AmeriFlux x NEON Workshop
July 9-10, 2024
Lawrence Berkeley National Laboratory, Berkeley, CA

Remote Sensing and Fluxes Upscaling for Real-world Impact

Welcome!

BERKELEY LAB
Bringing Science Solutions to the World

U.S. DEPARTMENT OF ENERGY

AMERIFLUX

NSF | neon Operated by Battelle

CARBON DEW Community of Practice
Fair & Equitable Climate Solutions
Anchored by Direct Atmospheric Measurements

LBNL - The Birthplace of Team Science

In 1931, Ernest O. Lawrence founded Berkeley Lab, pioneering "Team Science"- the foundation for today's national laboratory system.

- **Mission-oriented *science to support critical national goals.***
- **Interdisciplinary teams**
- **State-of-the-art research facilities**

Berkeley Lab Today

Berkeley Lab is one of the world's leading open research institutions.

- Annual budget of ~$1.1 billion
- ~4,000+ staff, including:
  - ~1,700 scientists & engineers
  - ~500 postdocs
  - ~330 grad students
  - ~160 undergrads
- 60+ companies spun off of Lab technologies

Berkeley Lab Today

- **Discovery science; solutions addressing critical energy and environmental challenges.**
- **Managed by the University of California, the Lab represents the most productive relationship between a national lab and university system – 2,000 scientific papers per year, 58% in top journals.**
- **16 Nobel Prizes, 16 National Medals of Science, and 82 members of the National Academies.**


Biosciences


Energy Technologies


Earth & Enviro Sciences


Physical Sciences

Computing Sciences


Basic Energy Sciences

Welcome and Workshop Objectives

Bringing the flux and remote sensing communities together

Promote the integration of remote sensing and flux datafor upscaling ecosystem processes

Identify challenges and opportunities for future development

Welcome and Workshop Objectives

Initiative of the AmeriFlux Year of the Remote Sensing committee and the Flux Upscaling working Group

(Kick-off meeting @ AGU Meeting 2023)

In collaboration with NEON and Carbon Dew

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Organizing Committee

Nicola Falco
(Berkeley Lab)

Stefan Metzger
(AtmoFacts)

David Durden
(NEON)

Chris Florian
(NEON)

Paul Stoy
(Univ. of Wisconsin-Madison)

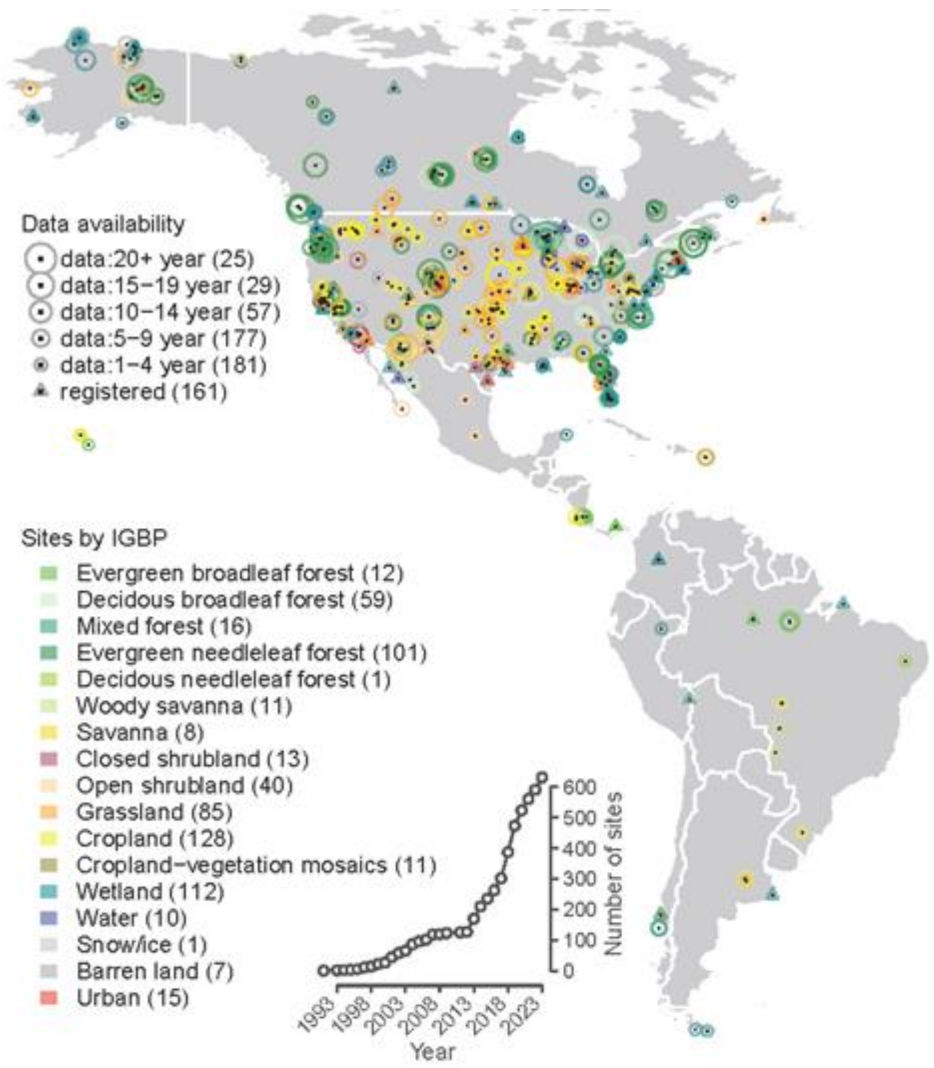
Mallory Barnes
(Indiana University)

Gavin McNicol
(Univ. of Illinois Chicago)

Koong Yi
(Berkeley Lab)

Coordinator:
Christin Buechner
(Berkeley Lab)

AmeriFlux



- **AmeriFlux** is a network of
  - Flux towers
  - Flux datasets
  - Scientists
- Total 665 registered sites; 492 sites offer flux data
- **Non-standardized instrumentation** driven by individual site teams
- **AmeriFlux Management Project (AMP)** provides technical & data support, and facilitates productive scientific community

AmeriFlux Theme Year of Remote Sensing

The goal of the theme year is to encourage research that combines eddy covariance and remote sensing at all levels, from ground to spaceborne, throughout the AmeriFlux community.

- Sessions at conferences

[AGU2024] B102. Surface-Atmosphere Interaction: Intersections between Eddy Covariance and Remote Sensing

- Remote sensing-related Webinar series and Tutorials
- Enhancing AmeriFlux website’s capabilities for flux and remote sensing data integration
- Developing Workshops
- Supporting Working Groups

AMERIFLUX
YEAR OF REMOTE SENSING

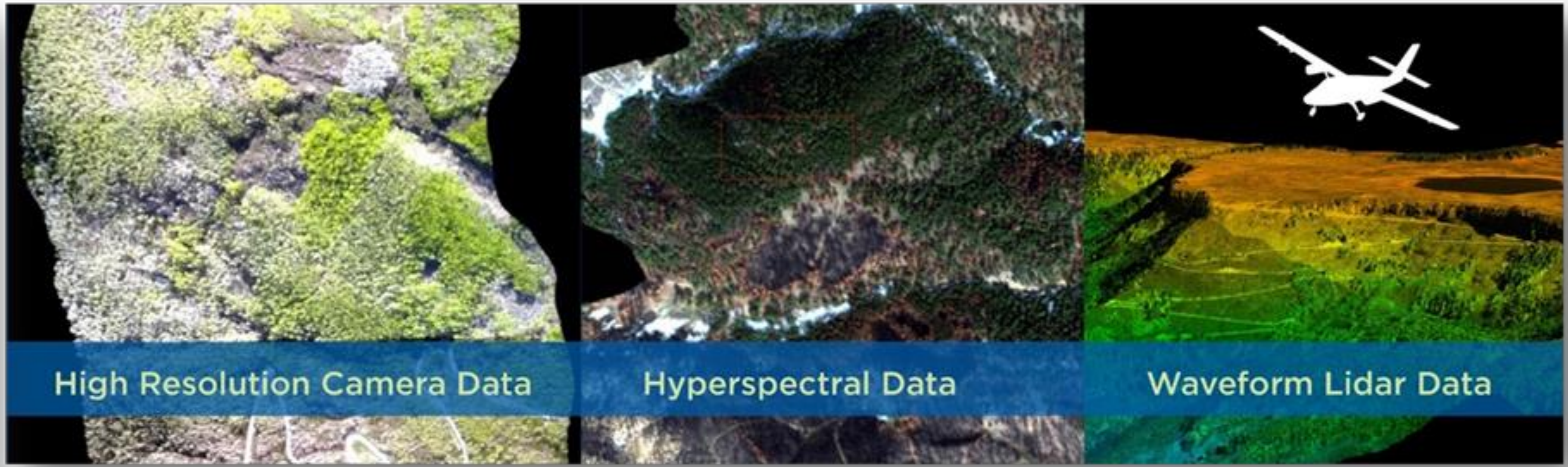
What is the National Ecological Observatory Network (NEON)?

- A US NSF large facility
- A continental-scale observatory
- Designed to enable understanding and forecasting of the effects of climate and environmental change

NEON's Linked Collection Systems

Standardized, colocated methods across 81 sites

Airborne remote sensing



Automated instruments

Observational sampling

About the CarbonDew Community of Practice

- **Vision:** Direct measurements of GHG exchange in and out of the atmosphere anchor fair and equitable climate solutions
- **Mission:** Bring together stakeholders across the entire climate spectrum to unlock cross-disciplinary expertise
- Members from over 200 public and private organizations
- Open to join for everyone: www.carbondew.org
- Example activities:

CARBON DEW Community of Practice
Fair & Equitable Climate Solutions
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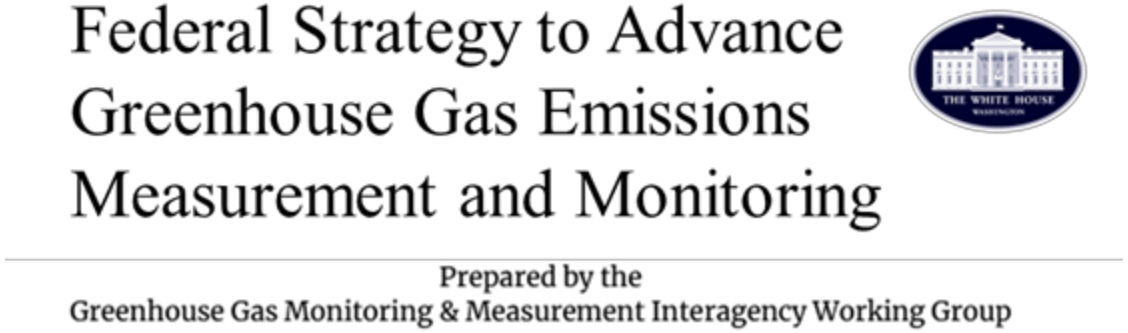

Federal Strategy to Advance Greenhouse Gas Emissions Measurement and Monitoring

Prepared by the
Greenhouse Gas Monitoring & Measurement Interagency Working Group

Workshop Goals

Review the current state of flux upscaling sciences and discuss techniques for integrating remote sensing data with flux tower measurements

Identify applications and end products, such as precision agriculture, carbon monitoring, and ET mapping

Provide learning experiences, networking opportunities, and understand community needs to shape future working group activities

Facilitate collaborations between research communities and industry sectors, including organizing joint meetings and workshops

Code of Conduct

We convene events and meetings that are welcoming, respectful, inclusive, and collaborative.

Do	Unacceptable behavior
• Be respectful and trustworthy	• Personal attacks
• Be direct but professional	• Derogatory language
• Be inclusive and welcoming	• Disruptive behavior
• Acknowledge contributions & celebrate achievements	• Harassment
• Collaborate and co-create	• Violence and threats

- Violation may result in being asked to leave an event or online space either temporarily or for the duration.
- If you experience or witness violations of this Code of Conduct, please talk to organizing committee member, or email koongyi@lbl.gov.
- In the case of life-threatening and illegal activities, call 911.

Hybrid meeting format

- Talks and breakout sessions are hybrid.
- Find all zoom links and breakout documents here: ***go.lbl.gov/scalingfluxes***
- All participants will use **Google Doc** to share ideas during the breakout sessions.
- For virtual attendees:
    - Please use the chat for questions and discussion,
    - Or raise your hand during the Q&A session.
    - Chairs will monitor the chat.

Remote Sensing and Fluxes Upscaling for Real-world Impact

Day 1: Tuesday, July 9

Pacific	Eastern	Agenda	Title
8:00	11:00	Welcome, workshop introduction	
		Session 1 - site scale	
9:00	12:00 PM	Keynote: Ankur Desai (University of Wisconsin-Madison)	Your site is not so special, or is it? Scaling fluxes from the specific to the general and back again
9:20	12:20 PM	Science Talk: David Durden (NEON)	From the plot to the plane: NEON's integrated scaled design
9:30	12:30 PM	Impact Talk: Carolina Lisboa (Verra)	Harnessing Remote Sensing and Flux Measurements for Verified Carbon Standard and Agricultural Land Management Methodologies
9:40	12:40 PM	Q&A	
9:50	12:50 PM	Breakout Session 1	
10:30	1:30 PM	BREAK	
		Session 2 - regional/landscape	
11:00	2:00 PM	Keynote: Troy Magney (UC Davis)	Scaling evergreen forest photosynthesis from the needle to the tower to space
11:20	2:20 PM	Science Talk: Housen Chu (LBNL)	Bridge the link between flux towers and models to enable upscaling
11:30	2:30 PM	Impact Talk: Levente Klein (IBM)	Foundation Models for Vegetation Growth and Carbon Sequestration
11:40	2:40 PM	Q&A	
11:50	2:50 PM	Breakout Session 2	
12:30 PM	3:30 PM	Lunch and engagement with speakers	
		Session 3 - global	
1:30 PM	4:30 PM	Keynote: Jacob Nelson & Samuel Upton (MPI BGC)	Reconciling Atmospheric Carbon and Water Fluxes: Integrated Top-Down and Bottom-Up Approaches with FLUXCOM-X and X-BASE
1:50 PM	4:50 PM	Science Talk: Tammy (Kunxiaojia) Yuan (LBNL)	Wetland CH4 Emissions Upscaling by Causality Guided Machine Learning: from Regional to Global Scale
2:00 PM	5:00 PM	Impact Talk: Robert Granat (CarbonSpace)	Flux Estimation Solutions and Impacts in the Food and Beverage Sector
2:10 PM	5:10 PM	Q&A	
2:20 PM	5:20 PM	Breakout Session 3	
3:00 PM	6:00 PM	BREAK	
		Session 4 - integration	
3:30 PM	6:30 PM	Keynote: Youngryel Ryu (Seoul National University)	Beyond Boundaries: The Future of Land Surface Fluxes through Hyper-Resolution Remote Sensing across Space, Time, and Spectrum
3:50 PM	6:50 PM	Science Talk: Stefan Metzger (AtmoFacts)	Linking Realms from Ground to Orbit: Matching Fluxes and States Across Scales
4:00 PM	7:00 PM	Impact Talk: Kevin Tu (Kateri)	Bridging the gap between science and social benefit: Eddy flux for measurement, reporting and verification of grassland carbon sequestration
4:10 PM	7:10 PM	Q&A	
4:20 PM	7:20 PM	Breakout Session 4	
5:00 PM	8:00 PM	Adjourn	

Day 2: Wednesday July 10

Pacific	Eastern	Agenda	Facilitator
8:00	11:00	Arrival and tutorial setup	
9:00	12:00 PM	TOPIC 1: Hands-on tutorial: From site-scale…	Nicola Falco (LBNL), David Durden (NEON)
10:00	1:00 PM	BREAK	
10:15	1:15 PM	TOPIC 2: Hands-on tutorial: … over regional-scale connectivity	David Durden (NEON), Stefan Metzger (CarbonDew)
11:15	2:15 PM	BREAK	
11:30	2:30 PM	TOPIC 3: Hands-on tutorial: … to continental-scale connectivity	Paul Stoy (University of Wisconsin-Madison)
12:30 PM	3:30 PM	Lunch and presentation: tools for data discovery	Margaret Torn (LBNL), Rachel Hollowgrass (LBNL), Bridget Hass (NEON AOP)
1:30 PM	4:30 PM	Report back from Breakouts	Workshop Organizers
2:00 PM	5:00 PM	~~Future workshop topics discussion~~	Workshop Organizers
2:30 PM	5:30 PM	Workshop Summary	Workshop Organizers
3:00 PM	6:00 PM	Adjourn	

Your site is not so special, or is it?

Scaling fluxes from the specific to the general and back again.

