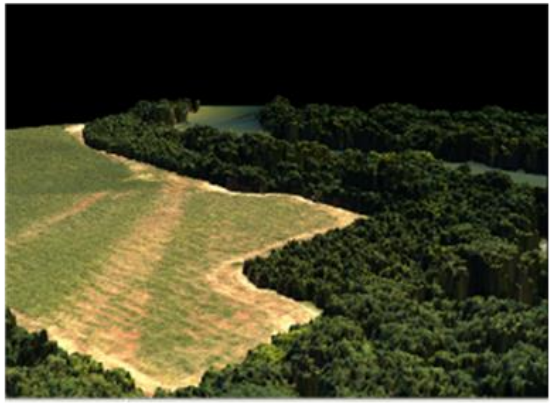
- Automated Instrument Systems
- Observational Sampling
- Airborne Observation Platform

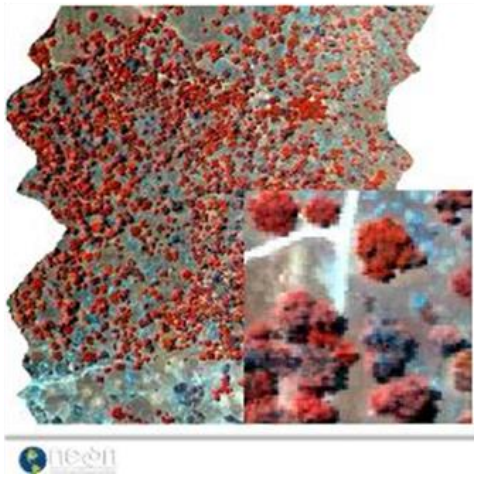
Multi-scale ecological analyses using NEON data



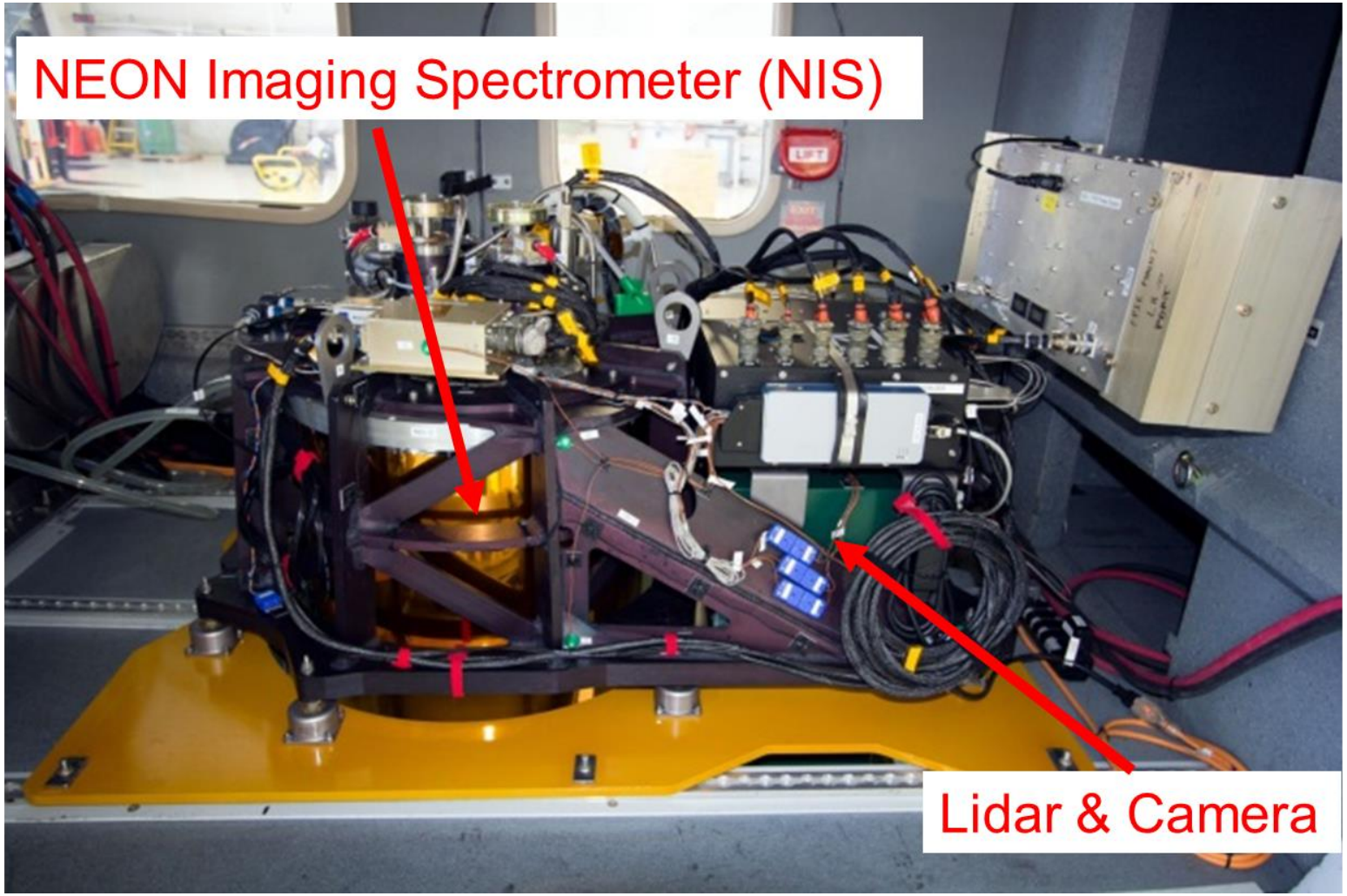
Airborne Observation Platform (AOP)

- Collects airborne remote sensing data
- Covers ‘regional scale’ (min of 100 km^2)
- Data products generated at high spatial resolution (<=1 m^2)
- Waveform Lidar, Imaging Spectrometer and RGB camera



