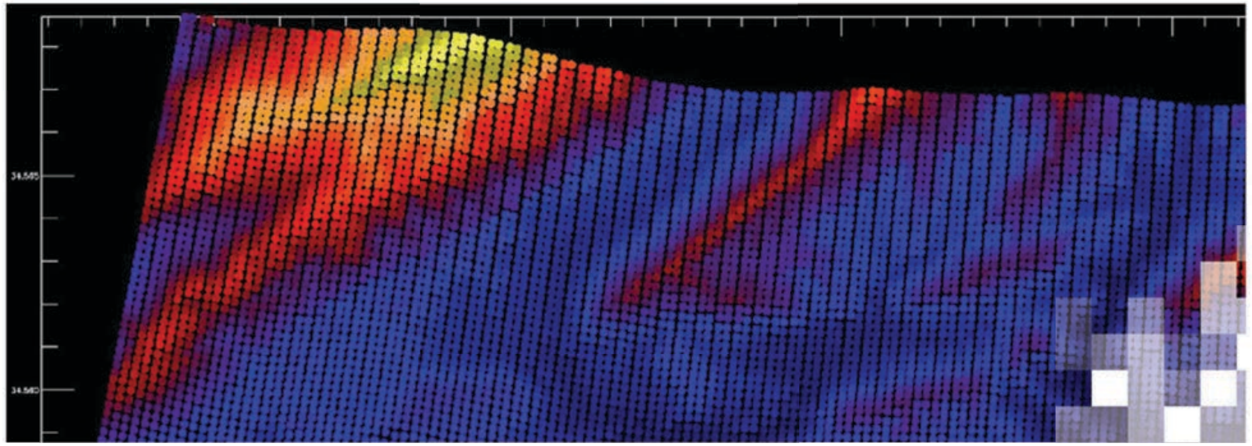
National Aeronautics and Space Administration



# Biodiversity Applications for Airborne Imaging Systems

Juan L. Torres-Pérez, Britnay Beaudry, Sativa Cruz, Amber McCullum
Guest Speakers: Atticus Stovall, Phil Townsend

April 3, 2023

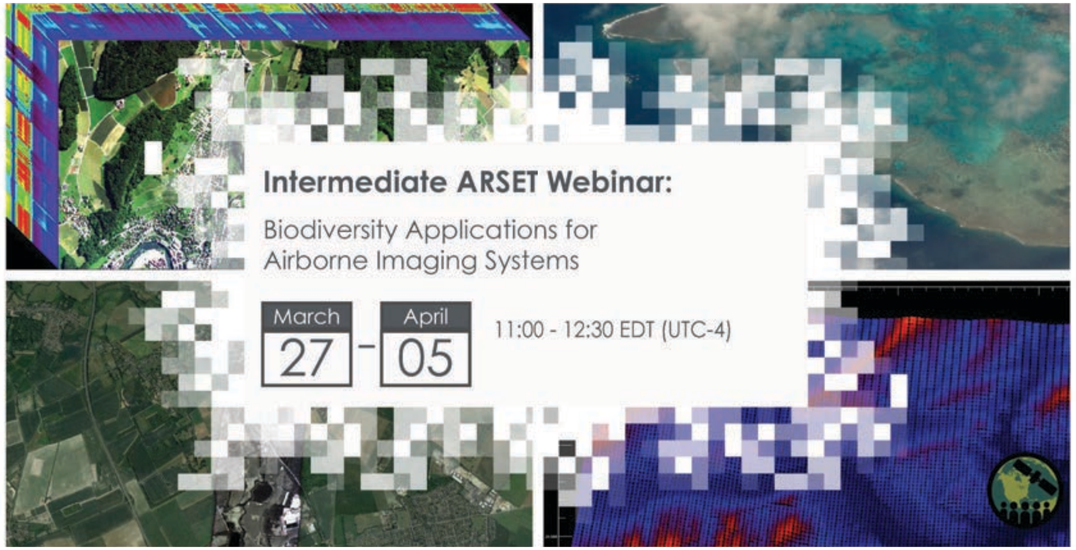
# Course Structure and Information

- Four, 1.5-hour sessions on March 27, 29 & April 3, 5
  - 11:00 am - 12:30 pm EDT (UTC-4:00)

- Each session will feature a lecture and a Q&A session where instructors will be online to answer questions.

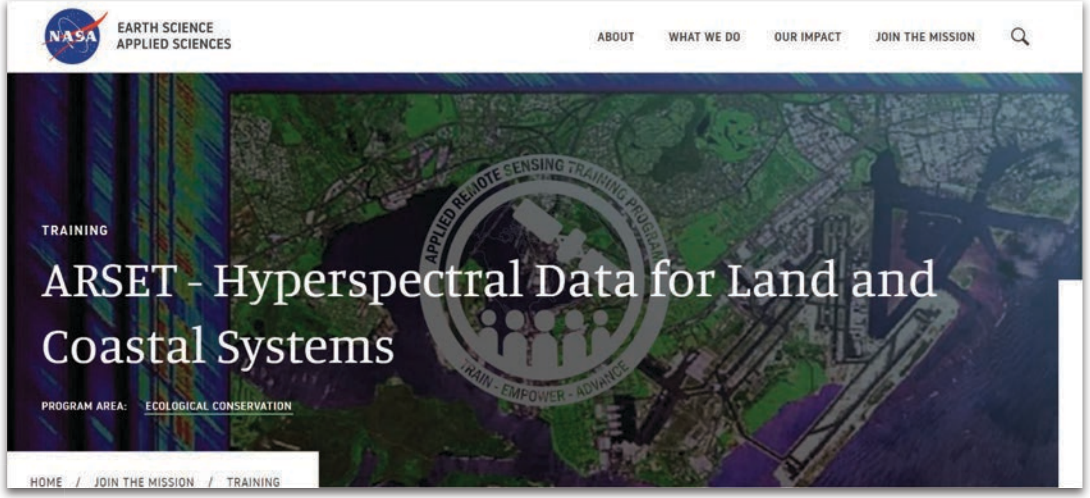
- Webinar recordings and PowerPoint presentations can be found after each session at: https://appliedsciences.nasa.gov/join-mission/training/english/arset-biodiversity-applications-airborne-imaging-systems

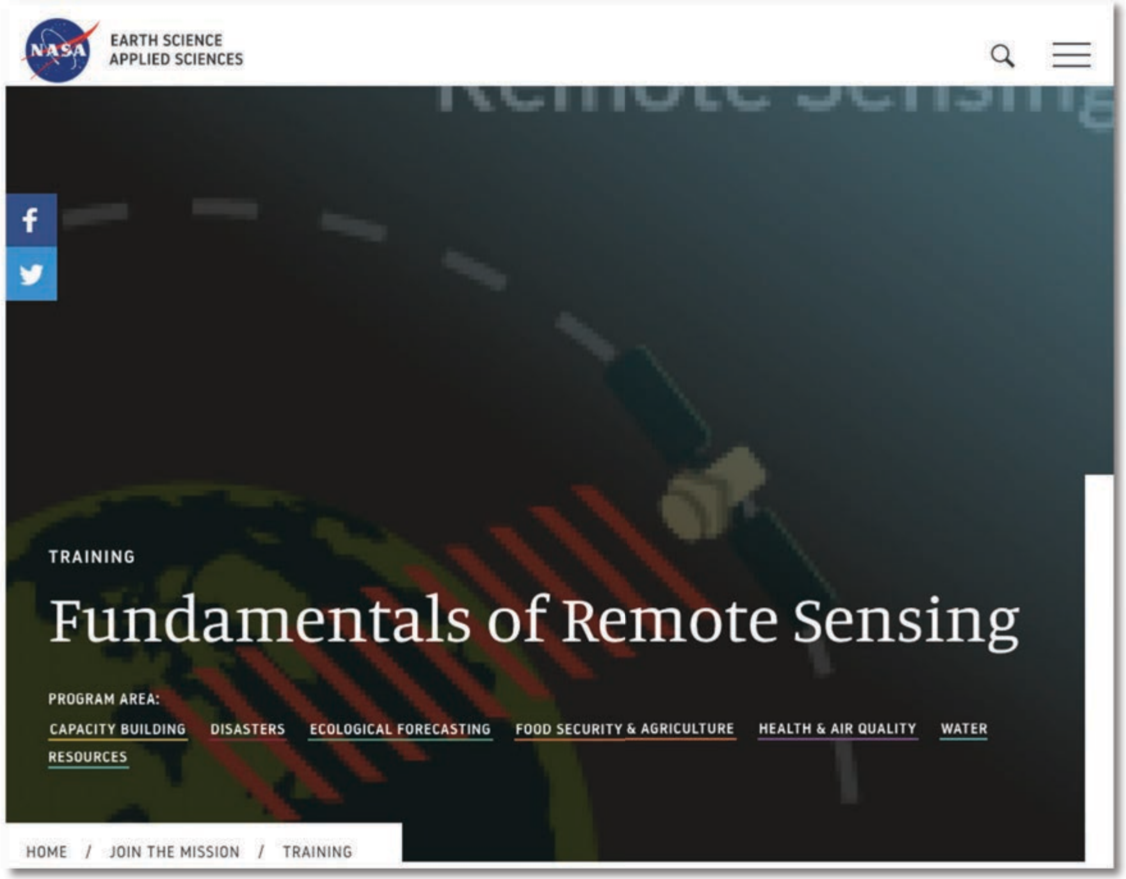
- For additional questions please email:
  - Juan L. Torres-Pérez (juan.l.torresperez@nasa.gov)
  - Amber McCullum (amberjean.mccullum@nasa.gov)
  - Britnay Beaudry (britnay.beaudry@nasa.gov)
  - Sativa Cruz (sativa.cruz@nasa.gov)



# Prerequisites

- Prerequisites:
  - Fundamentals of Remote Sensing
  - Hyperspectral Data for Land and Coastal Systems
    - or equivalent experience

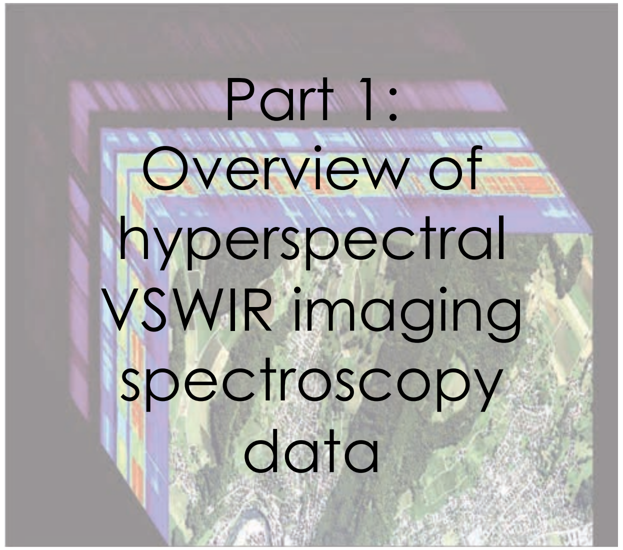


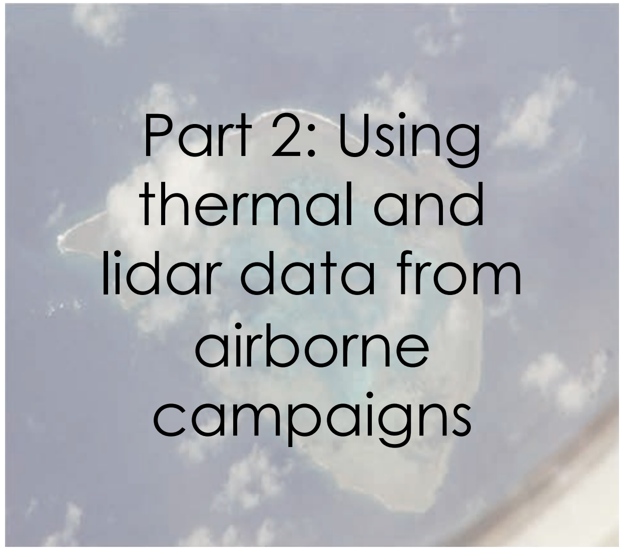



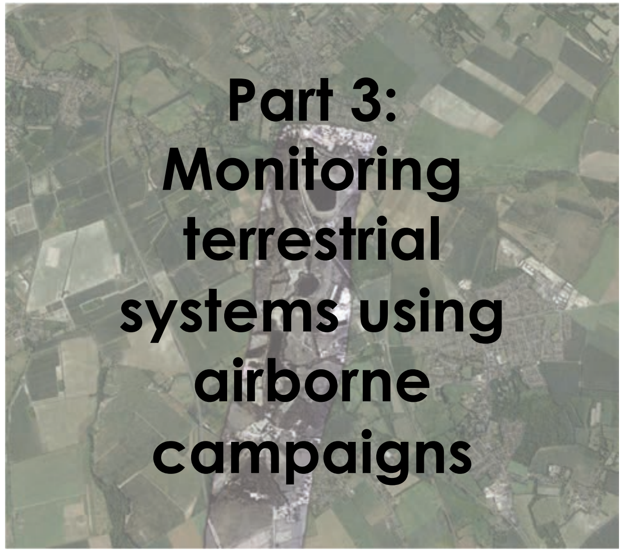
# Homework and Certificates

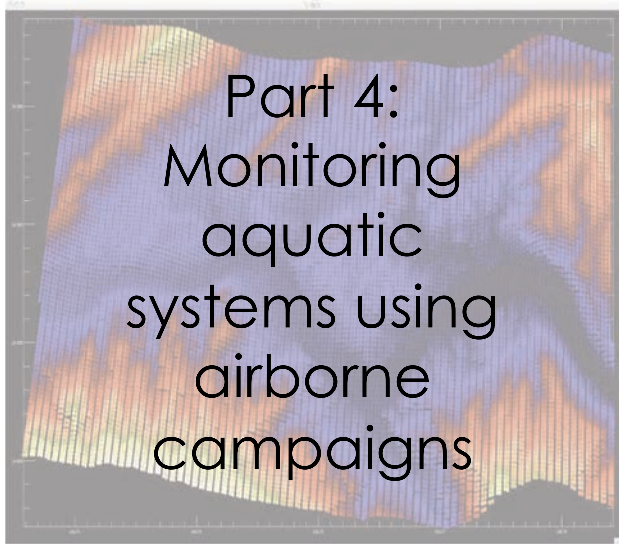
- **Homework:**
  - One homework assignment (available at the end of session four of this webinar series)
  - Answers must be submitted via Google Forms
  - **HW deadline: April 19th**
- **Certificate of Completion:**
  - Attend all four live webinars
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately two months after the completion of the course from: marines.martins@ssaihq.com

# Course Outline



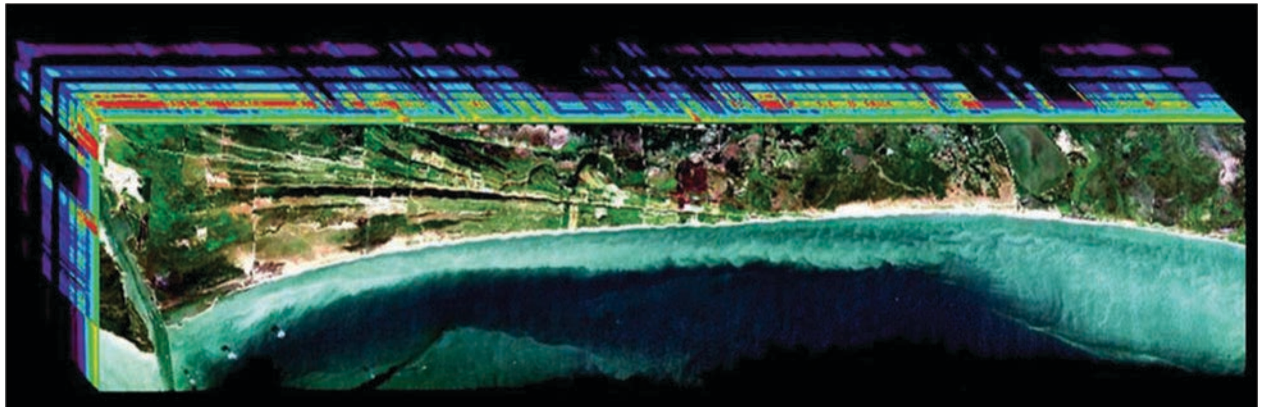



# Learning Objectives

**By the end of this training attendees will be able to:**

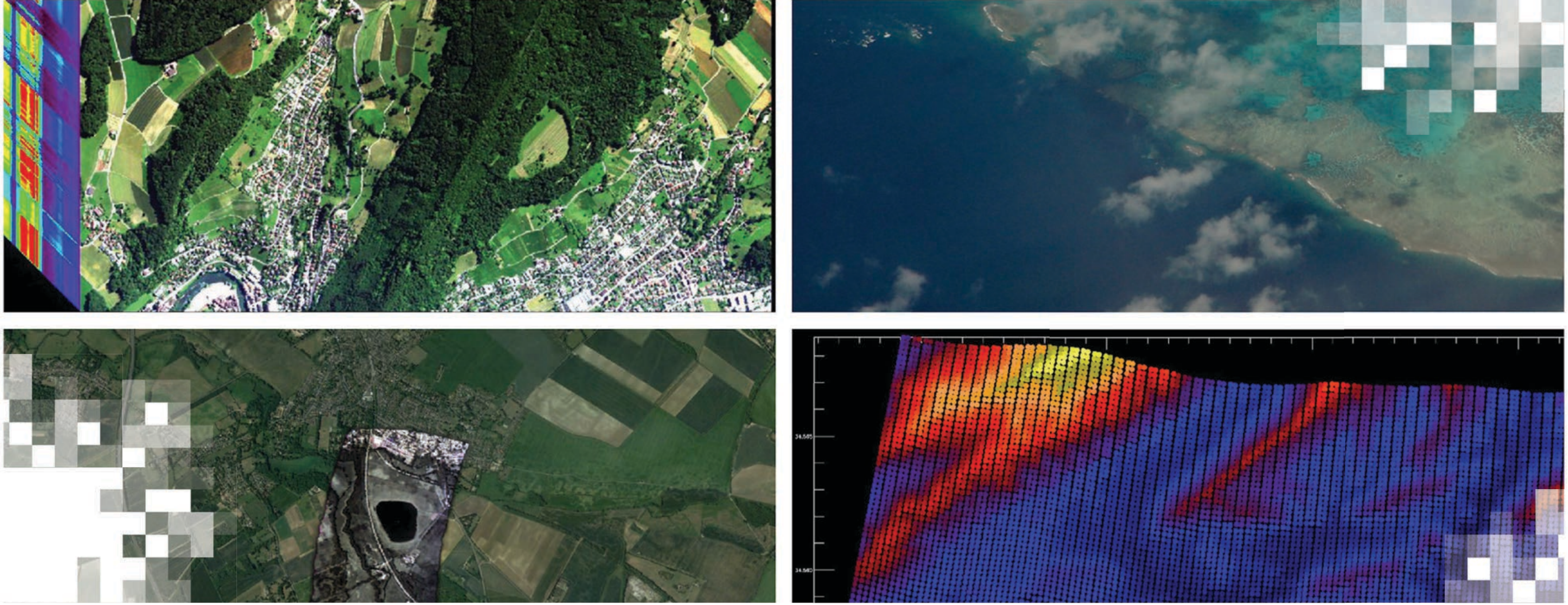
- Understand the applications of hyperspectral data, multispectral data, and LiDAR data for biodiversity monitoring and analysis
- Compare case studies that have used these datasets in preparation for upcoming NASA satellite missions and airborne campaigns



Source: NASA JPL

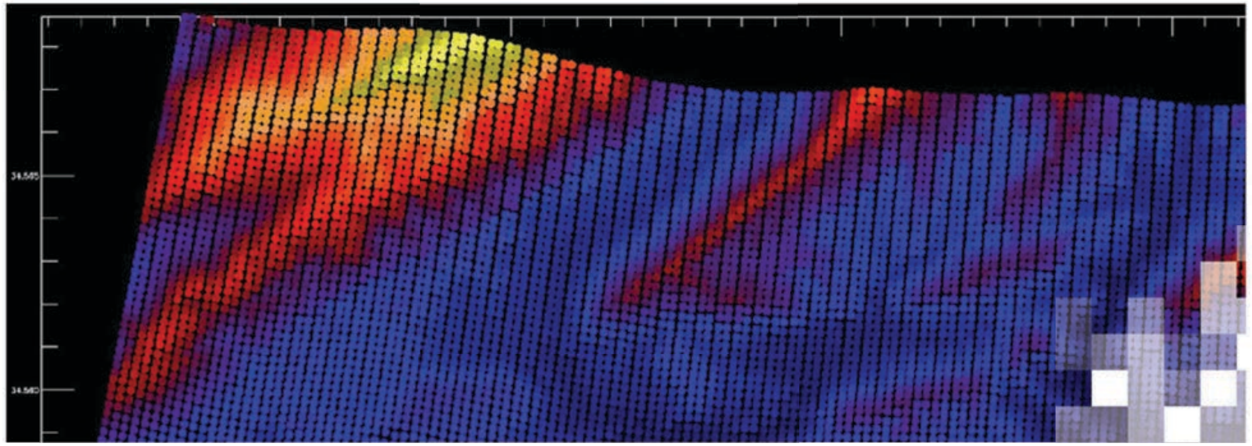
# Part 3 Agenda

- Capturing the structural component of wetland biodiversity with airborne LiDAR with Atticus Stovall
- Assessing biodiversity with plant functional traits using hyperspectral visible to Shortwave Infrared (VSWIR) imaging spectroscopy data and LiDAR data with Phil Townsend
- Q&A Session



Guest Speaker: Atticus Stovall, University of Maryland/NASA Goddard Space Flight Center

National Aeronautics and Space Administration



# Capturing the Structural Component of Wetland Biodiversity with Airborne LiDAR

Dr. Atticus Stovall – NASA Goddard Space Flight Center | University of Maryland

March 27, 2023

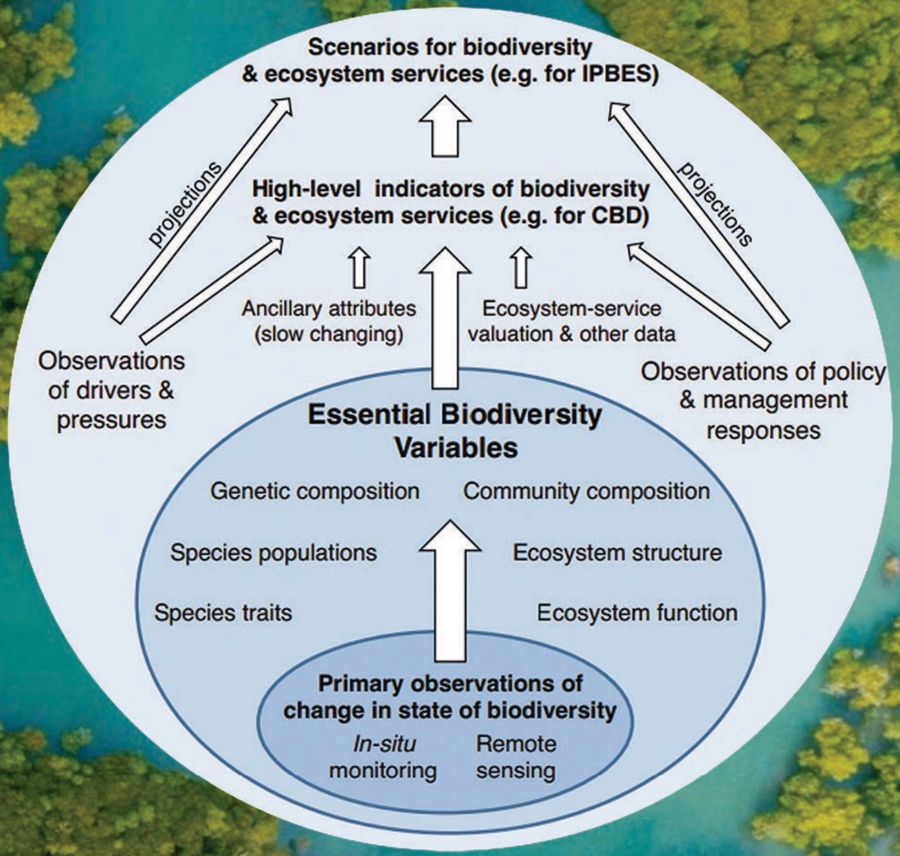
## How do we measure biodiversity?

# Essential Biodiversity Variables

https://geobon.org/

# Essential Biodiversity Variables (EBVs)

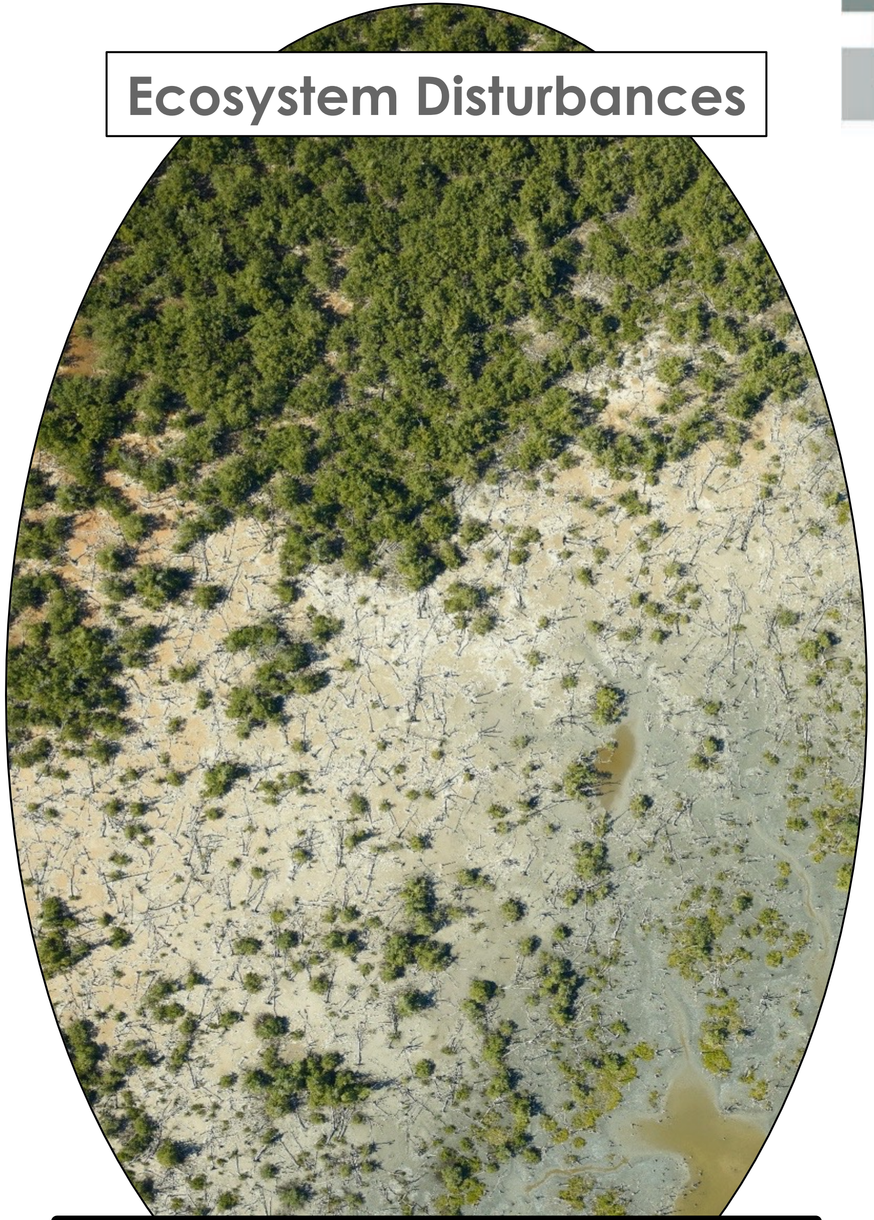
- An ideal EBV should…
  - *capture critical scales and dimensions of biodiversity.*
  - *be biological.*
  - *be a state variable.*
  - *be sensitive to change.*
  - *be ecosystem agnostic.*
  - *be technically feasible, economically viable, and sustainable over time.*




https://geobon.org/

GEO BON

# Essential Biodiversity Variables




**Ecosystem Functioning**

Attributes related to the performance of ecosystems that result from the collective activities of its organisms.

| EBV Name | EBV Description |
|---|---|
| Primary Productivity | The rate at which energy is transformed into organic matter, primarily through photosynthesis. |
| Ecosystem Phenology | Duration and magnitude of cyclic processes observed at the ecosystem level, such as in vegetation activity, phytoplankton blooms, etc. |
| Ecosystem Disturbances | Abrupt deviances in the functioning of the ecosystem from its regular dynamics. |

GEO BON

# Essential Biodiversity Variables

**Ecosystem Structure**
The spatial arrangement of ecosystem units collectively defined by organisms forming these units.

| EBV Name | EBV Description |
|---|---|
| Live Cover Fraction | The horizontal (or projected) fraction of area covered by living organisms, such as vegetation, macroalgae, or live hard coral. |
| Ecosystem Distribution | The horizontal distribution of discrete ecosystem units. |
| Ecosystem Vertical Profile | The vertical distribution of biomass in ecosystems, above and below the land surface. |

Ecosystem Vertical Profile

Images: Atticus Stovall

GEO BON


Case Study: Wax Lake Delta
Case Study: Pongara National Park
Sentinal 2 Imagery
Case Study: Zambezi River Delta
Image: NASA