Ankur Desai, UW-Madison

Ameriflux Upscaling Workshop

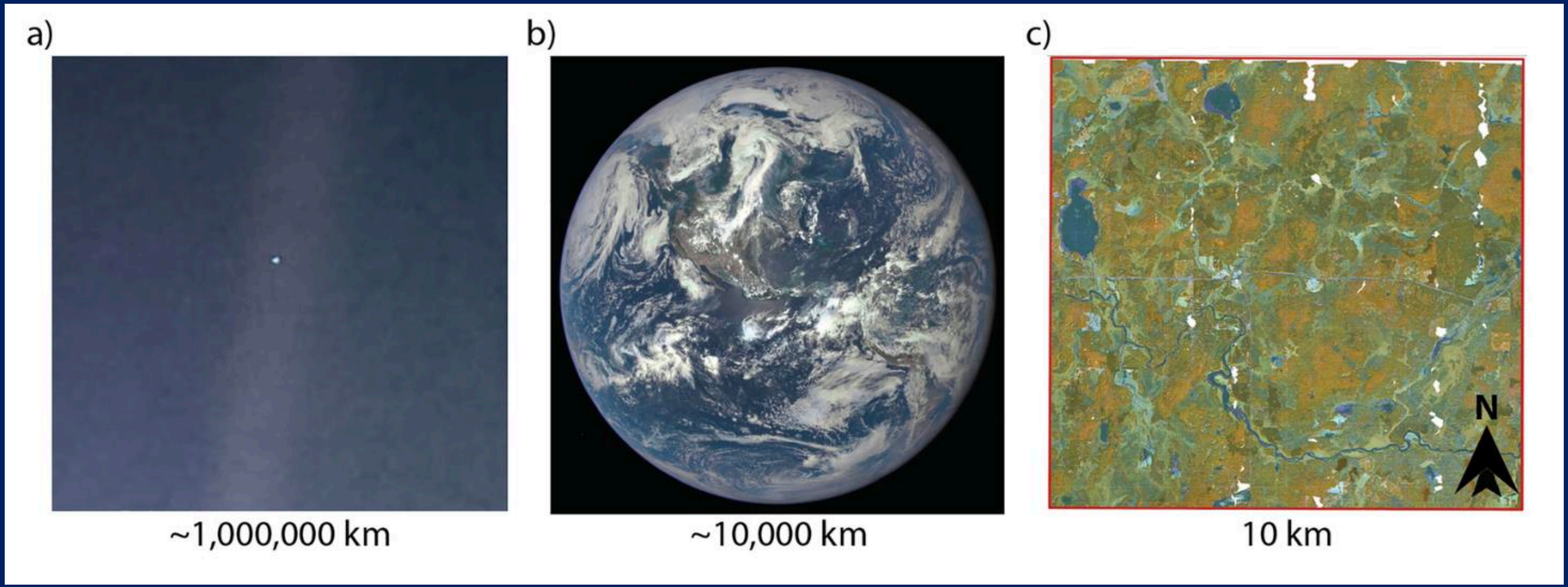
Jul 2024

Photo: B. Butterworth

What is scaling?

Photo: Jeff Miller, UW Communications

Scaling (for us) involves theories and methods that translate states, flows (fluxes), processes, and mechanisms from a specified spatial, temporal, or spectral dimension to a different granularity



Requires understanding what processes are *scale-invariant* vs *scale-dependent*

Is the whole the sum of its parts or something else?

Desai et al., 2022, JGR-Biogeo

Contents lists available at ScienceDirect

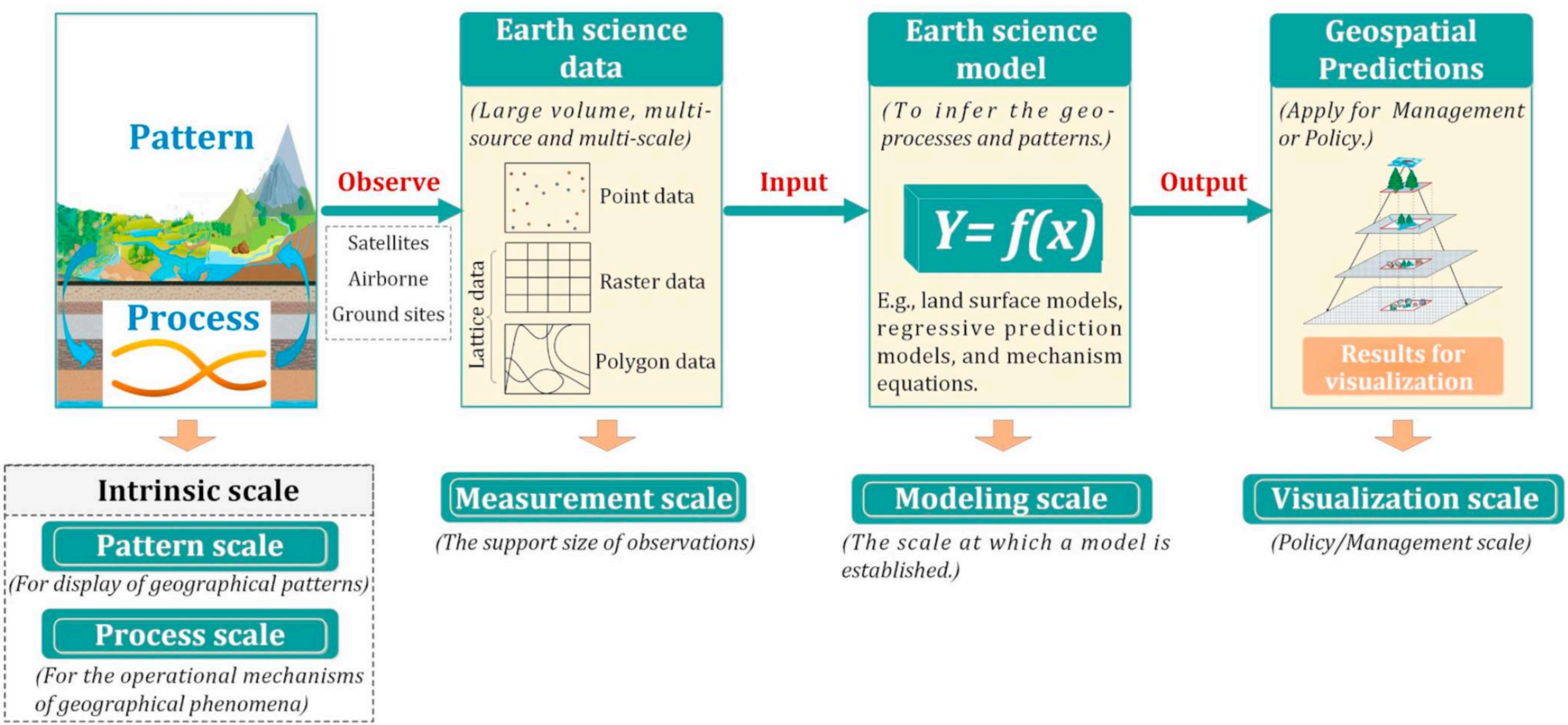
Earth-Science Reviews

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

Principles and methods of scaling geospatial Earth science data

Yong Ge[a,b,*], Yan Jin[c,d], Alfred Stein[e], Yuehong Chen[f], Jianghao Wang[a], Jinfeng Wang[a], Qiuming Cheng[g], Hexiang Bai[h], Mengxiao Liu[a,b], Peter M. Atkinson[i]

2019

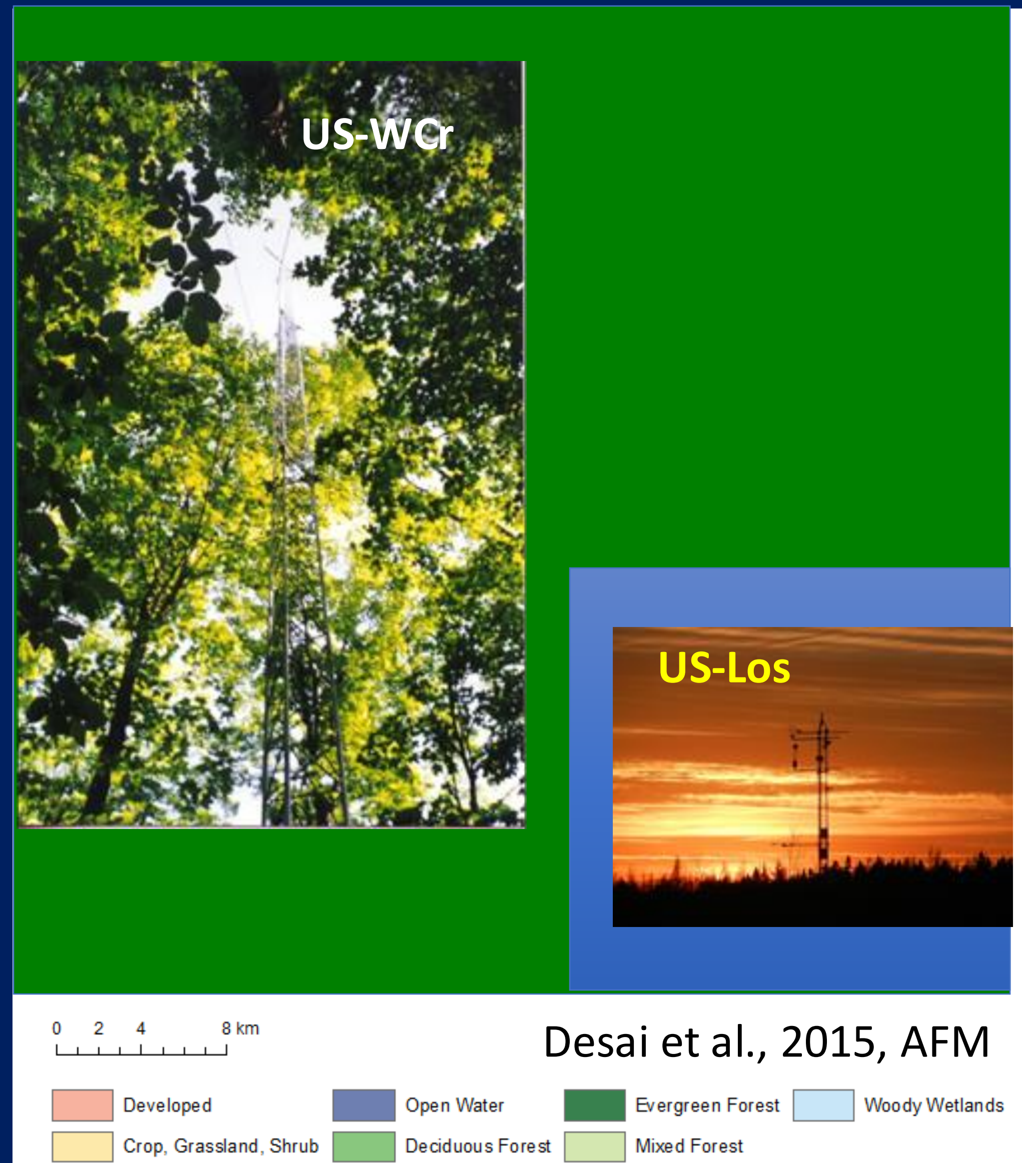


Scaling is essential for Earth system science

- Geophysical biological, aquatic/ocean, and atmospheric processes operate across a broad spectrum of scales
  - From microscale eddies, photons, and genes to gyres, global energy balance, and biomes
  - However, not all scales can be observed or simulated equally well
  - And it varies by process and the observing system
- "Upscaling" and "downscaling" and "rightscaling" are essential to integrate across observations, understand interactions between systems, and extrapolate insights from one scale to another
  - Sometimes it's easy, sometimes it's not!
  - Session 1 focuses on downscaling / rightscaling

Why can't we just "paint-by-numbers?"

Park Falls WLEF tower (US-PFa)
EC fluxes at 30, 122, 396 m



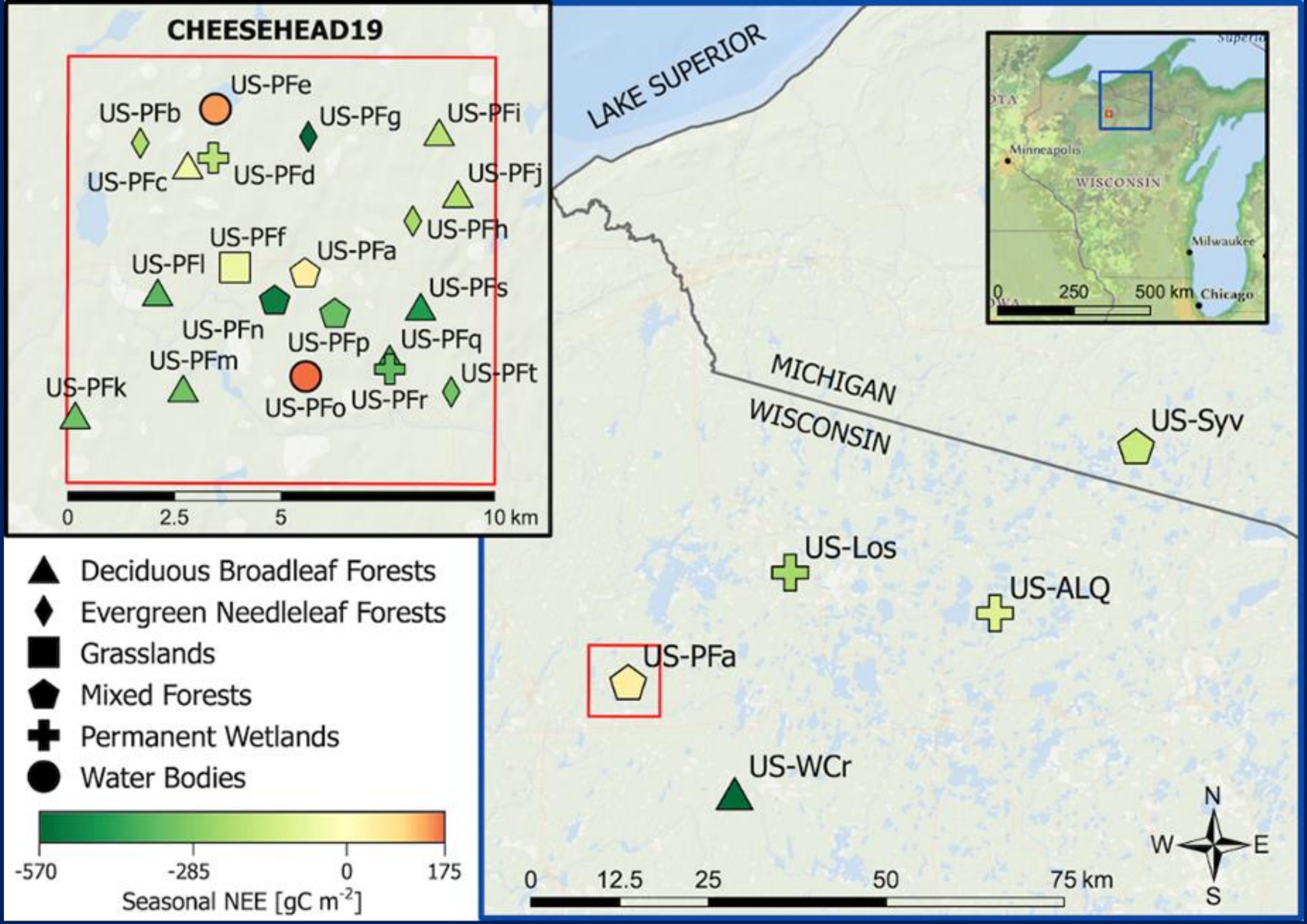
Desai et al., 2015, AFM

Does it add up?

- US-WCr : Representative forest
  - mean annual NEE -290 gC/m2/yr
- US-Los: Representative wetland
  - mean annual NEE -52 gC/m2/yr

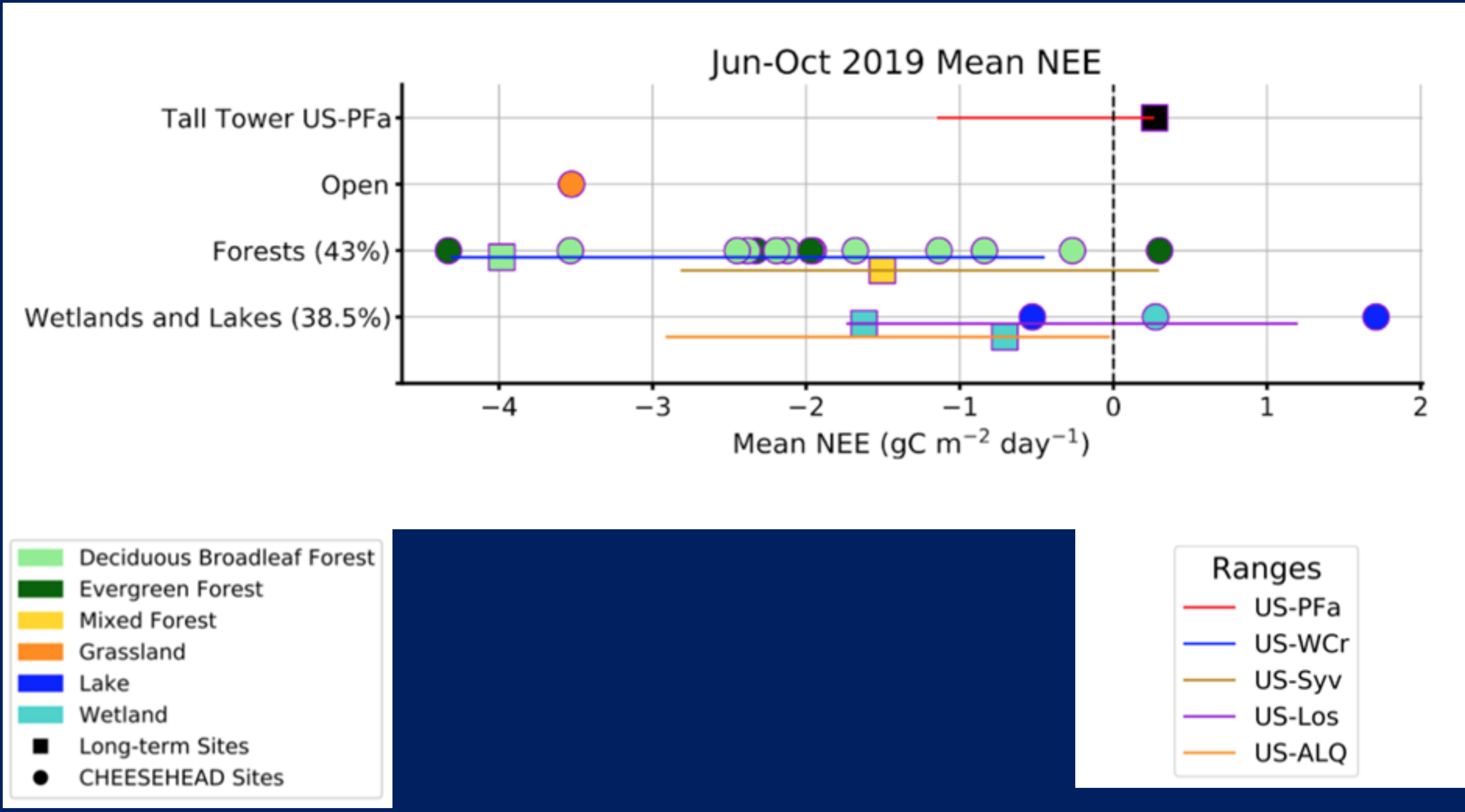
- US-PFa: Landscape – mean NEE +5 gC/m2/yr
- 0.8 * US-WCr + 0.2 * US-Los = -242 gC/m2/yr