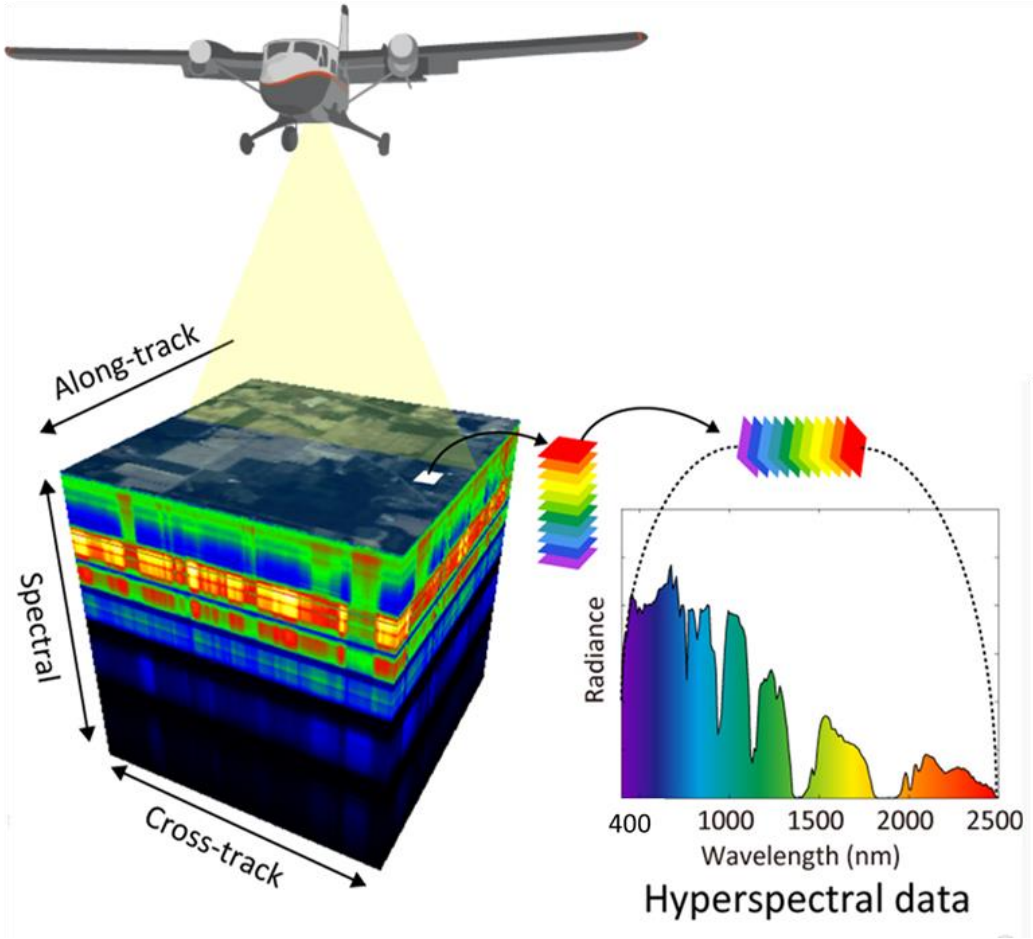


AOP Payloads

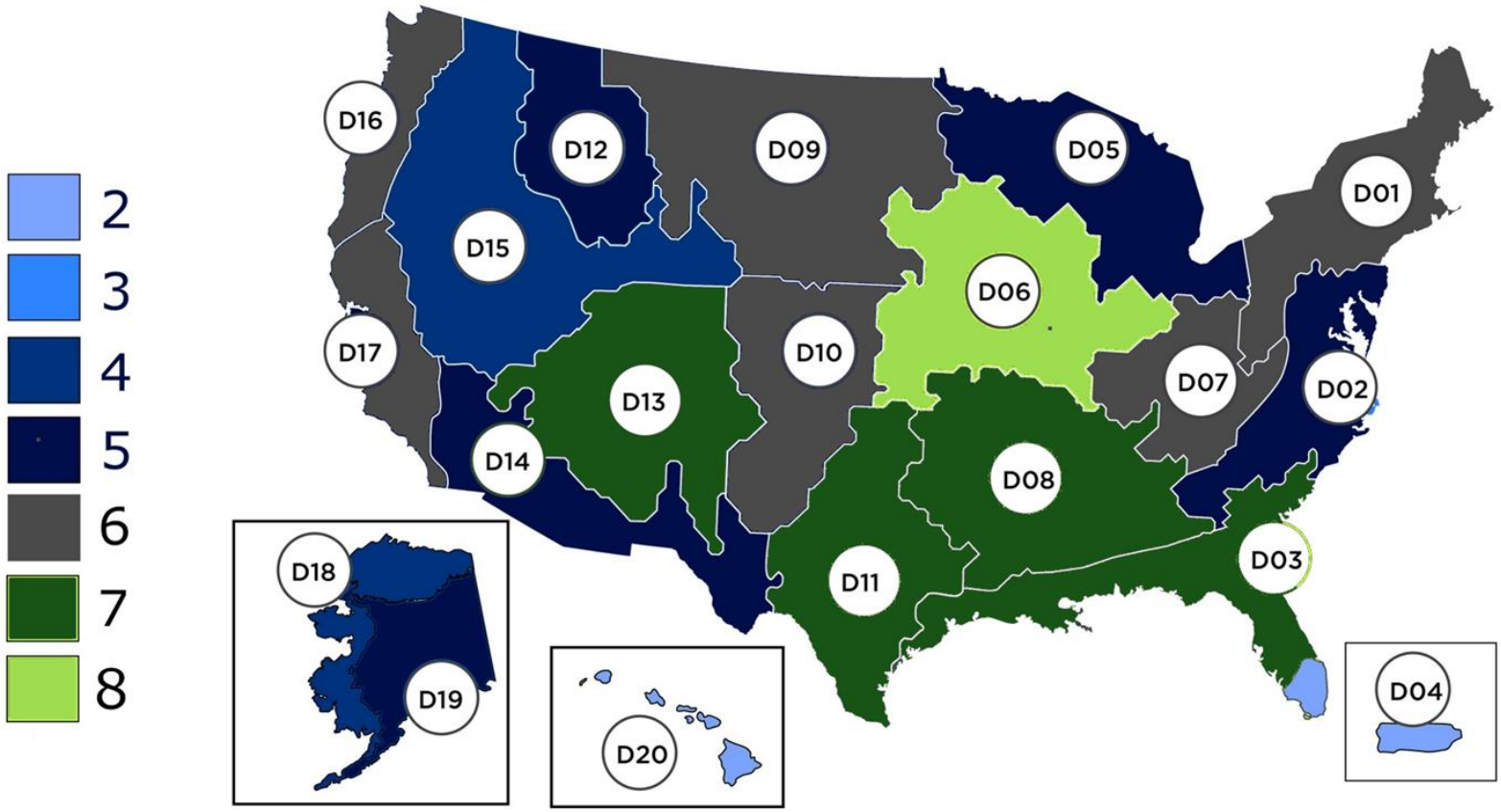


NEON Imaging Spectrometer (NIS)

- Images acquired in pushbroom configuration
  - 34 deg across-track
  - 1 mrad along-track
  - **1000m AGL = 1m² resolution**
- Each 1 mrad pixel imaged light is spread into its component wavelengths 380 - 2510 nm
- 5nm spectral sampling interval with <7.5nm FWHM
- Provides surface reflectance



2013 – 2023 AOP collections



NEON AOP data products

Level 1

- Spectrometer Orthrorectified at-Sensor Radiance
- LiDAR Slant Range Waveform
- Discrete Return LiDAR Point Cloud
- Spectrometer Orthorectified Surface Directional Reflectance
- High-resolution Orthorectified camera imagery

Raw data to physical units

Level 2

- Canopy Water Content
- Canopy Xanthophyll Cycle
- Canopy Lignin
- Canopy Nitrogen
- Vegetation Indices – Spectrometer
- Albedo - Spectrometer
- LAI - Spectrometer
- fPAR - Spectrometer
- Total Biomass Map - Spectrometer

Derived products e.g. indices

Level 3

- Spectrometer Orthorectified Surface Directional Reflectance
- High-resolution Orthorectified camera imagery mosaic
- Albedo - Spectrometer
- LAI - Spectrometer
- fPAR - Spectrometer
- Total Biomass Map - Spectrometer
- Canopy Nitrogen
- Canopy Water Content
- Canopy Xanthophyll Cycle
- Canopy Lignin
- Vegetation Indices - Spectrometer
- Ecosystem Structure
- Elevation - LiDAR
- Slope and Aspect - LiDAR