# Case Study: Wax Lake Delta

# Delta in Louisiana, USA Created after Major Flooding in 1973



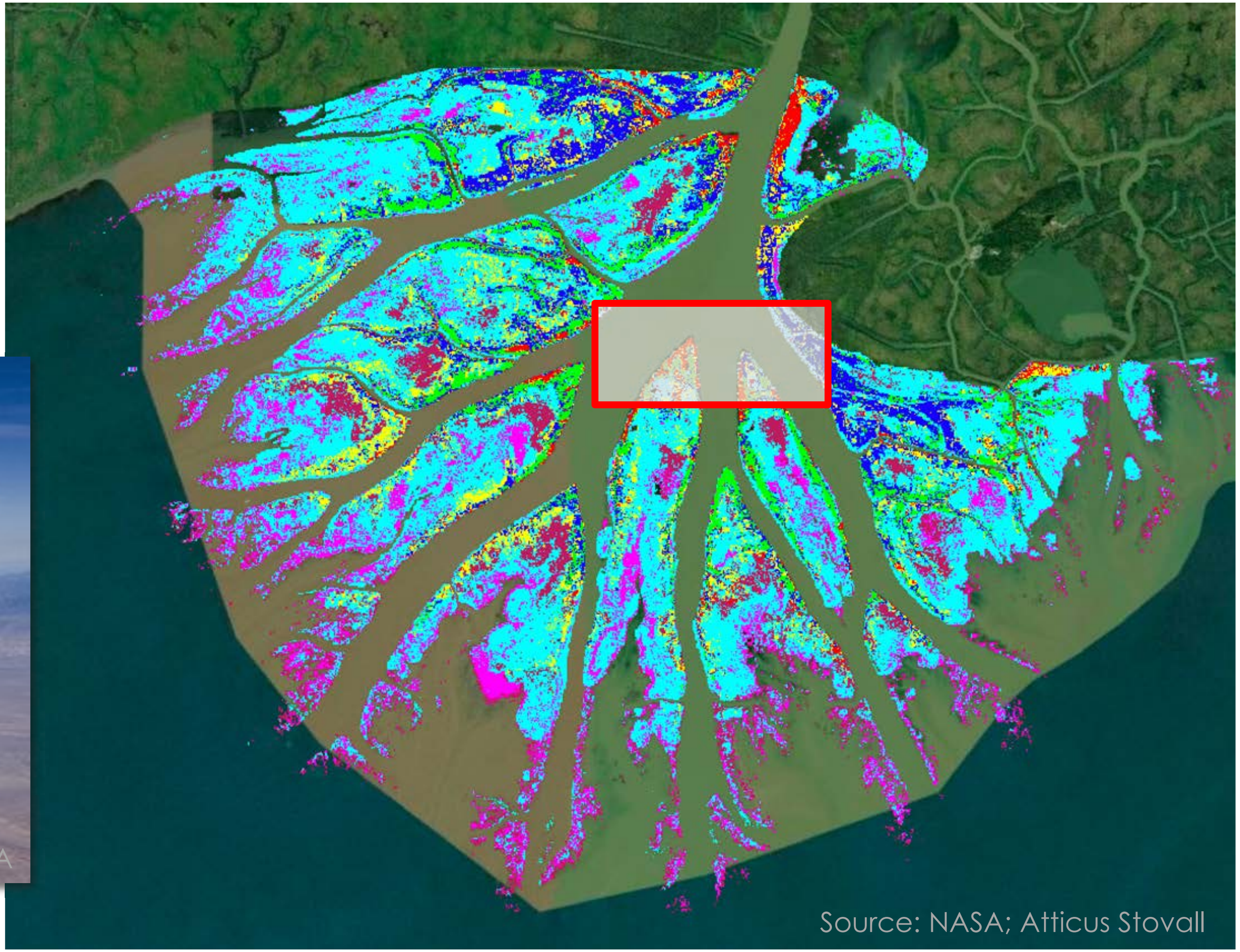
NASA/Jesse Allen

# Delta-X Field Campaign

**UAVSAR** (L-band SAR)

**AVIRIS-NG** (Airborne Visible / Infrared Imaging Spectrometer)

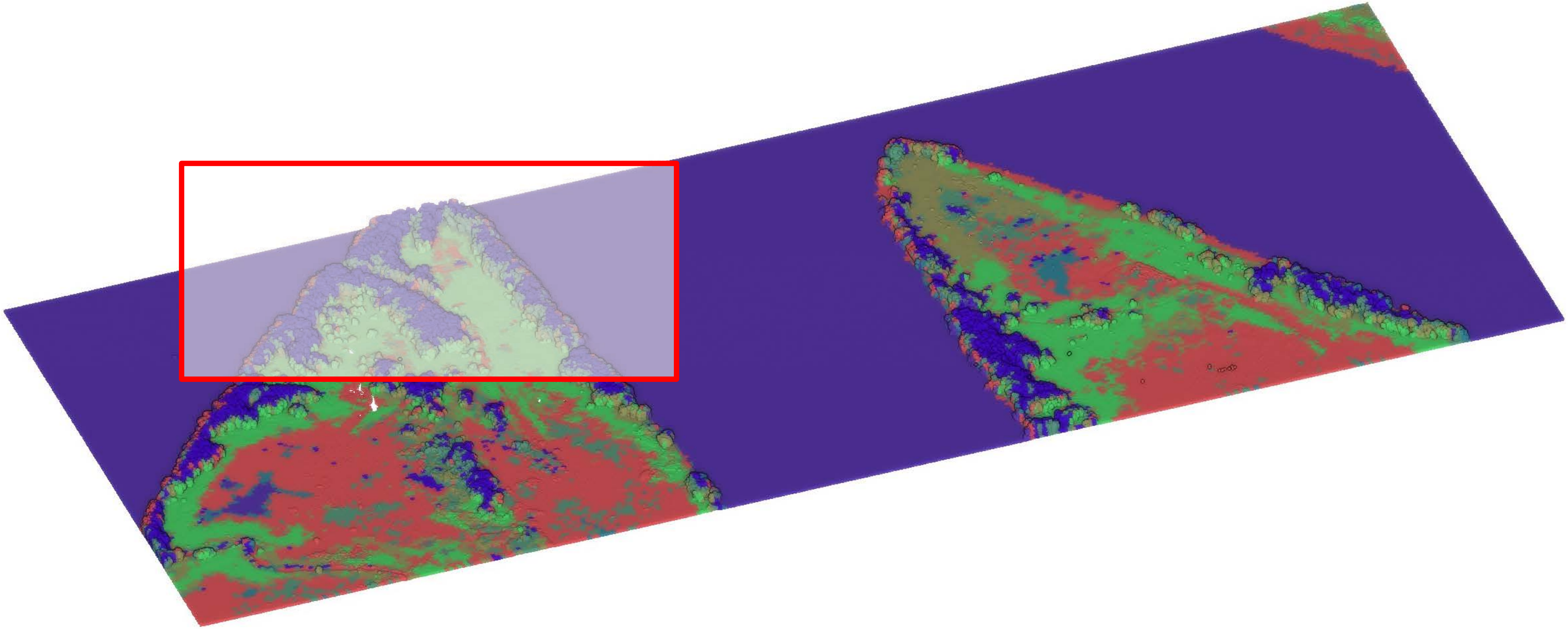
Source: NASA


Source: NASA; Atticus Stovall



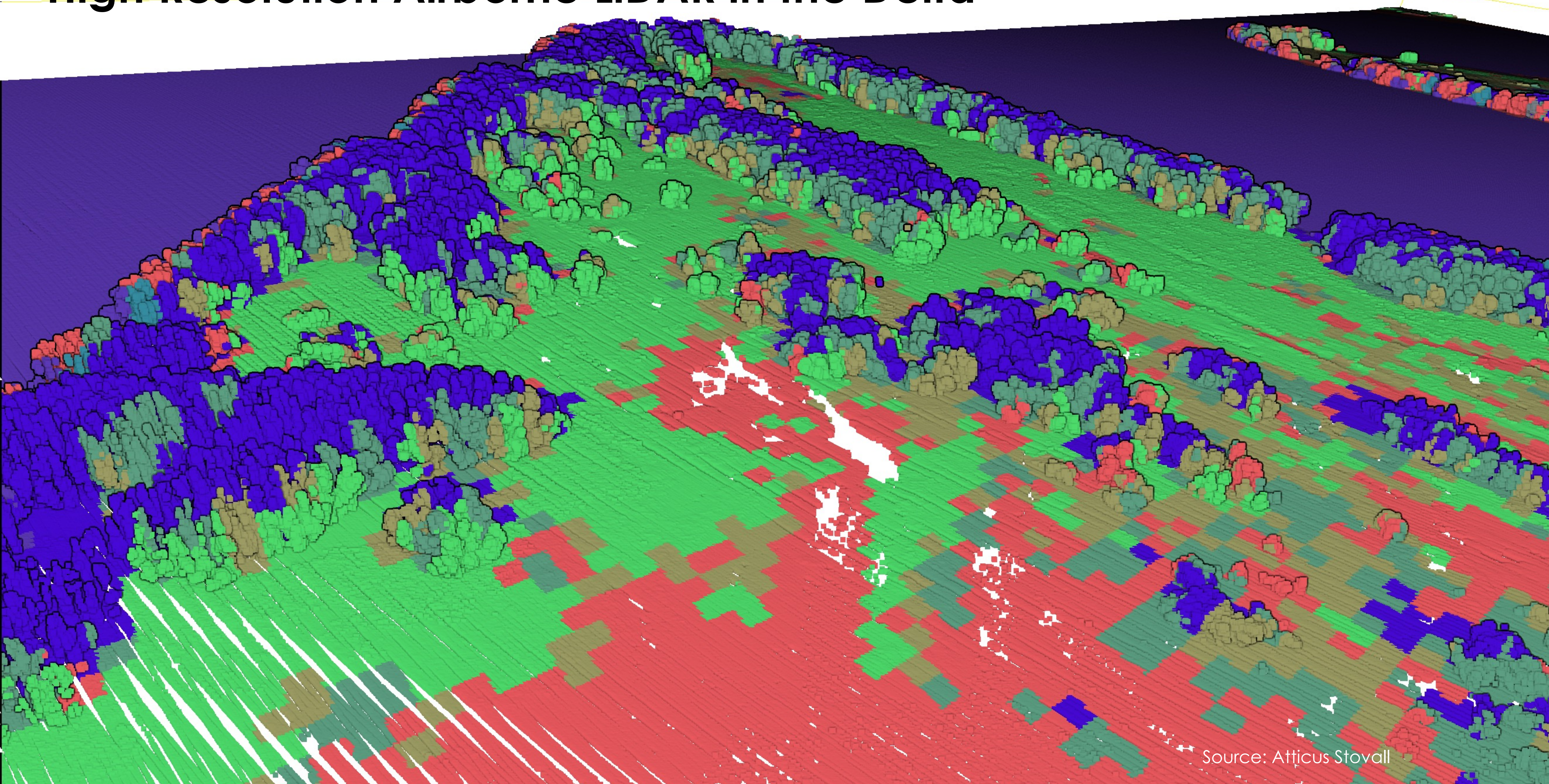
Source: Atticus Stovall

# High Resolution Airborne LiDAR in the Delta

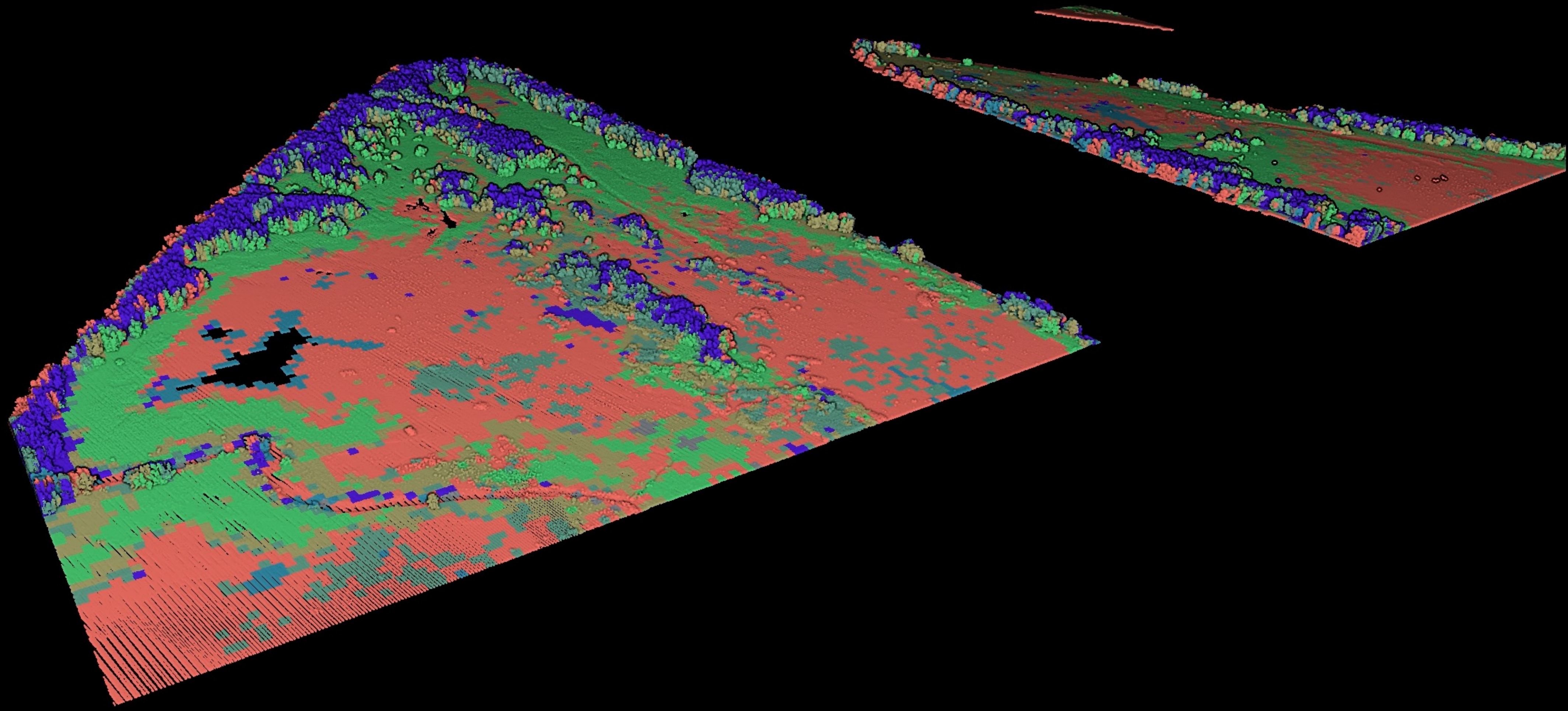


Source: Atticus Stovall

# High Resolution Airborne LiDAR in the Delta



Source: Atticus Stovall



Source: Atticus Stovall

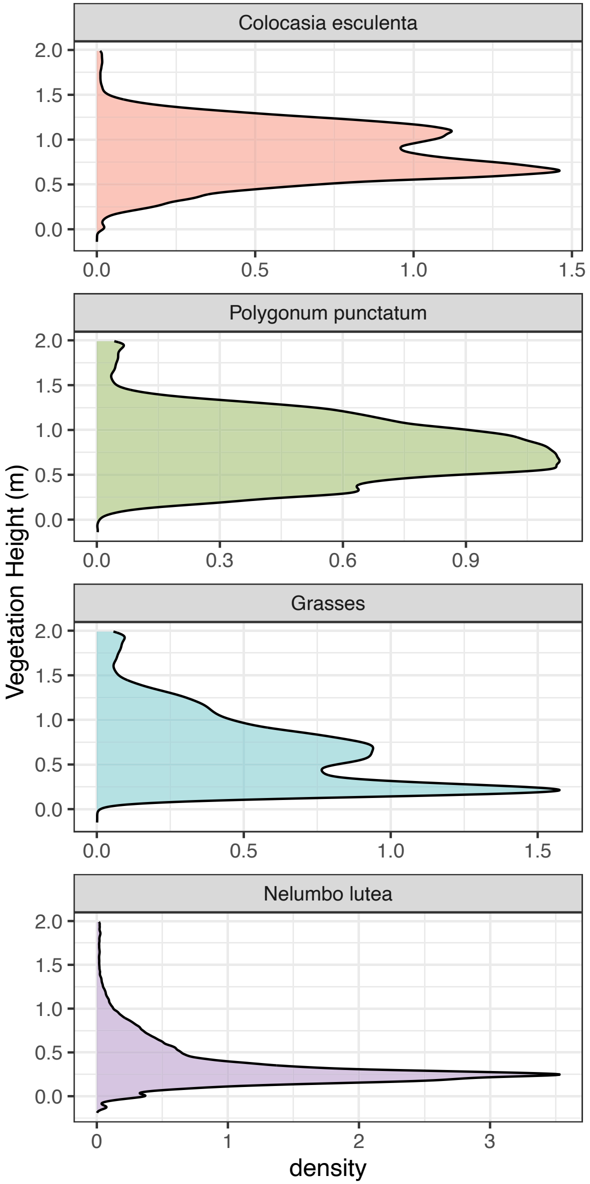
# Wax Lake Delta Vegetation Structure

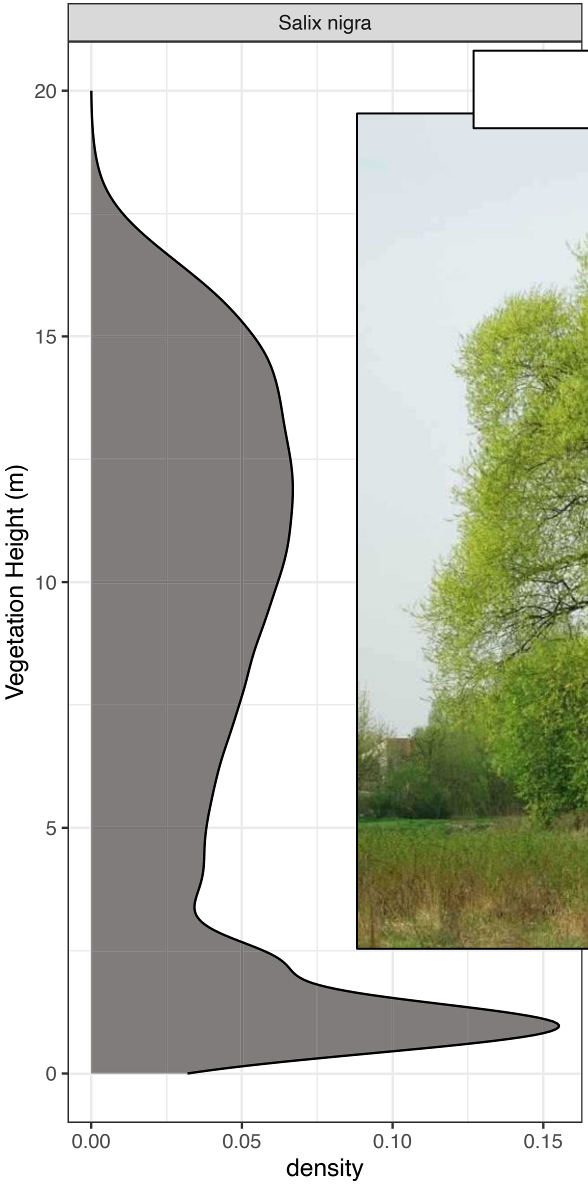
Elephant Ear

Dotted Smartweed

Grasses

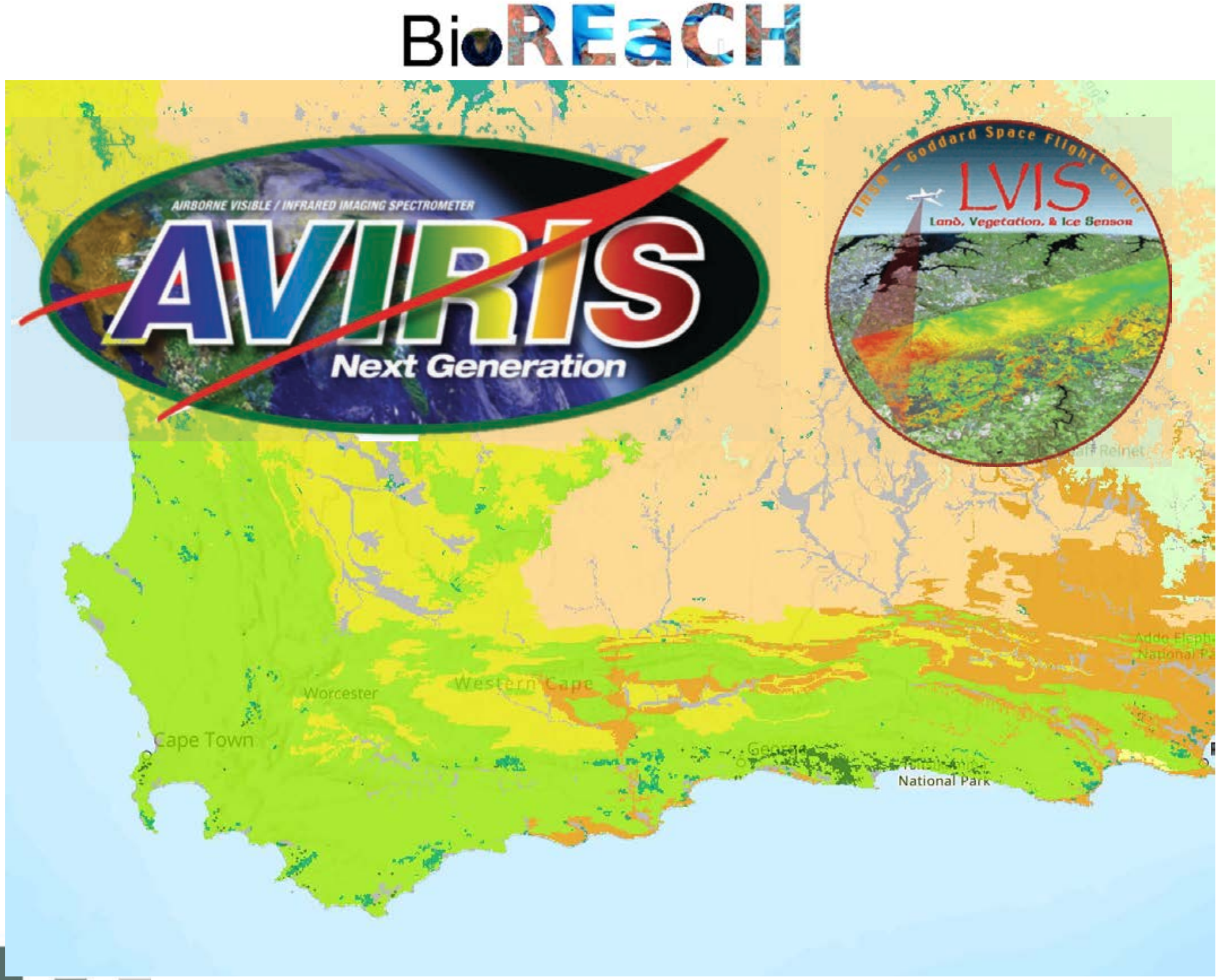
Yellow Lotus




Black Willow

# For BioSCape we will merge hyperspectral and LiDAR in estuaries




- Our team has 3 main goals:
- Map **plant functional type** and **essential biodiversity variables** across diverse **estuaries** with **imaging spectroscopy** and **waveform LiDAR.**
- Determine **drivers of biodiversity** within the **nine estuary classes**.
- How will climate impact estuaries of the greater cape floristic region?

# In Wetlands, LiDAR Improves:
# 1) Vegetation Classification
# and
# 2) Understanding of Ecosystem Structure

Ben Depp

# Case Study: Zambezi River Delta

Image: NASA

Image: NASA

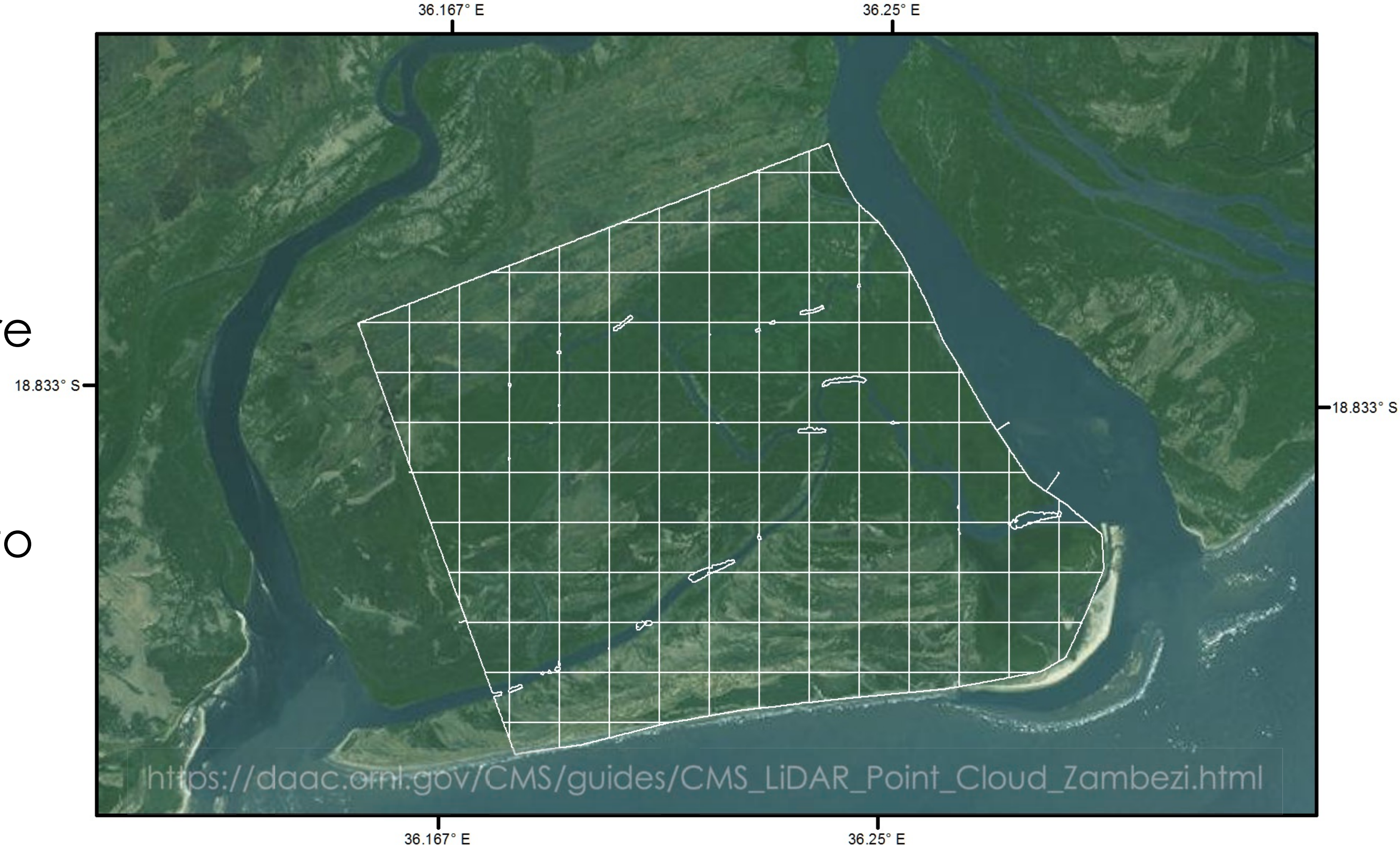
*“The Zambezi River sheds water from a 1,570,000 km² area encompassing eight African countries and eventually discharges into the Indian Ocean via the Zambezi Delta.*

*Mangroves are **ecologically** and **economically** important **forested wetlands** with the **highest carbon density** of all terrestrial ecosystems. Because of their large carbon stocks and importance as a coastal buffer, their **protection and restoration** has been proposed as effective **mitigation** strategy for **climate change and coastline loss**.”*

*– Fatoyinbo et al. 2017, NASA CMS*

# Zambezi River Delta Airborne Data on NASA ORNL DAAC

- LiDAR flown in 2014
- Field data from 2012
- High-resolution LiDAR is rare in mangroves.
- An excellent opportunity to capture vertical structural profiles