- 😢



Desai et al., 2022b, JGR-Biogeo

No, that’s not quite it either



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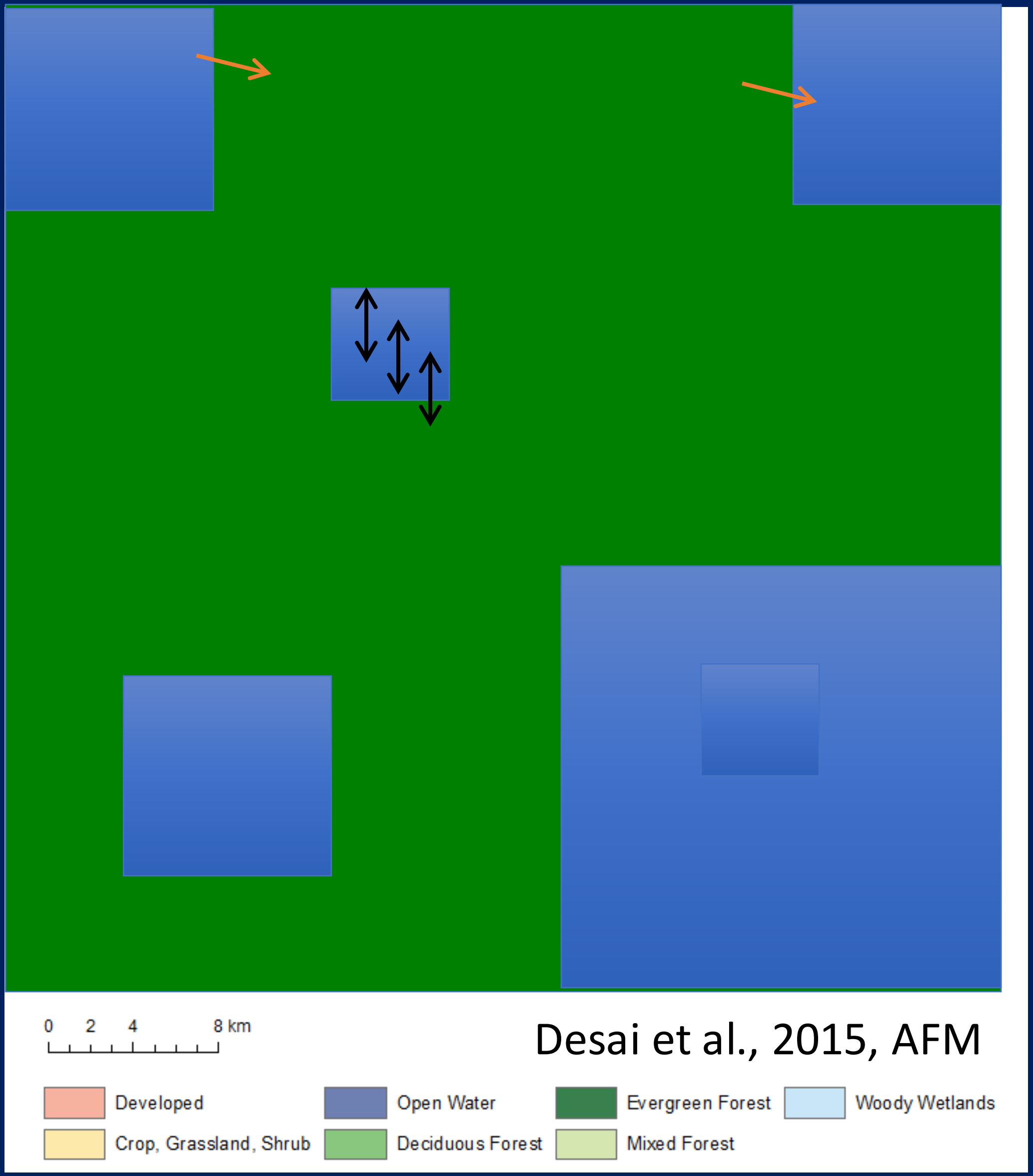


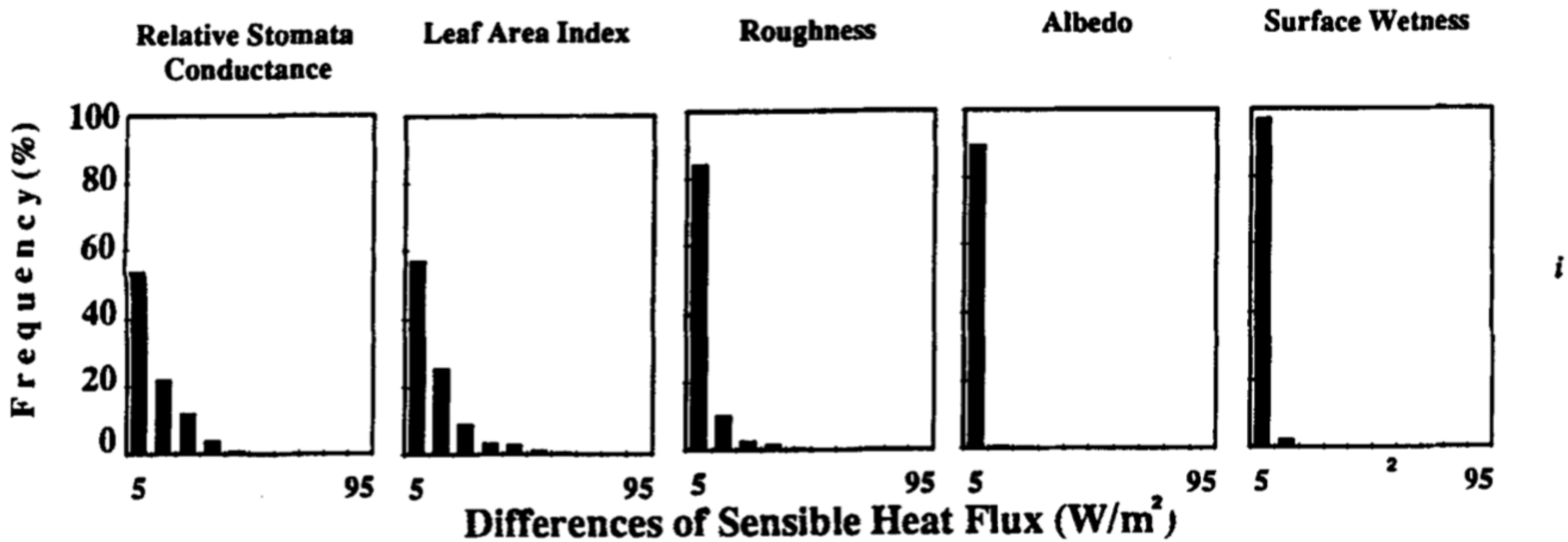
Desai et al., 2015, AFM

HYDROLOGICAL PROCESSES, VOL. 9, 679–695 (1995)

SCALING OF LAND–ATMOSPHERE INTERACTIONS: AN ATMOSPHERIC MODELLING PERSPECTIVE

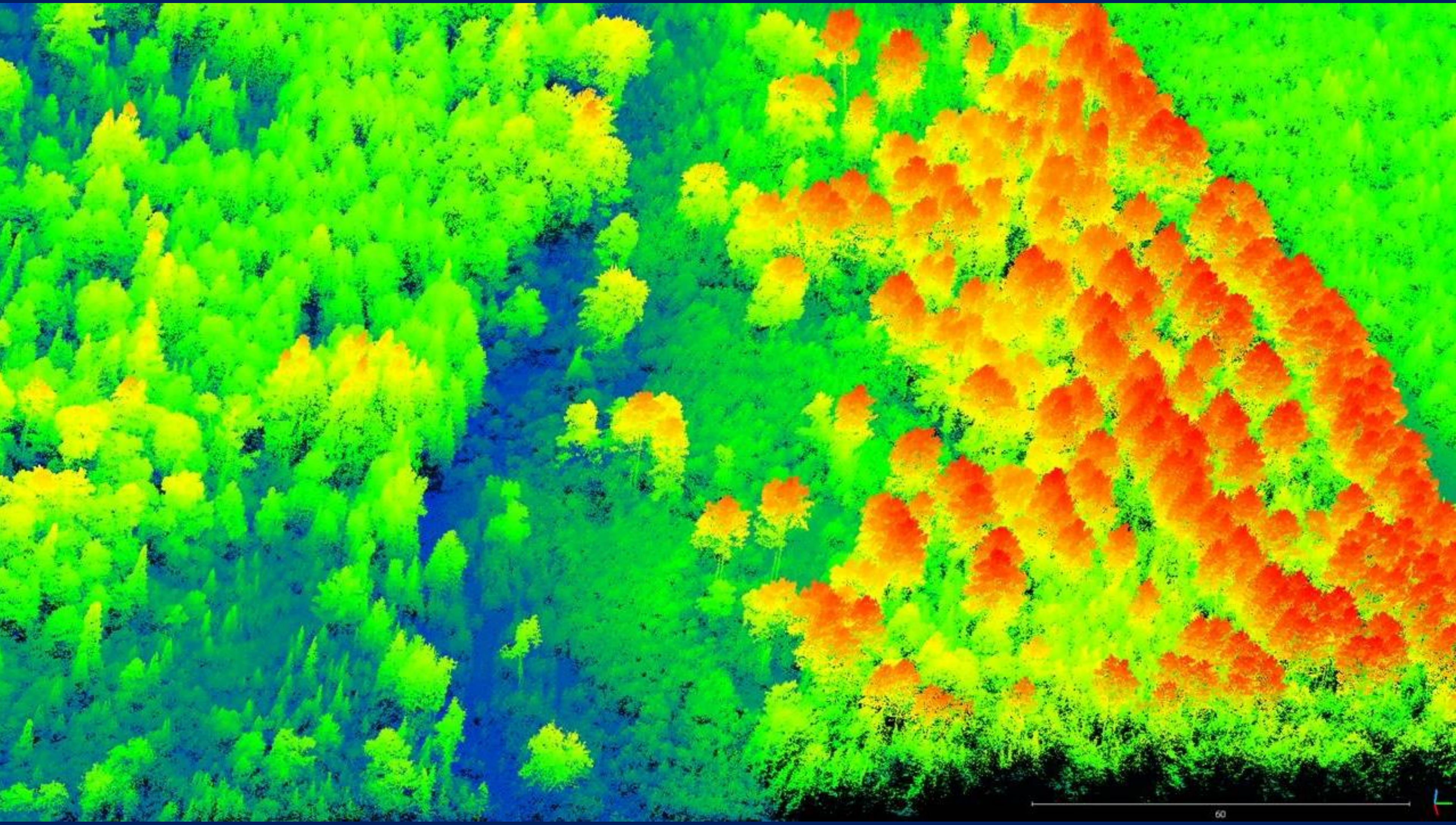
RONI AVISSAR

Department of Meterorology and Physical Oceanography, Cook College, Rutgers University, New Brunswick, NJ 08903, USA



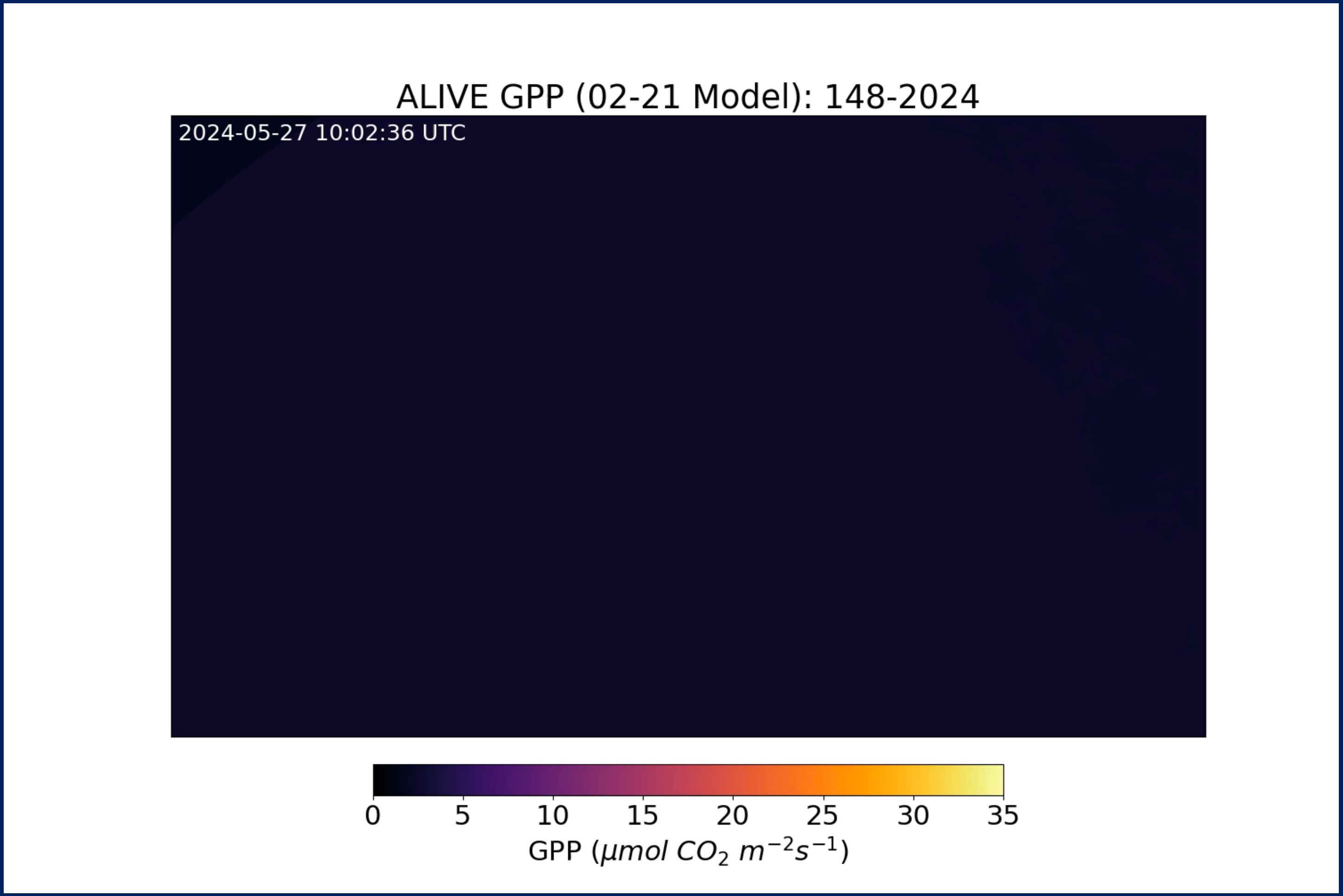
Why does this matter now?