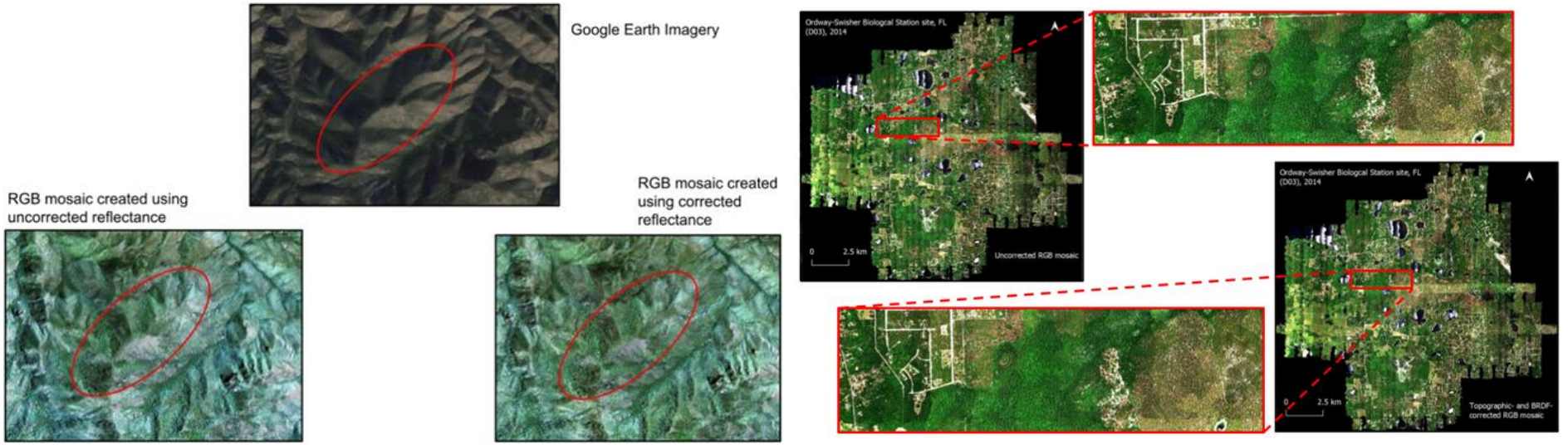
Derived product mosaics

Temporarily Suspended Products

ATBDs (Algorithm Theoretical Basis Documents) describing the process for data product creation

Update on spectrometer-derived AOP products

- 2022 and 2023 spectrometer data processing underway.
- We will now generate topographic and BRDF-corrected reflectance data using HyTools Python toolbox[1]. Directional reflectance product will continue to be generated.
- Plan to use the corrected reflectance data to generate higher-level products (LAI, FPAR, foliar trait products).

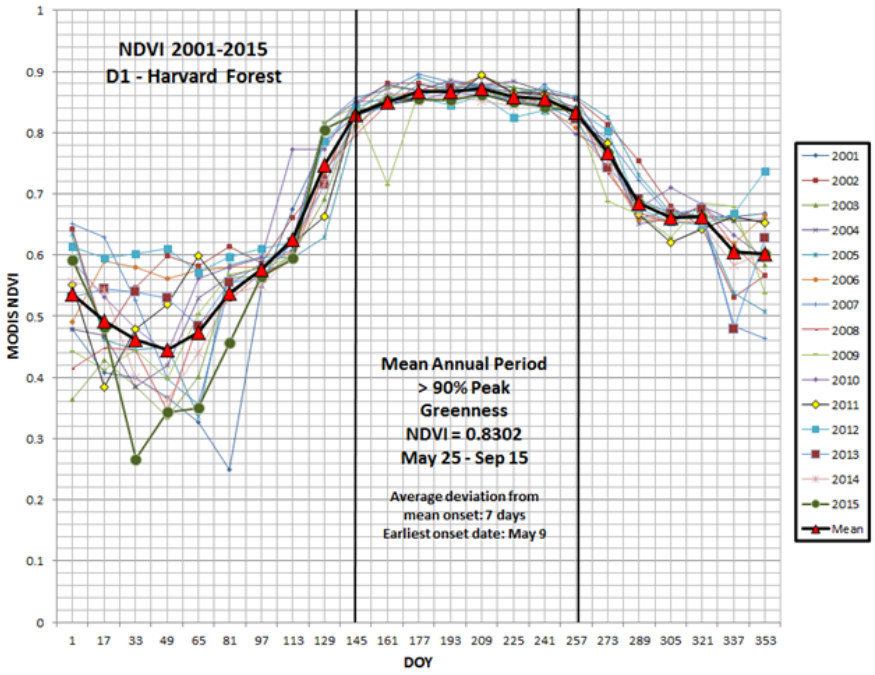


[1] Queally, Natalie, et al. "FlexBRDF: A flexible BRDF correction for grouped processing of airborne imaging spectroscopy flightlines." *Journal of Geophysical Research: Biogeosciences* 127.1 (2022): e2021JG006622.

Sampling protocols for conducting AOP surveys and foliar trait sampling

AOP sampling requirements

- Clear skies
- Nominal AOP flying altitude = 1000 m AGL
- Collect data at the scale of individual plants
- Minimum 10 km x 10 km box
- Collect regional scale area around NEON sites
- Fly at peak ‘greenness’
- Fly N-S lines when solar angles are above 40°



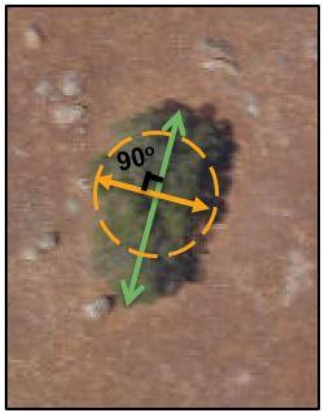
NEON foliar sampling protocol

Each site is sampled once every 5 years during peak greenness (closely coordinated with AOP overflights).

Leaf samples collected for woody individuals. Herbaceous cover sampled by clipping a full strip of vegetation.

Foliar traits measured:
- Canopy percent N, P
- Leaf mass per area (LMA), canopy water content
- Chlorophyll A and B
- Canopy lignin
- Stable isotopes of C and N
- Major/minor elements

Woody



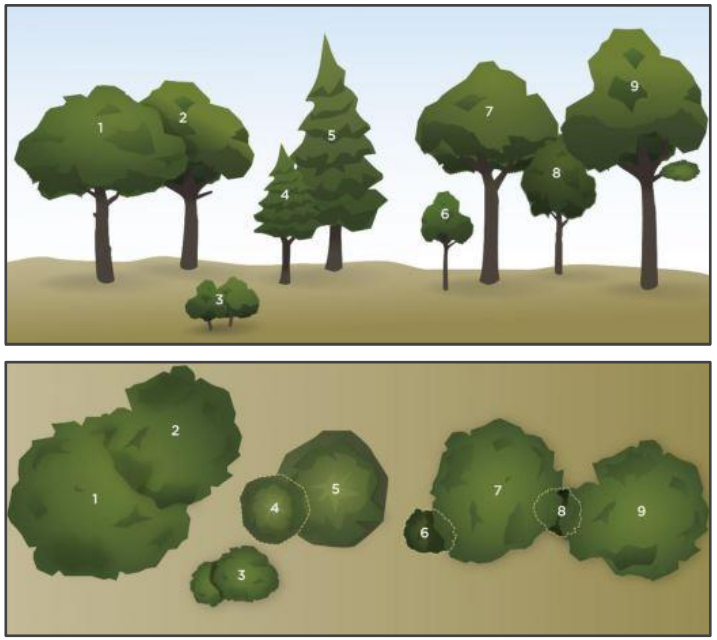
Herbaceous

NEON foliar sampling protocol – Woody individuals

Both 1 and 2 can't be sampled as their crowns overlap.

4 & 6 have much of their crowns shaded by larger trees.

8 can't be seen from above.



Record metadata about the woody individual

- **Plant status** – OK, Insect damaged, Disease damaged, physically damaged, Other damage, Leaves not fully expanded, Leaves beginning to senesce
- **Canopy position** – Open grown, Full sun, Partially shaded, Mostly shaded, Fully shaded
- **Canopy status** – True canopy, sunlit gap

Geolocation

Starting in 2020, hand-delineate a shapefile polygon that contains pixels from only the crown of the sampled individual, as 'seen' from above.

Before 2020, GPS coordinates of the plant stem recorded. No crown polygons available.

Leaf samples collected using a line launcher, slingshot, pole pruner, or UAS

LMA subsample

Chlorophyll subsample

NEON foliar sampling protocol – Herbaceous cover

- The foliar sampling team selects clip strips randomly for sampling.
- All the aboveground biomass collected from a strip is homogenized and subsampled.
- NEON provides a look-up table to obtain easting and northing offsets to determine the precise geolocation of the SW corner of a clip strip.