# Creating a High-Resolution Map of Forest Height from LiDAR

Read LiDAR Data

↓

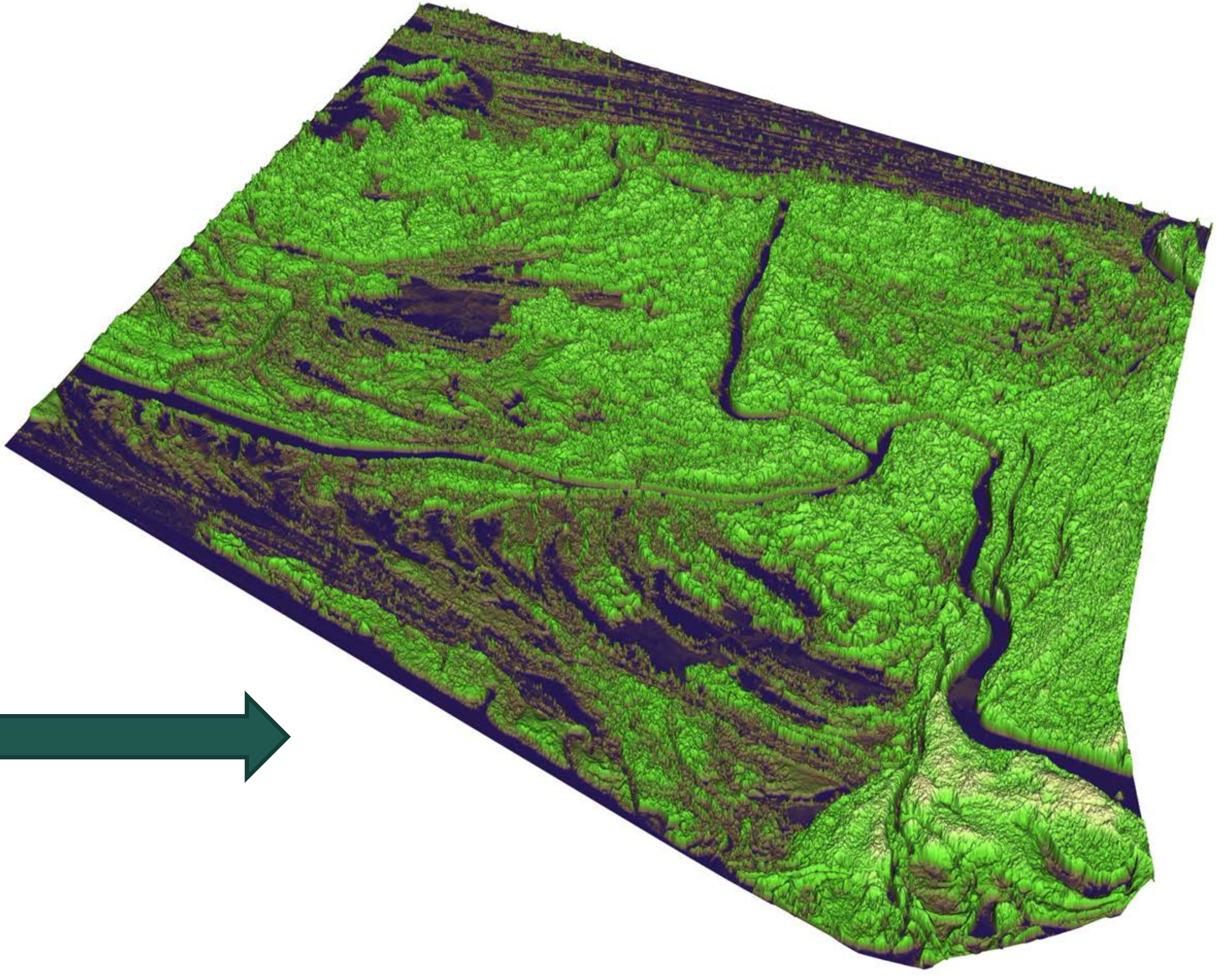
Find Ground Points and Create Model

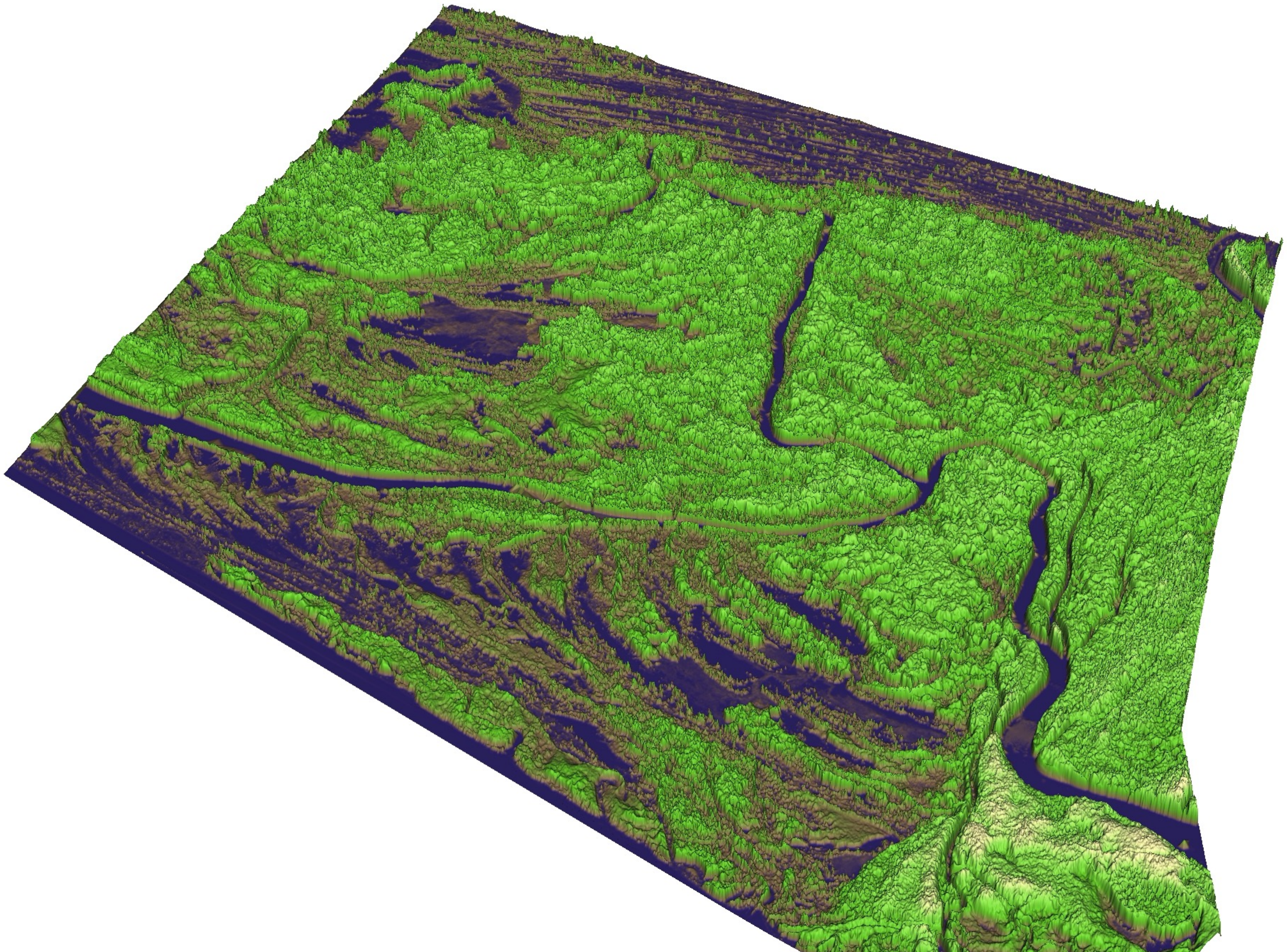
↓

Find Canopy Points and Create Model

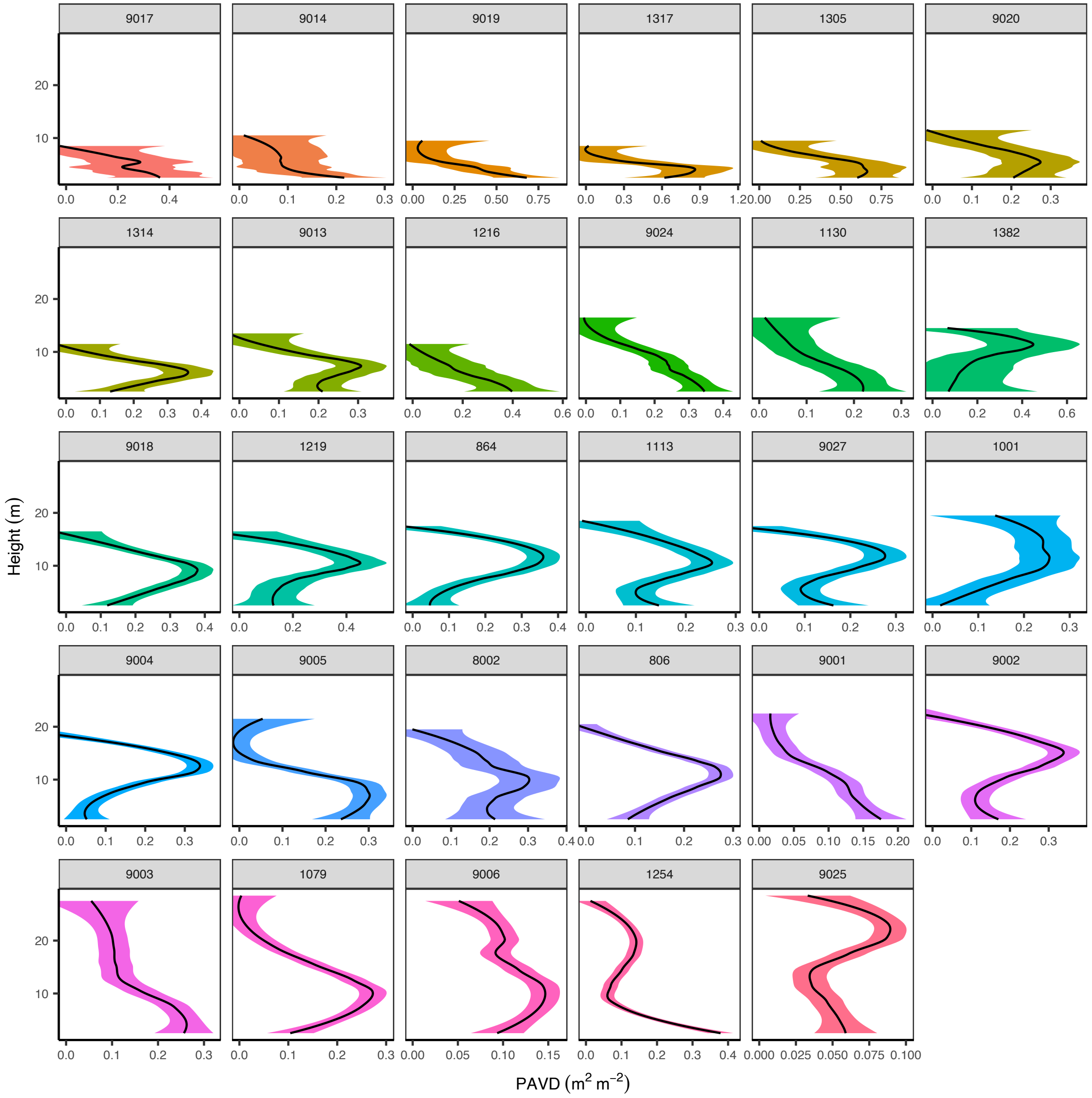
↓

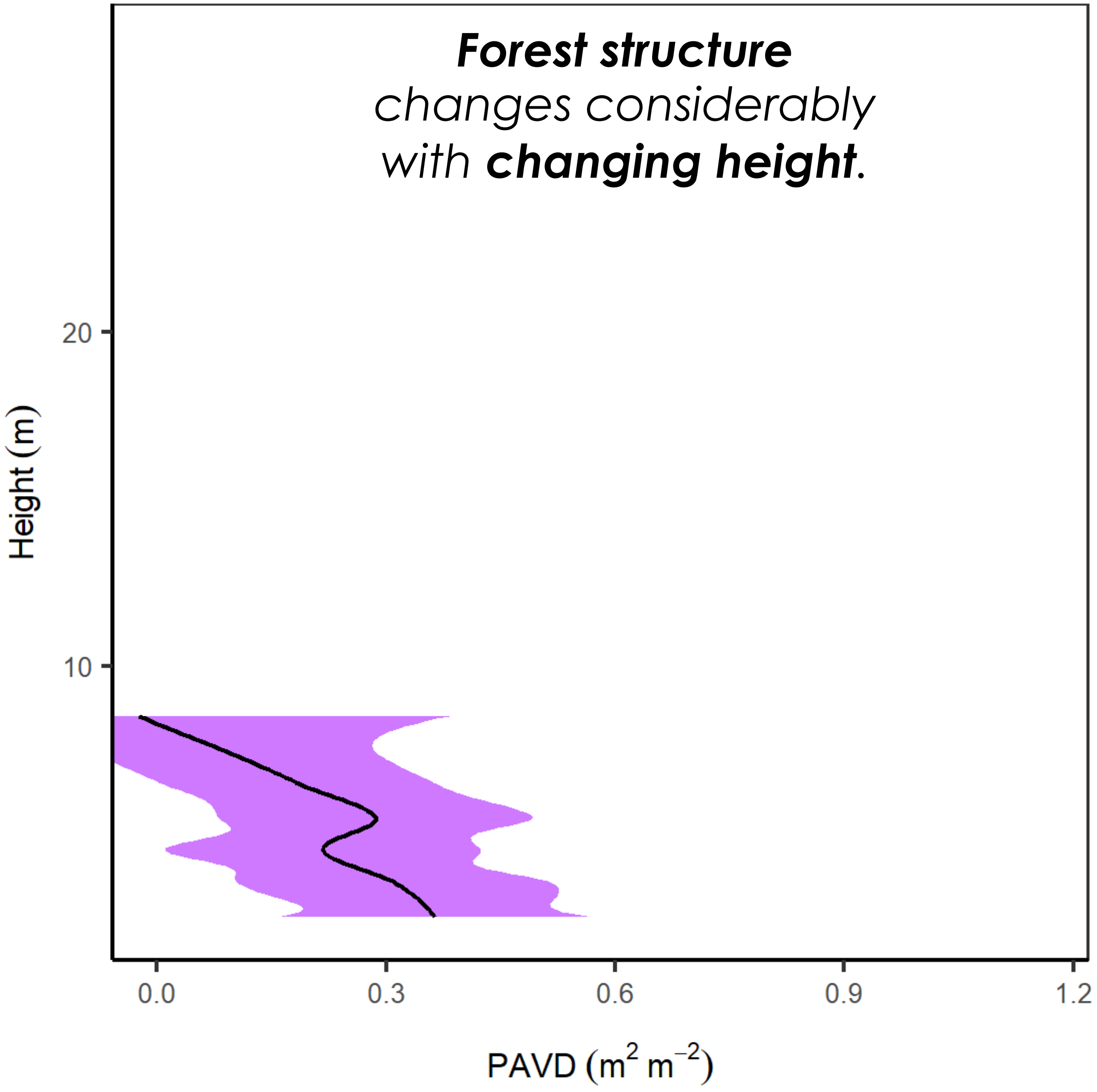
**Final Map of Forest Height** →





# Mangrove Profiles at Field Plots Highlight Structural Diversity



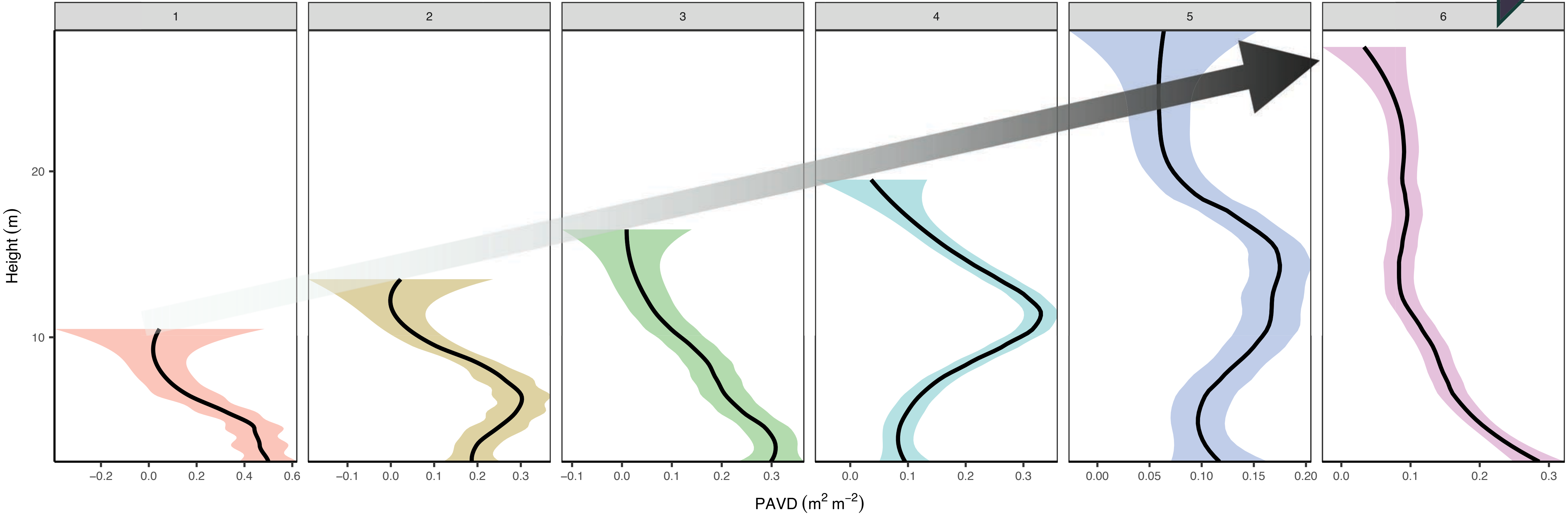






Source: Stovall et al. In Prep

# ~6 Height-Dependent Mangrove Structural Signatures

*As height increases, the structure of these forests change…*




*We can clearly see how the structure of the mangrove ecosystem evolves through time: Moving from **dense low forests** to **open- and closed-canopy tall forests**.*



Source: Stovall et al. In Prep

# In Mangroves, LiDAR Improves: Understanding of Changing Ecosystem Structure with Height

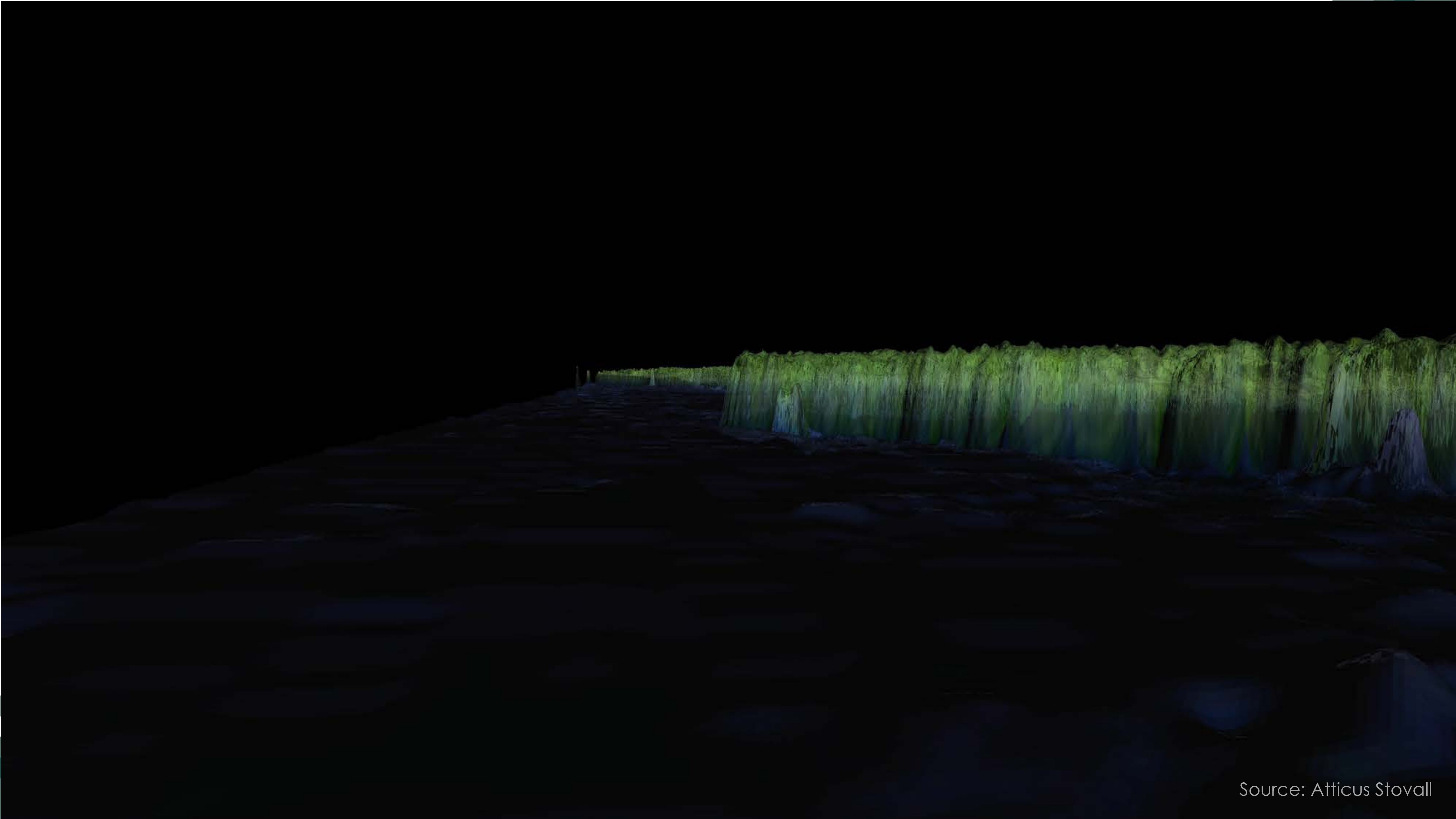
Image: NASA

# Case Study: Pongara National Park

Sentinel-2 Imagery

# Gabon Mangroves Identified as the Tallest (~60 m) on Earth

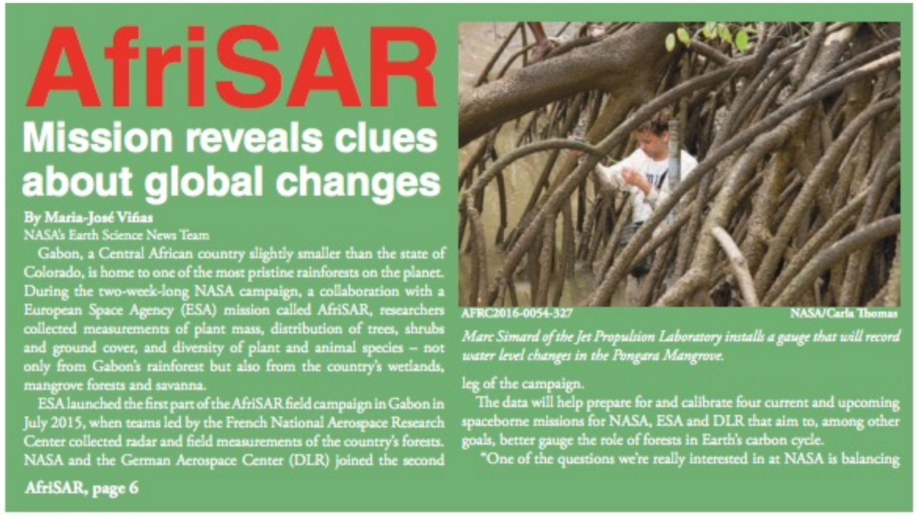

Image Credit: Simard et al. 2019



Source: Atticus Stovall

# We visited these mangroves in 2017 to study their 3D structure.

Image Credit: NASA



# AfriSAR

## Mission reveals clues about global changes

**By Maria-José Viñas**
NASA's Earth Science News Team

Gabon, a Central African country slightly smaller than the state of Colorado, is home to one of the most pristine rainforests on the planet. During the two-week-long NASA campaign, a collaboration with a European Space Agency (ESA) mission called AfriSAR, researchers collected measurements of plant mass, distribution of trees, shrubs and ground cover, and diversity of plant and animal species – not only from Gabon's rainforest but also from the country's wetlands, mangrove forests and savanna.

ESA launched the first part of the AfriSAR field campaign in Gabon in July 2015, when teams led by the French National Aerospace Research Center collected radar and field measurements of the country's forests. NASA and the German Aerospace Center (DLR) joined the second leg of the campaign.

AFRC2016-0054-327 NASA/Carla Thomas

*Marc Simard of the Jet Propulsion Laboratory installs a gauge that will record water level changes in the Pongara Mangrove.*

The data will help prepare for and calibrate four current and upcoming spaceborne missions for NASA, ESA and DLR that aim to, among other goals, better gauge the role of forests in Earth's carbon cycle.

"One of the questions we're really interested in at NASA is balancing

**AfriSAR, page 6**


Rhizophora mangle
Images: Atticus Stovall

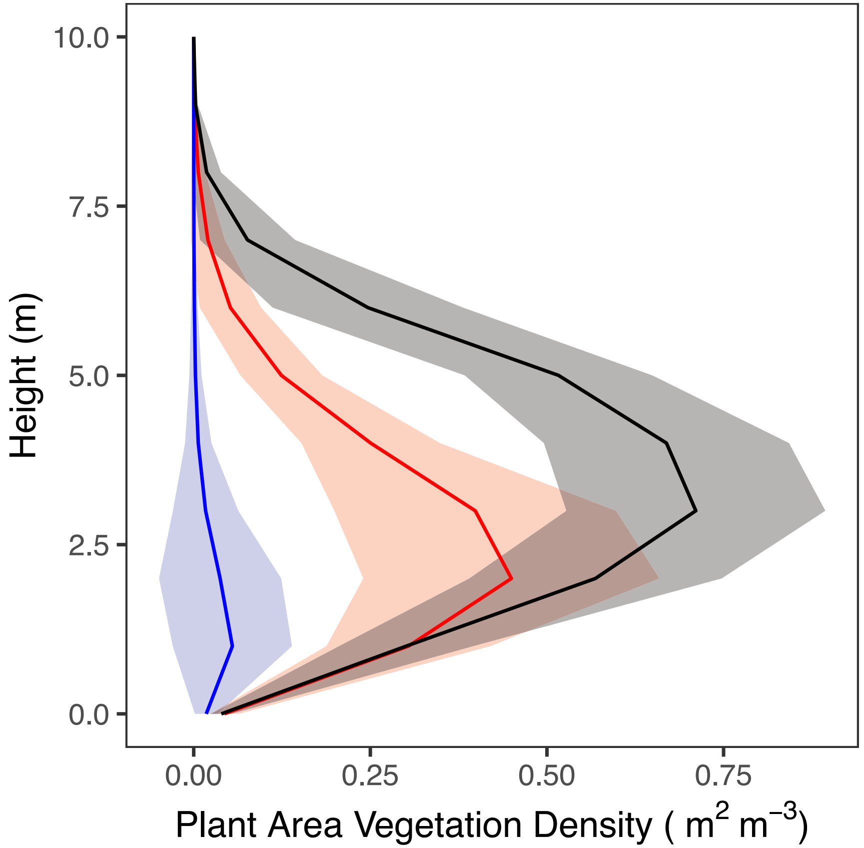
Images: Atticus Stovall

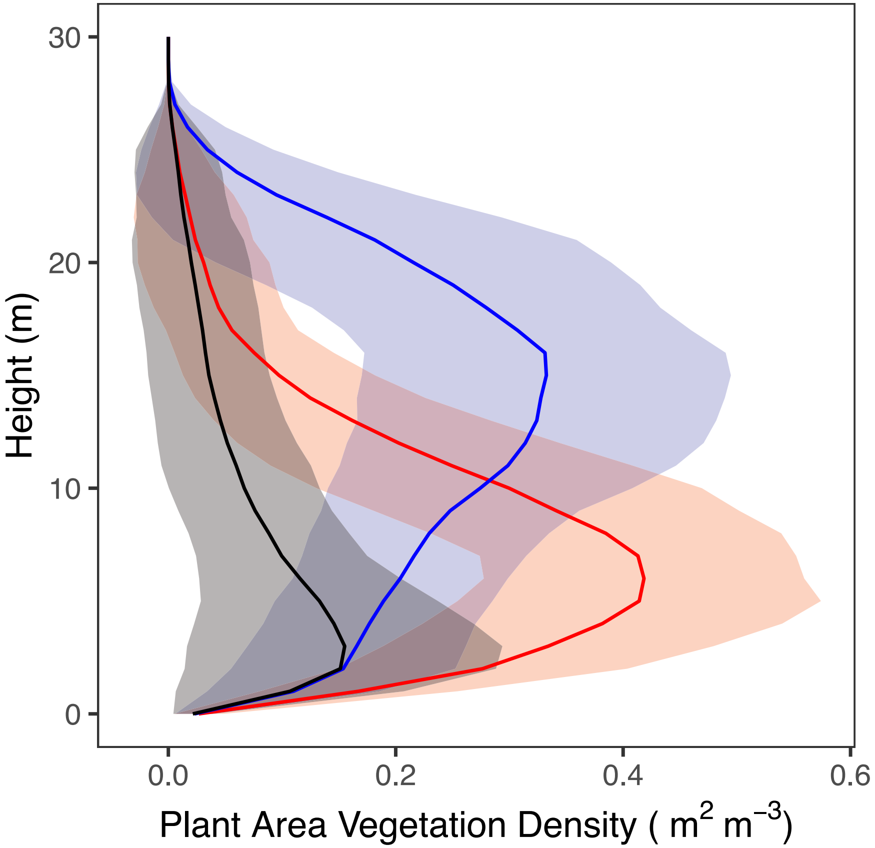
# NASA Land Vegetation Ice Sensor (LVIS) flew in 2016

| | |
|---|---|
| **Instrument Version:** | LVIS |
| **Flight Platform:** | [NASA Langley King Air B-200] |
| **Nominal Flight Altitude:** | 24,000' |
| **Nominal LVIS Swath Width:** | 1.5km (200mrad) |
| **Nominal LVIS Footprint Diameter:** | 18m (2.5mrad) |

# Low and Mid-Stature Mangroves had ~3 Structural Signatures

- Main difference is location of peak and foliage density




~2 m

~20 m

Image: Atticus Stovall; Nathan Thomas



Source: Stovall et al. In Prep

# Tallest Mangrove Stands had ~5 Structural Signatures

- Main difference is peak of understory or canopy

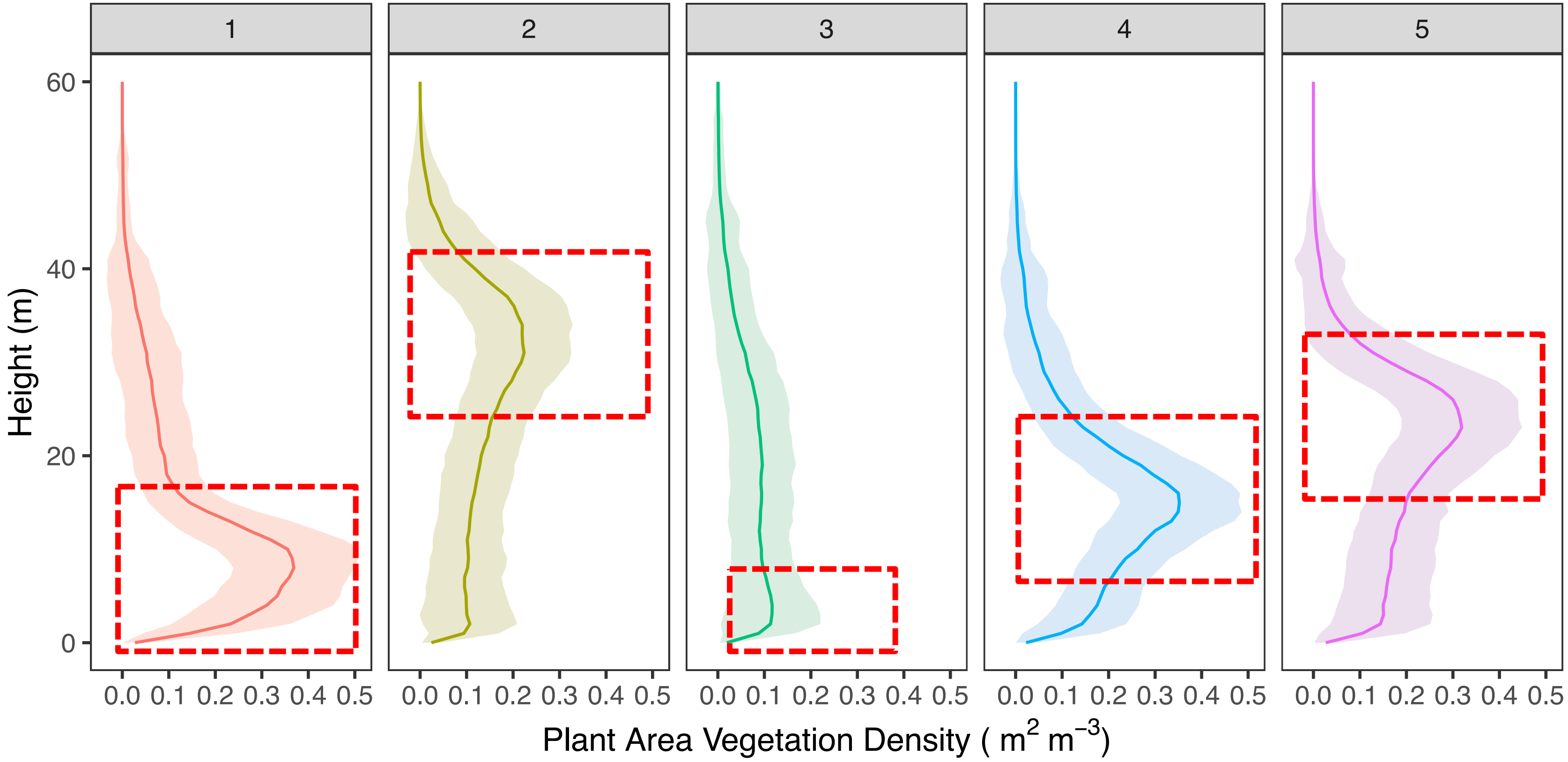
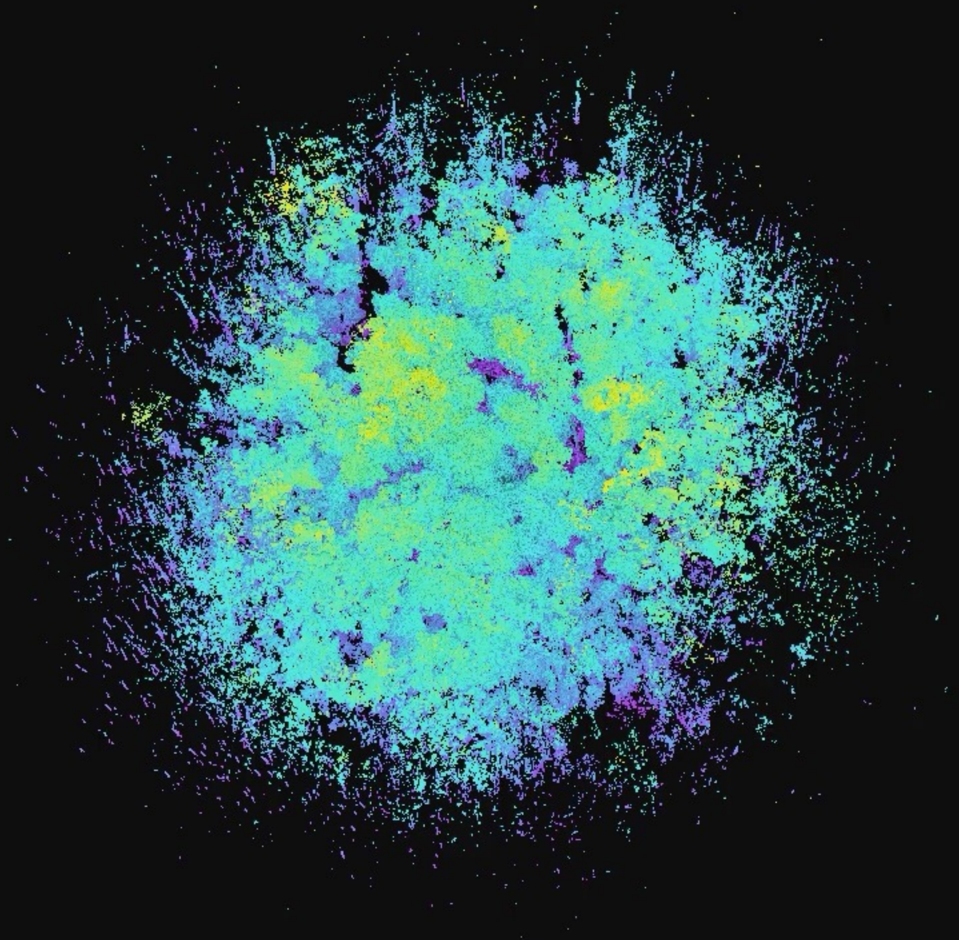




Image: Atticus Stovall



Source: Stovall et al. In Prep



DISCLAMER: THIS IN NOT AIRBORNE LIDAR

Source: Atticus Stovall

# In the Tallest Mangrove Forest, LiDAR Improves:
# 1) Classification of Ecosystem Structural Signatures
# 2) Understanding of Structural Diversity

With LiDAR, we can characterize the fine-scale structure of ecosystems in detail.