We are entering an era that is: hyperspatial



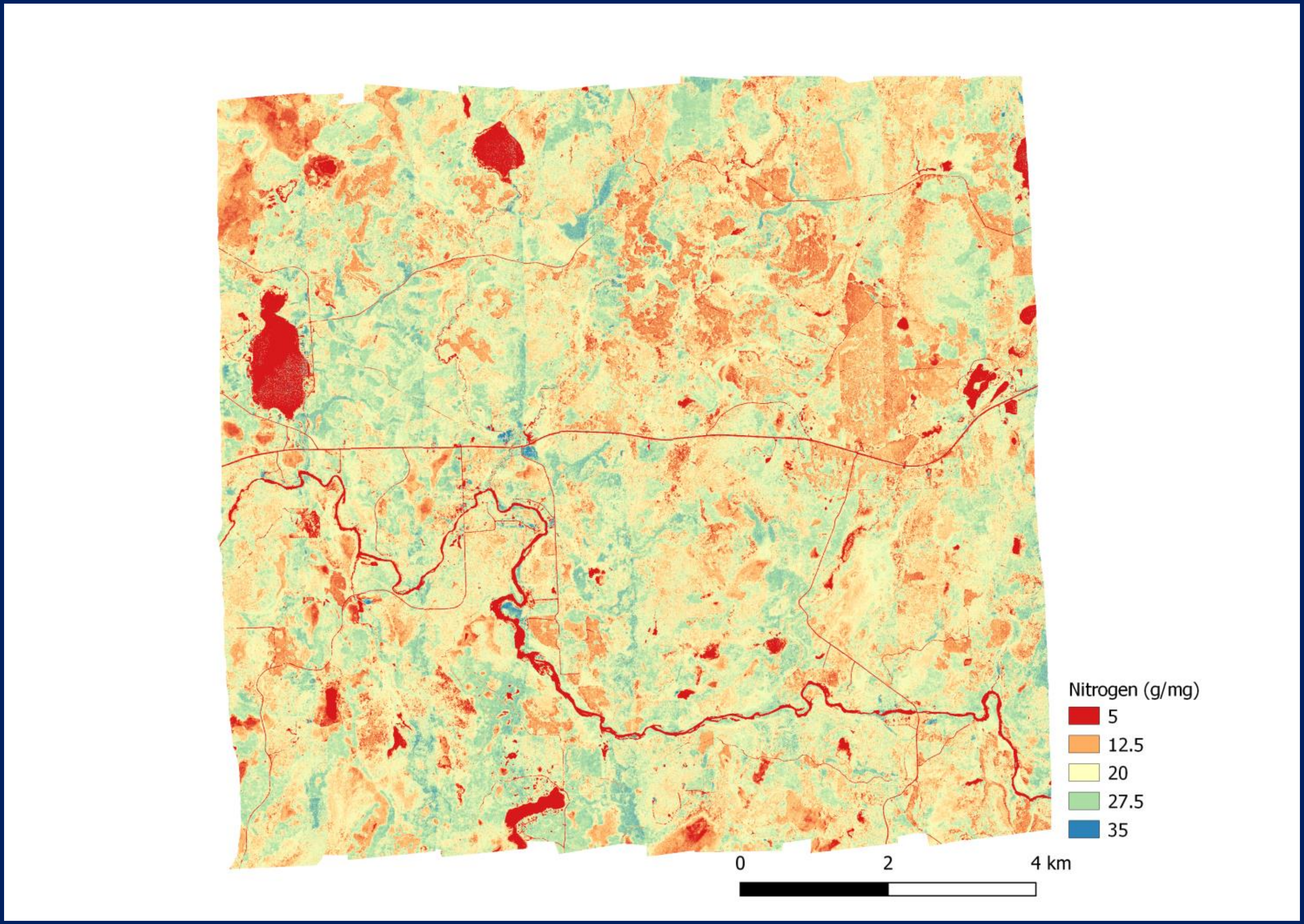
C. Andresen UW-Madison

We are entering an era that is: hypertemporal



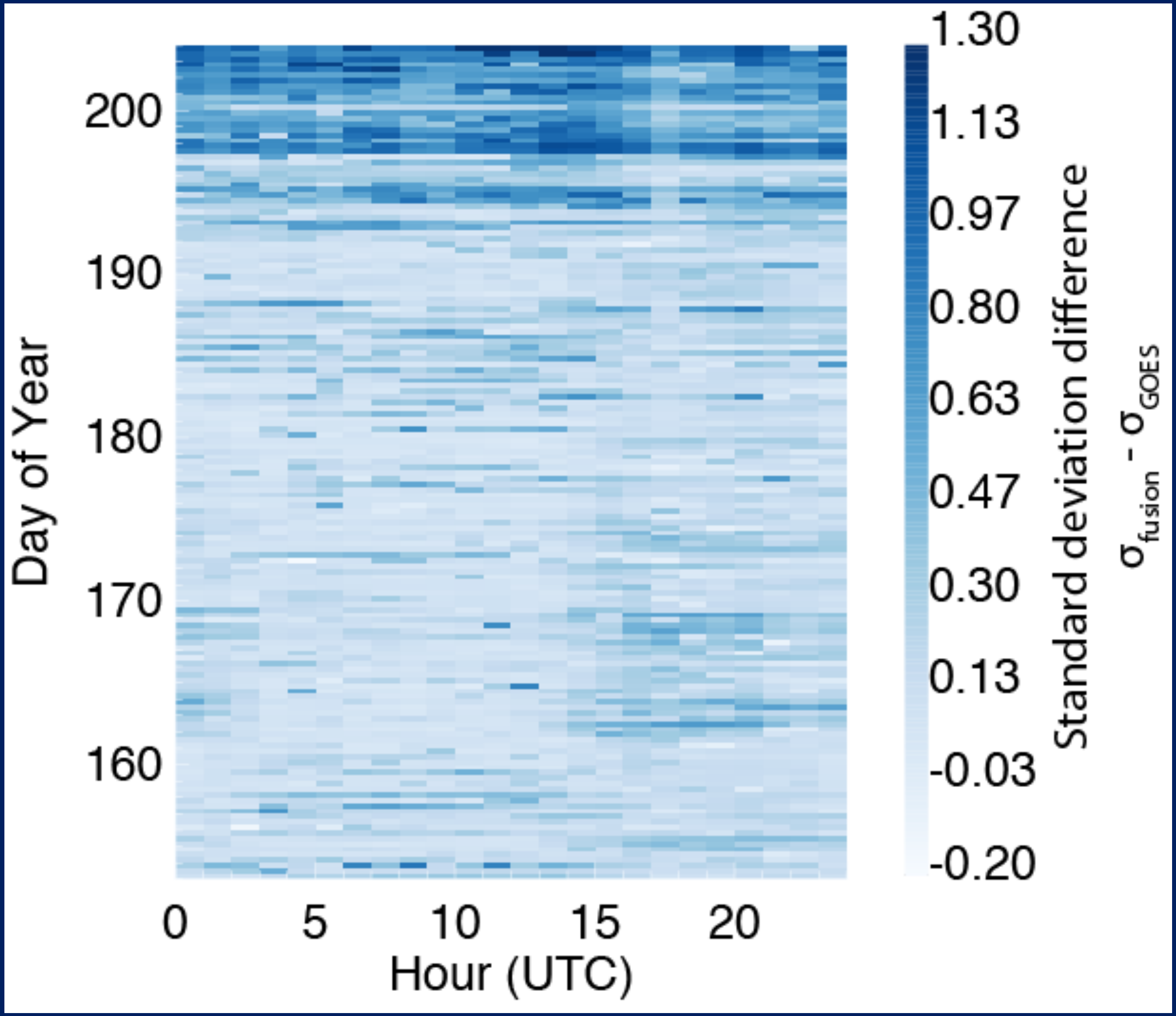
https://alive-abi.github.io/alive/index.html

We are entering an era that is: hyperspectral

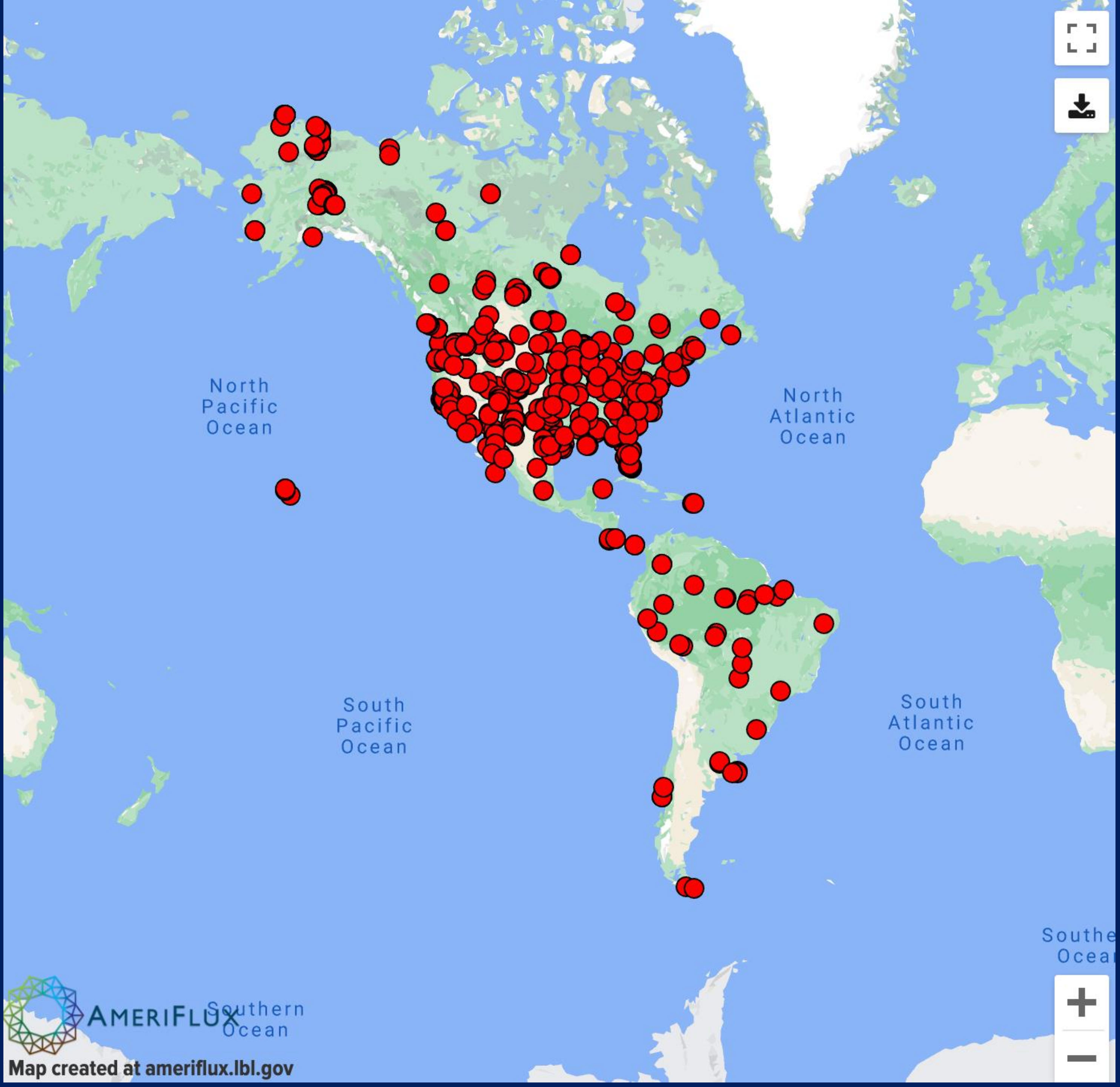


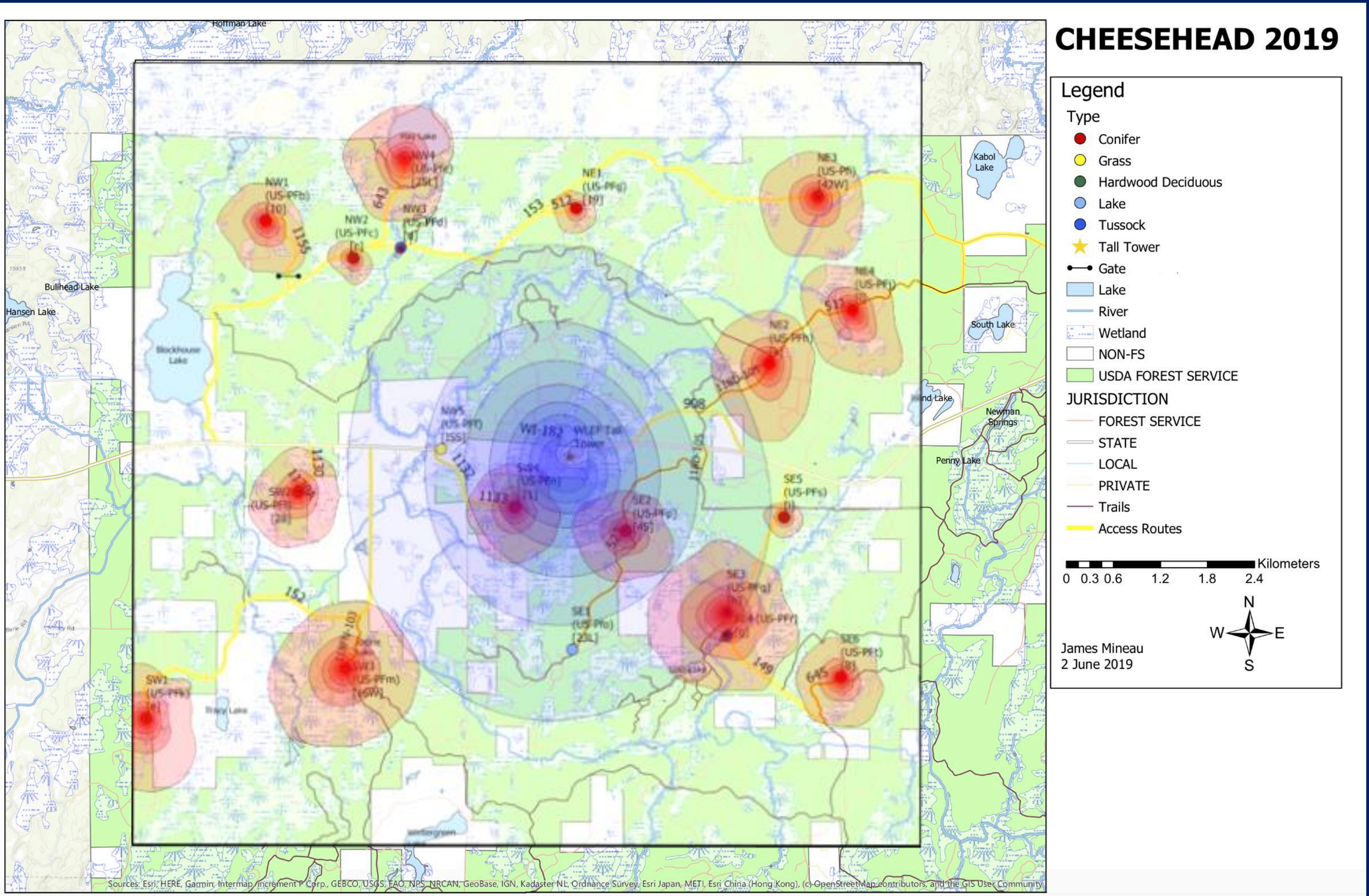
Phil Townsend and Ting Zheng, UW-Madison

And the spatial complexity of these features change in time



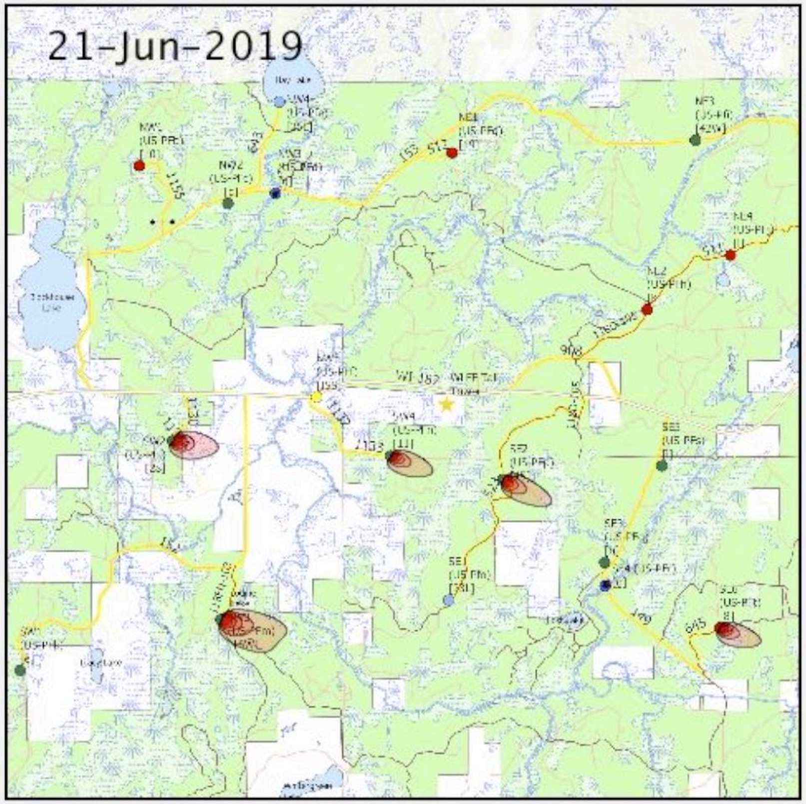
Desai et al., 2021, Earth and Space Sci


North Pacific Ocean
North Atlantic Ocean
South Pacific Ocean
South Atlantic Ocean
Southern Ocean
AmeriFlux
Map created at ameriflux.lbl.gov