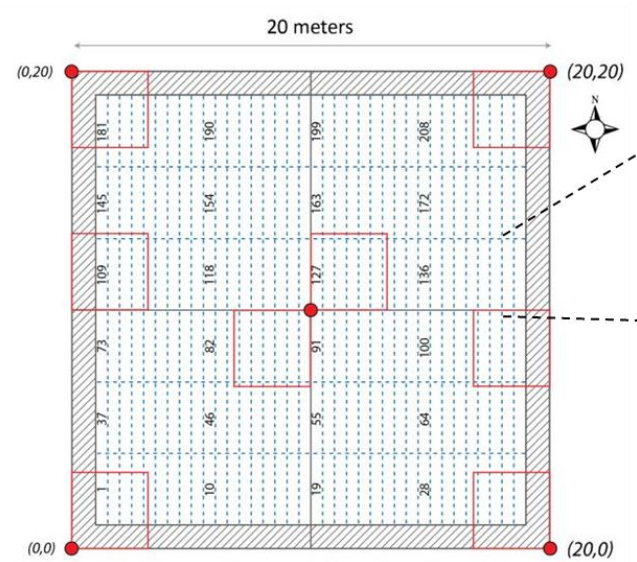
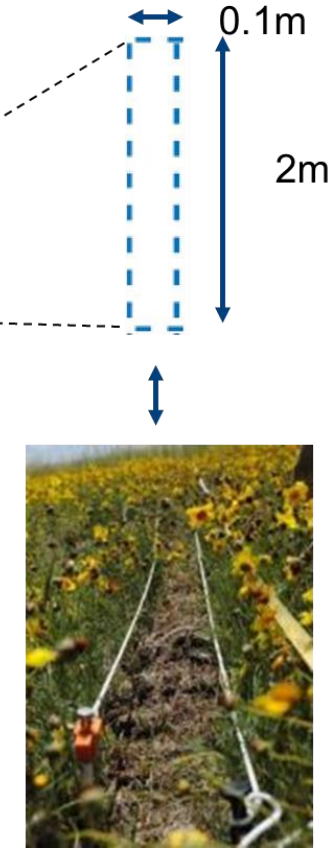
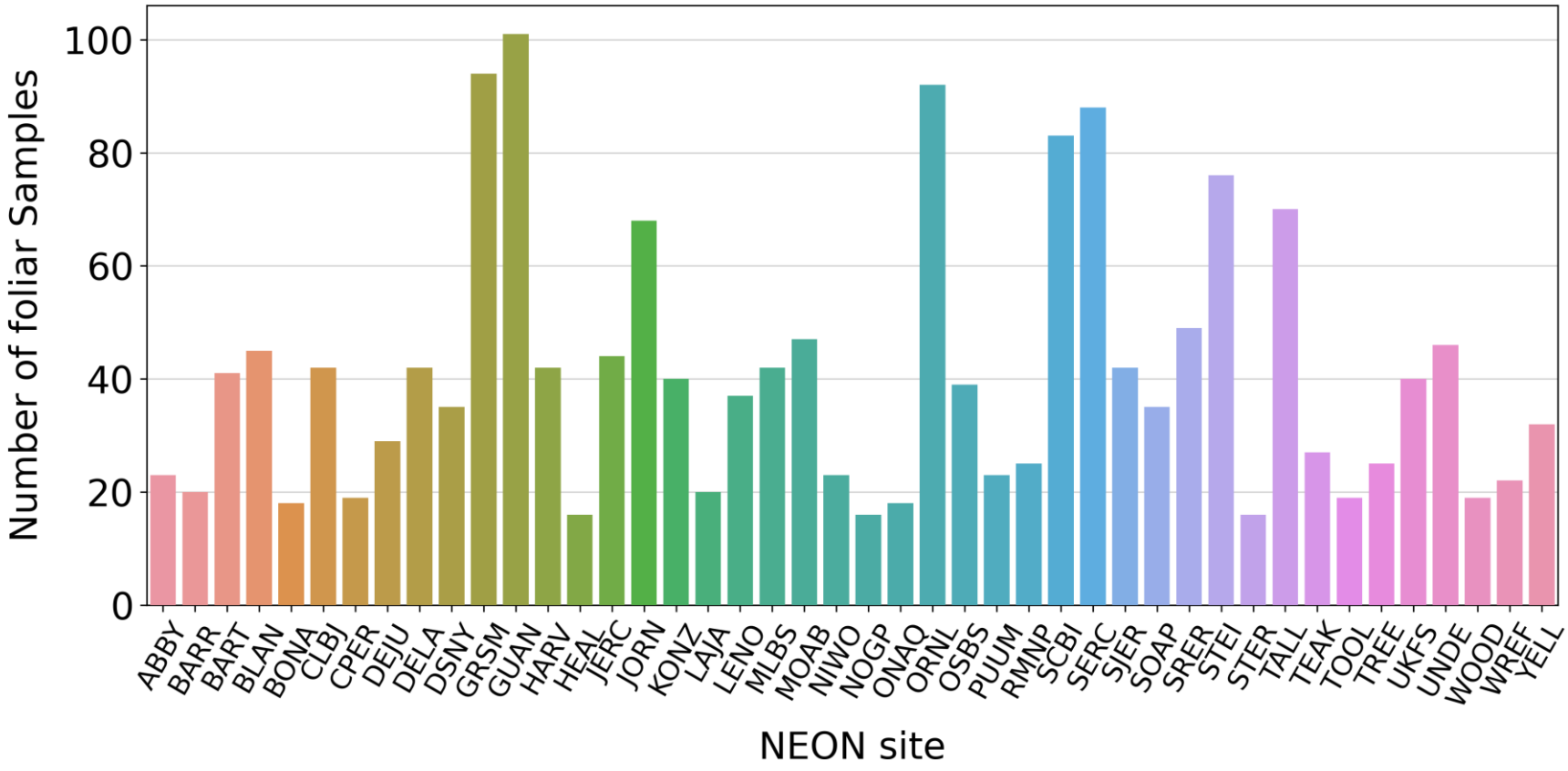


Figure 25. Map of clipCellNumbers in a 20m x 20m base plot (**subplotID = 31** in provided Clip Lists). Red squares indicate nested subplots; clip cells that significantly overlap red squares are not used for clip sampling. However, clip cells with minimal overlap (e.g., 48-54, 68-72, 145-149) do support clip harvest sampling.



foliar samples collected between 2016-2022 across all sites ~ 1800



Modeling Approach and Results

Modeling workflow

NEON Terrestrial Observation Sampling (TOS) Datasets

Geolocated foliar sampling performed for
- Woody Individuals
- Herbaceous cover

Foliar traits

Biophysical (LMA, canopy water content)
Biochemical (C,N,lignin, chlorophyll, elements etc.)
Stable isotopes (δ13 C, δ15 N)

Veg structure

Years ≥ 2020
Hand-delineated crown polygons

Years < 2020
Stem Distance, Stem Azimuth, Crown diameter → Create Crown polygons

NEON Airborne Observation Platform (AOP) Datasets

Hyperspectral

Level-1 reflectance data, 426 bands (385 - 2500 nm) at 1m resolution

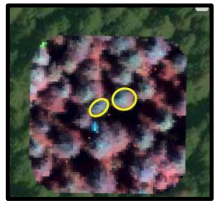
BRDF correction
Topographic correction
Wavelength resampling