LiDAR can precisely estimate…

Essential Biodiversity Variables

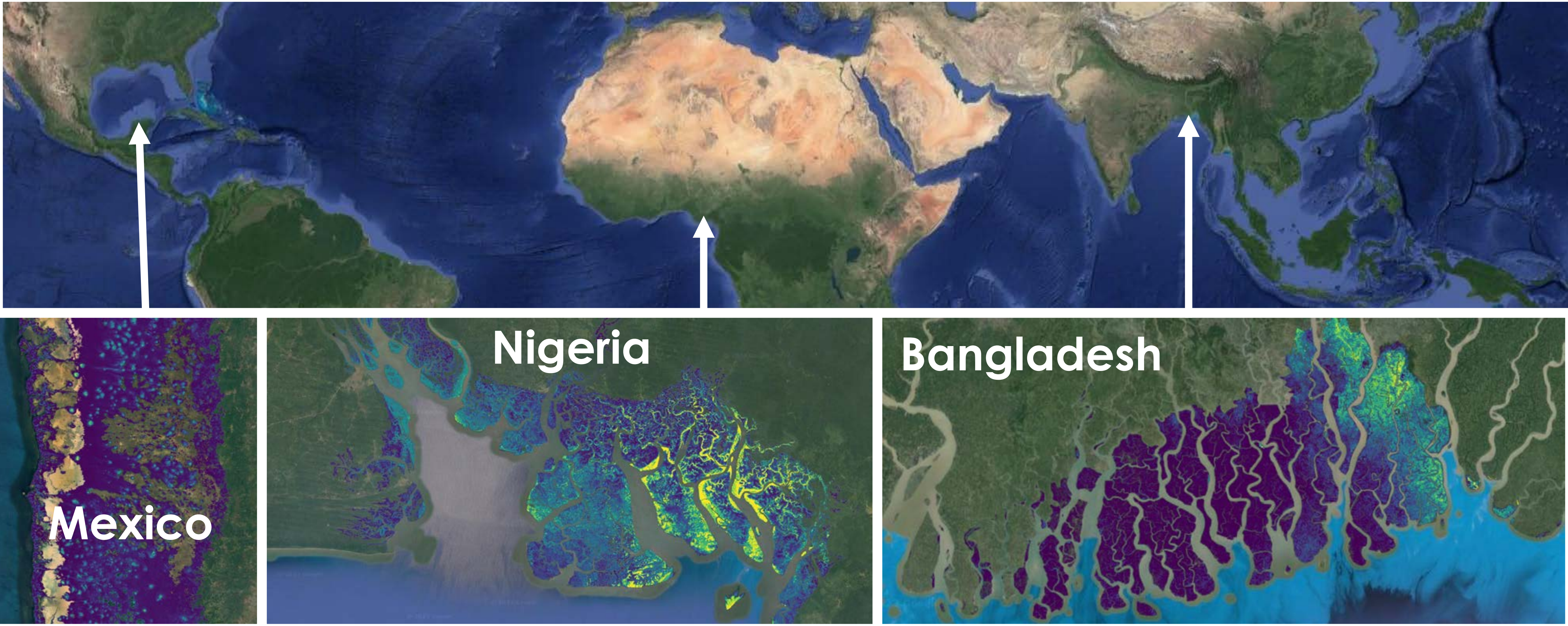
https://geobon.org/


Now, LiDAR is available globally, with the **Global Ecosystem Dynamics Investigation (GEDI)**
Enabling **global-scale mapping**…
…of wetland **structure** and **function**
https://geobon.org/

We are already using **GEDI** to create a **global mangrove height** and **biomass map**

https://geobon.org/

# Soon, we will have 12 m global mangrove height and biomass




By merging with **GEDI**, we can **understand the structural signature of mangrove forests around the world.**

Lola Fatoyinbo

Isamar Marie Cortés

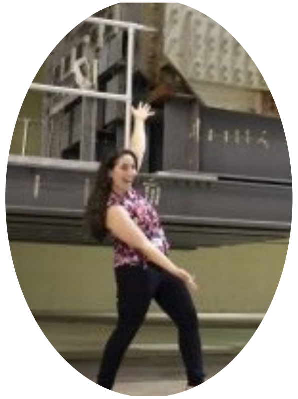
Atticus Stovall

Anthony Campbell

*All of this is a group effort!*

# Thank You!

***#LolaLAB***

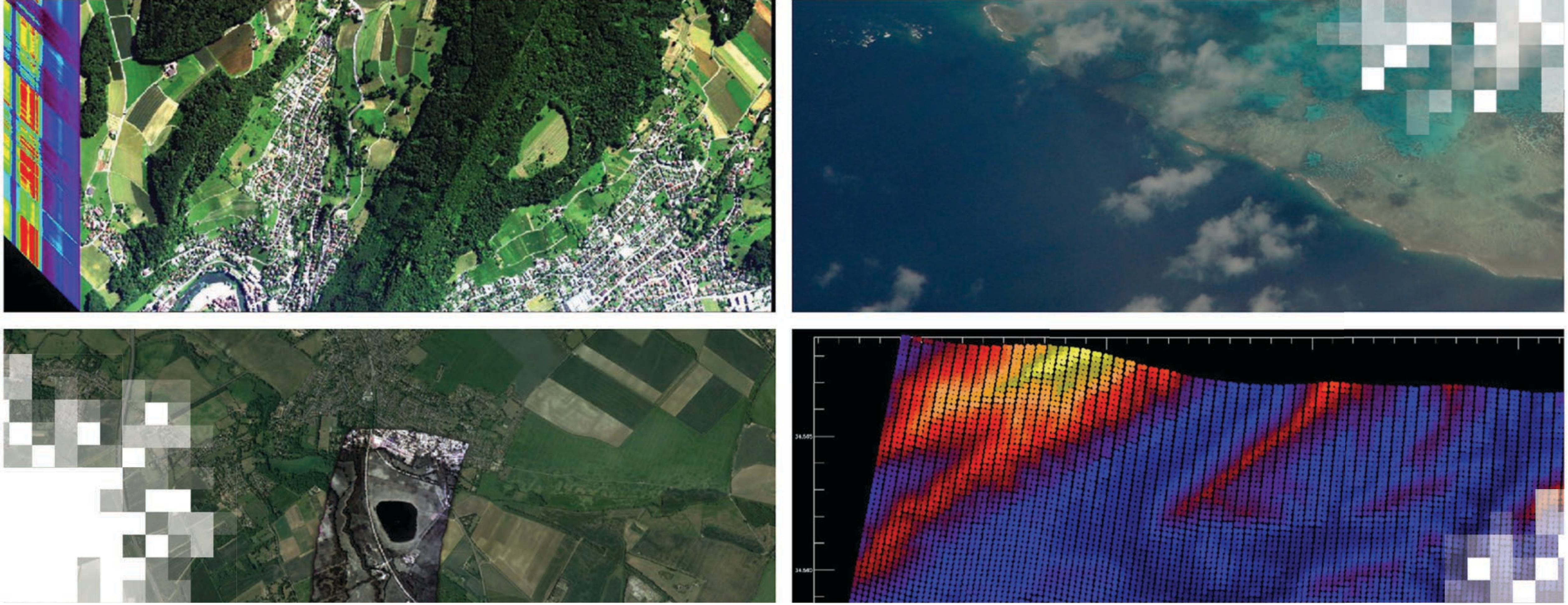


Abigail Barenblitt

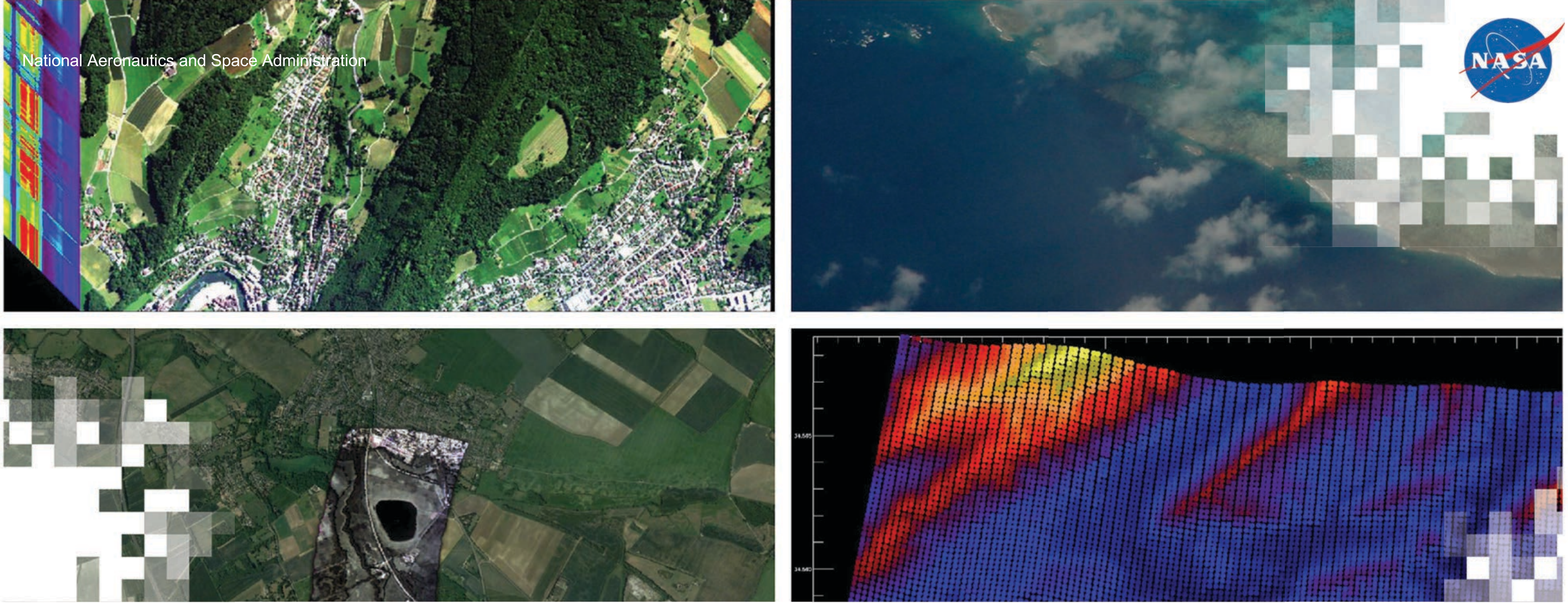
Nathan Thomas

Celio Souza

Cheryl Doughty



Guest Speaker: Phil Townsend, University of Wisconsin–Madison




# Airborne Hyperspectral Imagery for Biodiversity and Ecosystem Functioning

Phil Townsend and Ting Zheng – University of Wisconsin-Madison

March 27, 2023

*Botanical Gazette*, Vol. 87, No. 5 (Jun., 1929), pp. 583-607

# A SPECTROPHOTOMETRIC STUDY OF REFLECTION OF LIGHT FROM LEAF SURFACES

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY

CHARLES A. SHULL

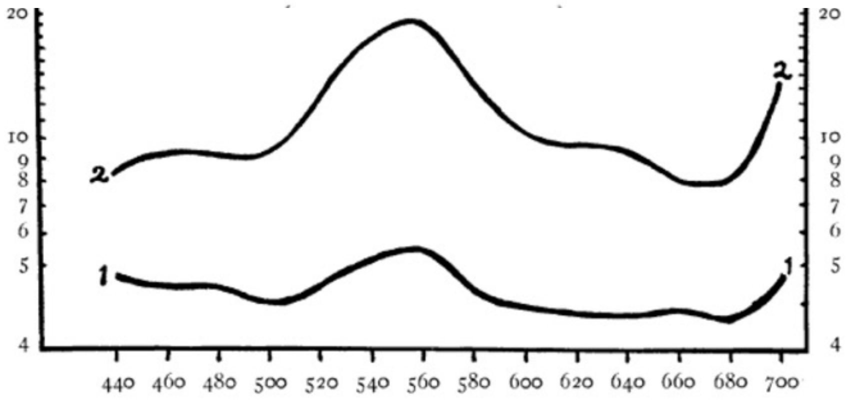



FIG. 1.—Reflection curves for leaves of rhododendron (1), and jonquil (2); note maximum at about 560 mμ, and trough at 680 mμ.

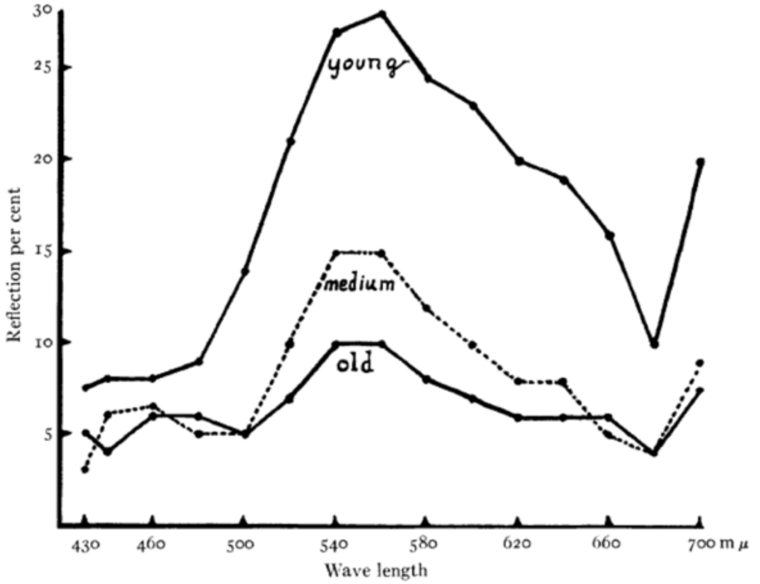


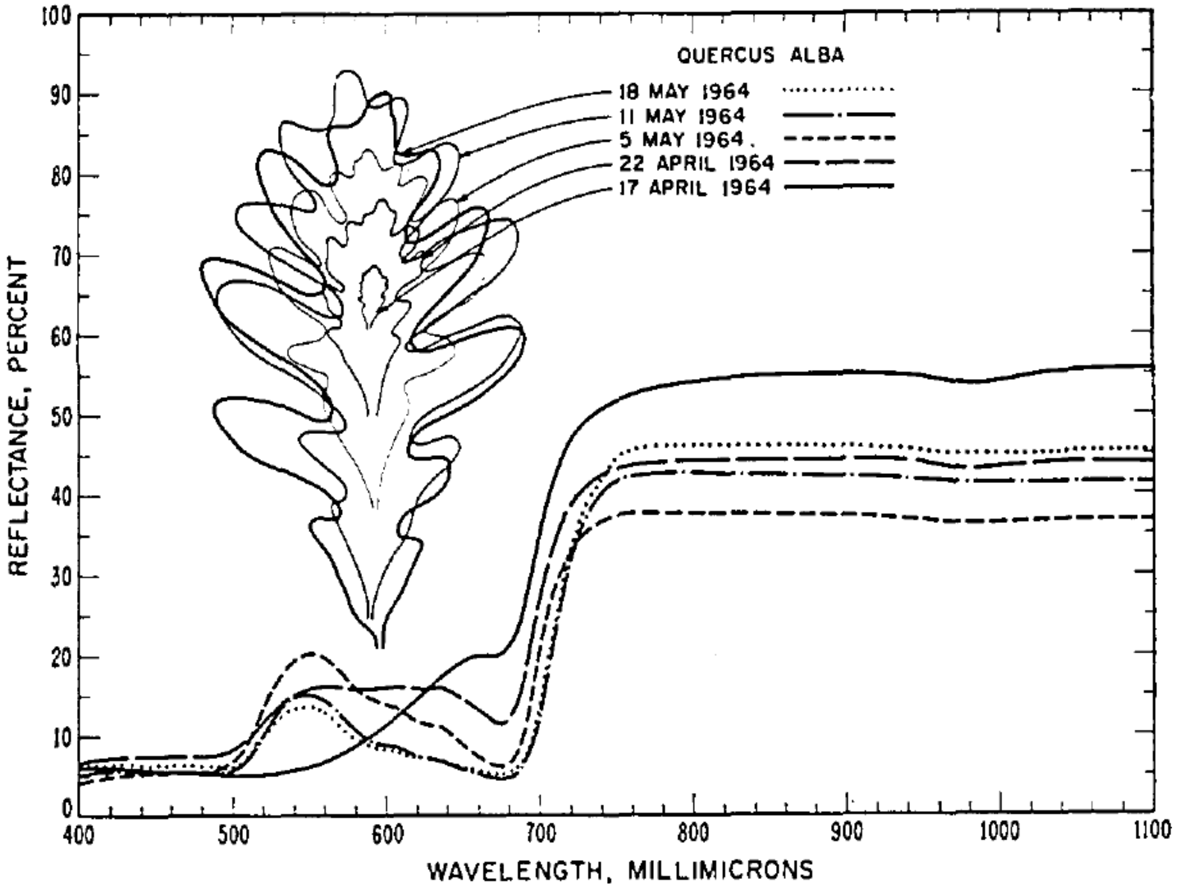

FIG. 4.—Curves of reflection showing effects of aging on leaves of *Tilia americana*; chlorophyll development brings decreased reflection.

# Spectral Properties of Plants

David M. Gates, Harry J. Keegan, John C. Schleter, and Victor R. Weidner

The spectral properties of plant leaves and stems have been obtained for ultraviolet, visible, and infrared frequencies. The spectral reflectance, transmittance, and absorptance for certain plants is given. The mechanism by which radiant energy interacts with a leaf is discussed, including the presence of plant pigments. Examples are given concerning the amount of absorbed solar radiation for clear sky and overcast conditions. The spectral properties of desert plants are compared with those of more mesic plants. The evolution of the spectral properties of plant leaves during the early growing season is given as well as the colorimetric behavior during the autumn.

January 1965 / Vol. 4, No. 1 / APPLIED OPTICS 11



# Reflectance Spectroscopy

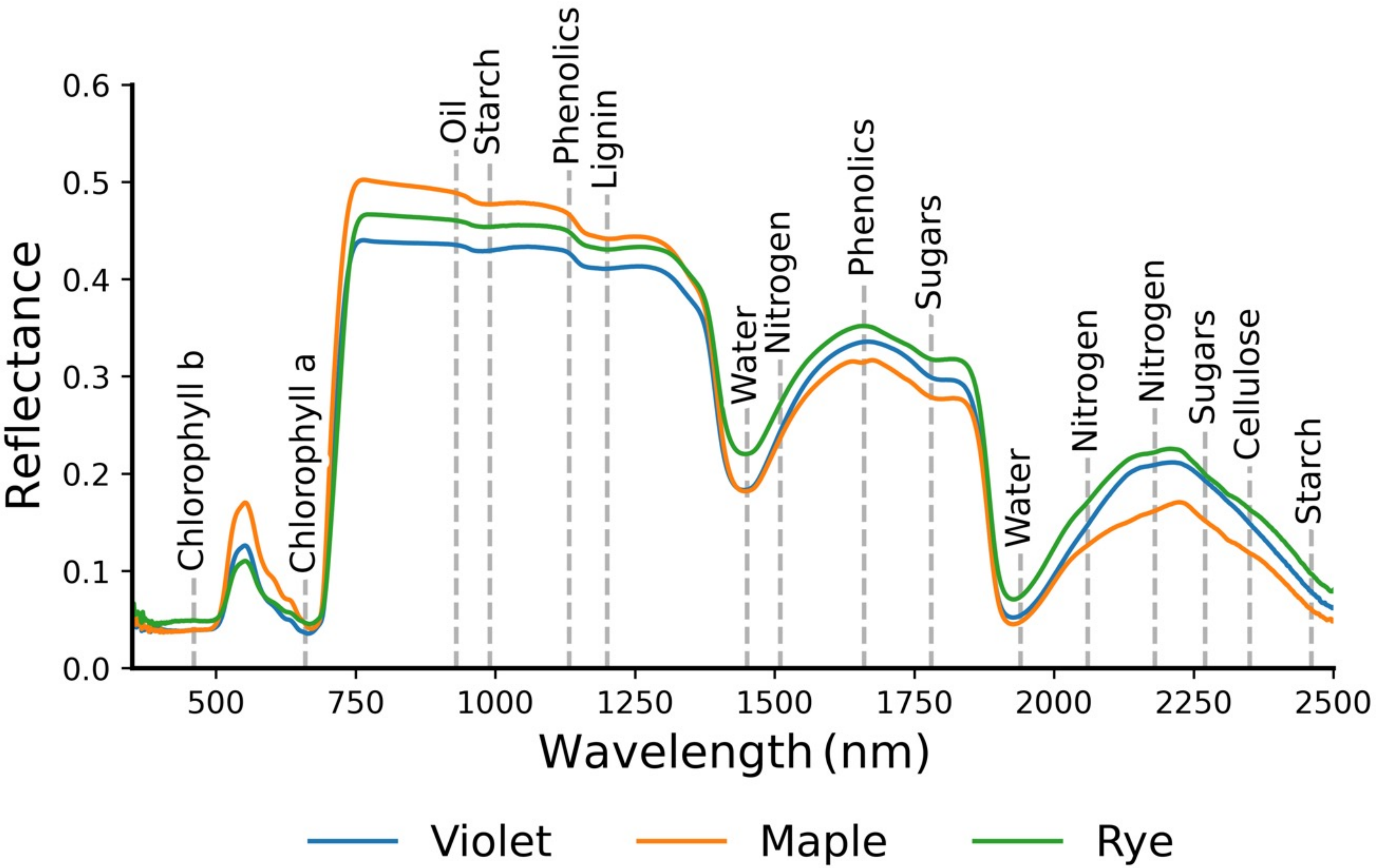


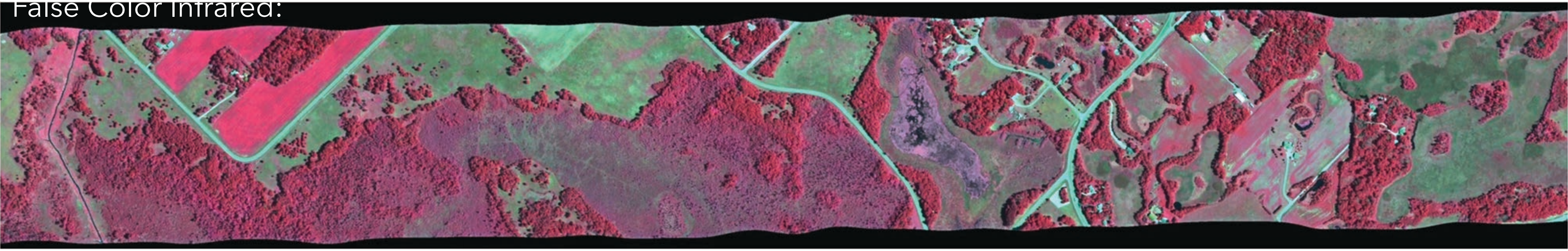




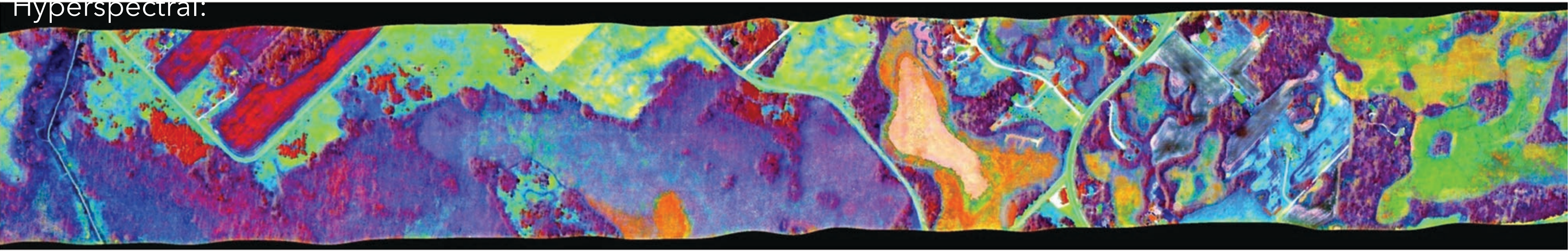
Figure: Adam Chlus

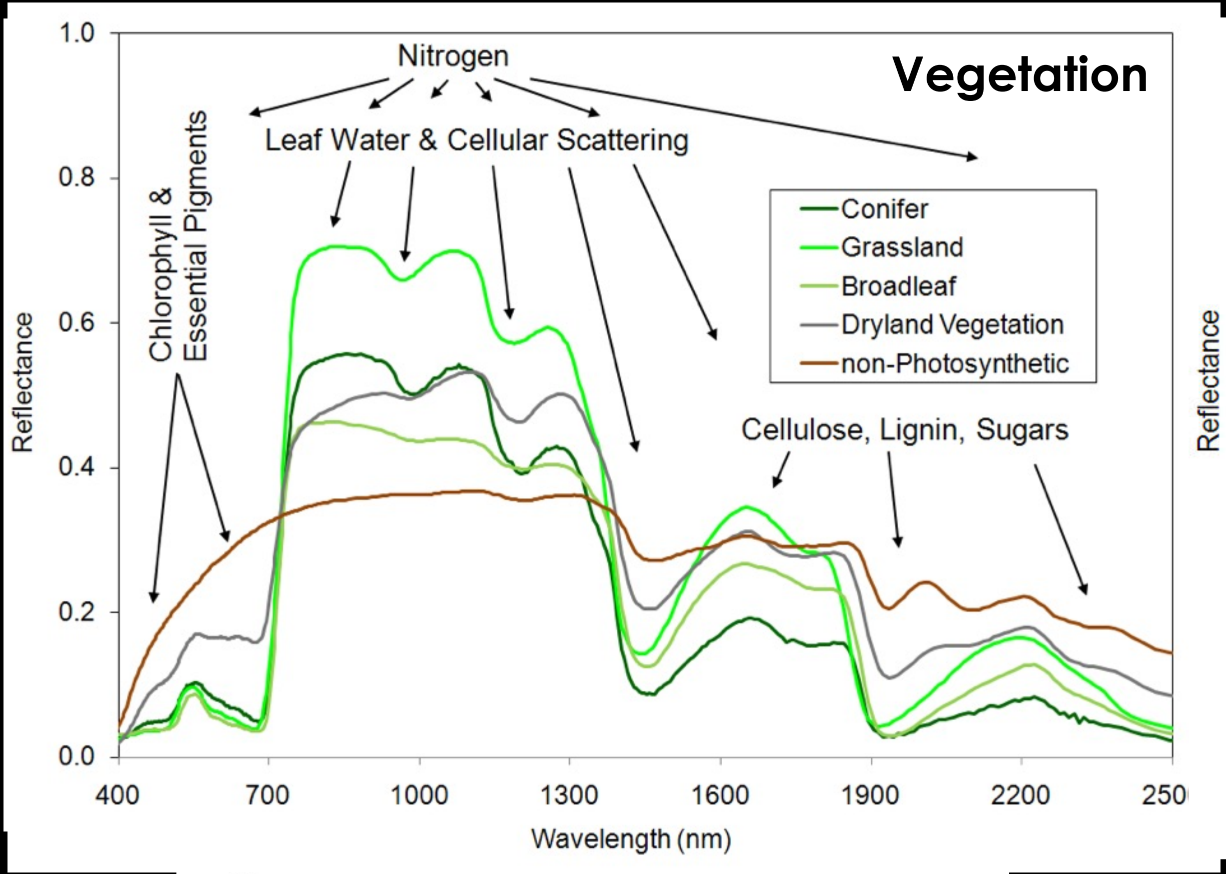
True Color:

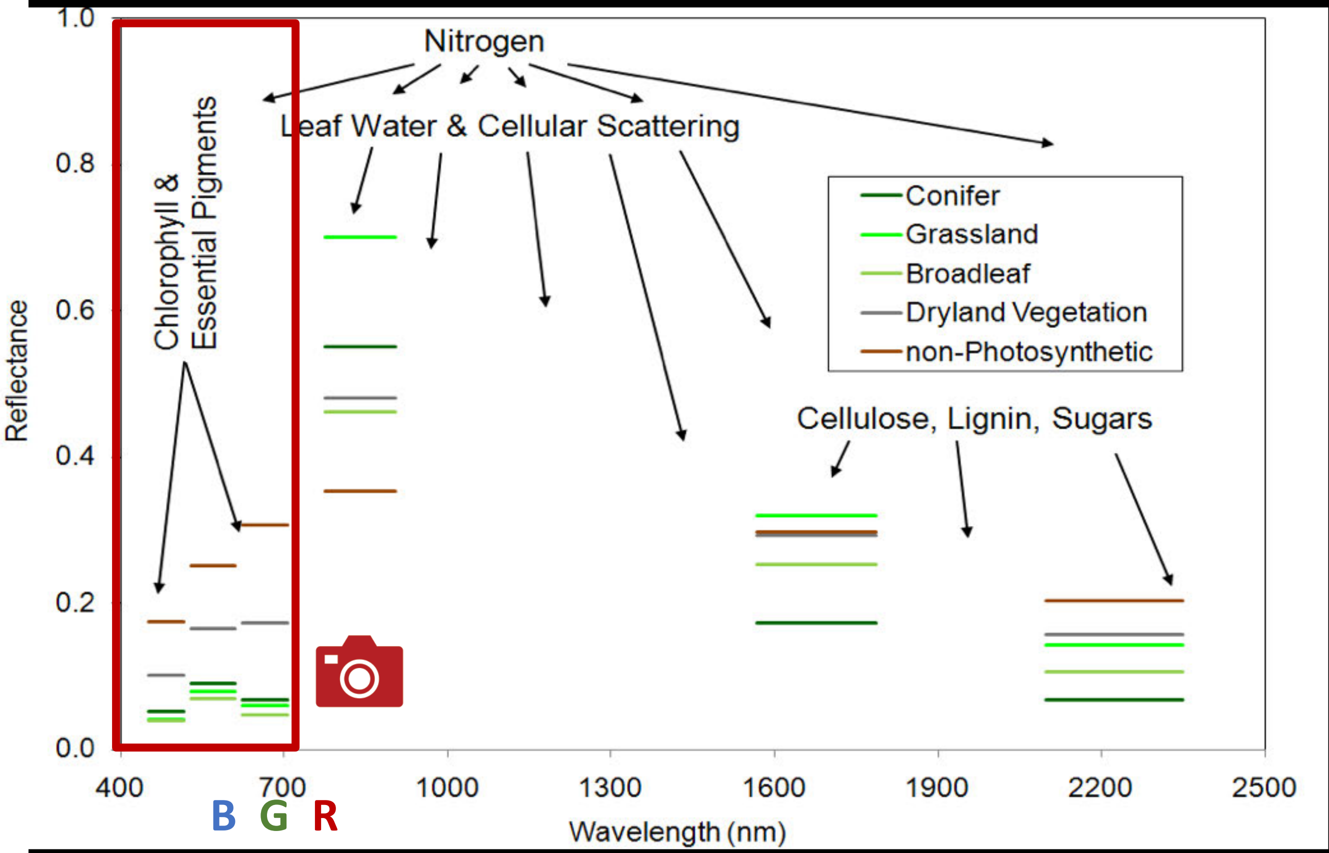
False Color Infrared:



Hyperspectral:




Vegetation
Nitrogen
Leaf Water & Cellular Scattering
Chlorophyll & Essential Pigments
Cellulose, Lignin, Sugars
Conifer
Grassland
Broadleaf
Dryland Vegetation
non-Photosynthetic
Reflectance
Wavelength (nm)


Nitrogen
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Broadleaf
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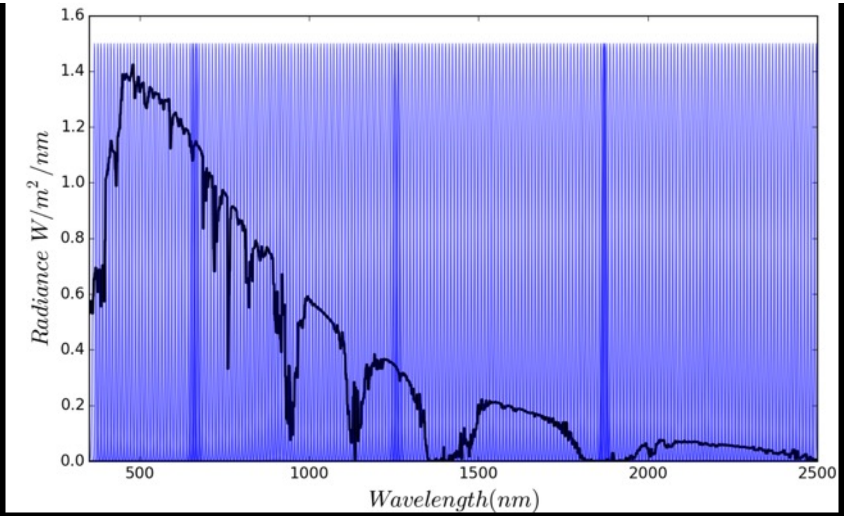
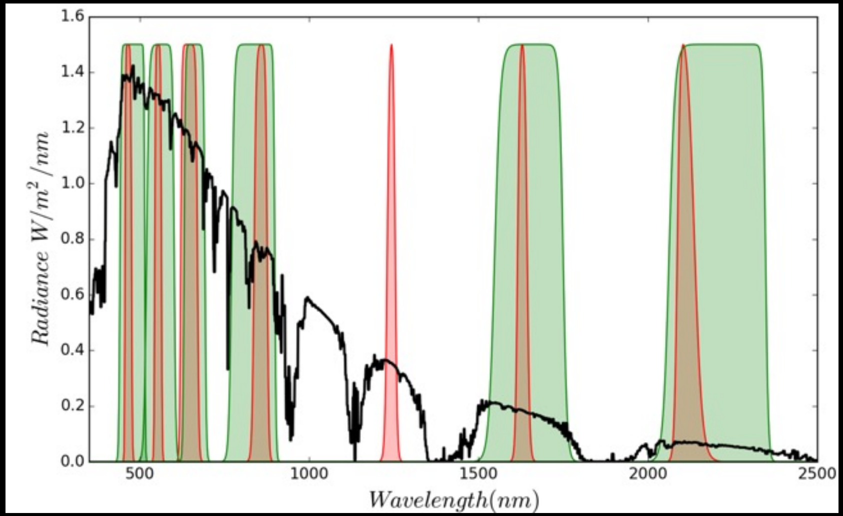
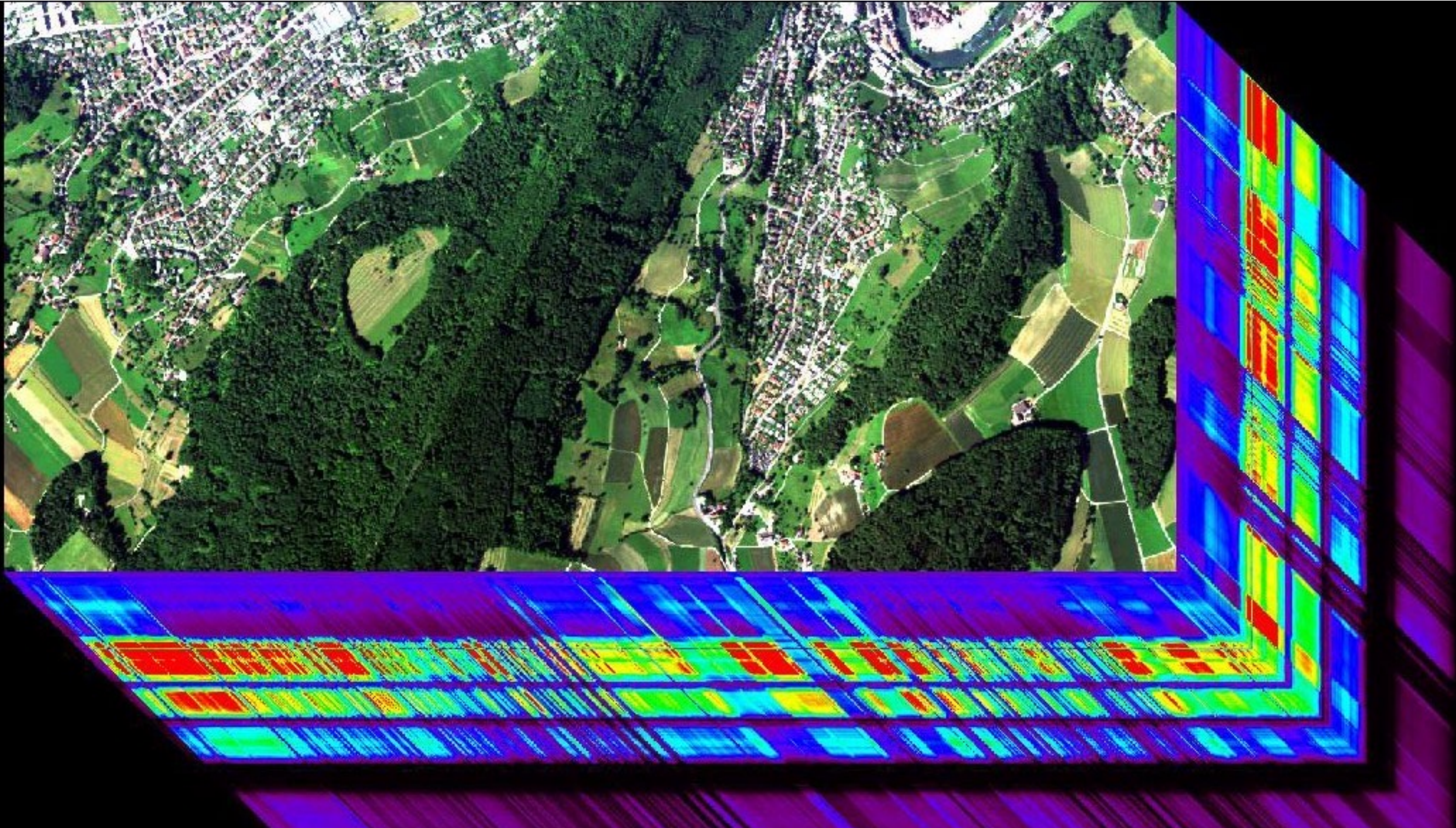
non-Photosynthetic
Reflectance
Wavelength (nm)
B G R