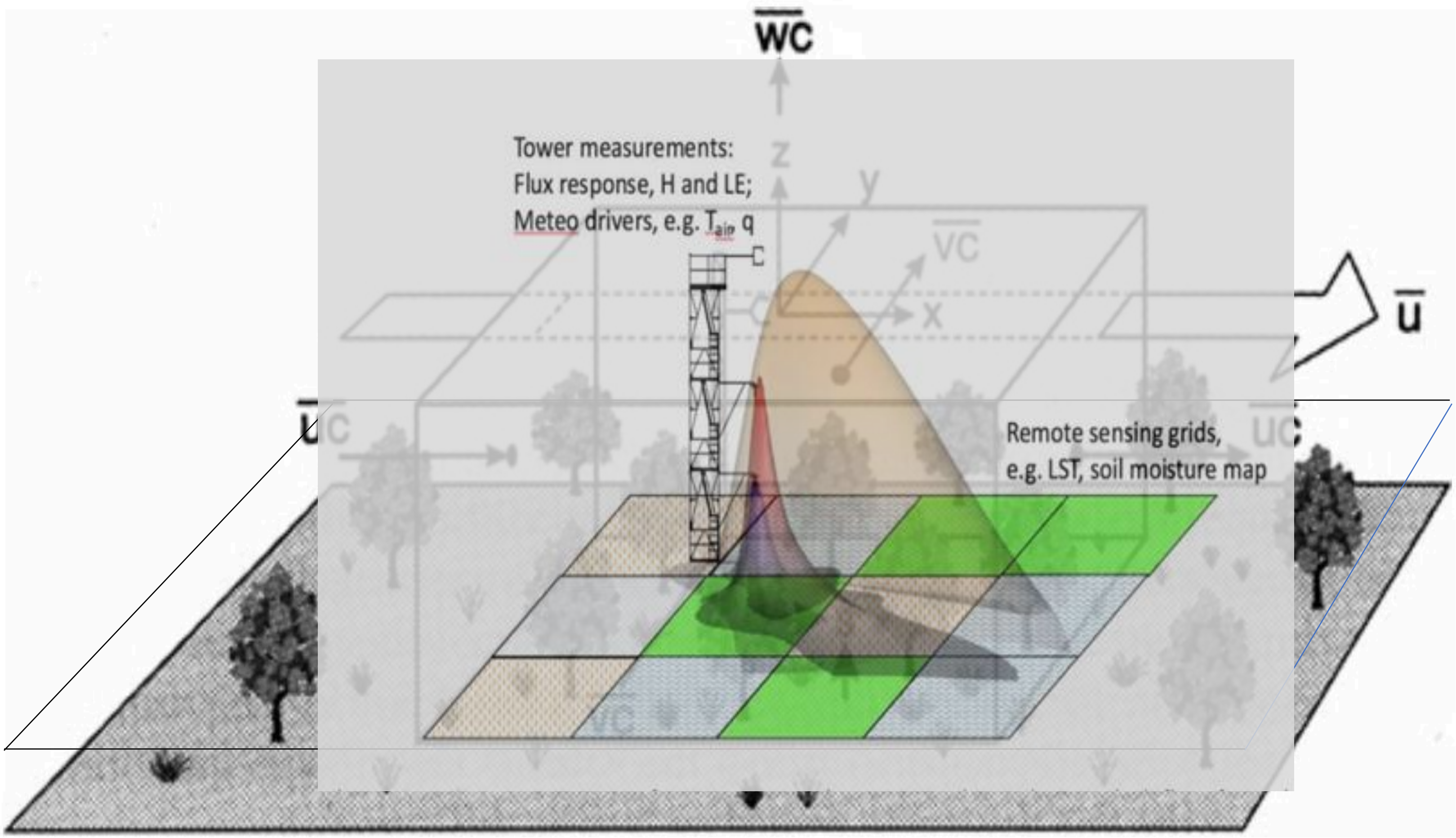
Butterworth et al., 2021

Flux footprints also vary in space and time



B. Butterworth

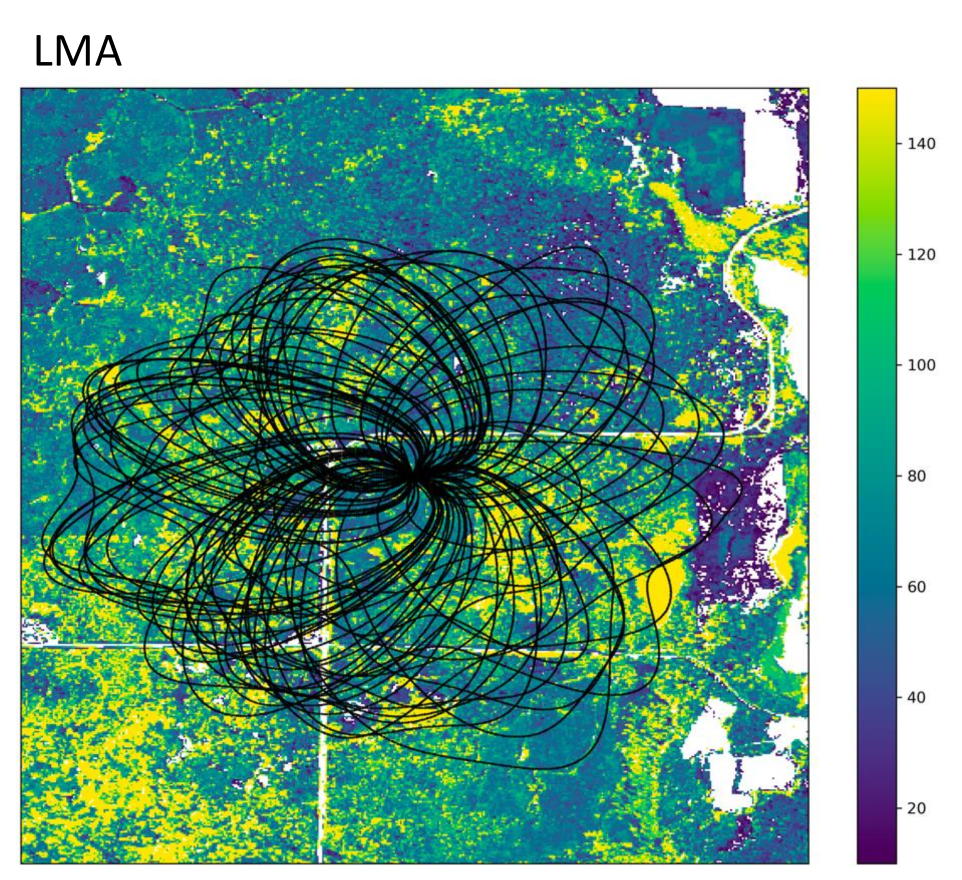
Remote sensing space/time/spectral grids and community research needs call on flux towers to re-think how we calculate and scale eddy fluxes

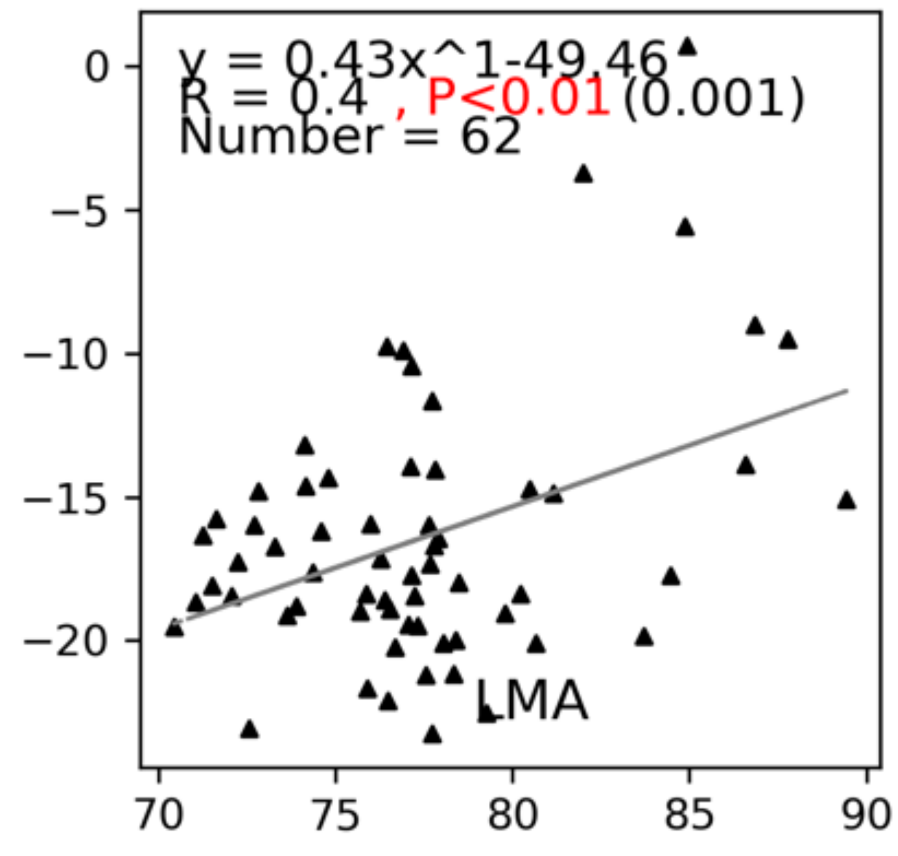


Finnigan et al (2003)

Can't we just assume homogeneity?

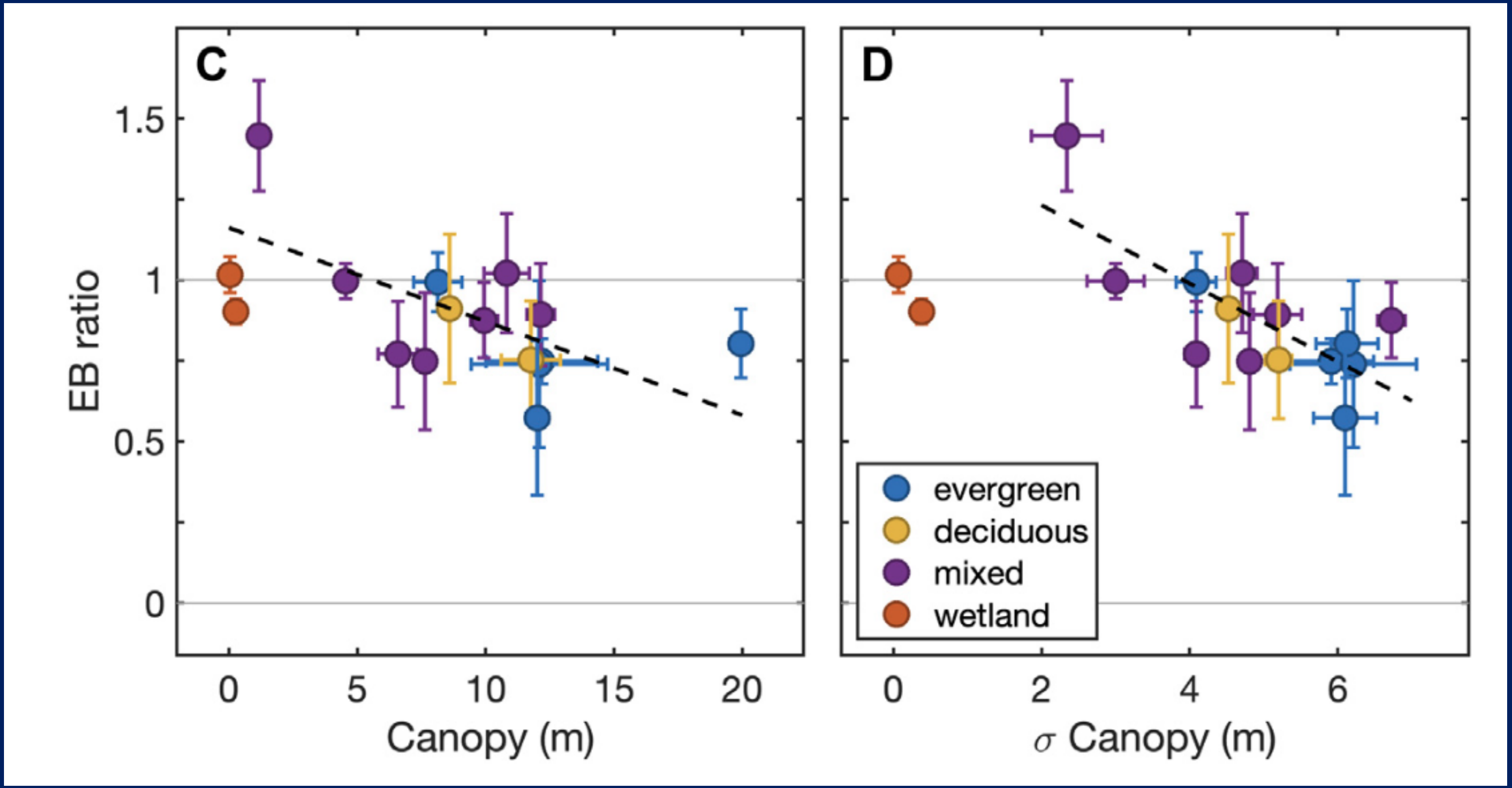
- In many cases, we can ignore it – under homogenous conditions. Is this one homogenous?





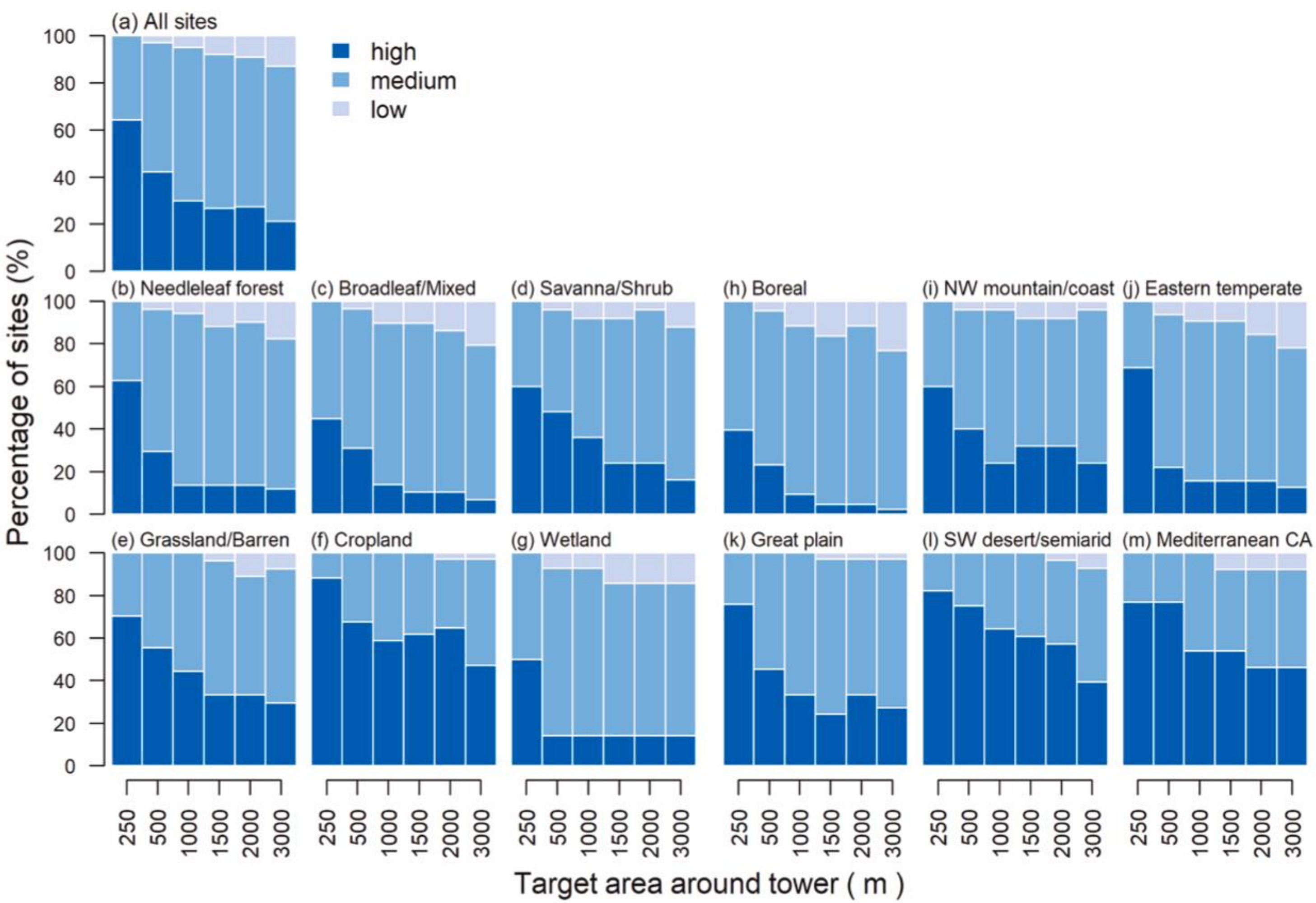
Phil Townsend and Ruqi Yang, US-Madison

Eddy covariance energy imbalance is sensitive to small scale features

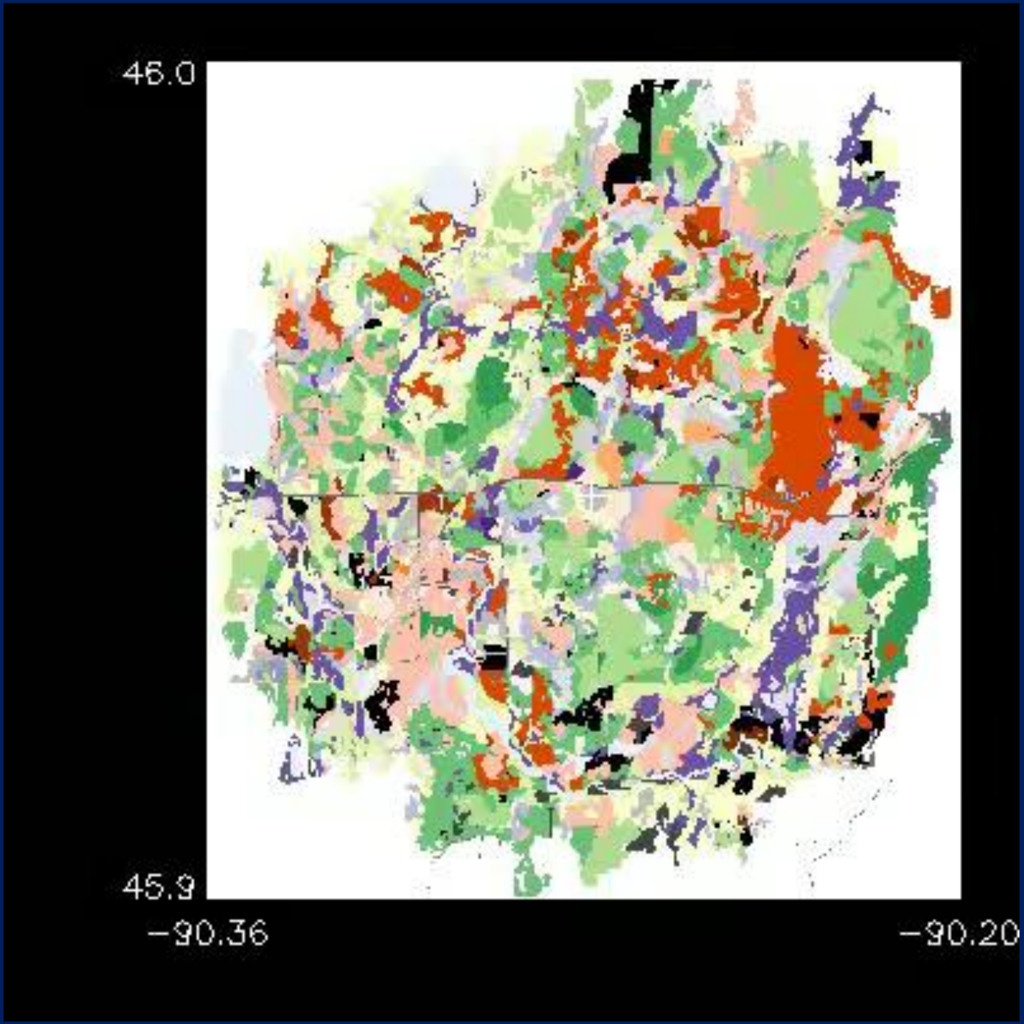


Butterworth et al., 2024

Site footprints are rarely fully "representative"