Corrected reflectance

Select flight lines which are least cloud-affected

Extract AOP Data for Foliar Sampling Locations

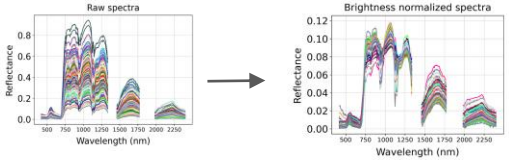
Woody individuals



Herbaceous clip strips

Select only those 1m pixels within a tree crown which are,
1) Vegetated (NDVI > threshold)
2) Not understory vegetation (CHM > threshold)
3) Not affected by cloud shadows (NIR > threshold)

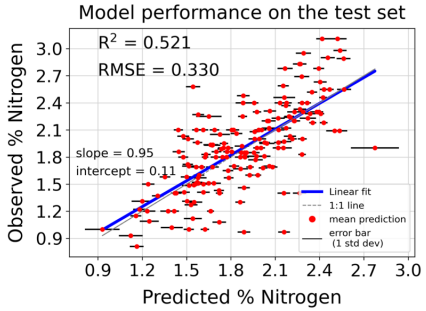
For the remaining 1m pixels within a crown, perform brightness normalization on the spectra to reduce the effect of internal canopy shadows



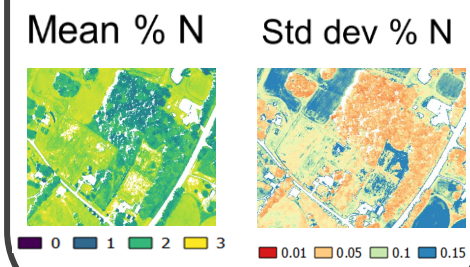
Calculate average value for the spectra and lidar-derived variables for the tree crown/clip strip

Model inputs: 331 hyperspectral bands

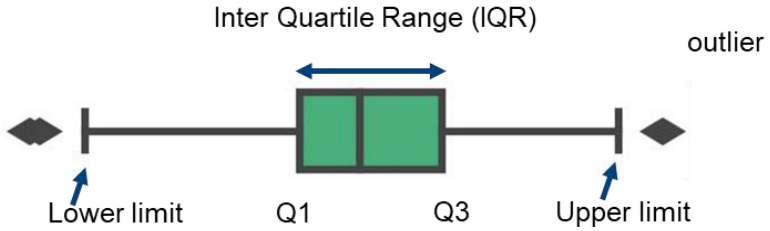
Partial Least Squares Regression (PLSR) modeling



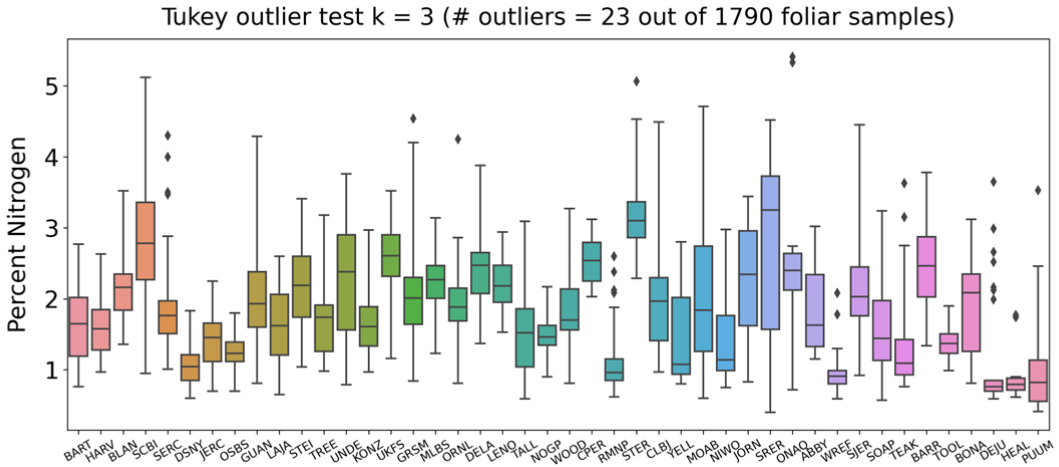
Map Foliar Traits and Characterize Uncertainty



Modeling Approach – Outlier detection



Lower limit = Q1 – (IQR x k)
Upper limit = Q3 + (IQR x k)

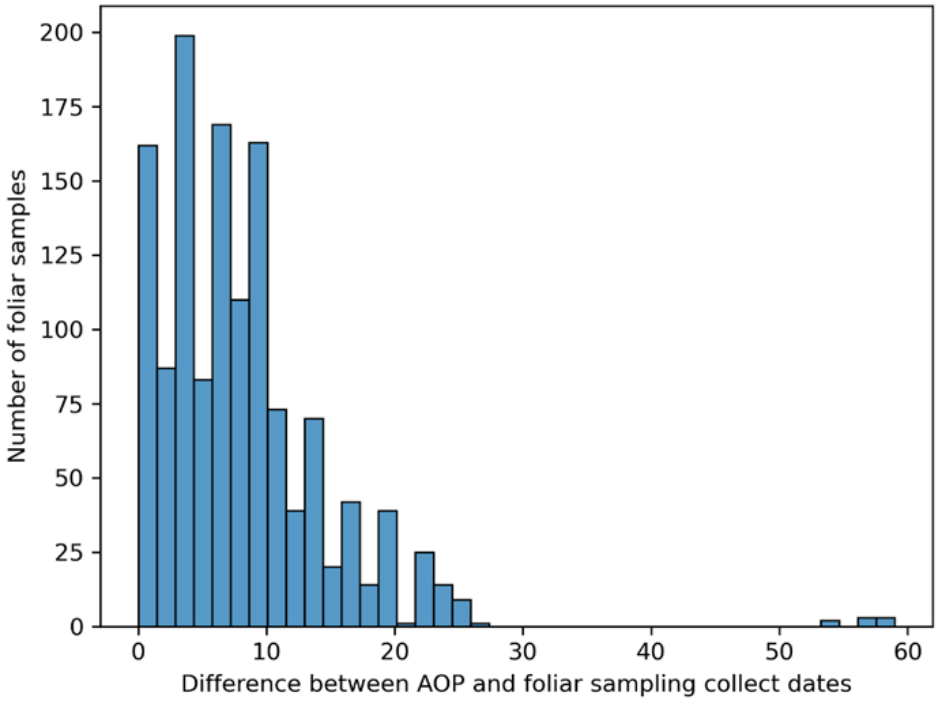


Use k = 3* to identify extreme outliers for foliar traits by site

*Kamoske, A. G., Dahlin, K. M., Serbin, S. P., & Stark, S. C. (2021). Leaf traits and canopy structure together explain canopy functional diversity: An airborne remote sensing approach. *Ecological Applications*, *31*(2), e02230. https://doi.org/10.1002/eap.2230

Temporal gap between AOP and foliar sampling collect dates

What is the maximum allowable time gap (days) between the AOP flight date and the foliar sampling dates?



- A larger time gap could result in a disconnect between what the AOP “saw” and what the field sampling team measured on the ground.
- Research papers have typically used a cutoff of 2 weeks.
- Usually, NEON foliar sampling happens within 3 weeks of AOP overflights.
- Tighter coupling for samples flagged as “leaves beginning to senesce” or “leaves not fully expanded”?
- Separate cutoff values for each trait?

Tighter coupling requirement during green-up and senescence?