Radiance $W/m^2/nm$
Wavelength(nm)


Radiance $W/m^2/nm$
Wavelength(nm)

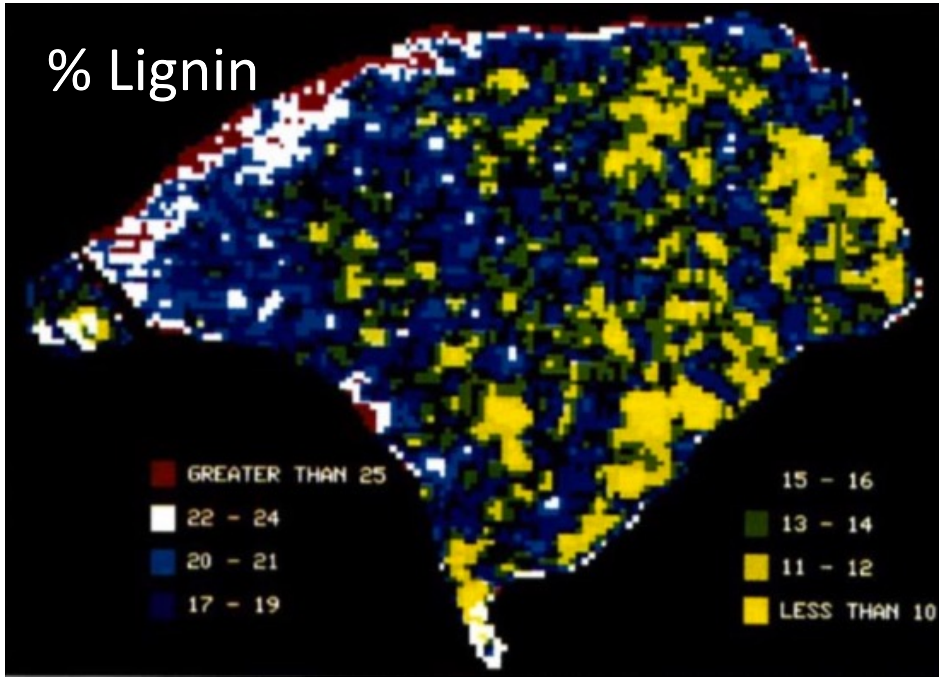


Imaging Spectroscopy Image Cube

# 3+ Decades of Airborne Studies (and now space): Setting the Stage for Upcoming Spaceborne Missions

NATURE — NATURE VOL. 335 8 SEPTEMBER 1988

**Remote sensing of canopy chemistry and nitrogen cycling in temperate forest ecosystems**




Wessman et al. 1988


GAO

Global Airborne Observatory

neon

National Ecological Observatory Network

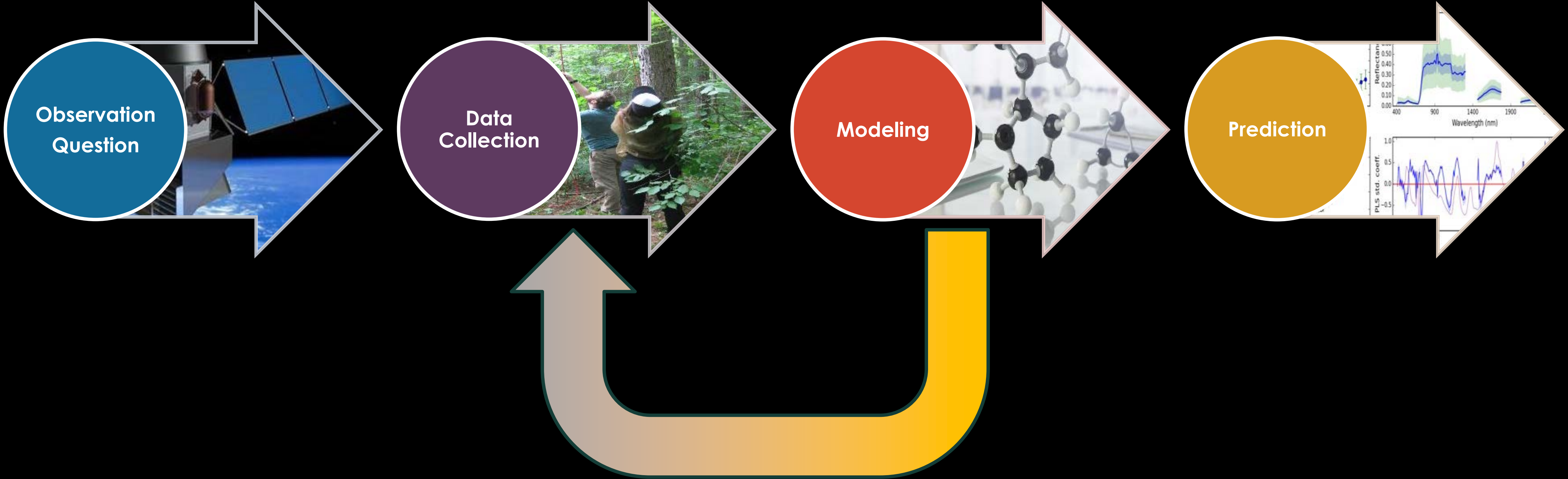
HySpex by neo

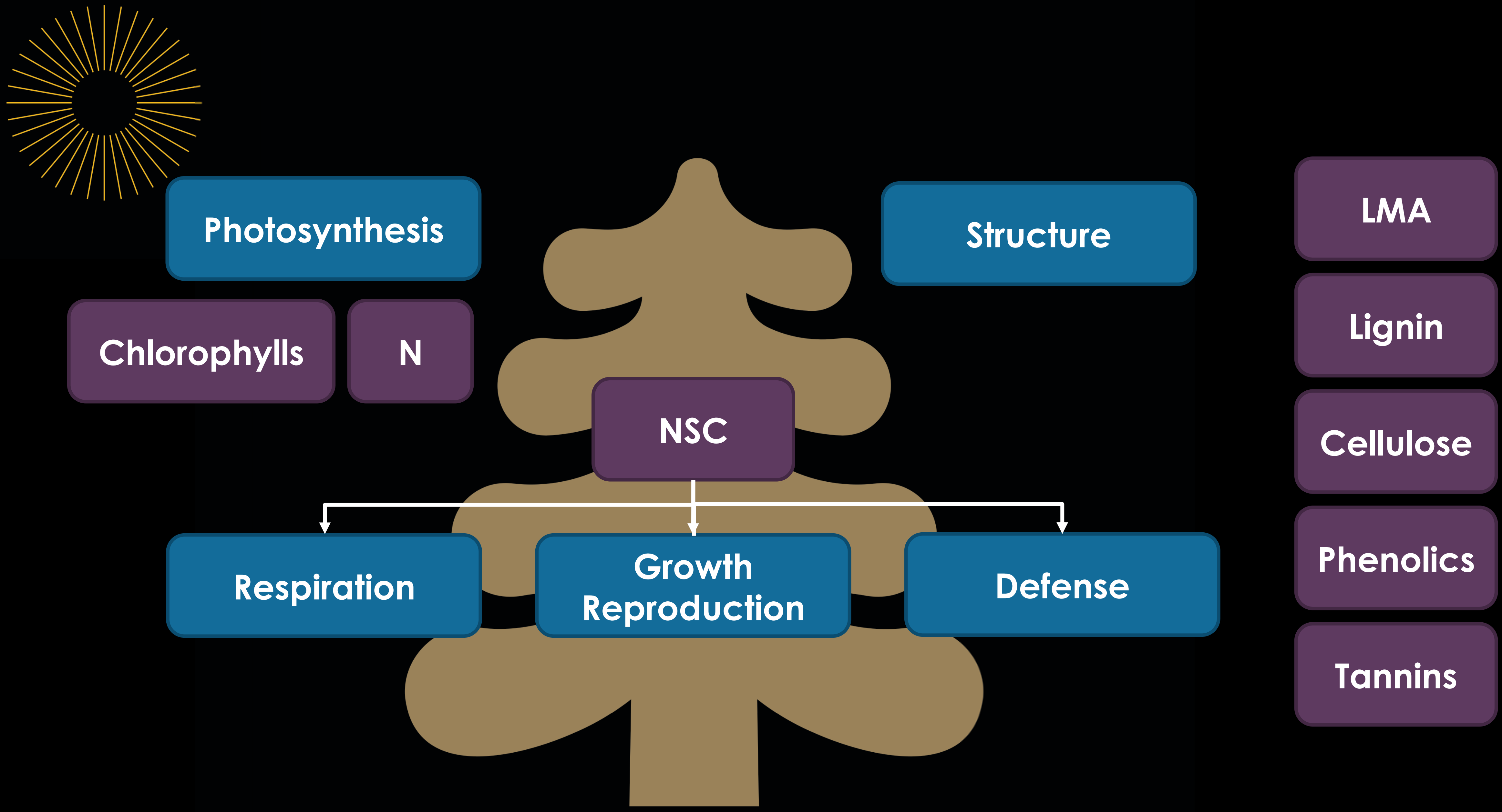

AVIRIS NEXT GENERATION

CABO

apex Airborne Prism Experiment

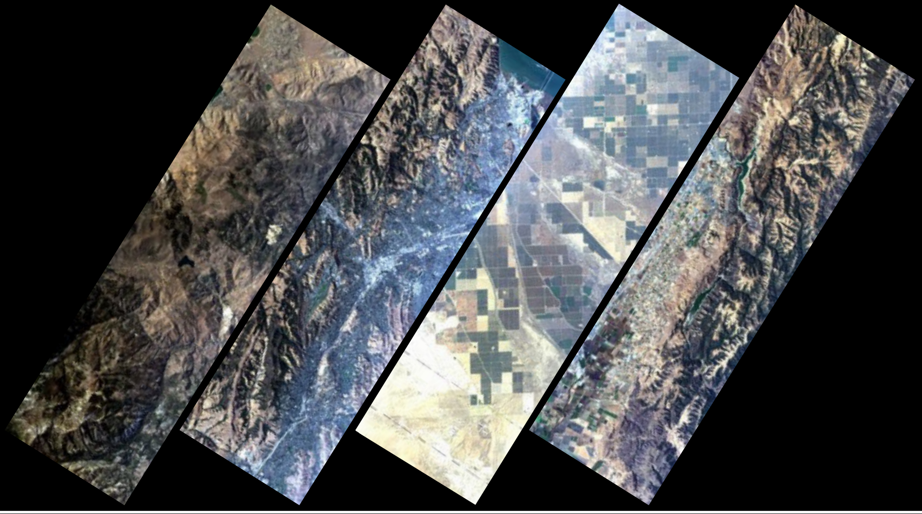
G-LiHT


Observation Question
Data Collection
Modeling
Prediction
Wavelength (nm)



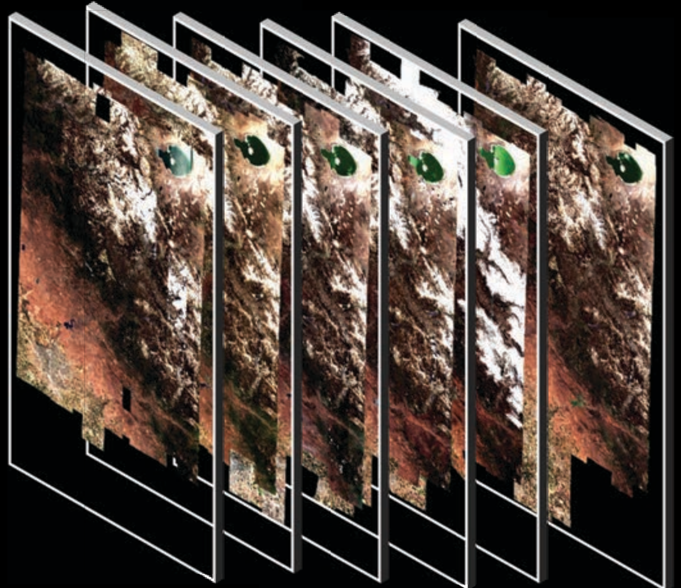

Adapted from Huang et al. (2020)

Plant Functional Traits for Diverse Biomes

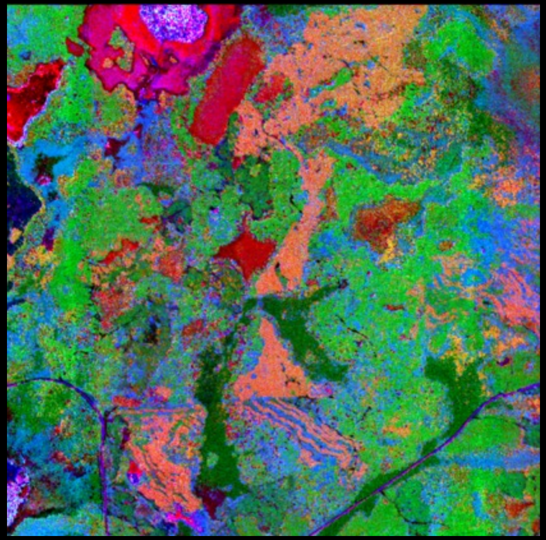


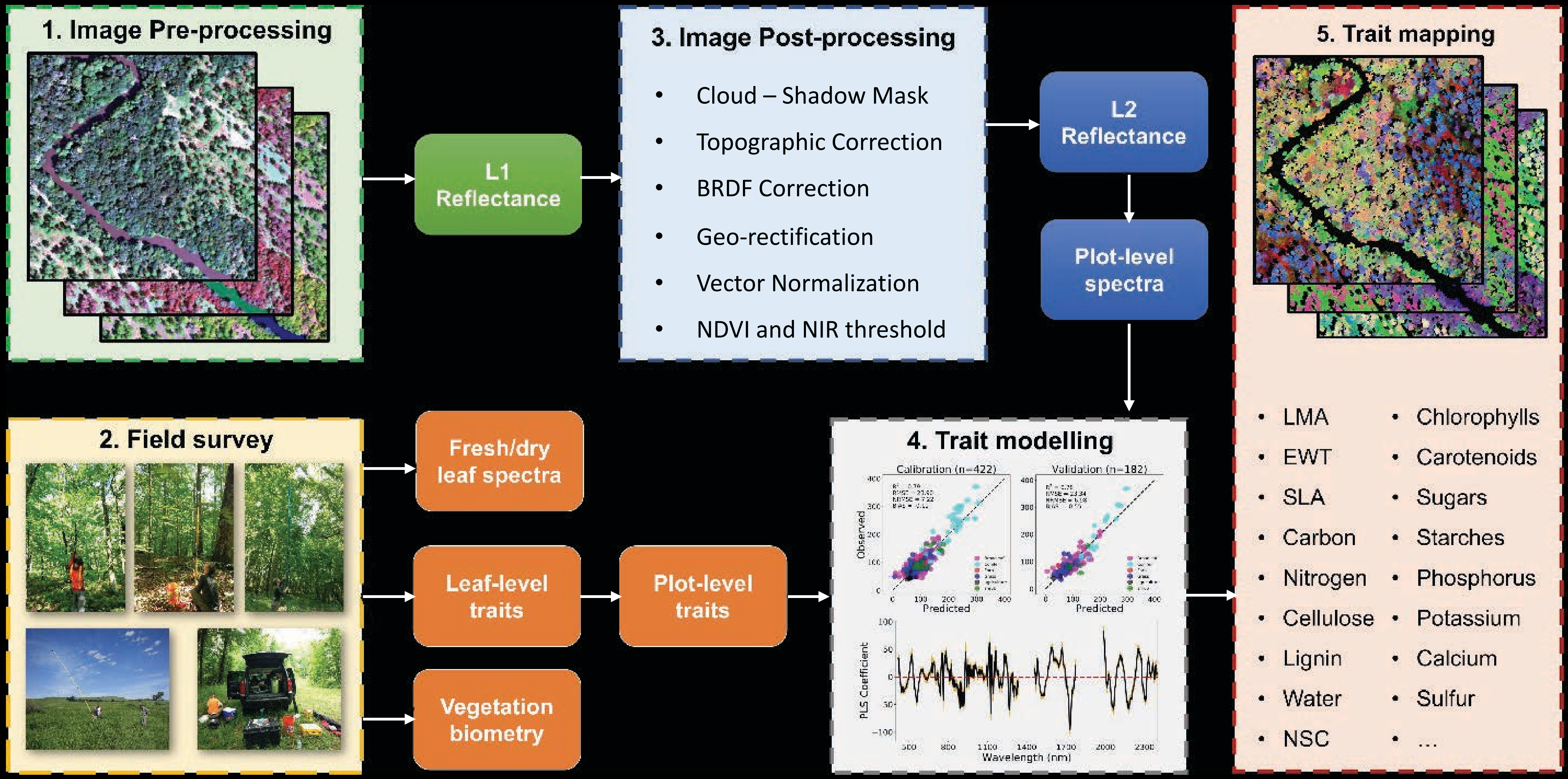
Seasonal Trajectory (Phenology)

Respond to Environmental Changes



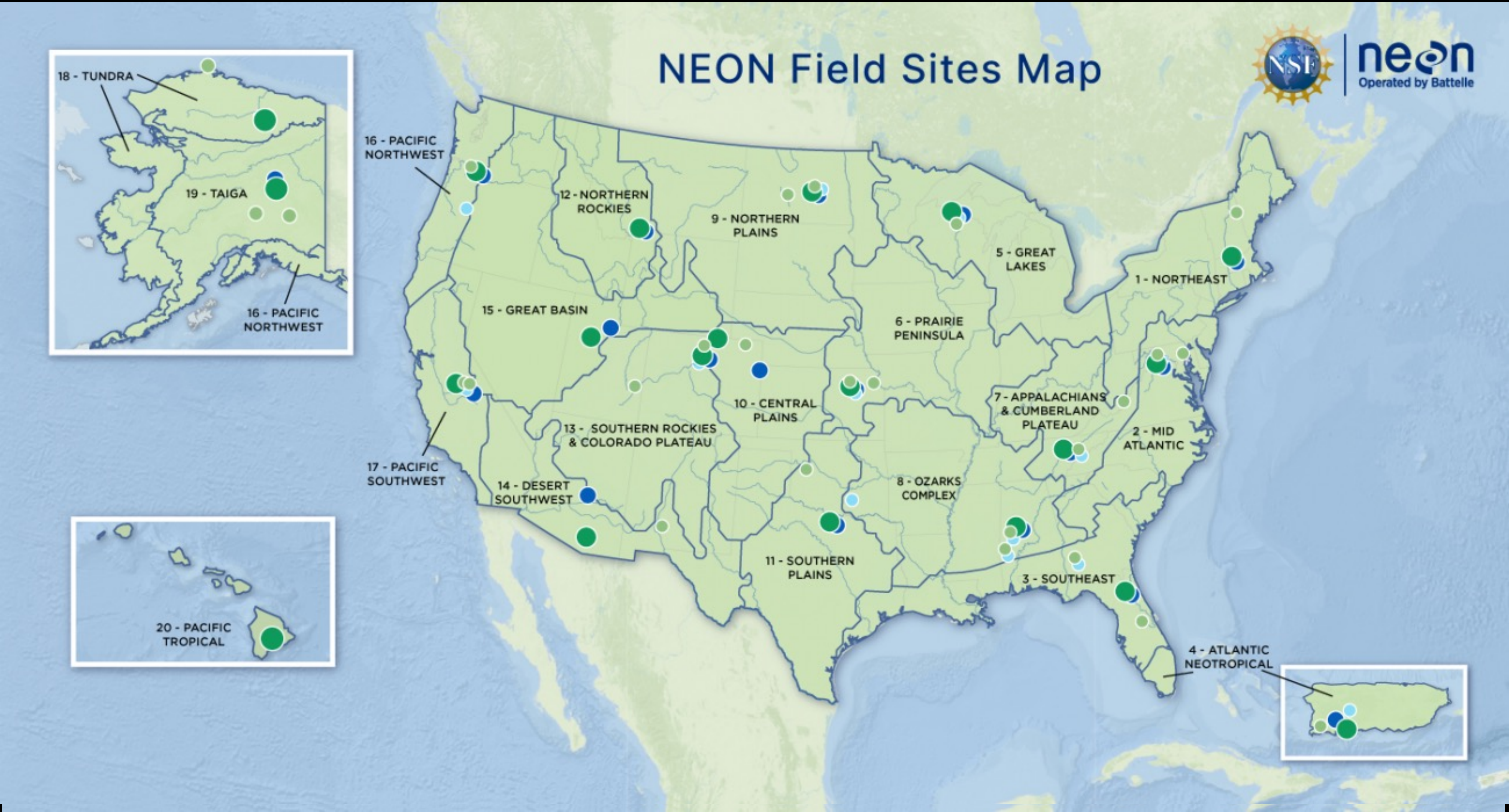
Satellites Enable Global Monitoring






Wang et al. 2020

# NEON Field Sites Map




https://www.neonscience.org/field-sites/about-field-sites


Single/Mixed Species
Homo/Heterogeneous
Open/Closed Canopy

Wide Climate Range


- Broadleaf Tree
- Conifer Tree
- Shrubland
- Grassland
- Forb

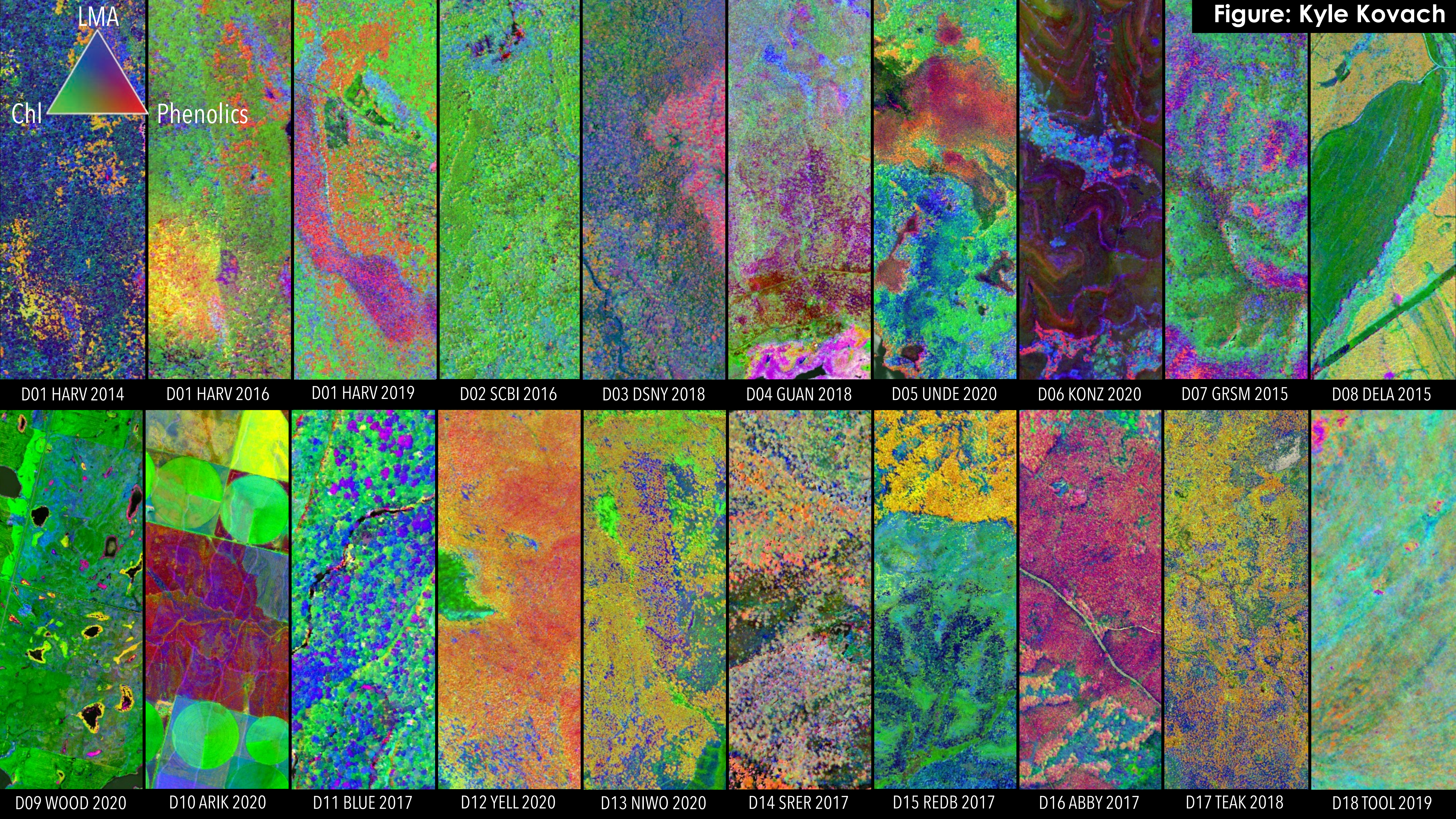
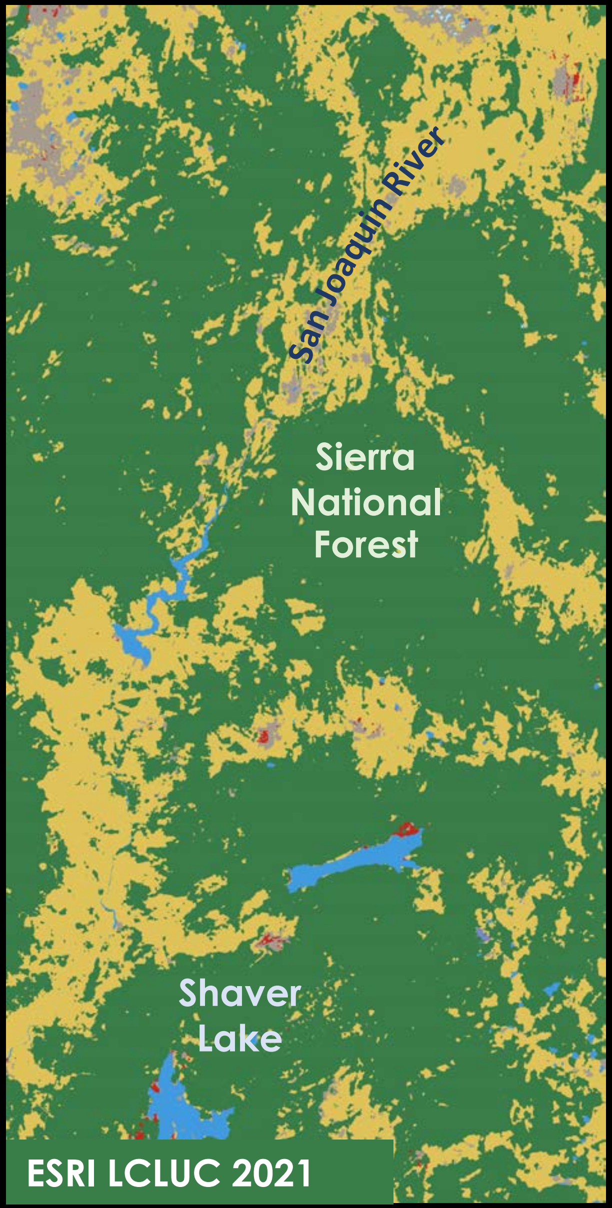


Figure: Kyle Kovach
LMA
Chl
Phenolics
D01 HARV 2014
D01 HARV 2016
D01 HARV 2019
D02 SCBI 2016
D03 DSNY 2018
D04 GUAN 2018
D05 UNDE 2020
D06 KONZ 2020
D07 GRSM 2015
D08 DELA 2015
D09 WOOD 2020
D10 ARIK 2020
D11 BLUE 2017
D12 YELL 2020
D13 NIWO 2020
D14 SRER 2017
D15 REDB 2017
D16 ABBY 2017
D17 TEAK 2018
D18 TOOL 2019

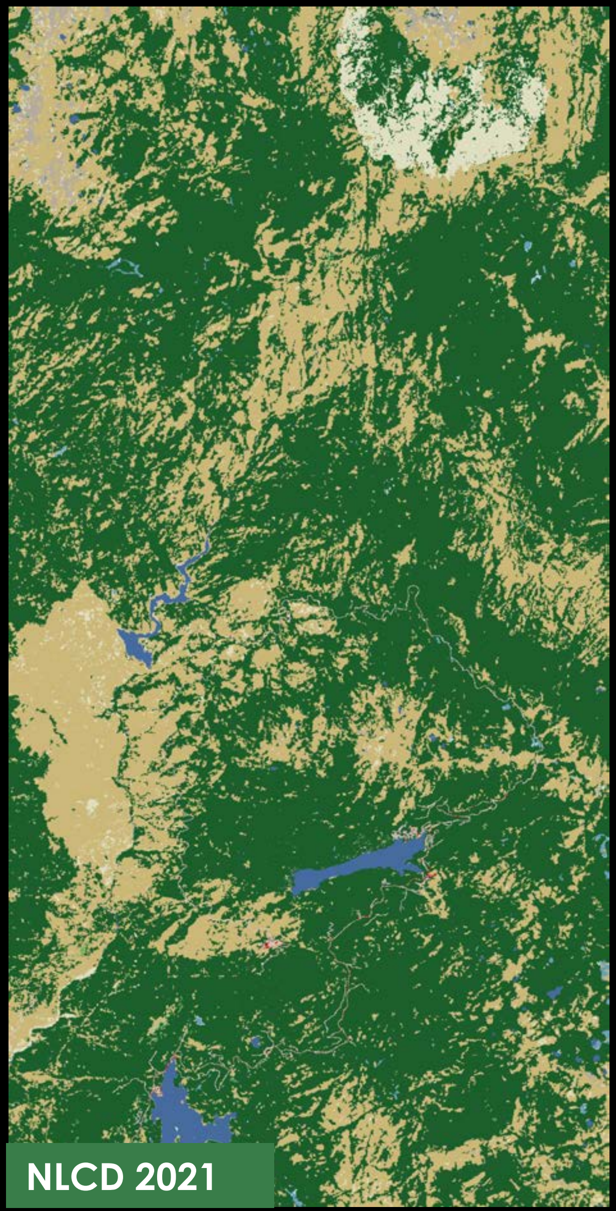
# State-Of-The-Art Landcover vs. Plant Traits