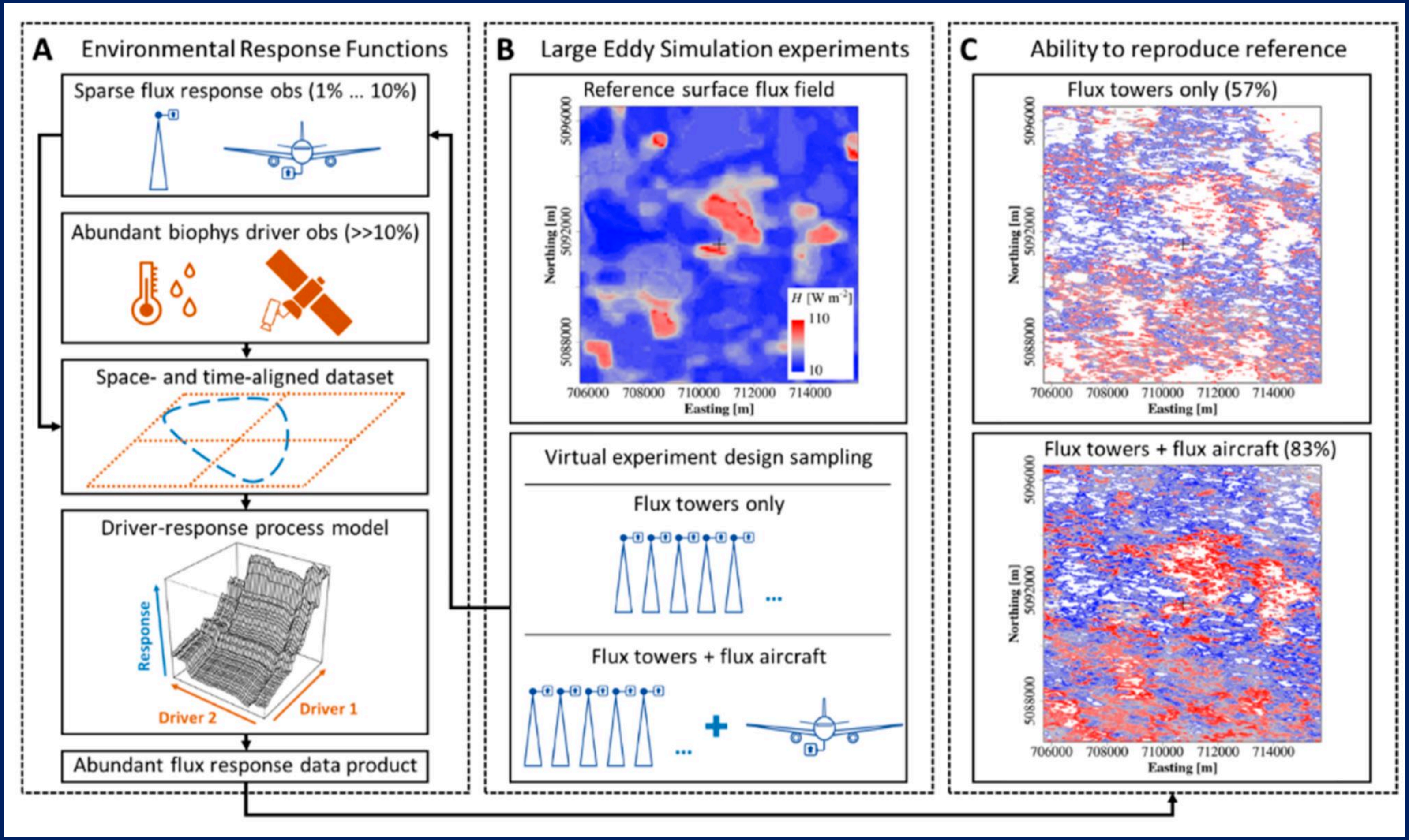


What if we re-envisioned what flux towers do?

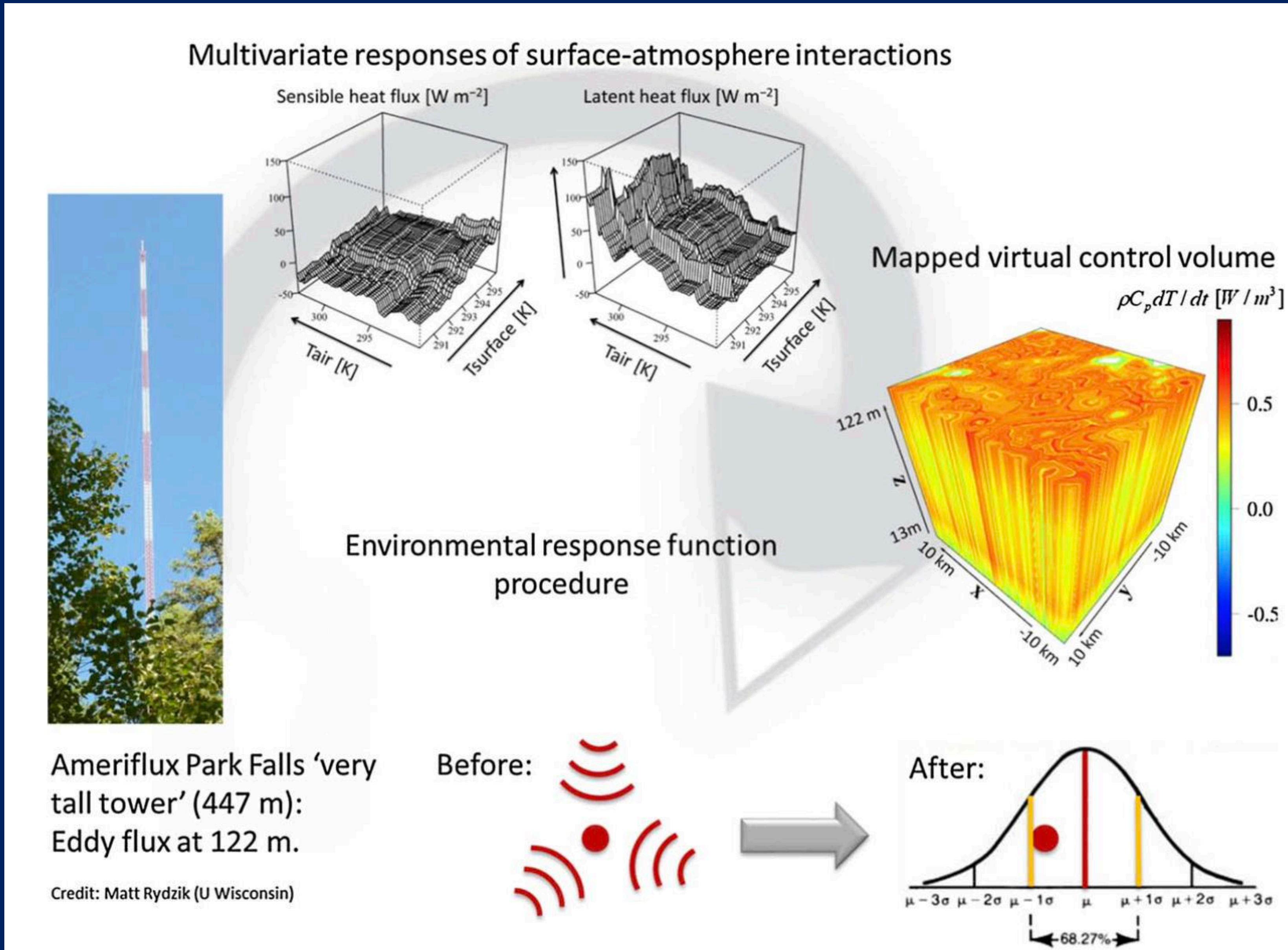


Adopted from a version by HaPE Schmid (KIT)

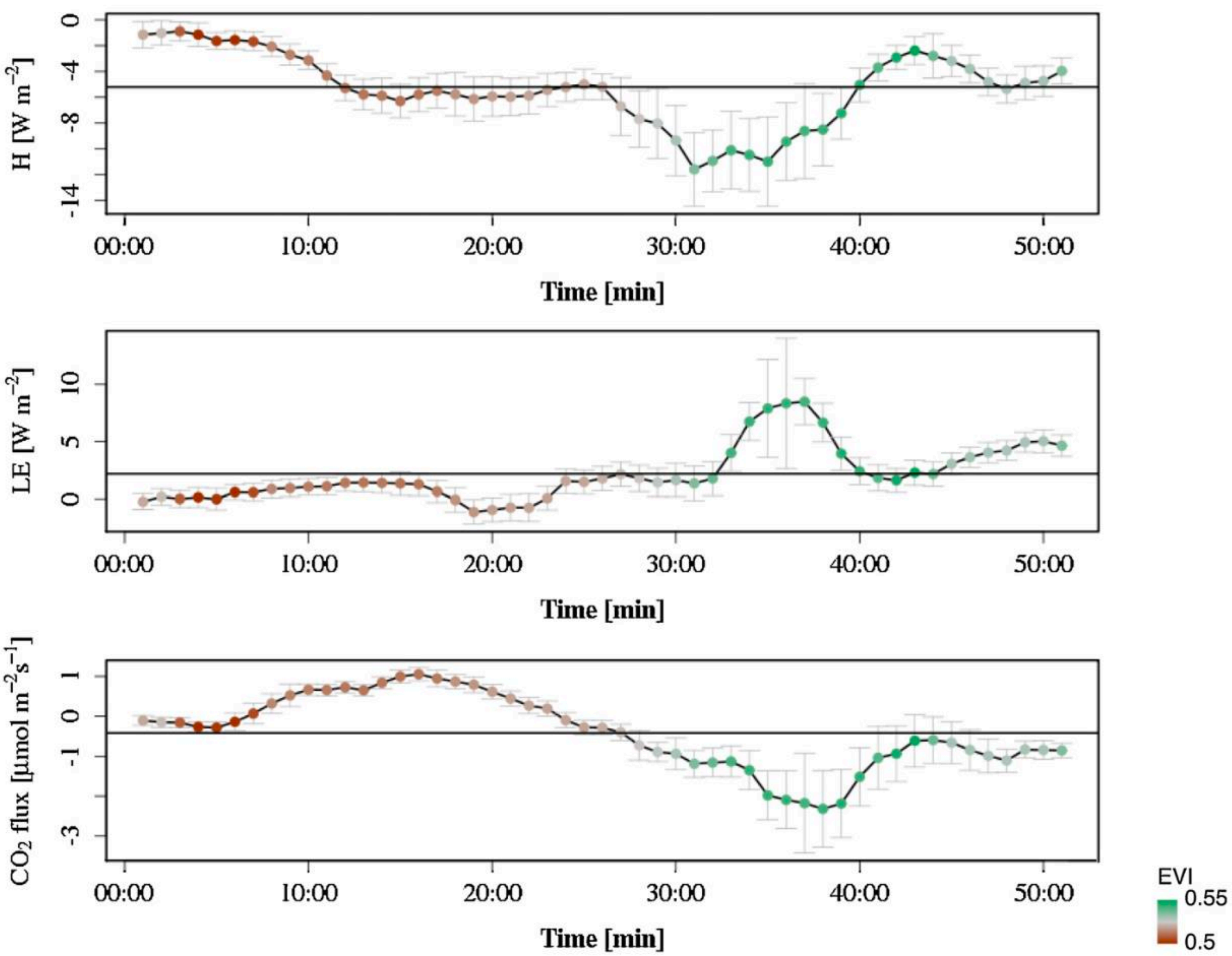
Mapping fluxes across space



Metzger et al., 2013, 2021 and others



Metzger et al., 2013; Xu et al., 2017, 2020



H [W m^{-2}]
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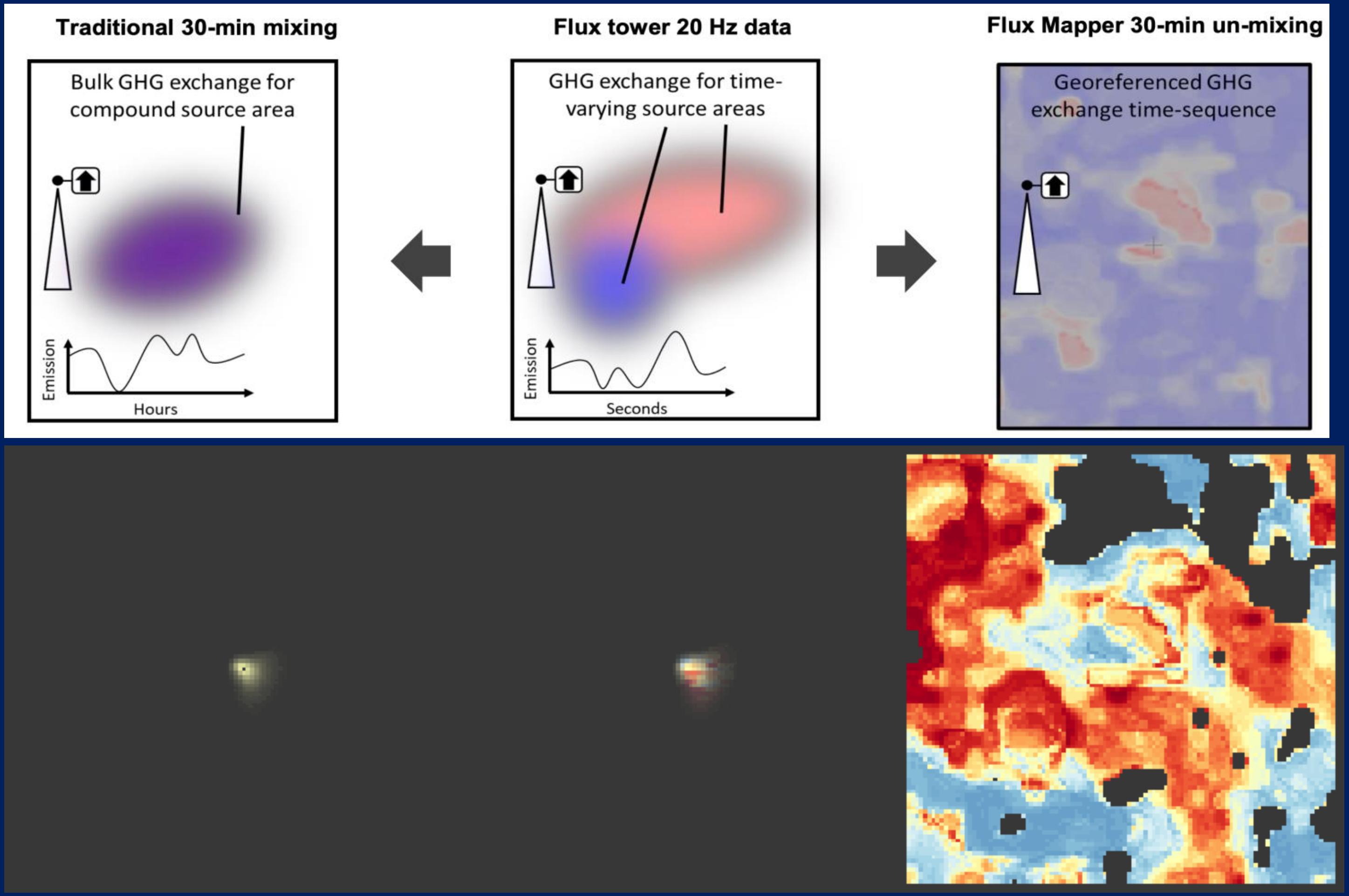
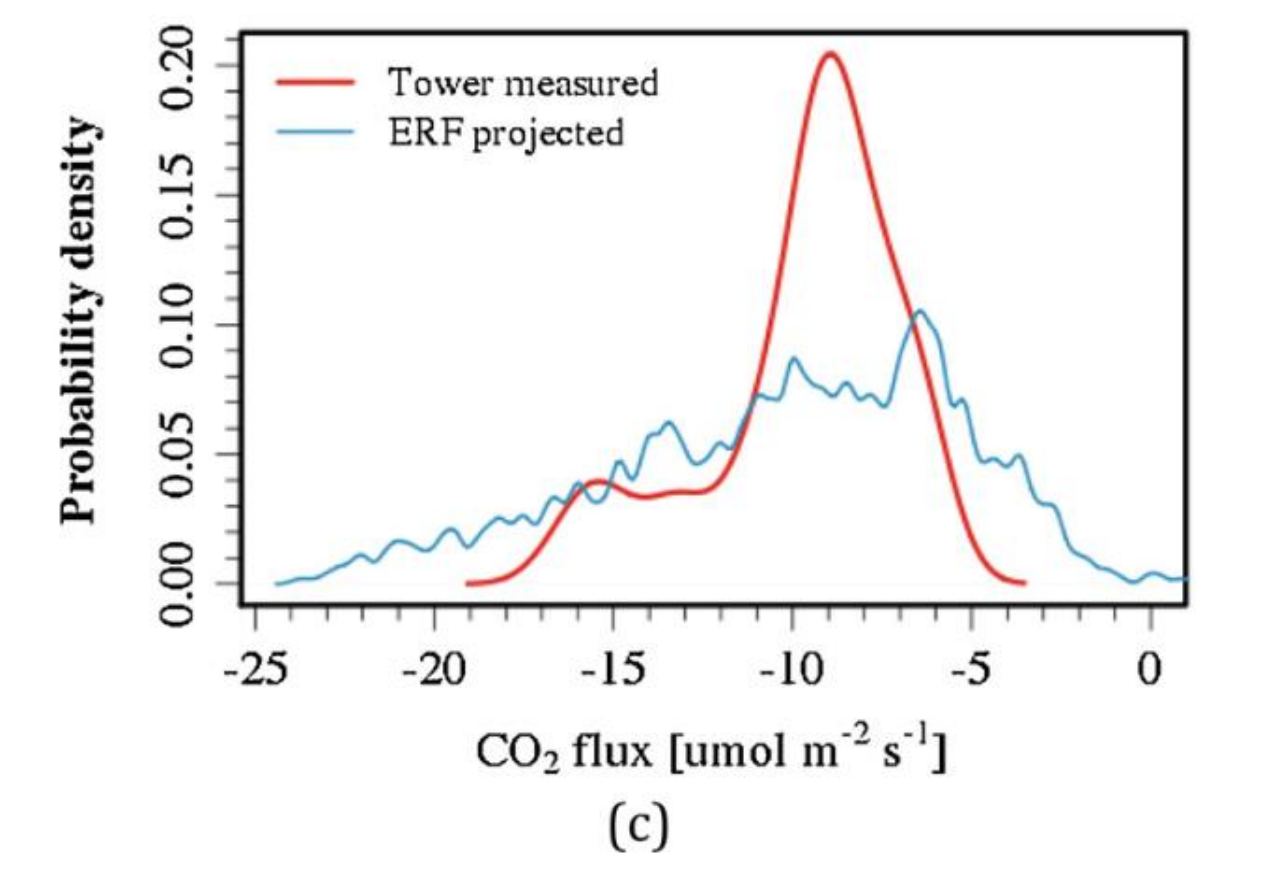
0.5