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

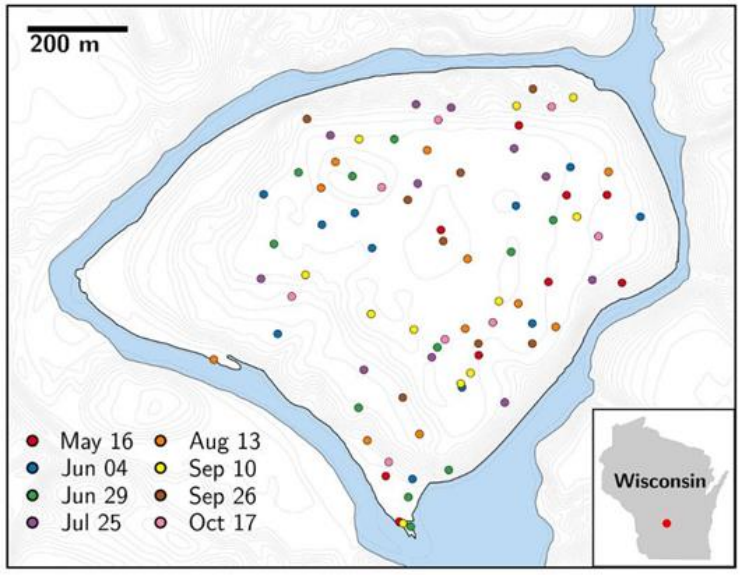
Characterizing seasonal variation in foliar biochemistry with airborne imaging spectroscopy

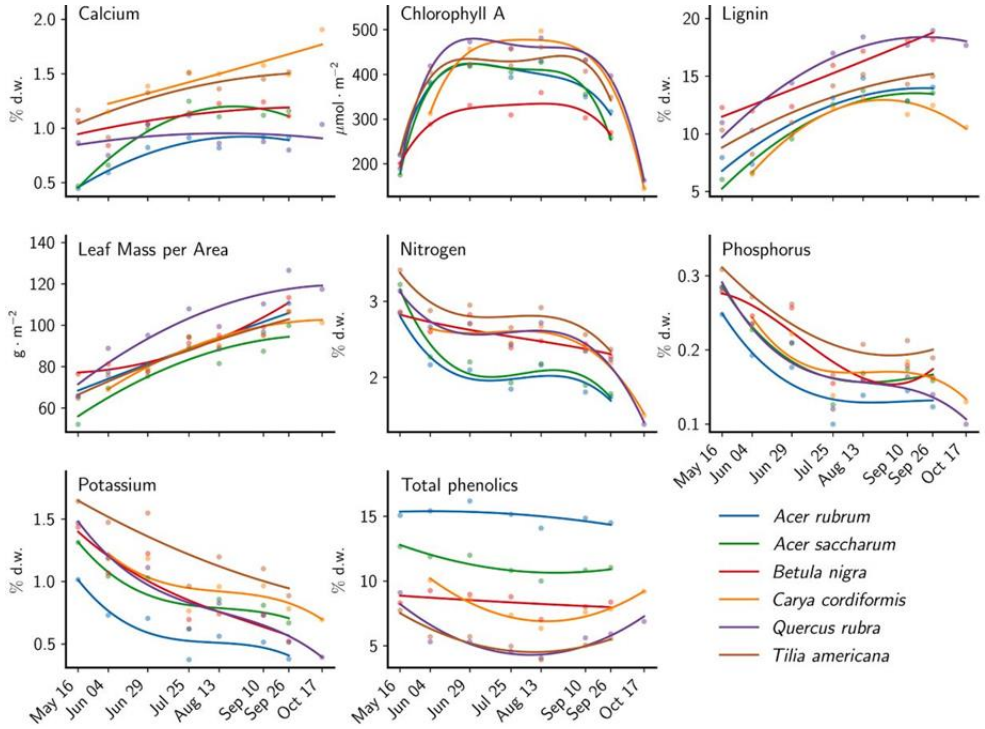
Adam Chlus *, Philip A. Townsend

Department of Forest and Wildlife Ecology, University of Wisconsin, Madison, WI, USA

Table 1
Airborne HySpex imagery used in the study.

Overflight date	Mean local acquisition time	Local solar noon	Mean solar zenith angle
May 16, 2018	12:22	12:55	25°
June 04, 2018	11:19	12:57	29°
June 29, 2018	12:18	13:02	22°
July 25, 2018	13:38	13:05	25°
August 13, 2018	14:26	13:04	34°
September 10, 2018	12:18	12:56	39°
September 26, 2018	12:40	12:50	45°
October 17, 2018	12:22	12:44	53°



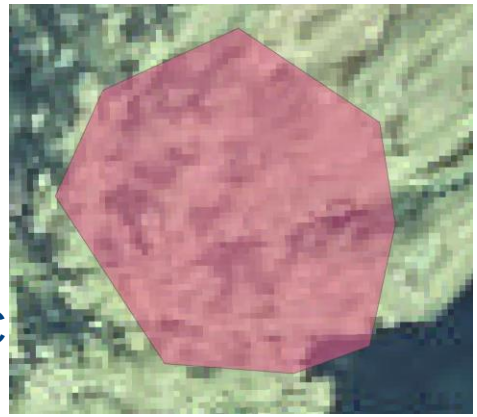


How to select pixels for modeling?

Use an NDVI threshold? Different thresholds for sites?

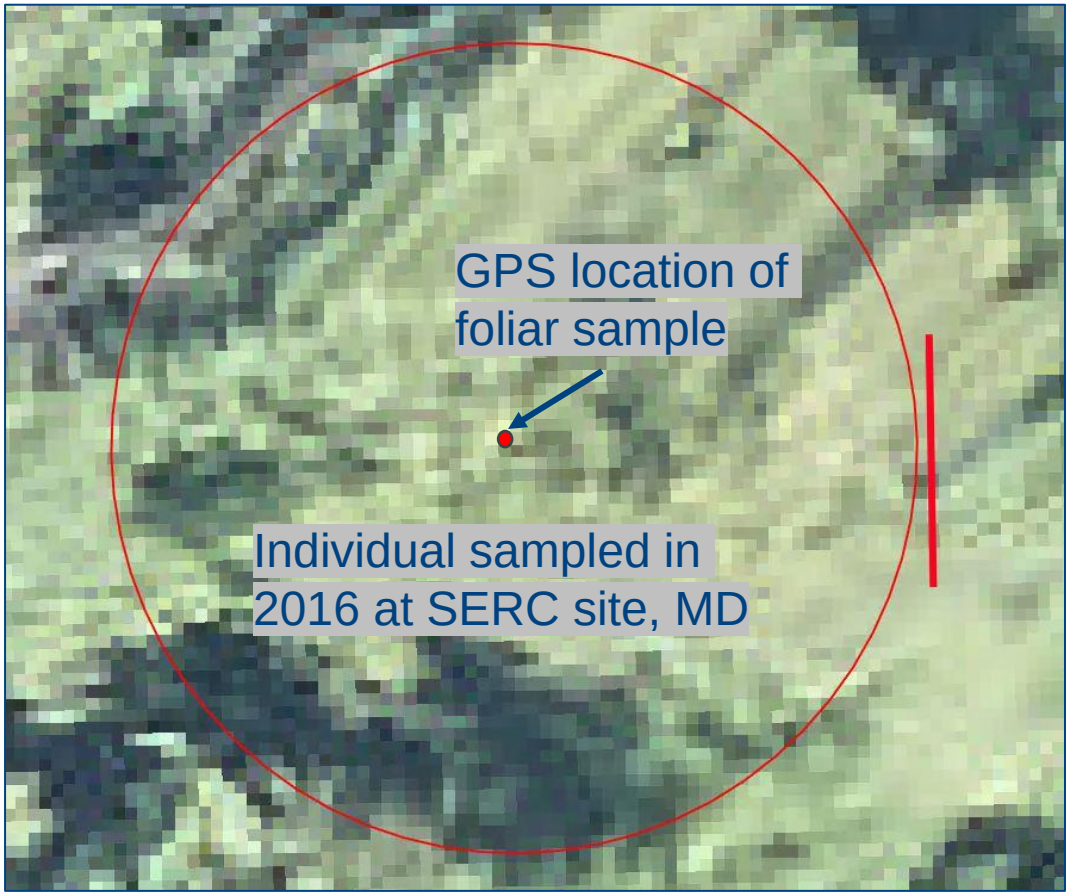
Use lidar-derived canopy height model to separate woody from understory?