Figure: Fabian Schneider

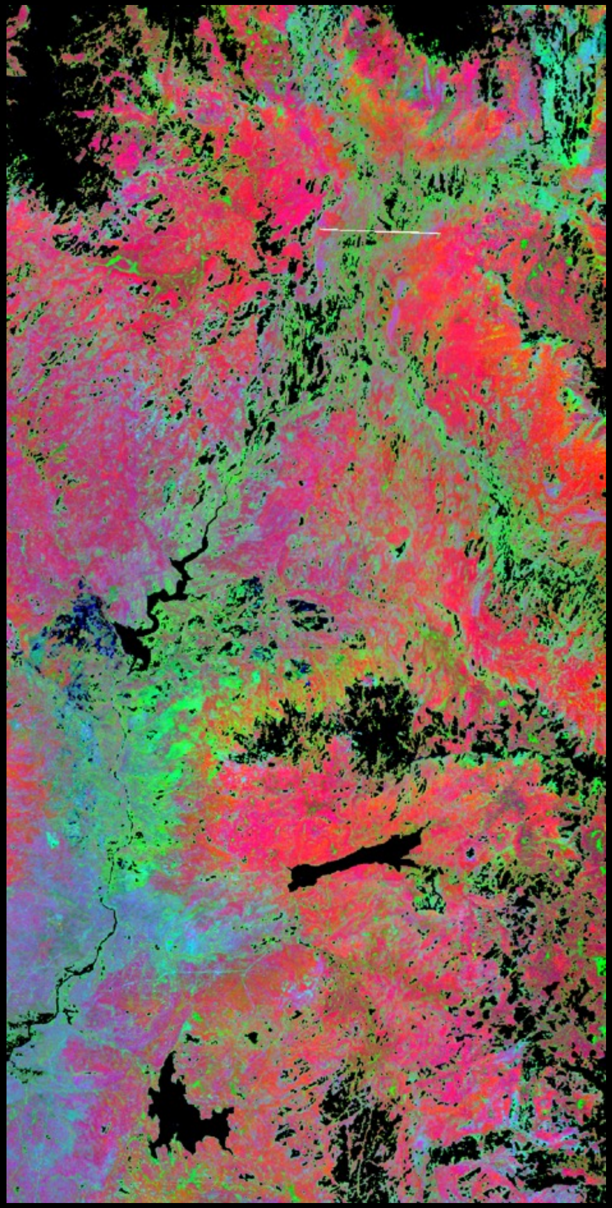
### Global Landcover



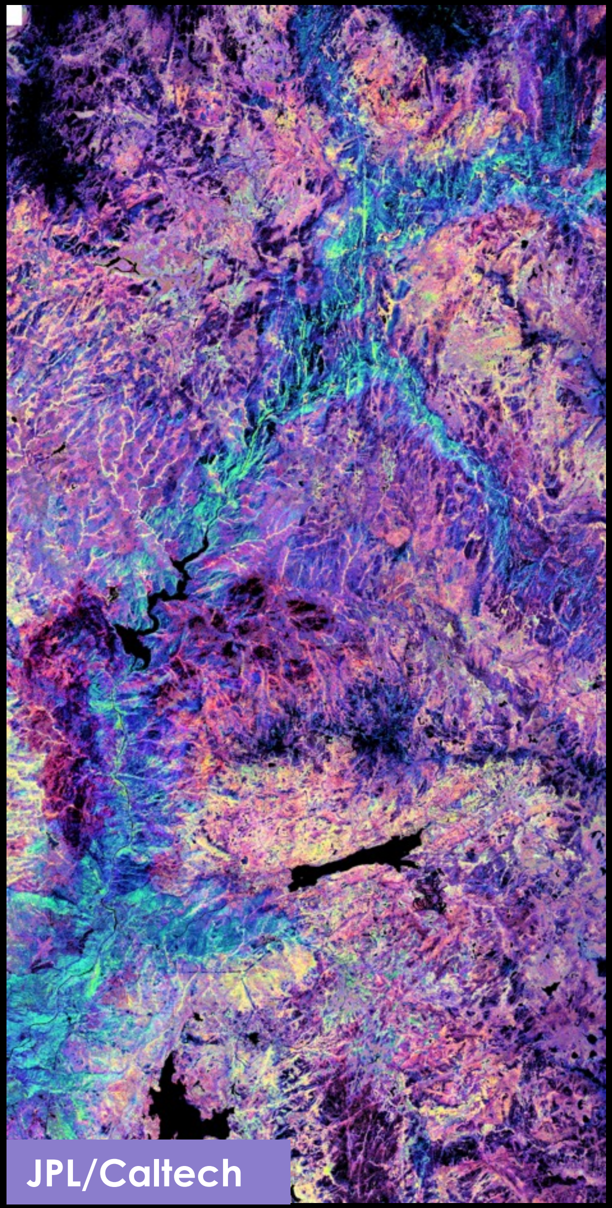

### US Landcover




### Plant Physiology



### Plant Structure



# Phenology

May 8$^{th}$

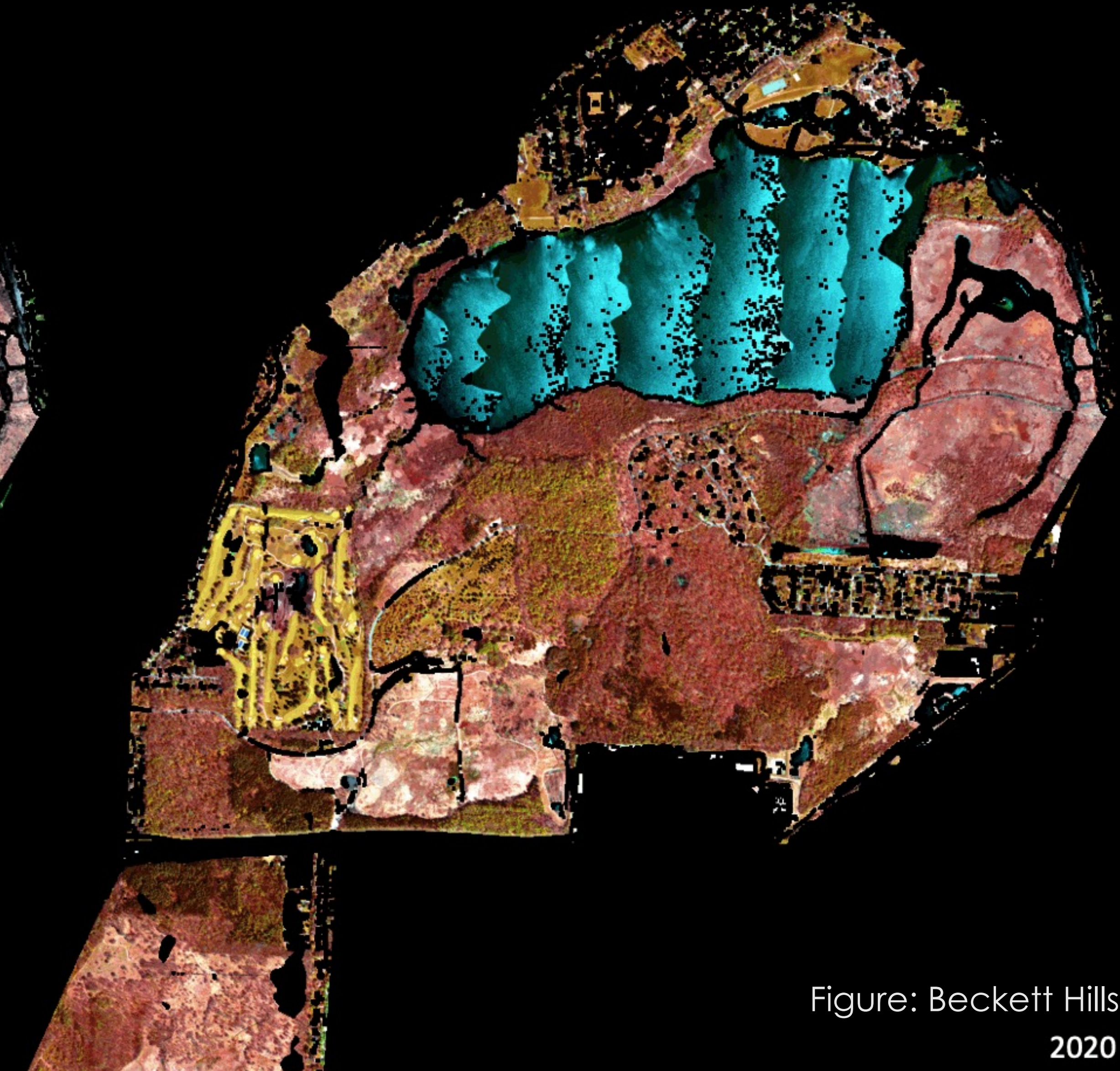
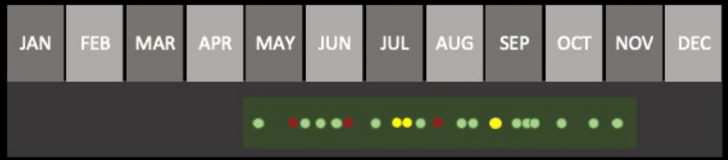
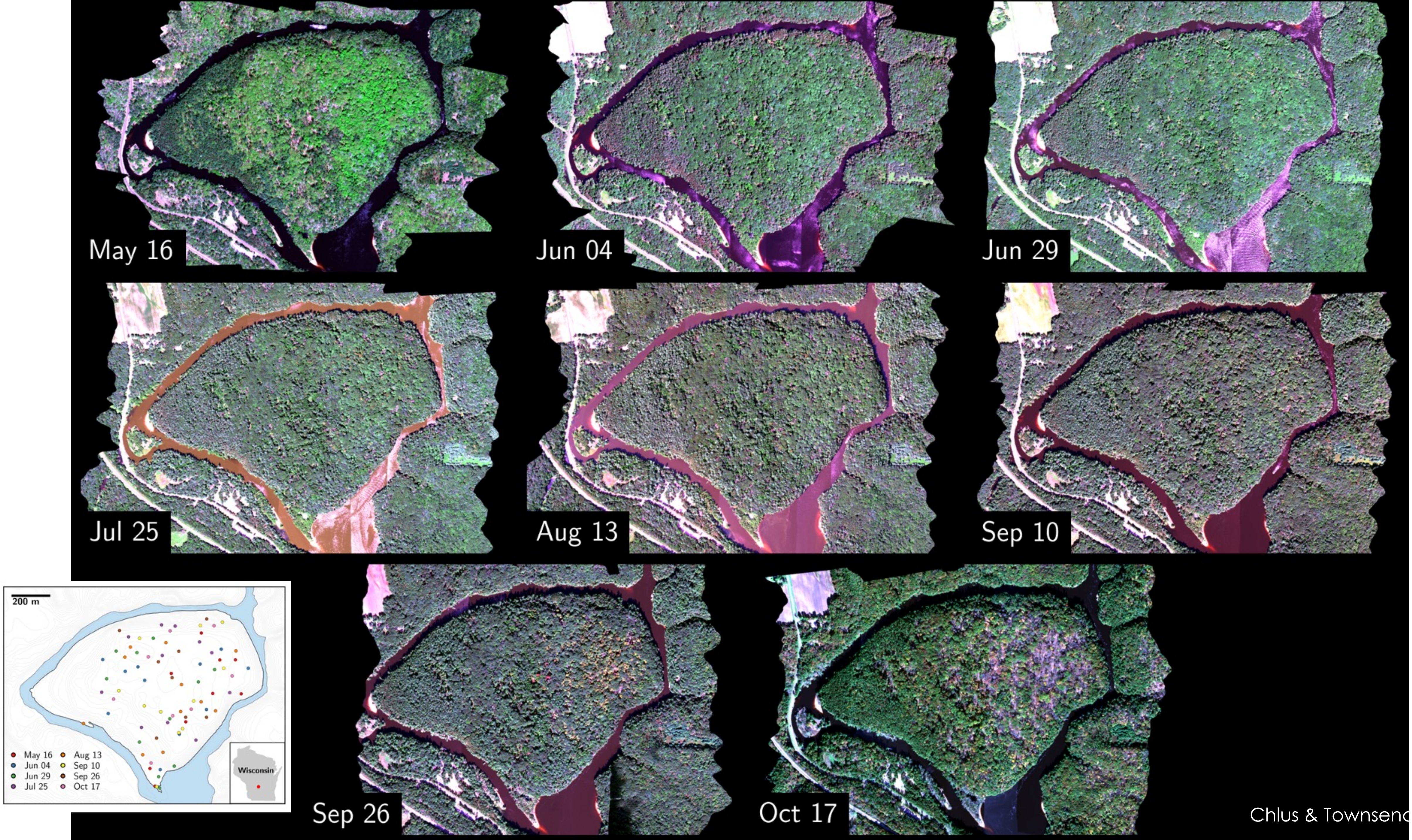
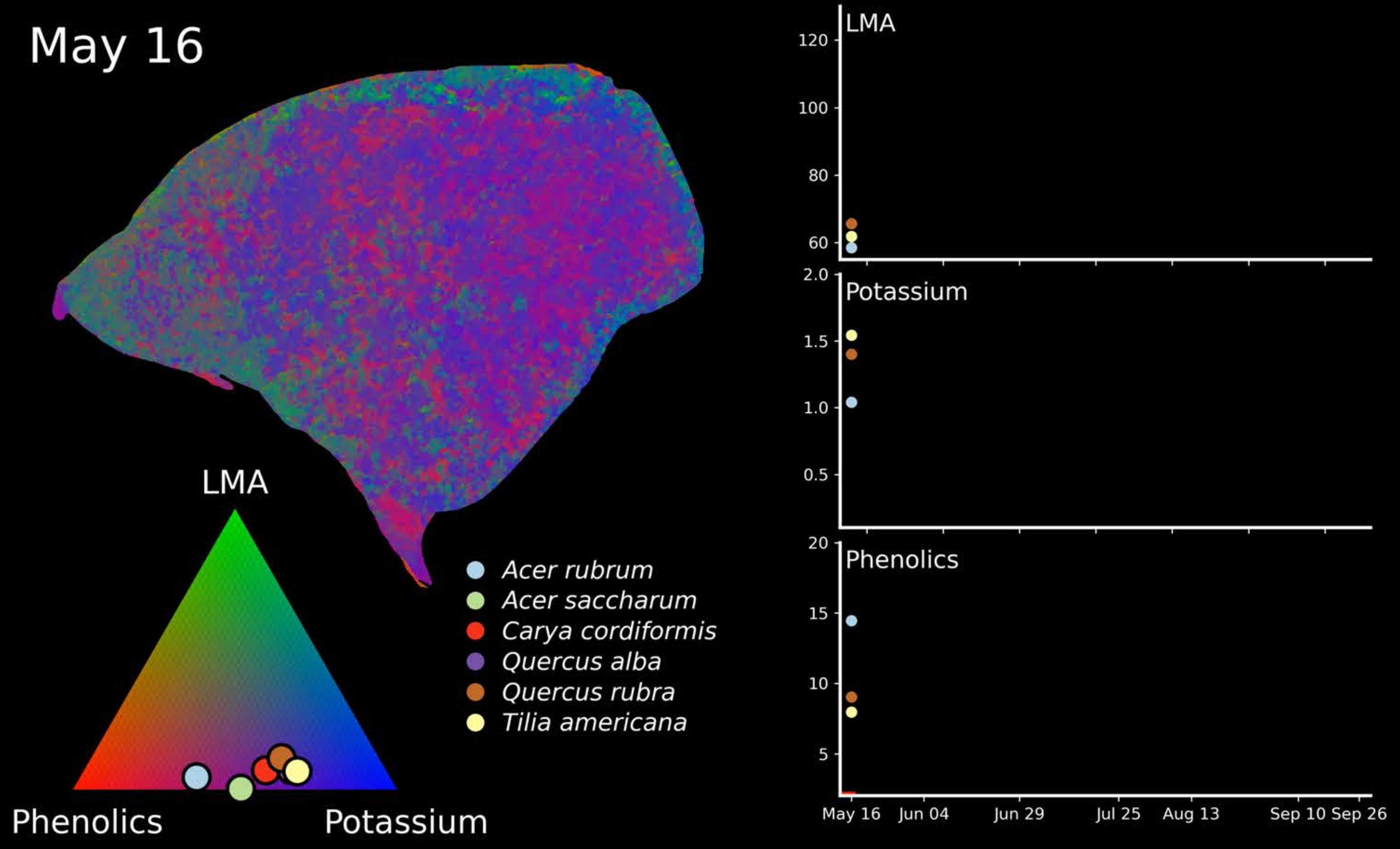


Figure: Beckett Hills

**2020**




May 16
Jun 04
Jun 29
Jul 25
Aug 13
Sep 10
Sep 26
Oct 17
200 m
May 16
Jun 04
Jun 29
Jul 25
Aug 13
Sep 10
Sep 26
Oct 17
Wisconsin
Chlus & Townsen

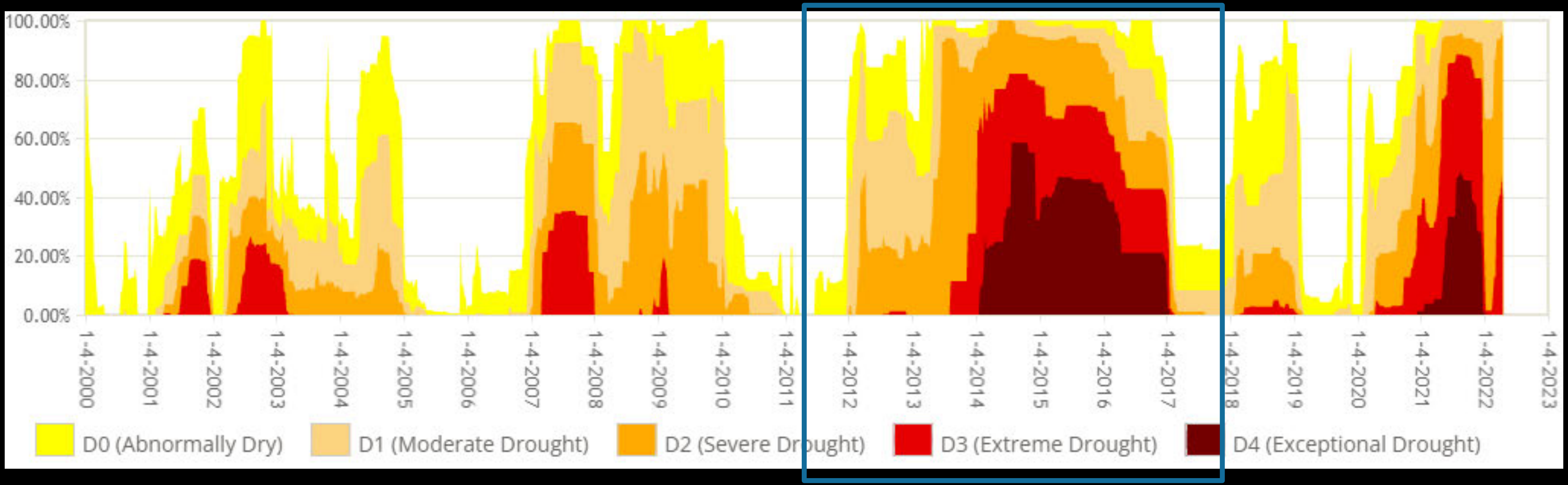



Chlus & Townsend, 2022

Ecosystem Response to Environmental Change:

# The California Mega-Drought – 2012 to 2018

California Percent Area in Drought




https://droughtmonitor.unl.edu/DmData/TimeSeries.aspx

# Background

Global Change Biology

**Warming increased bark beetle-induced tree mortality by 30% during an extreme drought in California**

JOURNAL OF CLIMATE

**Greater Temperature and Precipitation Extremes Intensify Western U.S. Droughts, Wildfire Severity, and Sierra Nevada Tree Mortality**

Environmental Research Letters

Chronic historical drought legacy exacerbates tree mortality and crown dieback during acute heatwave-compounded drought

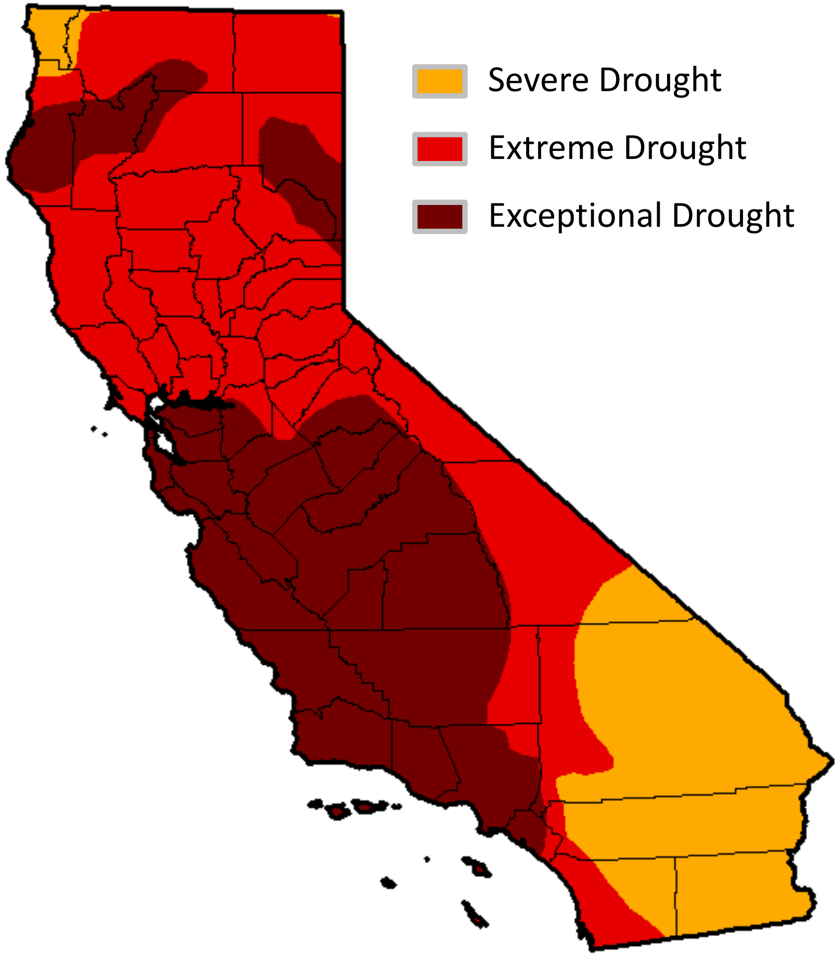
nature COMMUNICATIONS

Tree height explains mortality risk during an intense drought

nature geoscience

**California forest die-off linked to multi-year deep soil drying in 2012–2015 drought**

U.S Drought Monitor - California
July 1, 2014



# Background

Global Change Biology

**Warming** increased **bark beetle**-induced tree mortality by 30% during an extreme drought in California

JOURNAL OF CLIMATE

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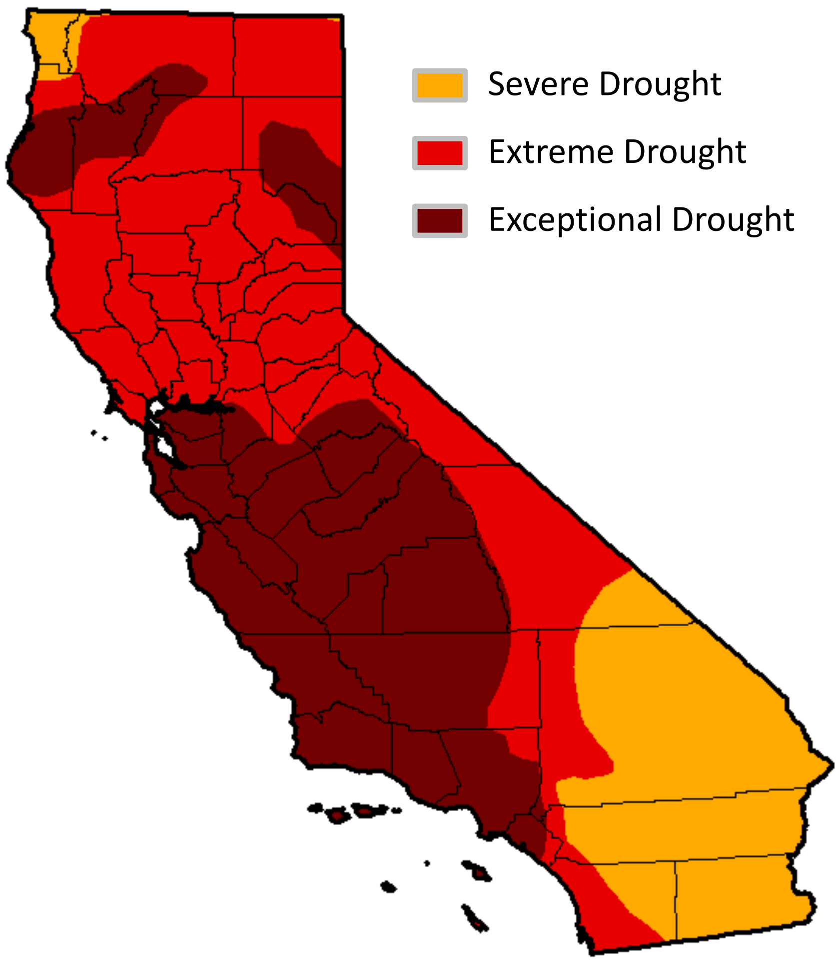
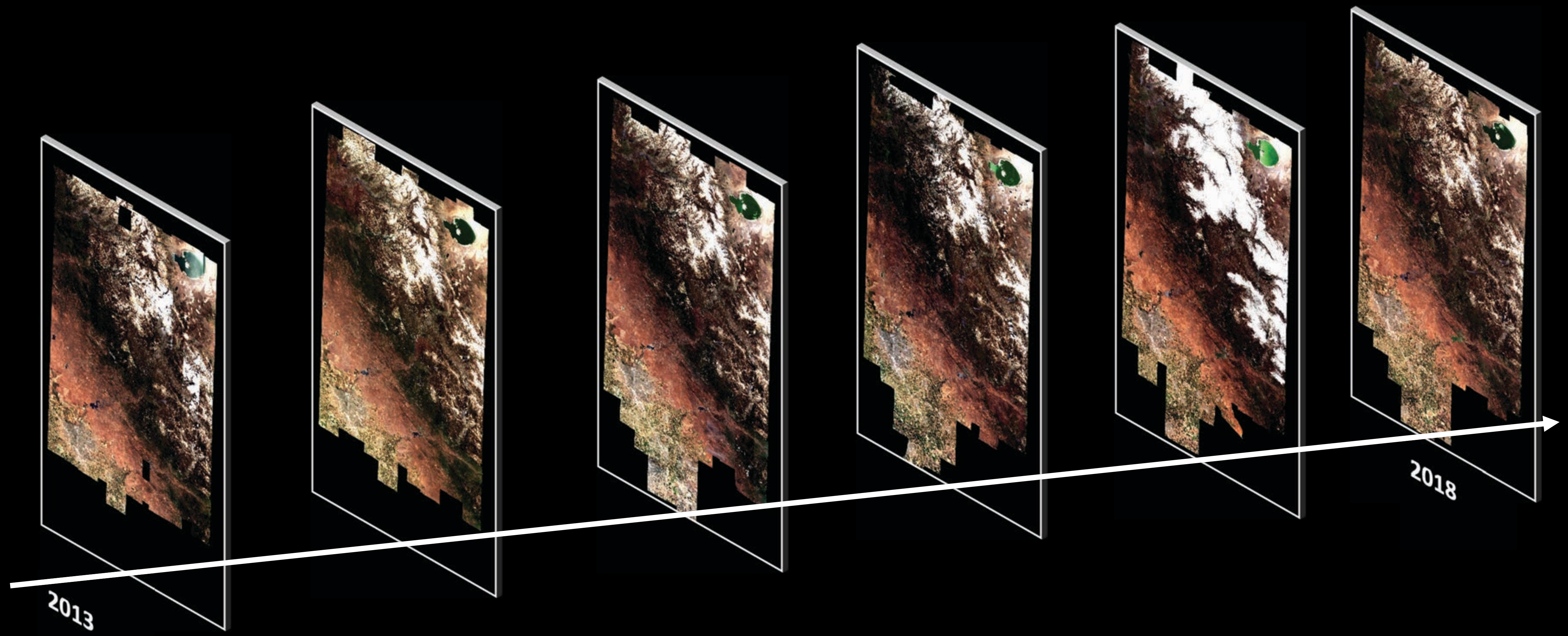
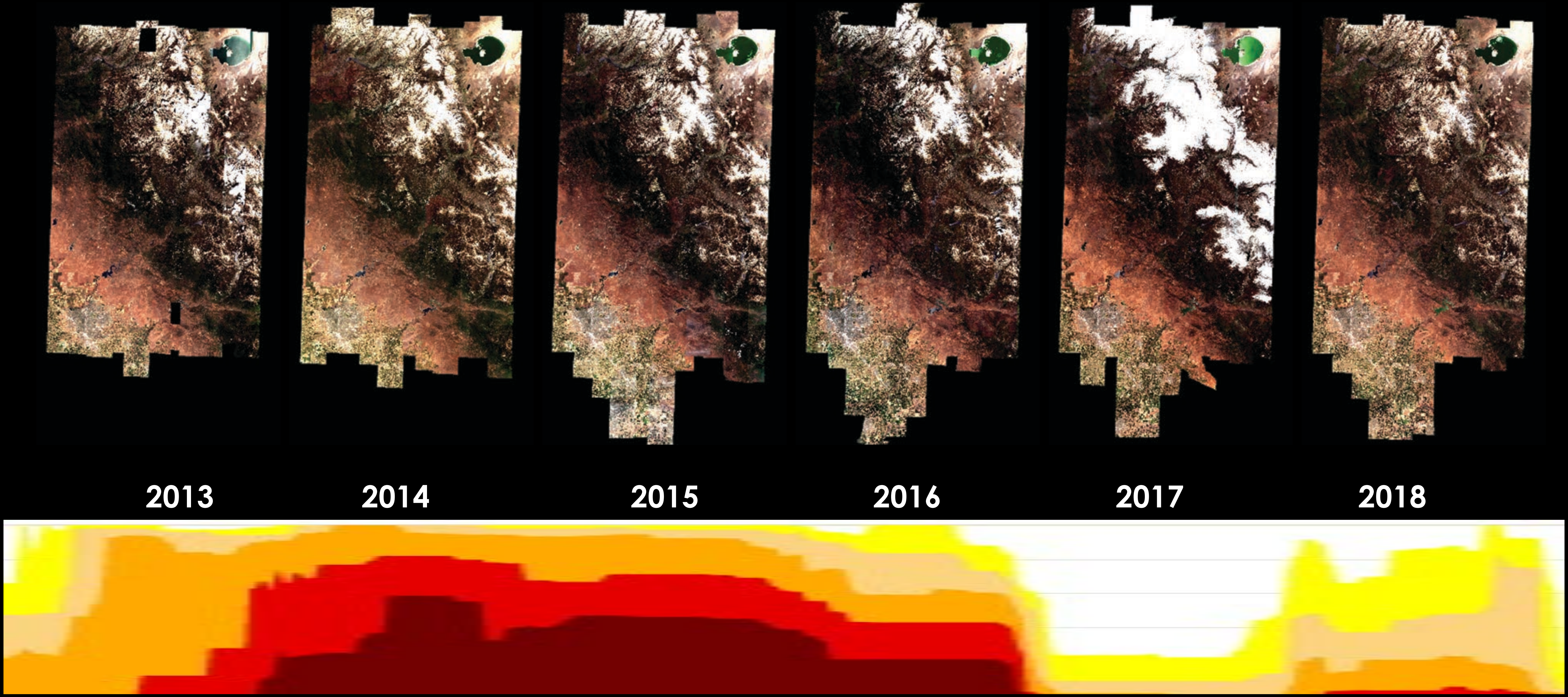
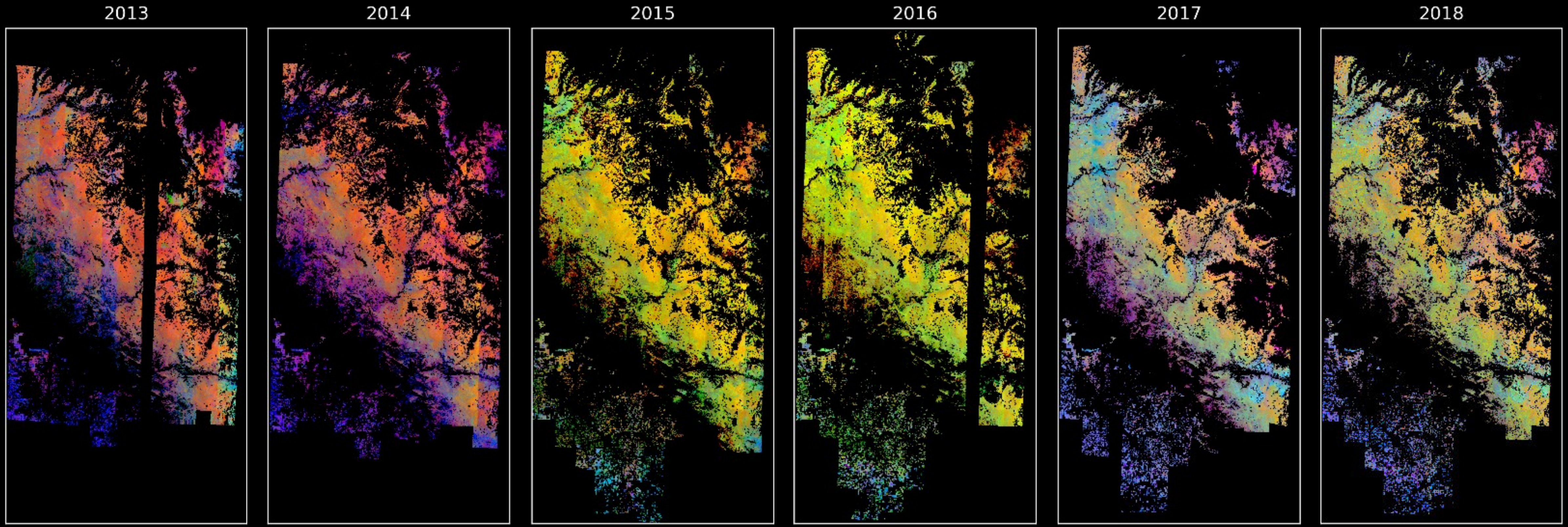


**Western Diversity Time Series (AVIRIS-Classic)**

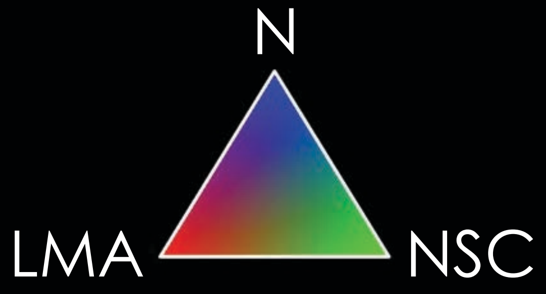
2012 ~ Present
AVIRIS-Classic
5 flight boxes