Gaining more information by scaling



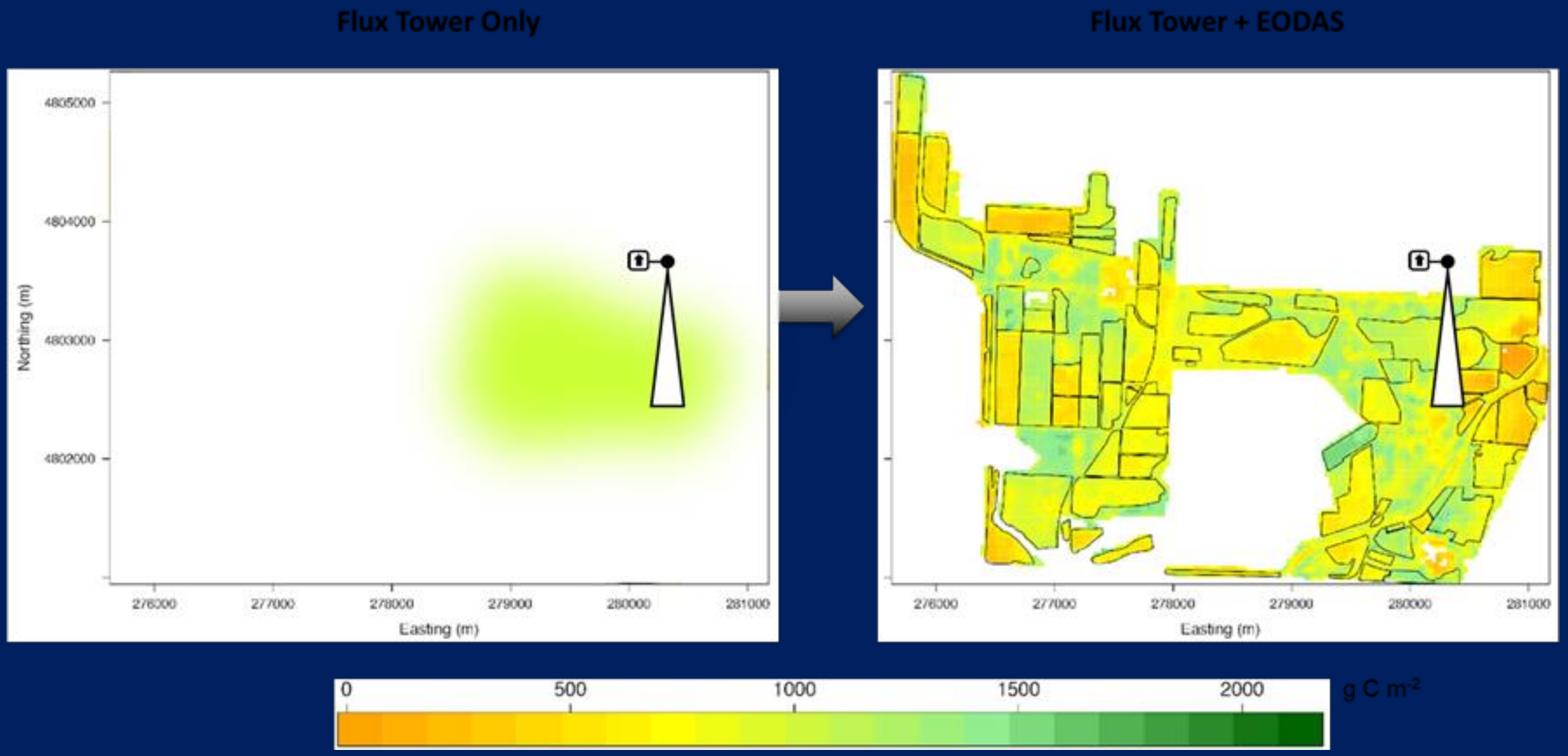
Metzger et al., 2018, AFM
https://www.atmofacts.com/

Right-scaling makes a difference in estimation of mean and spatial variability of fluxes



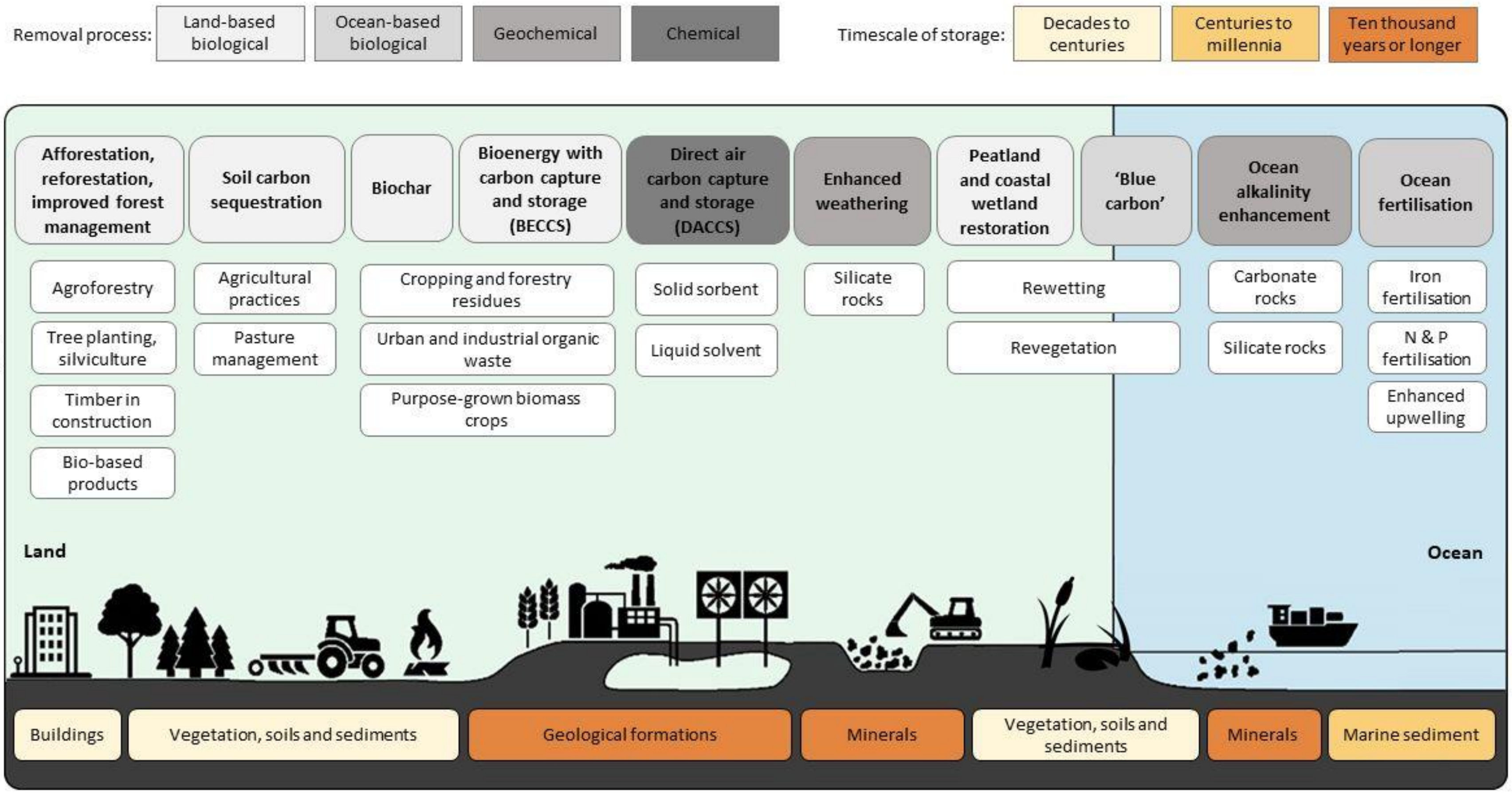
Xu et al., 2017, AFM

And let's us more reliably upscale too!



S Metzger + Wiesner et al., 2022,, JGR-Biogeo

Corporations invested in carbon offsets



IPCC 6th assessment Working Group 1

Some questions to ponder

- Can we develop community tools for properly down/up/right scale individual site tower fluxes in a world of hyper-everything remote sensing?
- Can we gain information from additional plot-level measurements (and rectify biases with towers)?
- How might this "information-gain" lead to better evaluation of Earth system models, quantification of Nature-based climate solutions, and decision-making around ecosystem resource management?

Thank you!

Ankur Desai
desai@aos.wisc.edu
https://flux.aos.wisc.edu
@profdesai

- Contributions from:
  - Stefan Metzger and many ChEAS Ameriflux core site and CHEESEHEAD19 collaborators
  - Phil Townsend lab @ UW
- Support:
  - DOE Ameriflux Network Management Project contract to ChEAS core site cluster, NSF AGS 2313772 + 1822420 (CHEESEHEAD), NOAA ESRL

Photo: A. Desai

David Durden
09 July 24

From the plot to the plane: NEON’s integrated scaled design

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

National Ecological Observatory Network (NEON)

…a continental-scale, long-term (30 year) Observatory, funded by NSF and operated by Battelle

Enables:

- Analysis: Free and open data and samples on the drivers of and responses to environmental change
- Comparison: Standardized and reliable framework for research and experiments
- Interoperability: Integration with other national and international network science projects

BATTELLE






PEOPLE

~600 total staff

320+ full time

250-290 SEASONAL Domain techs

National Ecological Observatory Network

BY THE NUMBERS

DATA PRODUCTS 180+

500,000+ SAMPLES TO DATE

100,000+ SAMPLES ADDED PER YEAR

34 AQUATIC

47 TERRESTRIAL

81 FIELD SITES

PHYSICAL INFRASTRUCTURE

airborne observation platforms	3
flux towers	47
water quality stations	57
meteorological stations	89
groundwater wells	197
soil sensor arrays	235

20 ecoclimatic Domains

24 states +1 territory

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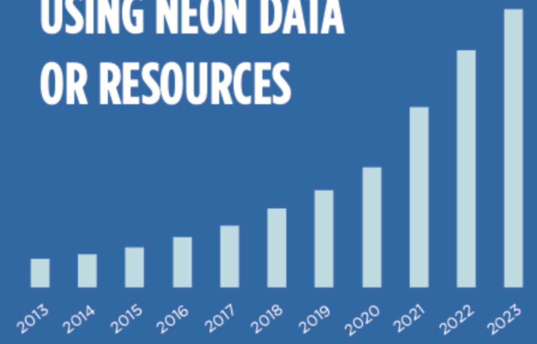
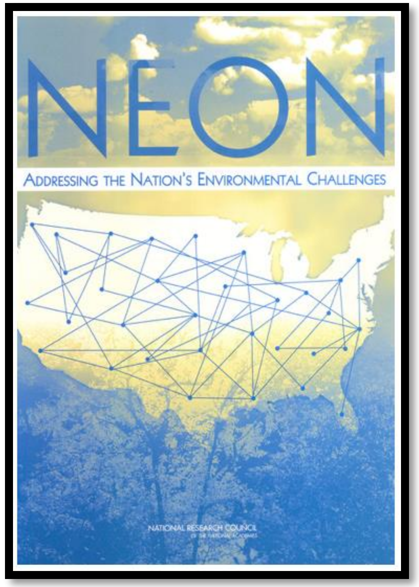
900+ PUBS

USING NEON DATA OR RESOURCES



NSF | neon Operated by Battelle

NEON: Designed to understand and forecast the effects of environmental change



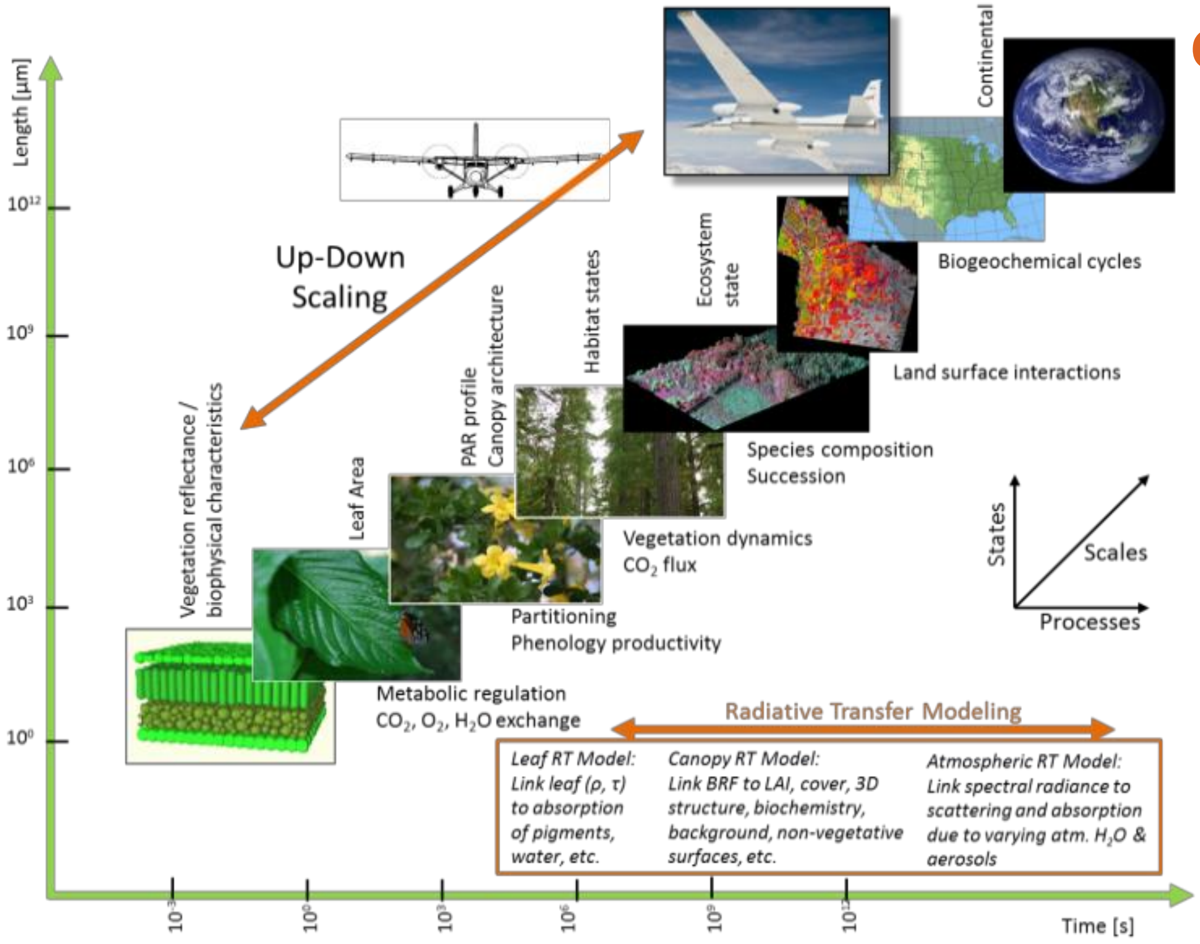
"The central goal of NEON should be to perform comprehensive, regional- to continental-scale experimental and observational research on the nation's natural and managed ecosystems to obtain an in depth understanding of the environment in order ***to assess vulnerability and resilience of ecosystems to environmental change."***

-NRC, 2003

Still an urgent need!