Starting 2020, tree crowns were hand-delineated in the field during foliar sampling



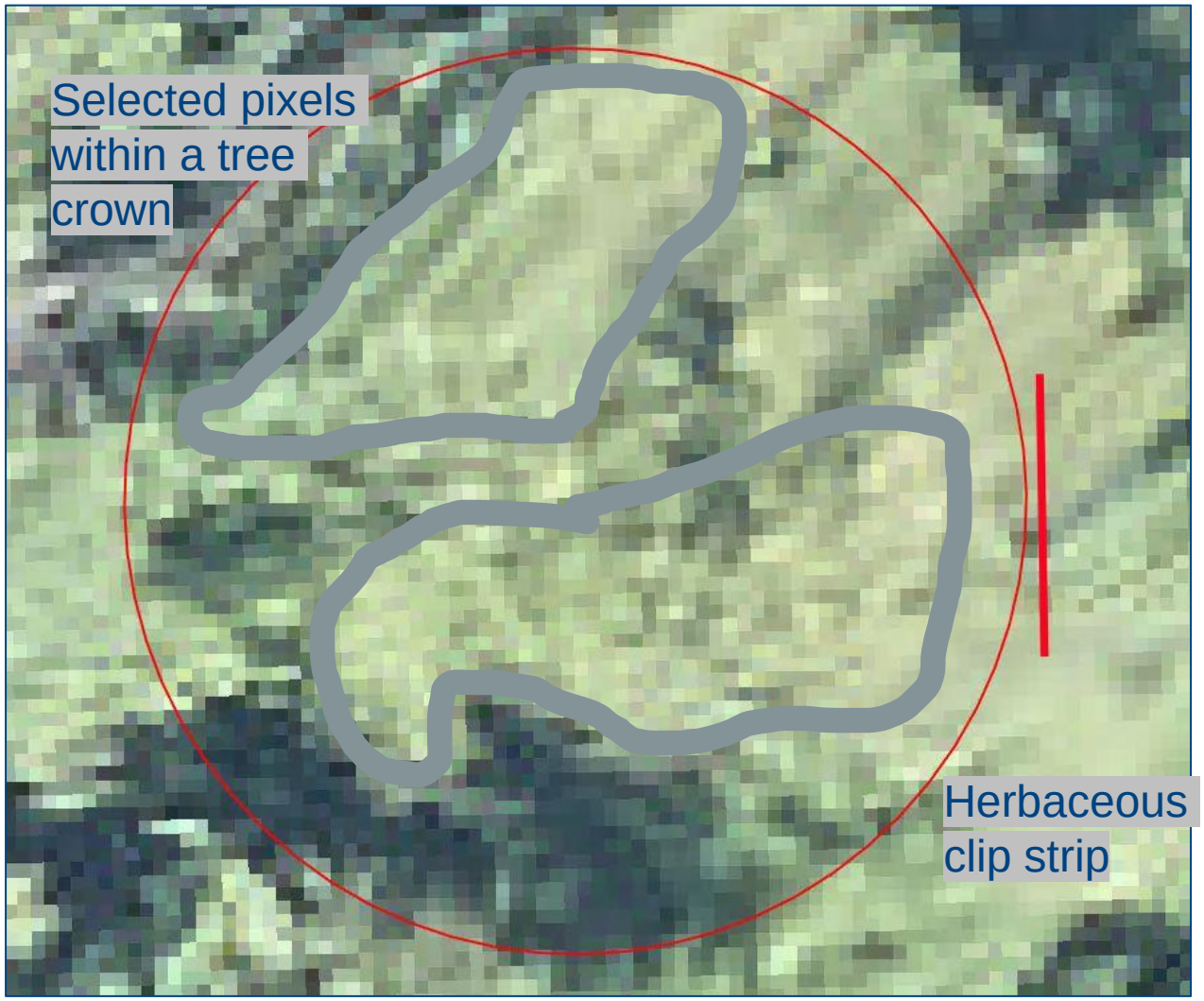
Individual sampled in 2021 at SERC site, MD

For years prior to 2020, when tree crowns were not hand-delineated in the field, we created tree crown polygons post hoc by drawing a circle centered on the GPS location of foliar sample. Crown diameter info is available sometimes in the veg structure measurements.



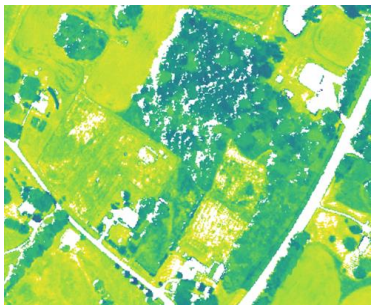
What to do with selected pixels?

- **Average the spectra for all the selected pixels?**
- **Treat each pixel separately for modeling?** Possibility of class imbalance with many more samples for the woody individuals vs herbaceous cover
- **Fit an ensemble of PLSR models with each model trained on a different sample from the selected pixels**