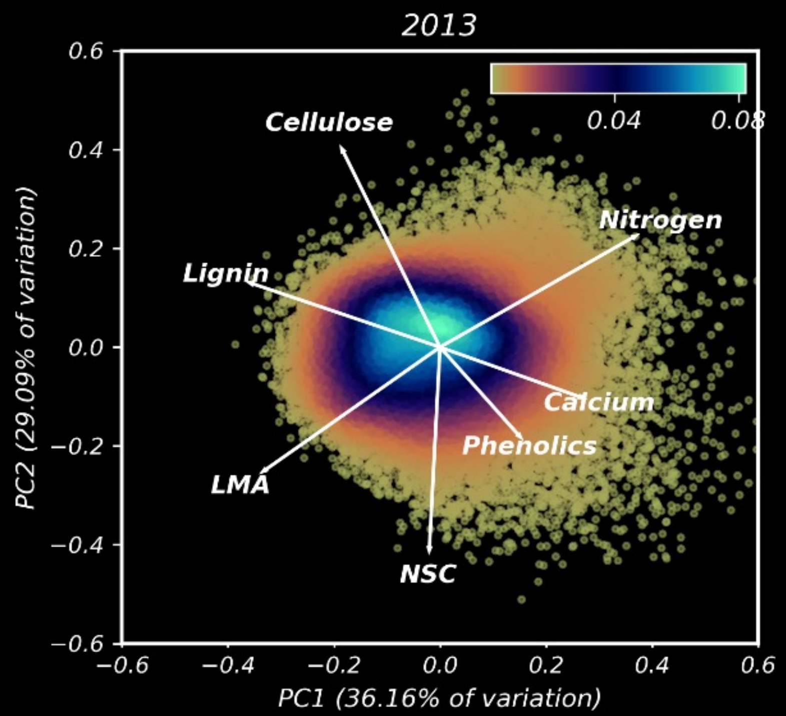

2013
2018


2013
2014
2015
2016
2017
2018

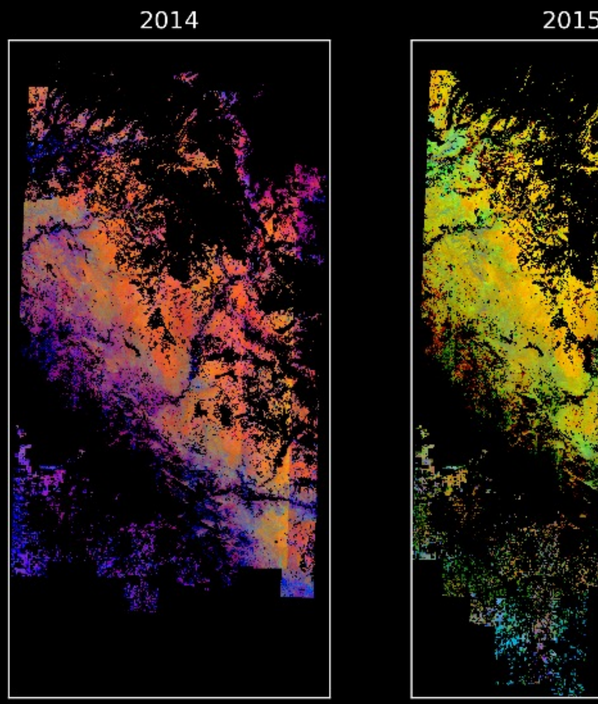


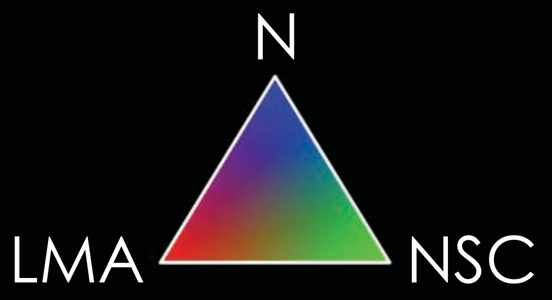

LMA: 0~330 $g/m^2$
N: 10~32 mg/g
NSC: 150~350 mg/g

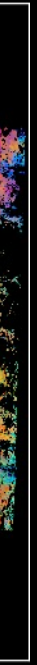


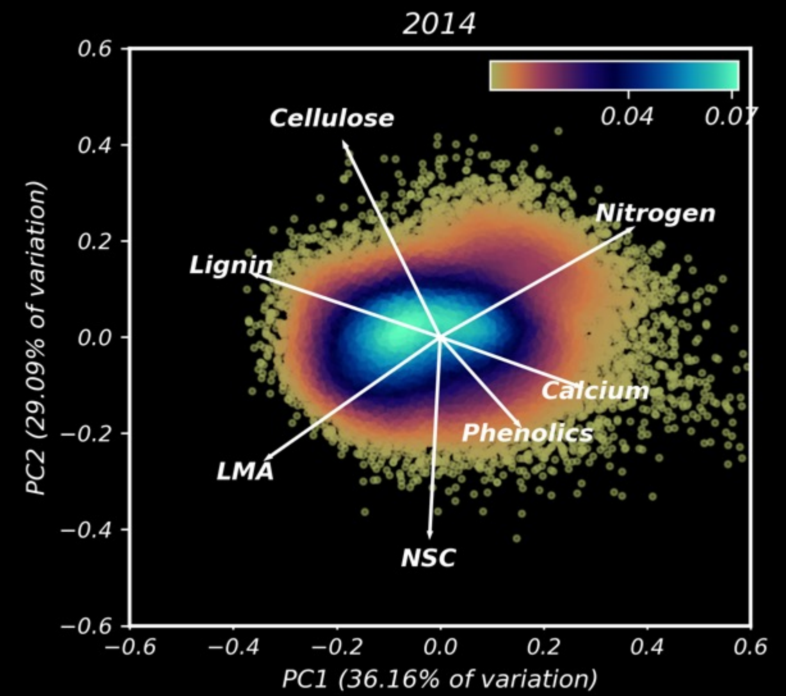

2013
0.04
0.08
Cellulose
Nitrogen
Lignin
Calcium
Phenolics
LMA
NSC
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
PC2 (29.09% of variation)
PC1 (36.16% of variation)

2013

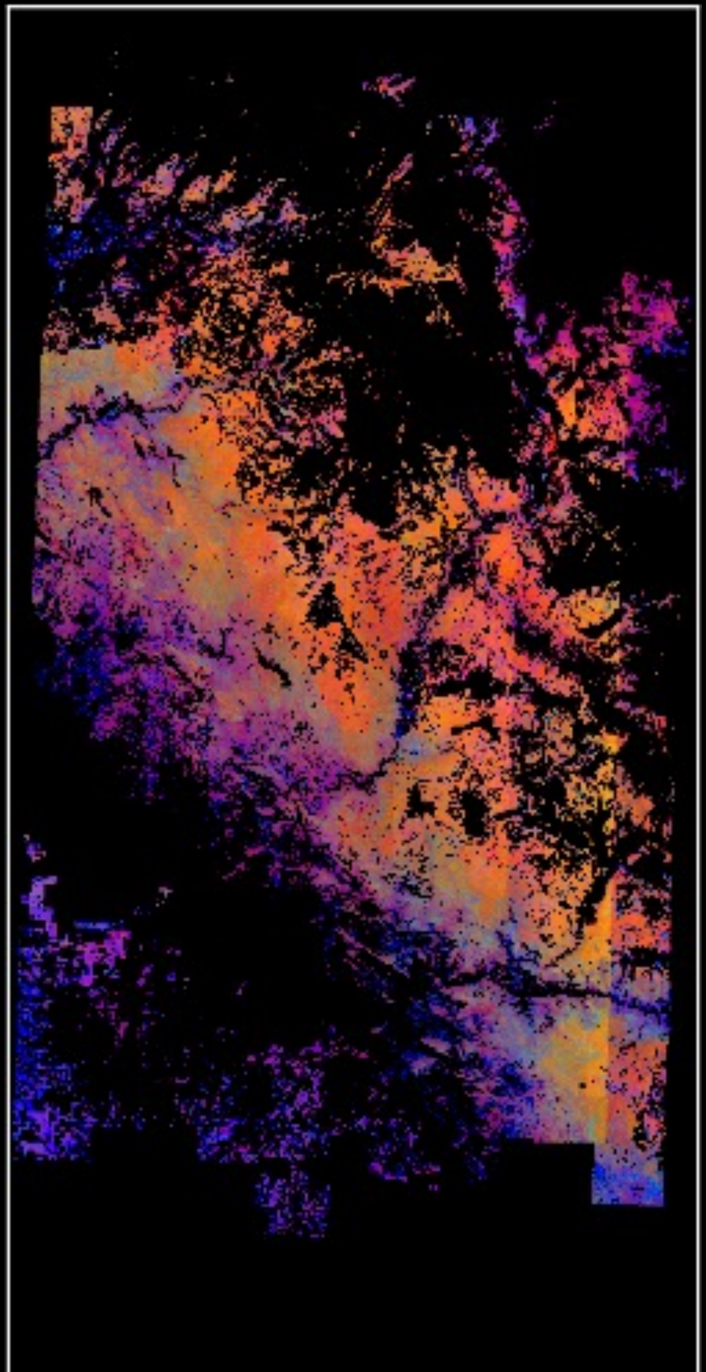

2014
2015


N
LMA
NSC

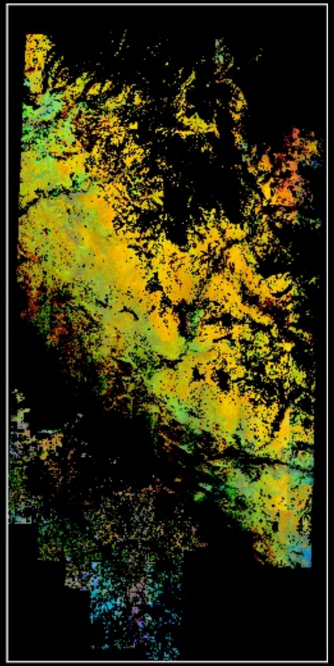




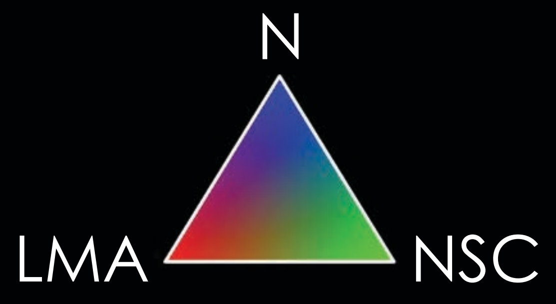

2014

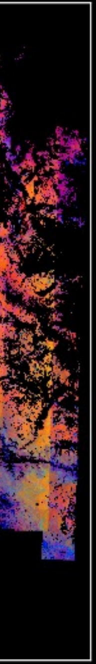


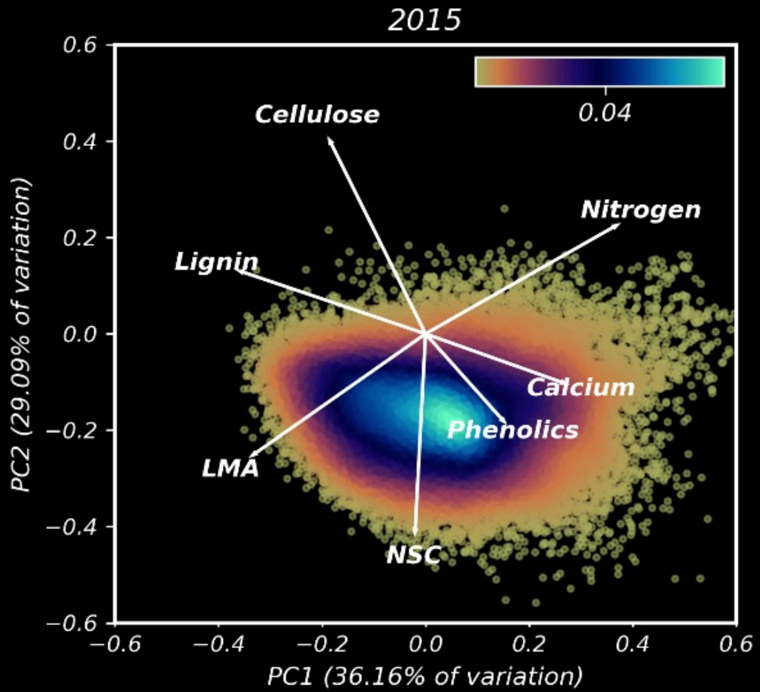
2015



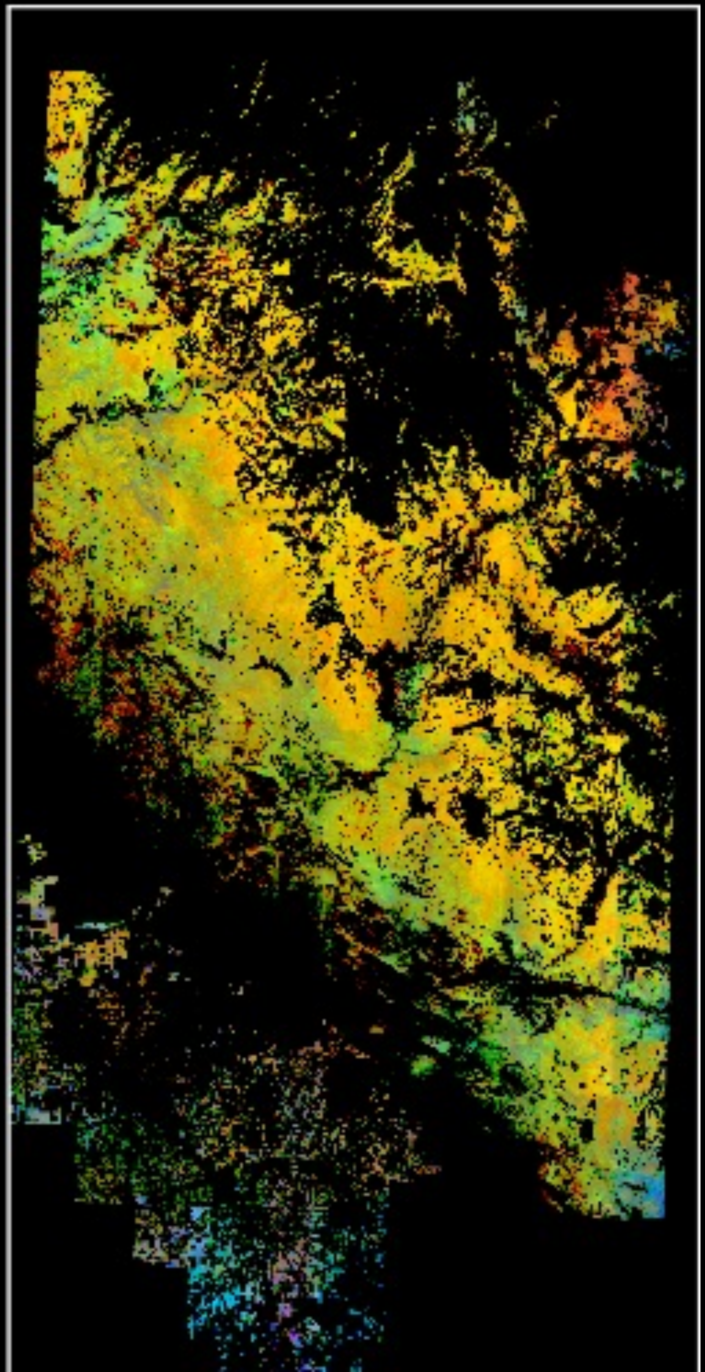
2016





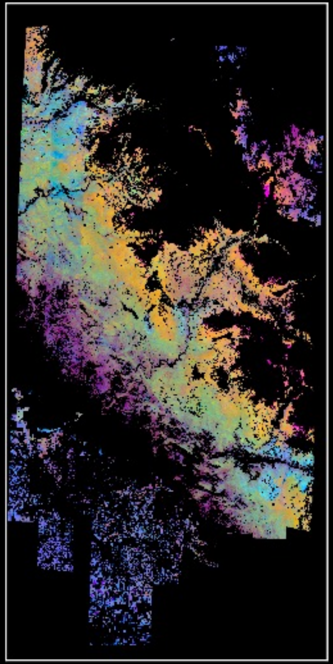


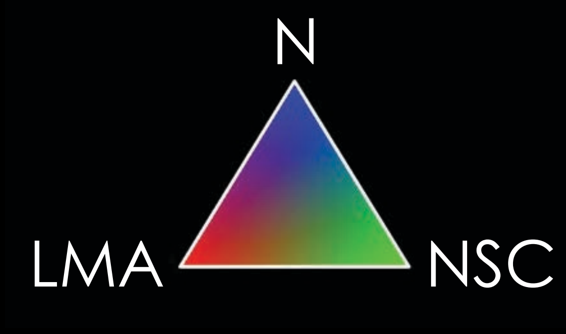

2015

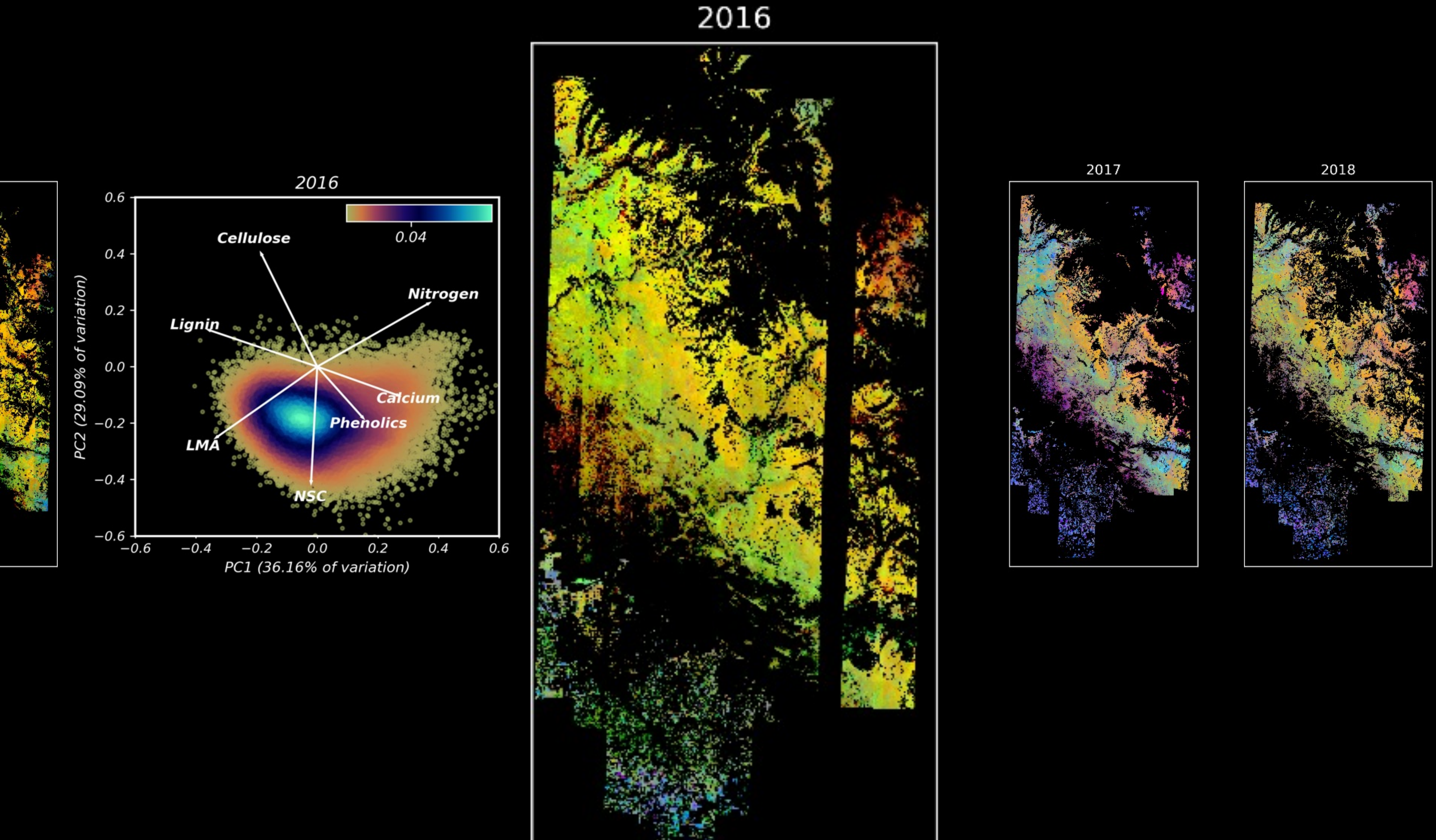


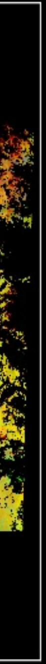
2016

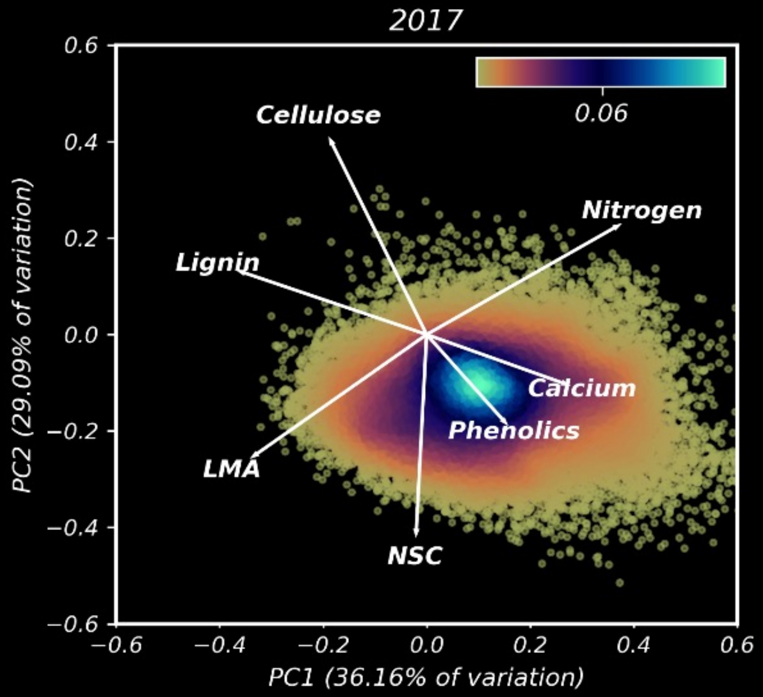
2017

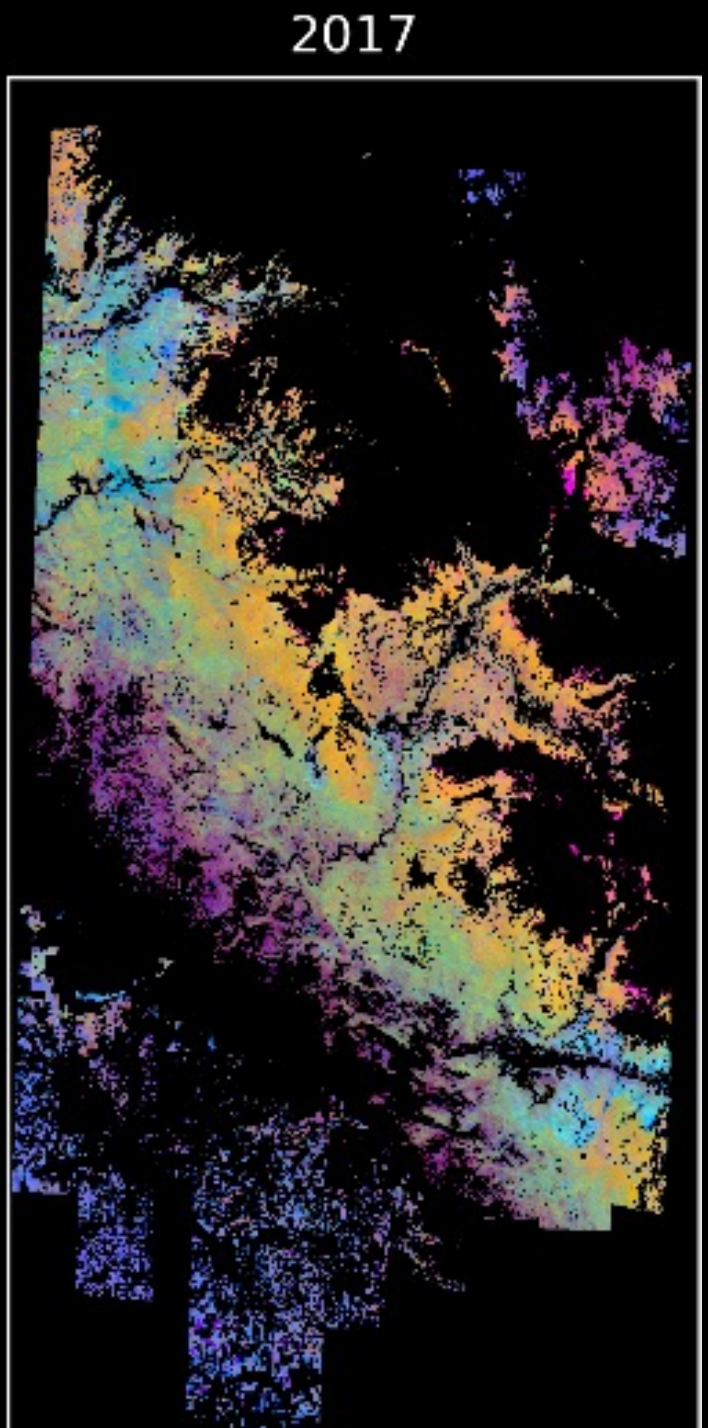


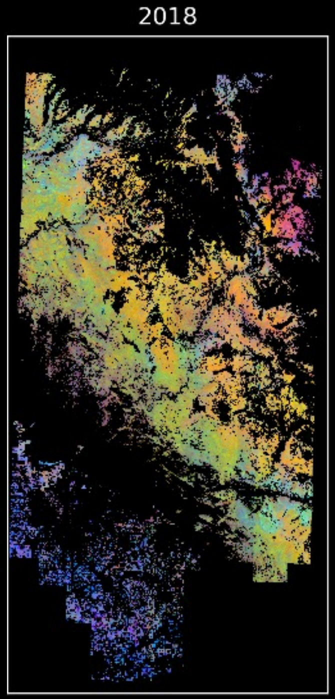


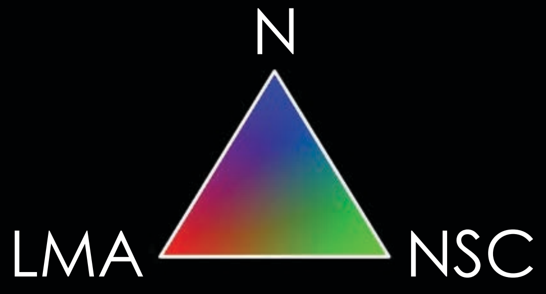

2016
2016
Cellulose
Nitrogen
Lignin
Calcium
Phenolics
LMA
NSC
0.04
PC2 (29.09% of variation)
PC1 (36.16% of variation)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
2017
2018

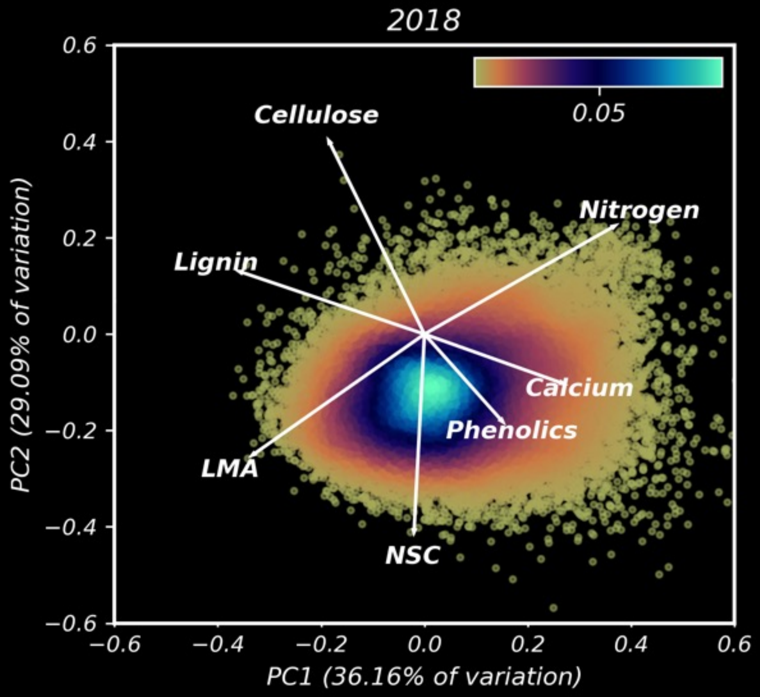



2017
0.06
Cellulose
Nitrogen
Lignin
Calcium
Phenolics
LMA
NSC
PC2 (29.09% of variation)
PC1 (36.16% of variation)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6

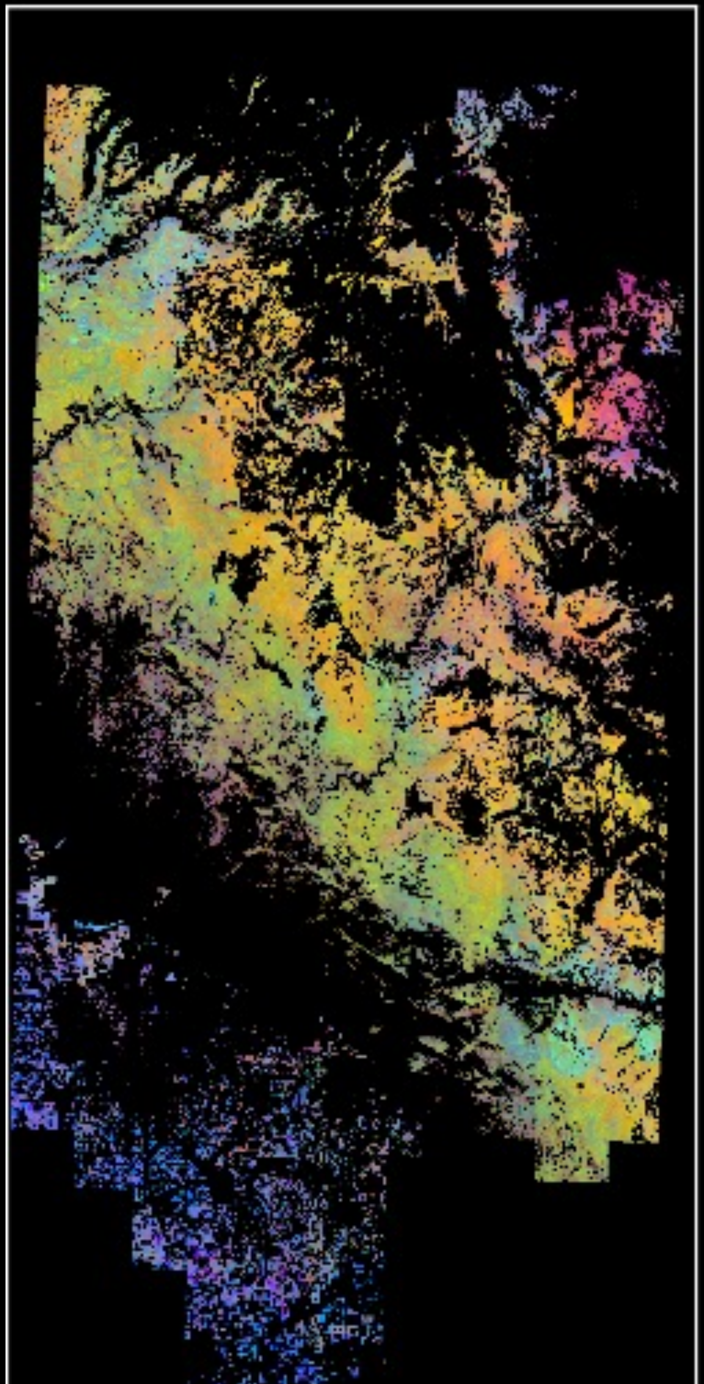

2017

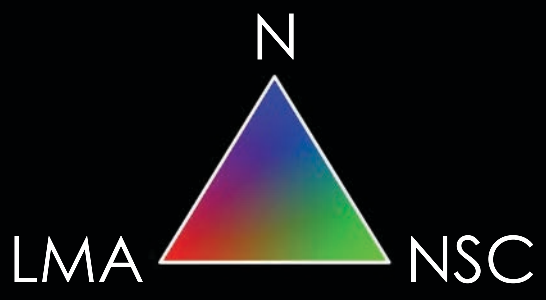

2018

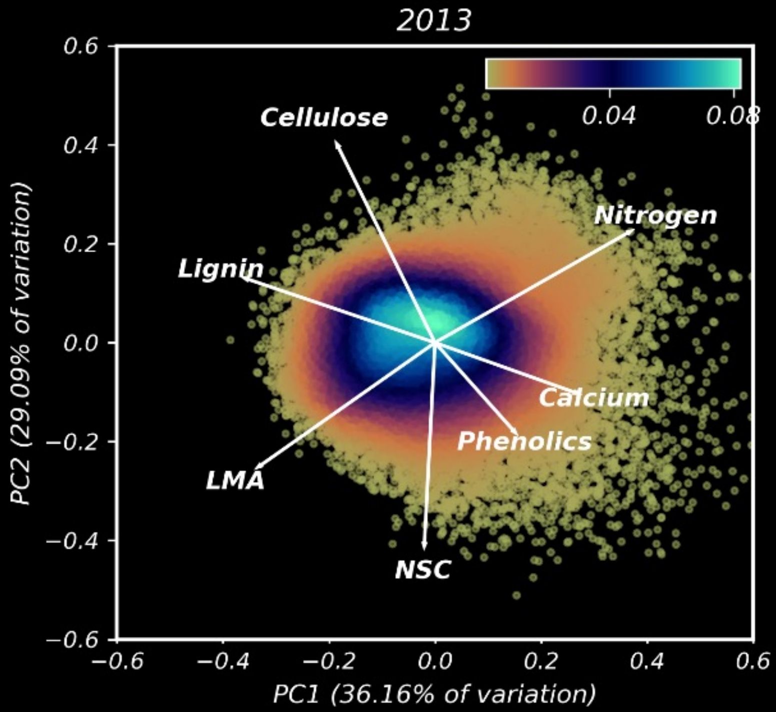

N
LMA
NSC


2018
0.05
Cellulose
Nitrogen
Lignin
Calcium
Phenolics
LMA
NSC
PC2 (29.09% of variation)
PC1 (36.16% of variation)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6

2018

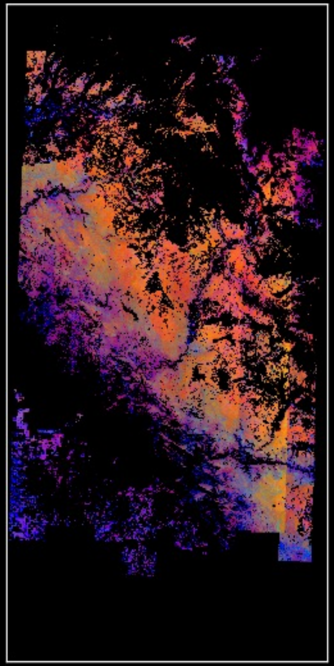



N
LMA
NSC

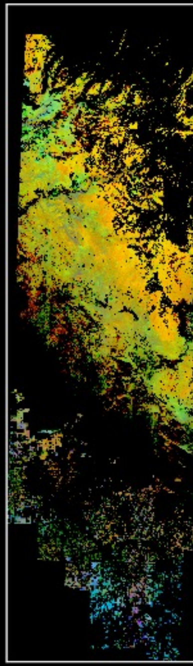


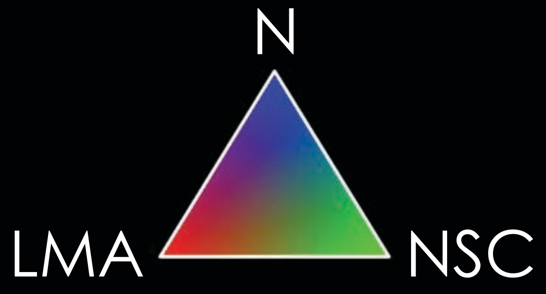

2013

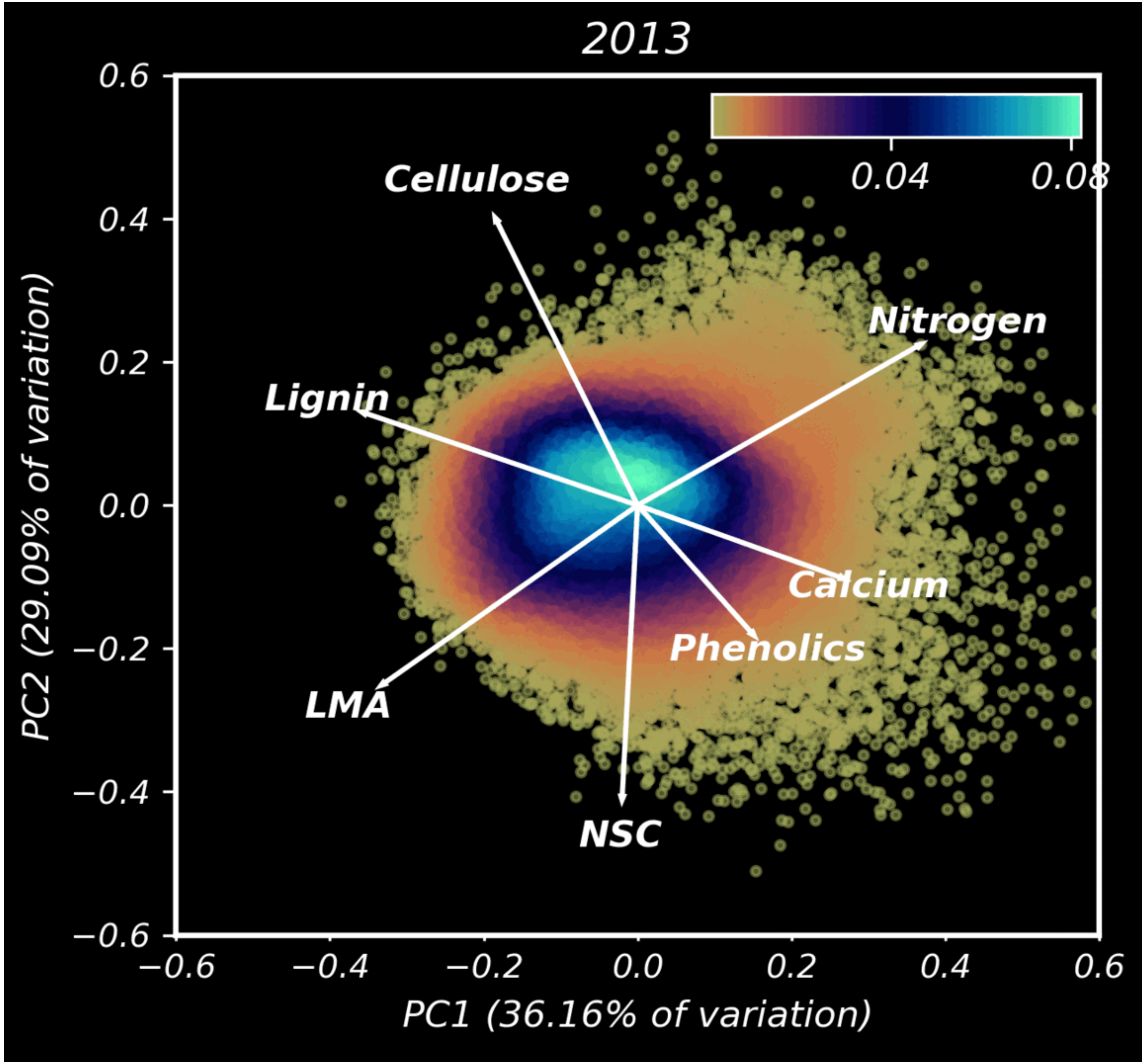
2014



2015







2013
0.04
0.08
Cellulose
Nitrogen
Lignin
Calcium
Phenolics
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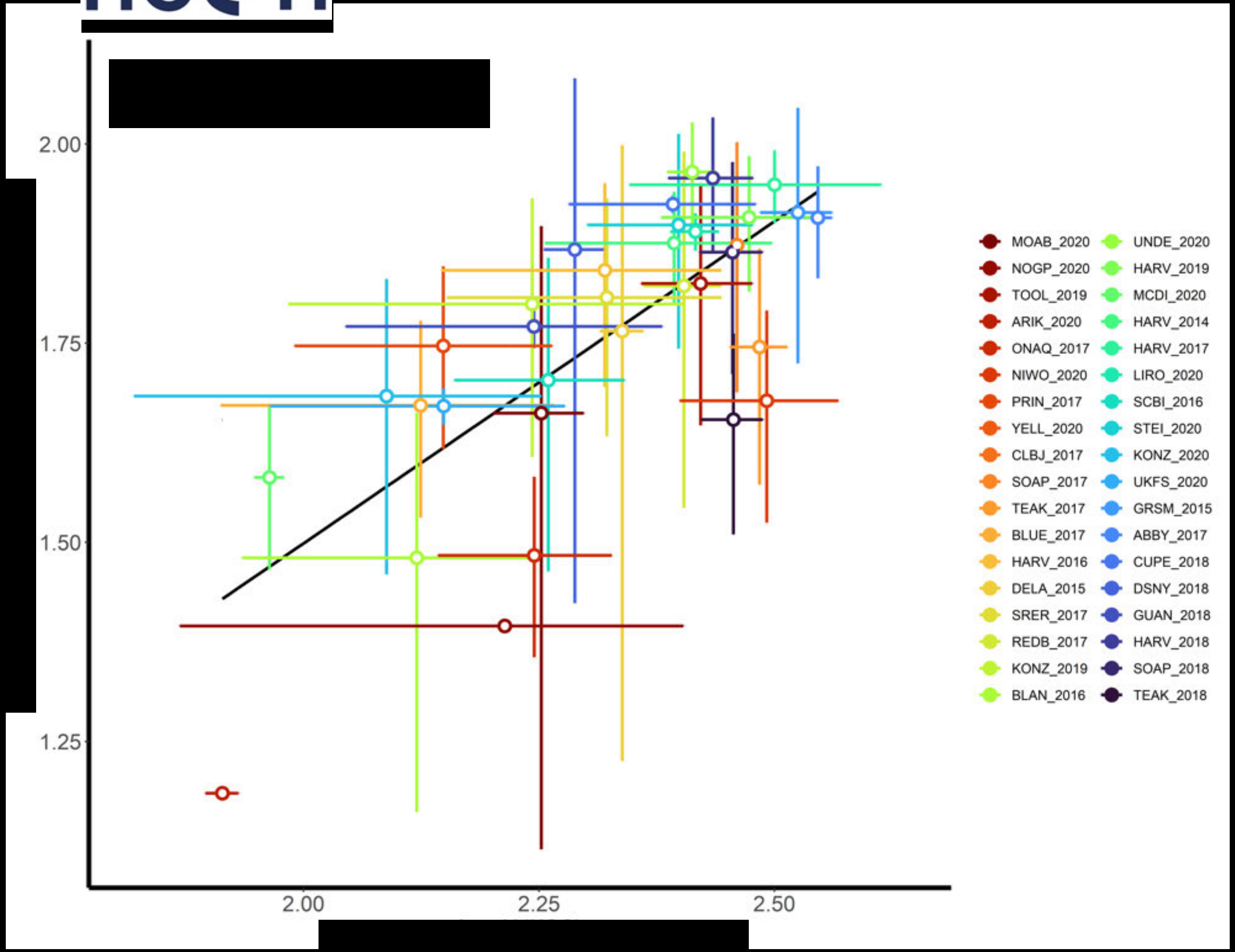
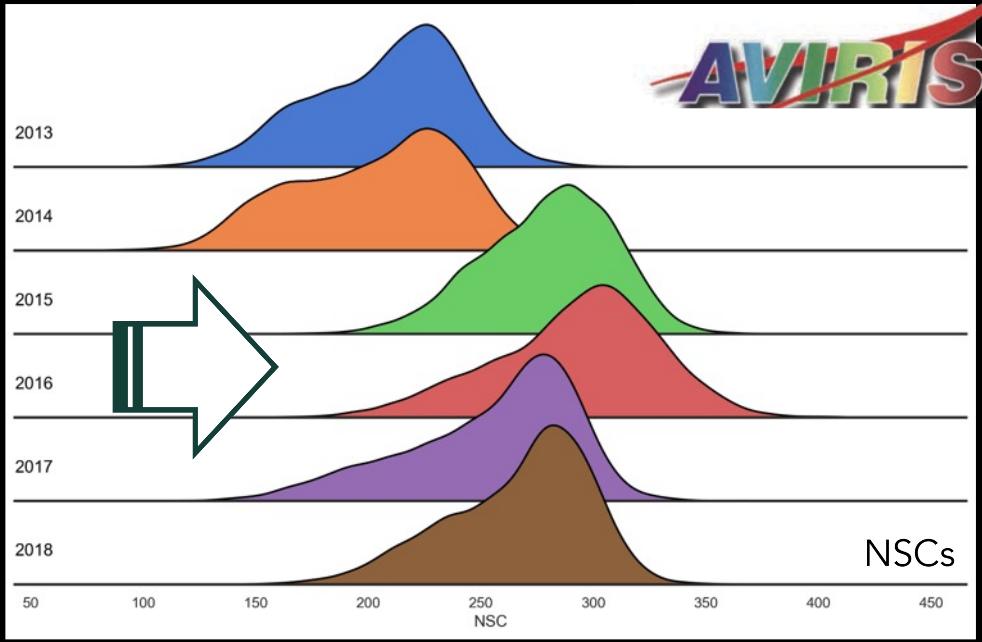
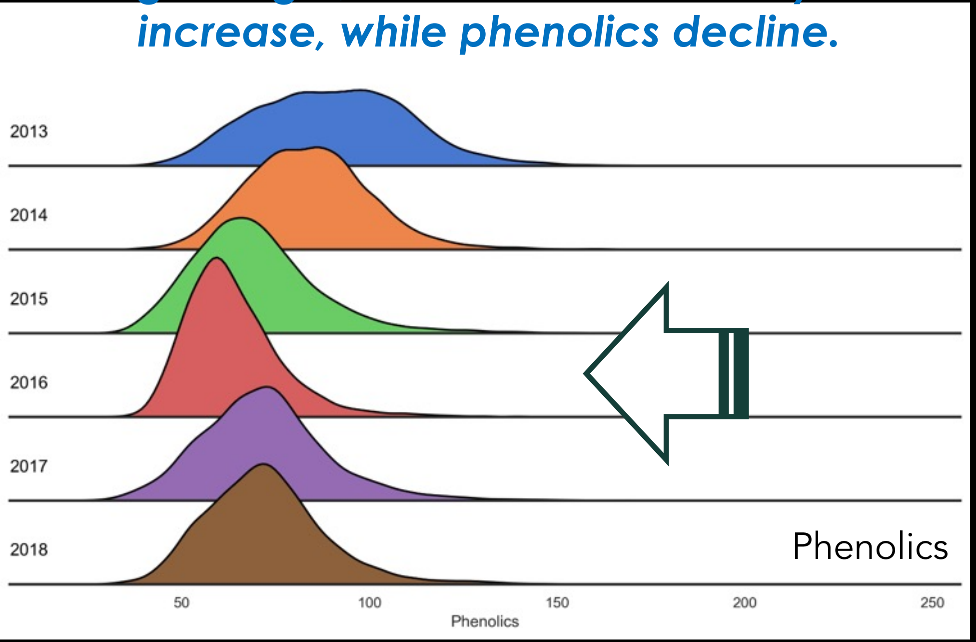
PC2 (29.09% of variation)
PC1 (36.16% of variation)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6



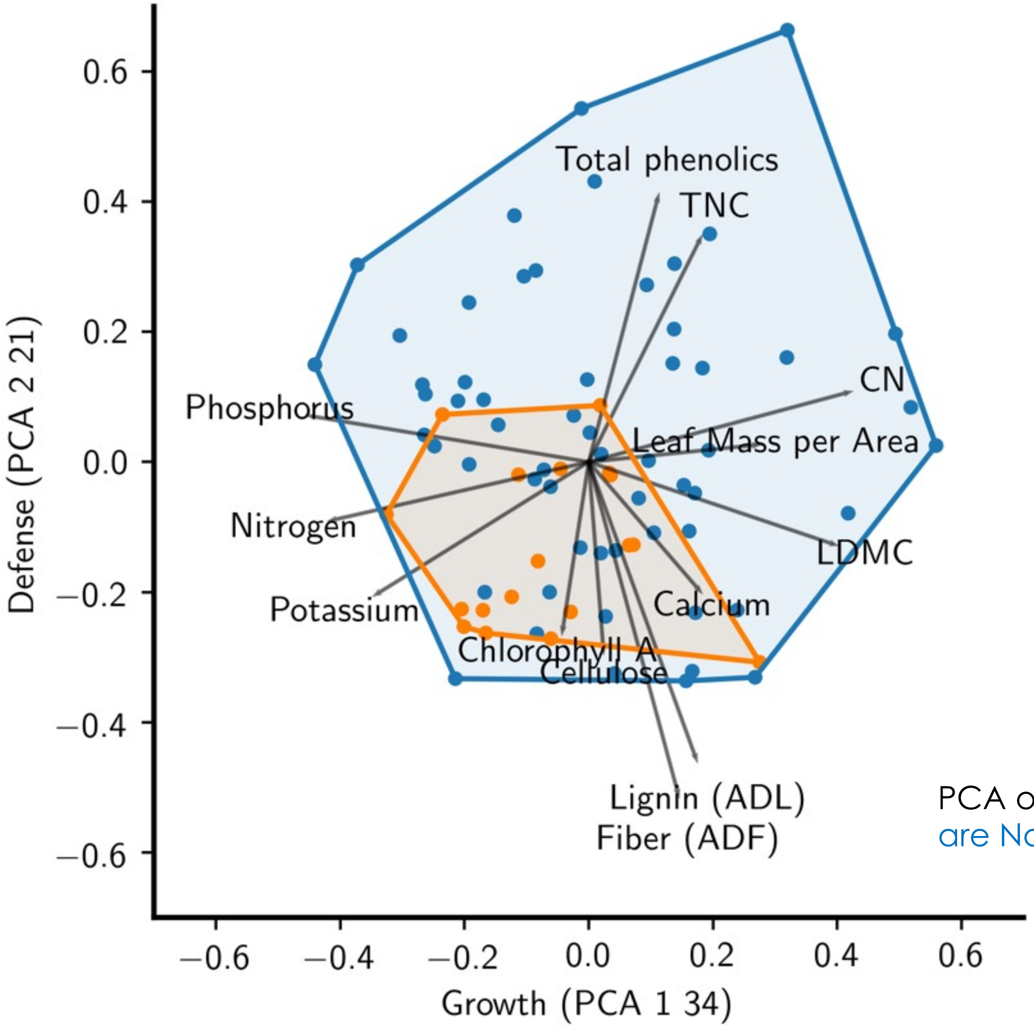

***During drought, nonstructural carbohydrates increase, while phenolics decline.***




- At the continental scale, ecosystems that invest in maintenance (NSC) also invest in defense (phenolics).
- Under drought stress, ecosystems reallocate investments away from defense (phenolics) and more towards maintenance (NSCs providing reserve safety margins).

# Additional Applications: Biodiversity

- Invasive Species




PCA on Traits from Forbs: Blue are Native, Orange are Invasive

Figure: Adam Chlus

# Additional Applications: California Mediterranean Ecosystems

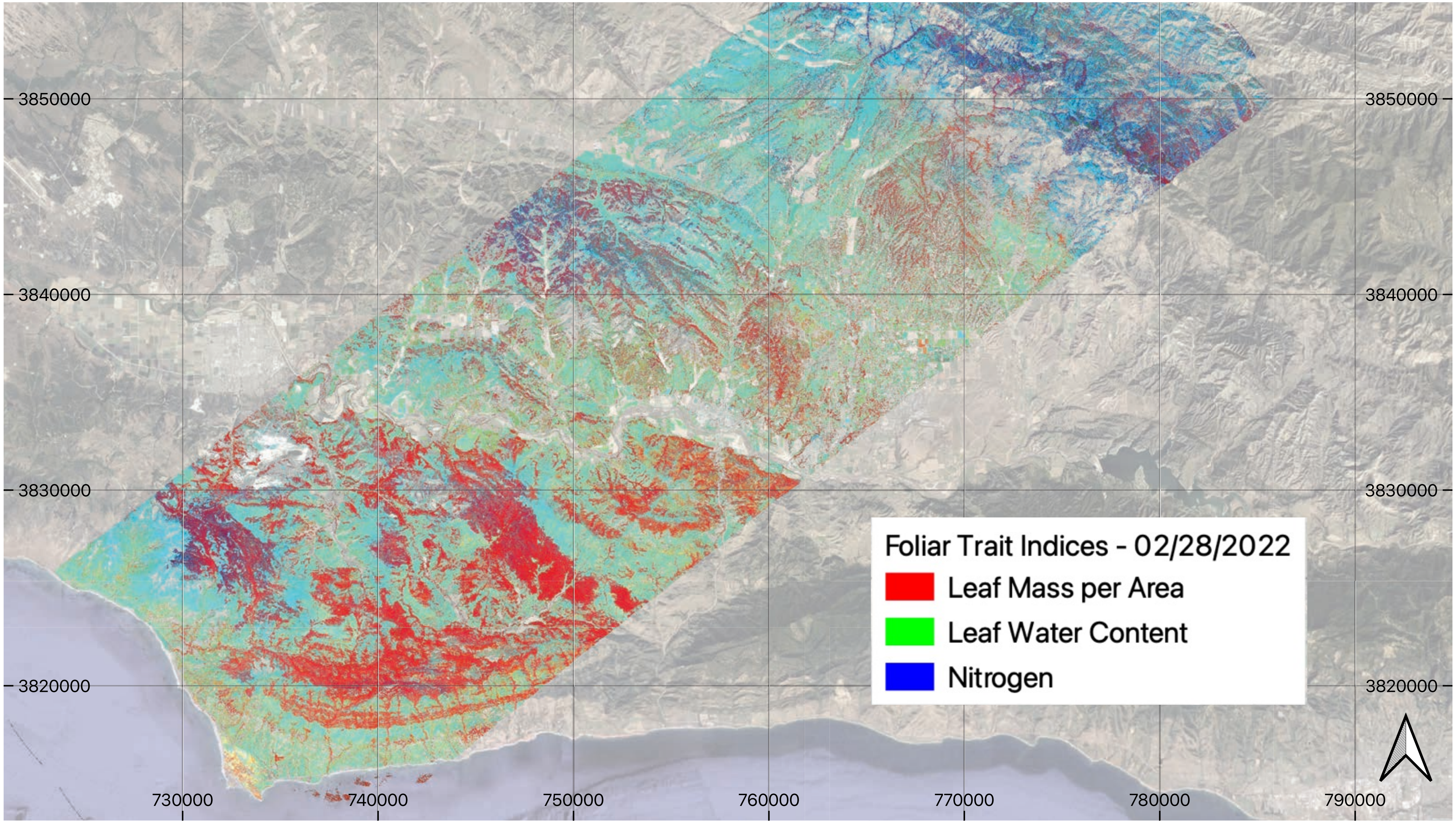



Figure: Dana Chadwick

# Additional Applications: California Mediterranean Ecosystems

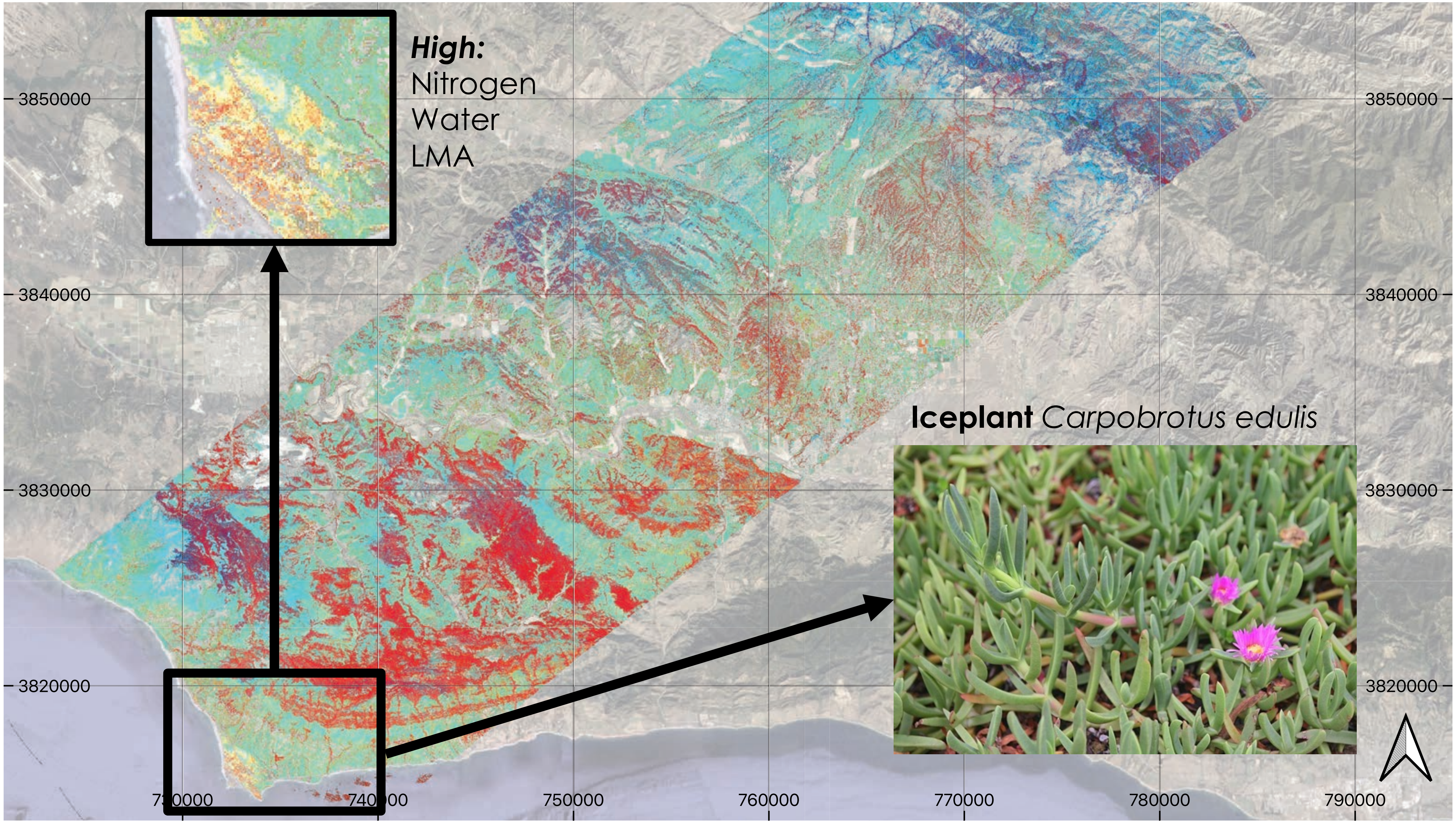



Figure: Dana Chadwick

# Additional Applications: Carbon Dynamics

- Flux Towers

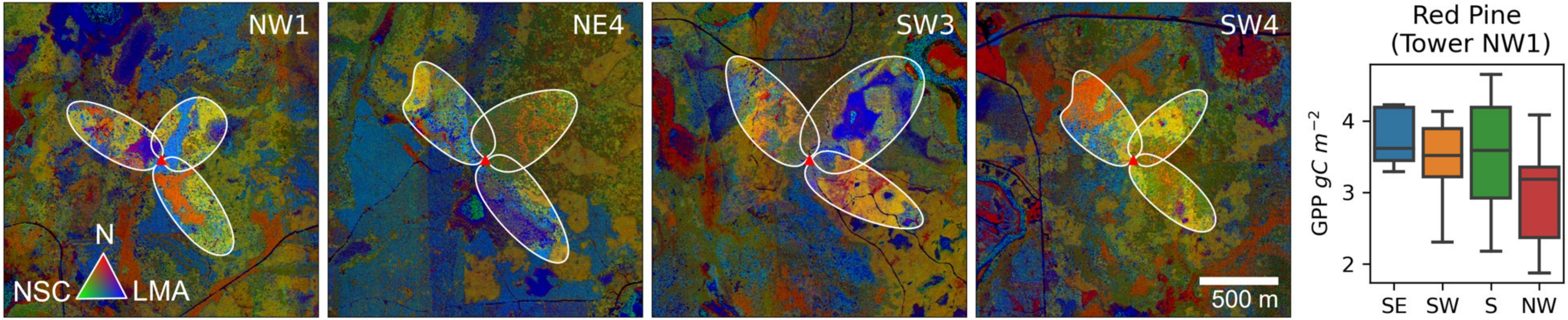



Figure: Ting Zheng

# Additional Applications: Carbon Dynamics

- Flux Towers

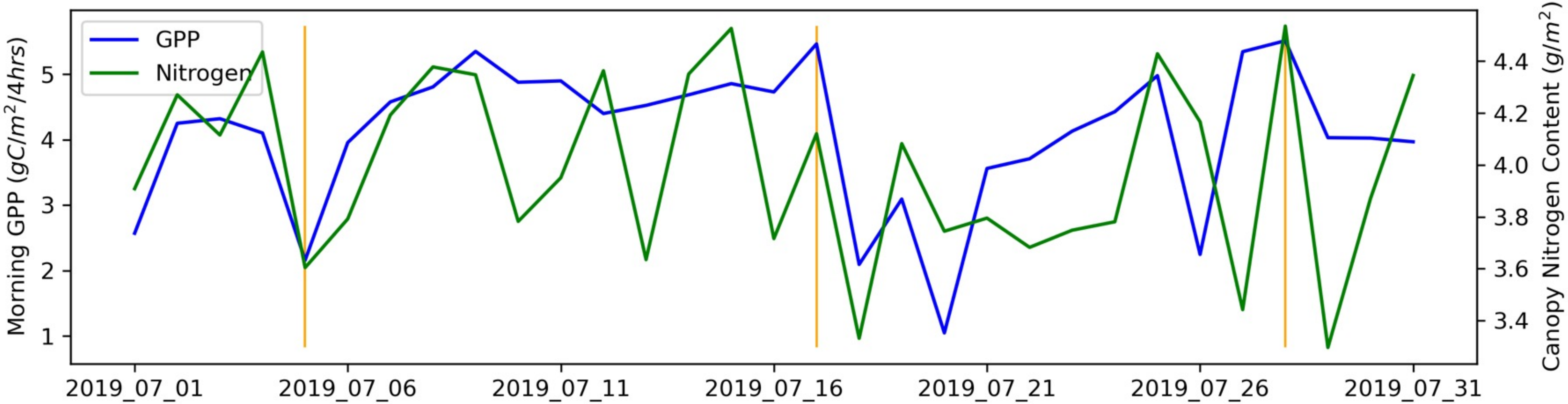


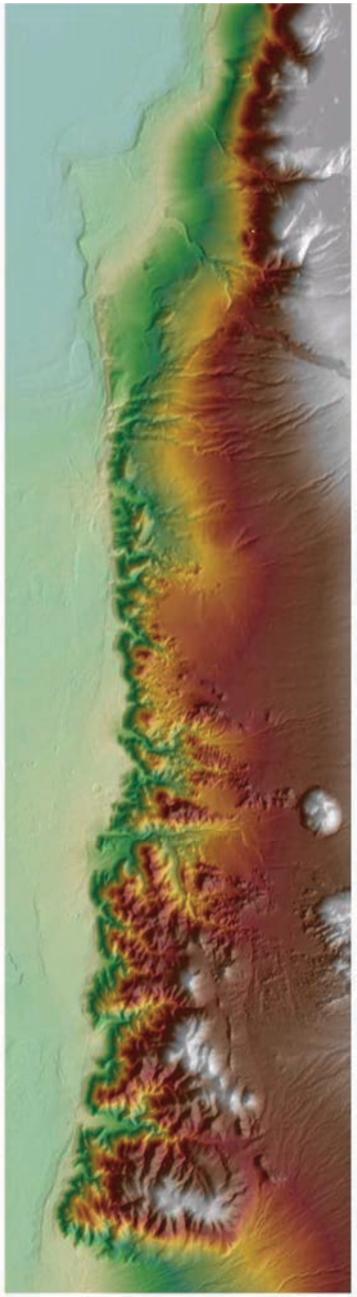

Figure: Ting Zheng

# What does the future hold?

- Map functional traits and functional diversity
- Quantify biodiversity in places where it is hard to measure *in situ*
- Use this information to characterize the role of biodiversity in ecosystem function
- Within a year (phenology) and across years (in response to change)
- Identify threats to biodiversity
- Answer the Question: Are ecological processes the same across similar ecosystem types (e.g., Mediterranean ecosystems in South Africa and California)?

# Summary

- LiDAR and hyperspectral data can help us better understand the biodiversity and function of vegetation.
- LiDAR measurements can assist in the development of canopy height models, which help us better understand forest structure.



Source: NASA GSFC

# Resources

- https://airbornescience.nasa.gov/
- https://lvis.gsfc.nasa.gov/Home/index.html
- https://deltax.jpl.nasa.gov/
- https://www.earthdata.nasa.gov/sensors/gedi
- https://uavsar.jpl.nasa.gov/education/what-is-uavsar.html
- https://avirisng.jpl.nasa.gov/

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- Training Webpage: https://appliedsciences.nasa.gov/join-mission/training/english/arset-biodiversity-applications-airborne-imaging-systems

- ARSET Webpage: https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

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# Thank You!