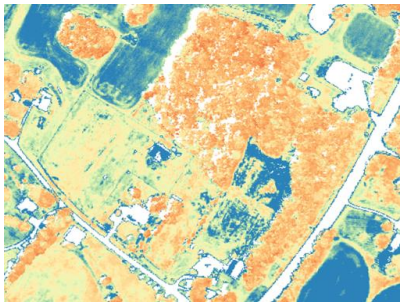


Preliminary Results

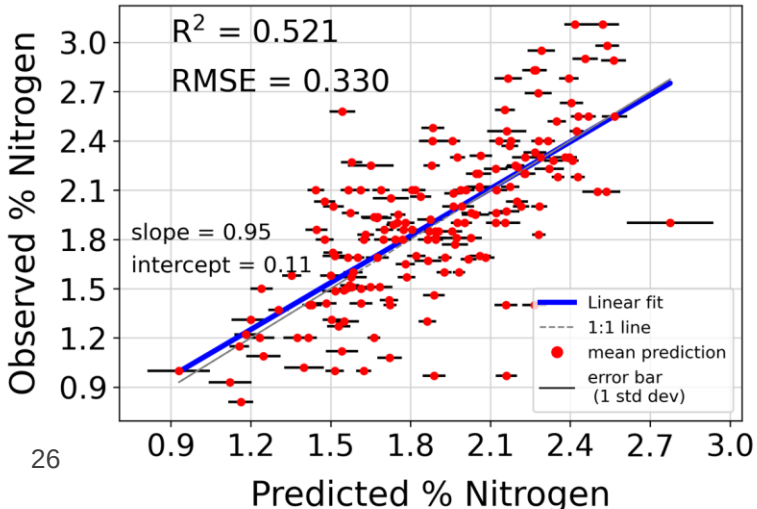
Mean %N



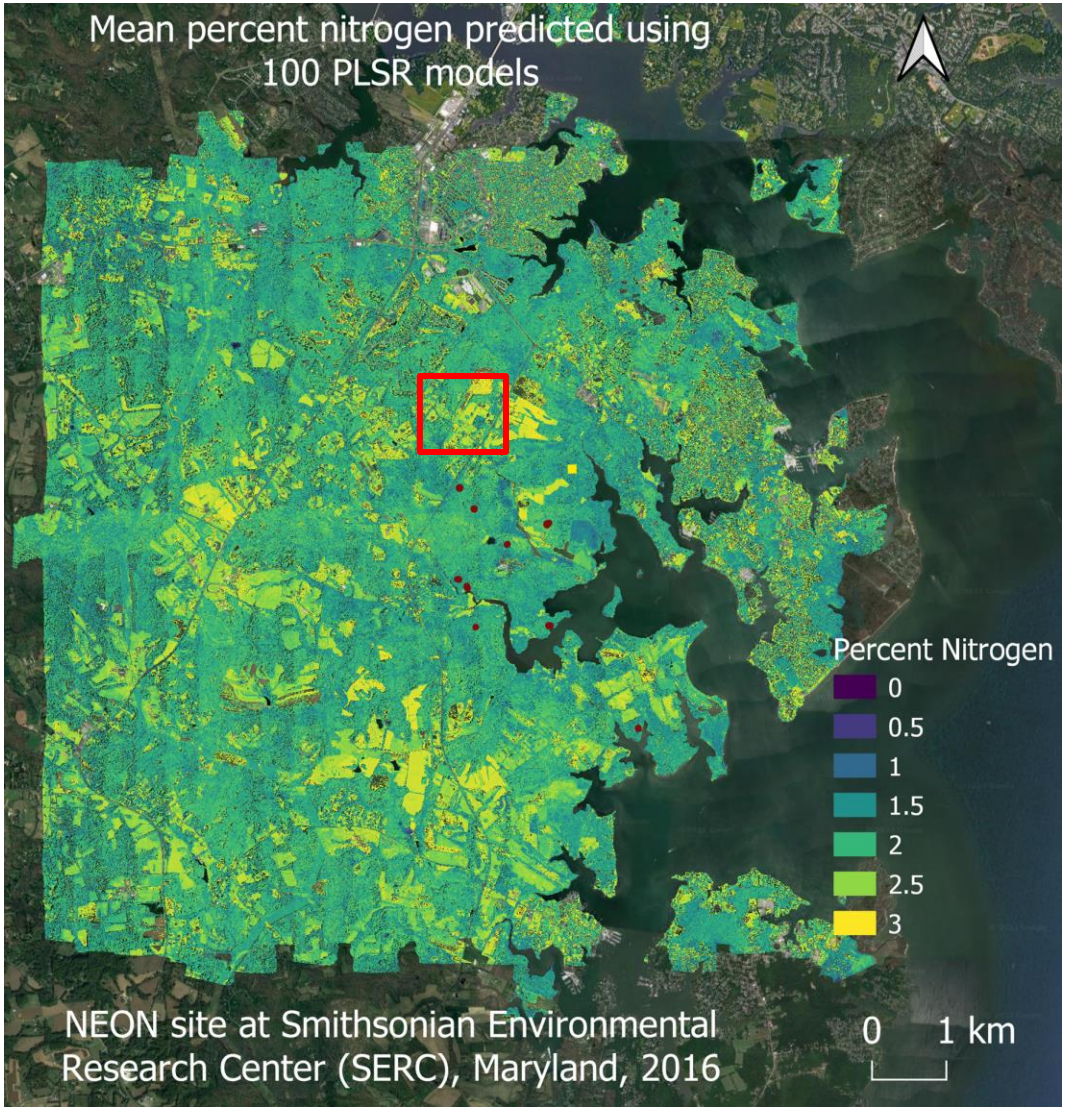
Std Dev %N



Model performance on the test set



PLSR models trained on percent nitrogen data collected from three NEON Domains (D01, D02 and D07).



Ongoing Work

Different models for confier and non-conifer vegetation types

Separate models for Herbaceous v/s woody?

Include more PFT types: Broadleaf, Needleleaf, shrub, forbs, etc.

more PFT types --> less data available to train the PFT-specific model

Methods in Ecology and Evolution
BRITISH ECOLOGICAL SOCIETY

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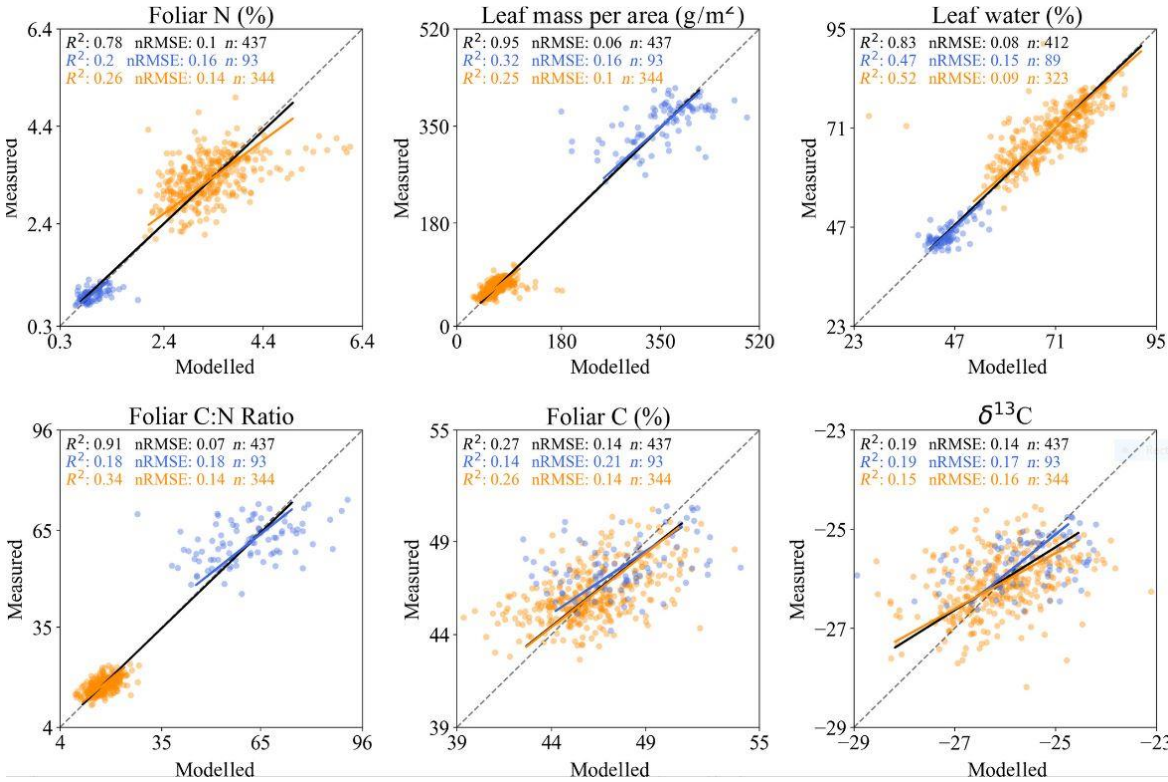
Integrating airborne remote sensing and field campaigns for ecology and Earth system science

K. Dana Chadwick, Philip G. Brodrick, Kathleen Grant, Tristan Goulden, Amanda Henderson, Nicola Falco, Haruko Wainwright, Kenneth H. Williams, Markus Bill, Ian Breckheimer, Eoin L. Brodie, Heidi Steltzer, Charles F. Rick Williams, Benjamin Blonder, Jiancong Chen, Baptiste Dafflon, Joan Damerow, Matt Hancher, Aizah Khurram, Jack Lamb, Corey R. Lawrence, Maeve McCormick, John Musinsky, Samuel Pierce, Alexander Polussa, Maceo Hastings Porro, Andea Scott, Hans Wu Singh, Patrick O. Sorensen, Charuleka Varadharajan, Bizuayehu Whitney, Katharine Maher

Separate models for Conifer and Non-conifer



Ongoing Work

- Test different criteria for selecting pixels, for different sites.
- Test different modeling approaches
  - One model for all domains
  - Domain-specific model
  - Site-specific model
- Compare the distribution of predicted foliar traits with global trait databases like TRY.
- Develop an operational algorithm for generating trait maps.

Operated by Battelle

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