Addressing questions of scale with an observatory

Addressing questions of scale: from the plot to the plane



Observing system design

- Optimize spatial representativeness
  - Eco-climatic domains
  - Representative ecosystems
  - Proper site and measurement density
- Reduce and quantify uncertainty
  - Site selection and design
  - Calibration and maintenance
  - Algorithmic processing
  - QAQC

Scaling techniques

- Data driven
  - Relationships directly from data
- Process driven
  - Theoretically prescribed
- Data fusion & machine learning
  - Using data with models to drive understanding

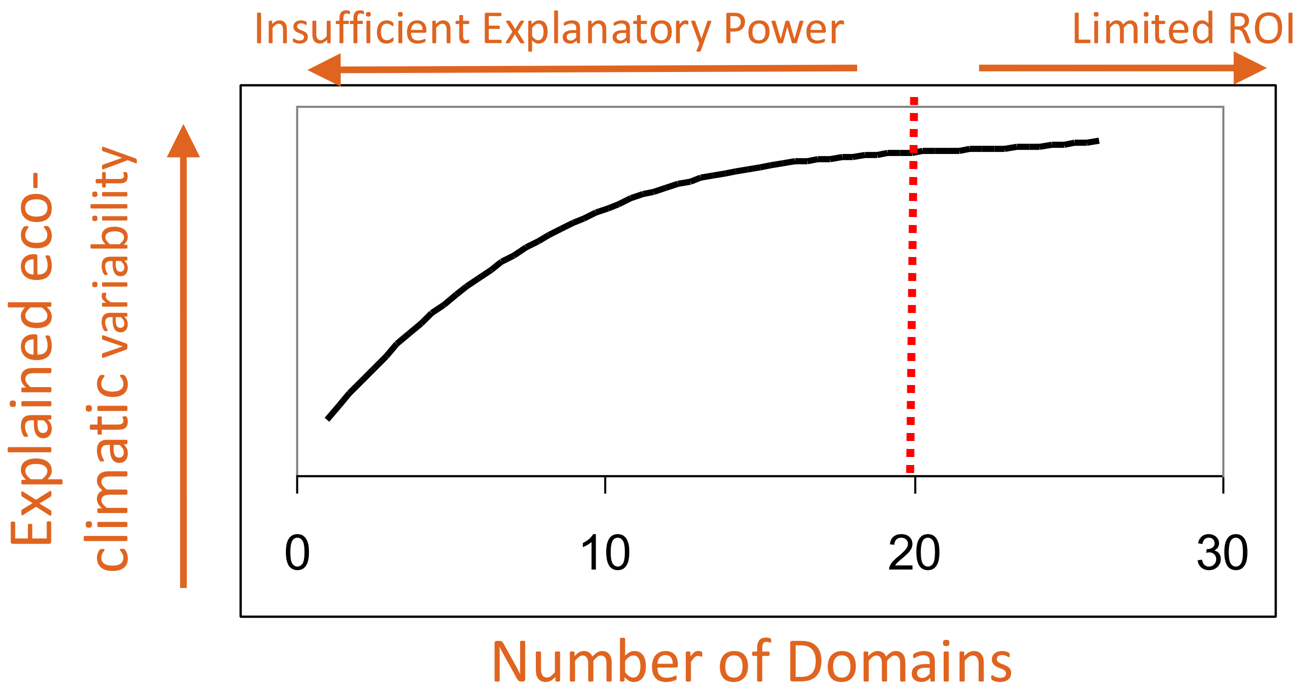
Why 20 domains?

DOI: 10.1007/s00267-003-1084-0

Potential of Multivariate Quantitative Methods for Delineation and Visualization of Ecoregions

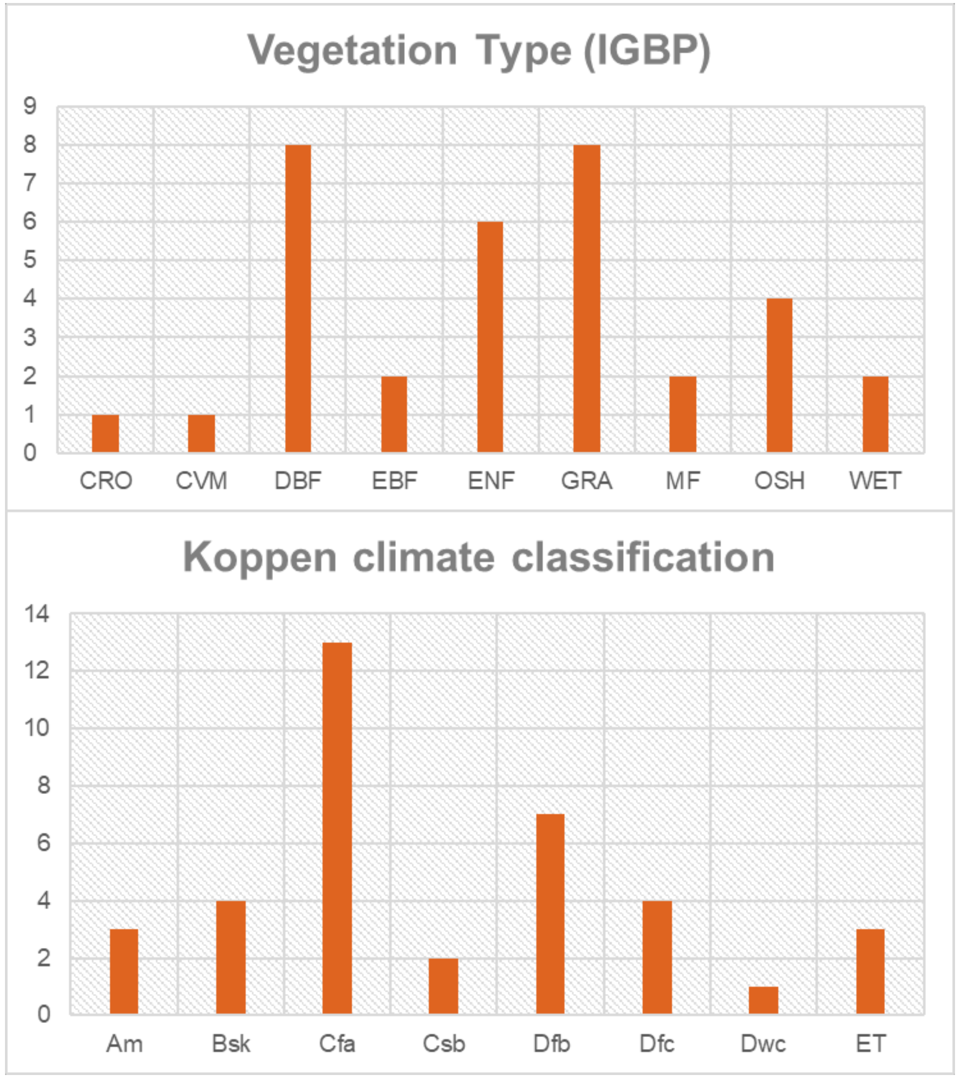
WILLIAM W. HARGROVE*
FORREST M. HOFFMAN
Environmental Sciences Division
Computer Science and Math Division
Oak Ridge National Laboratory
P. O. Box 2008, M.S. 6407
Oak Ridge, Tennessee 37831-6407

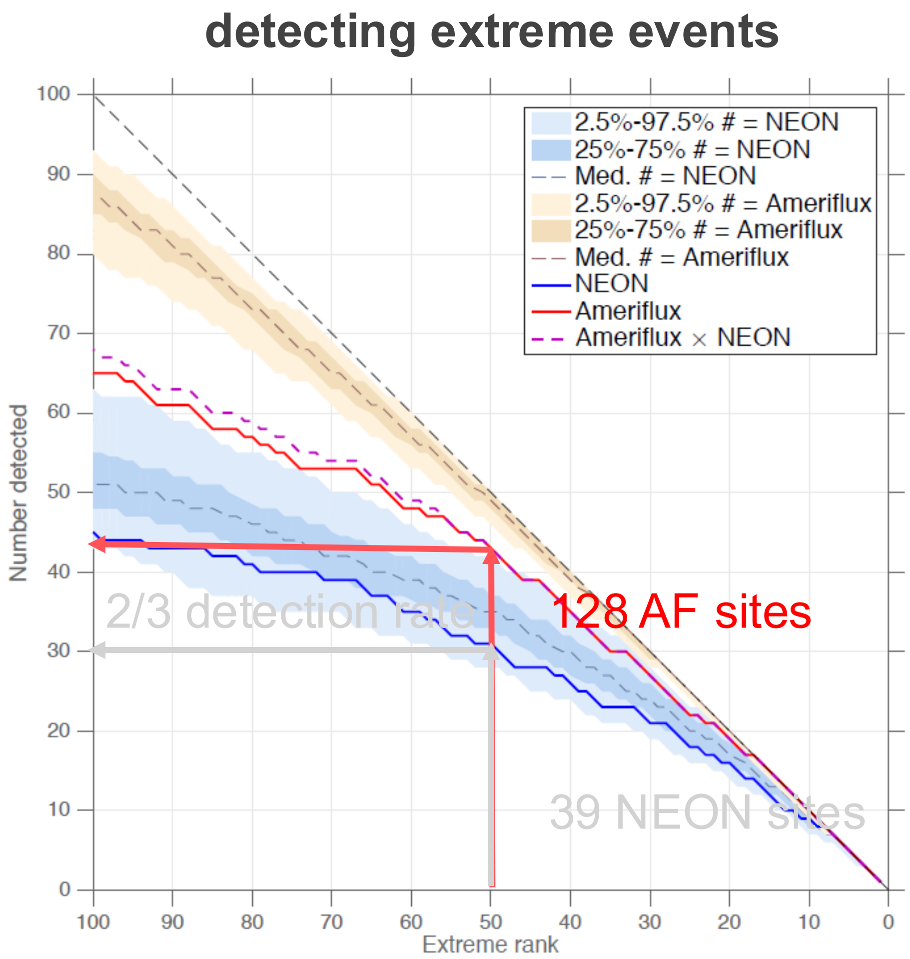
from the limitations of human subjectivity, making possible a new array of ecologically useful derivative products. A red–green–blue visualization based on principal components analysis of ecoregion centroids indicates with color the relative combination of environmental conditions found within each ecoregion. Multiple geographic areas can be classified into a single common set of quantitative ecoregions to pro-



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

Measurement representativeness

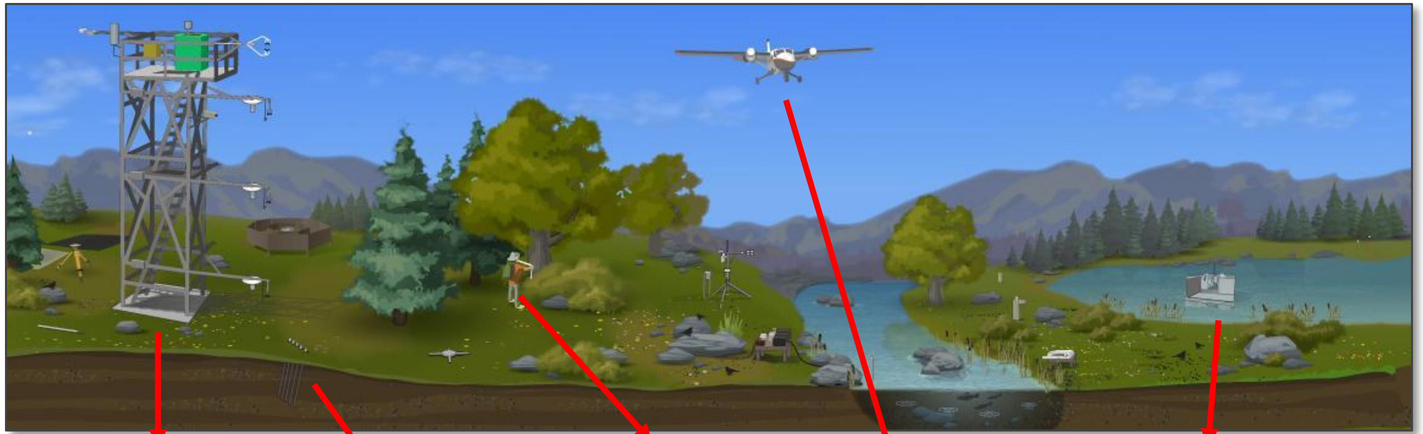




Mahecha et al., 2017

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

Standardized data collection



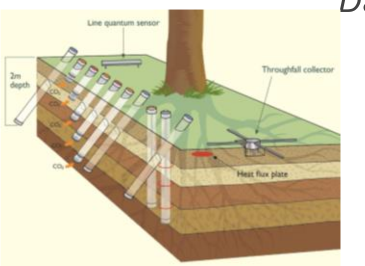
Tower for atmospheric data & eddy flux

Soil sensors

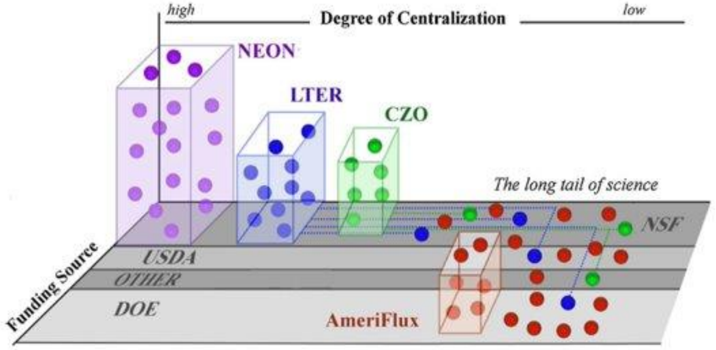
Terrestrial Observations
Data and sampling

Aquatic Observations & Instruments
Sensors, data, sampling

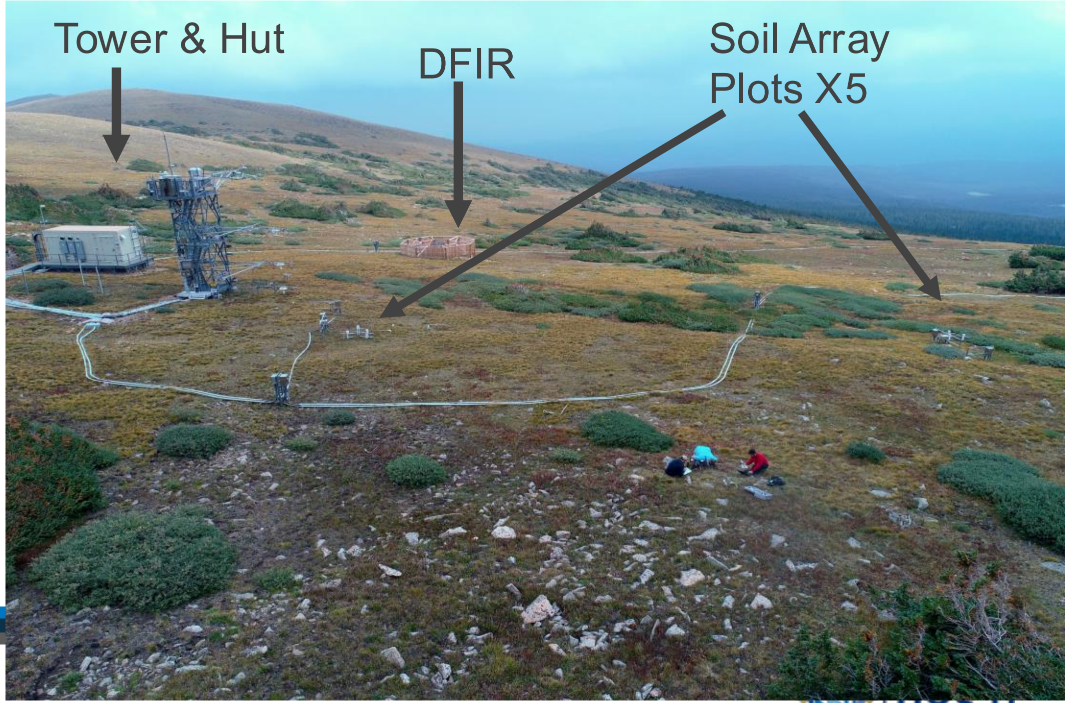
Terrestrial Instruments



Airborne observations
Hyperspectral, LiDAR, RGB

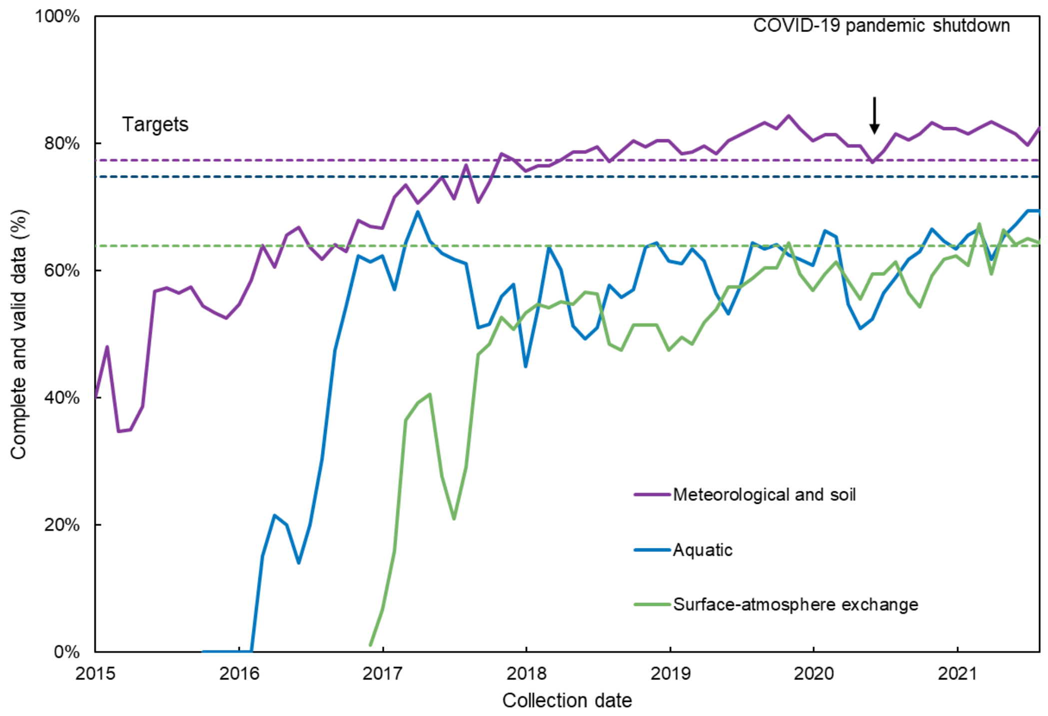


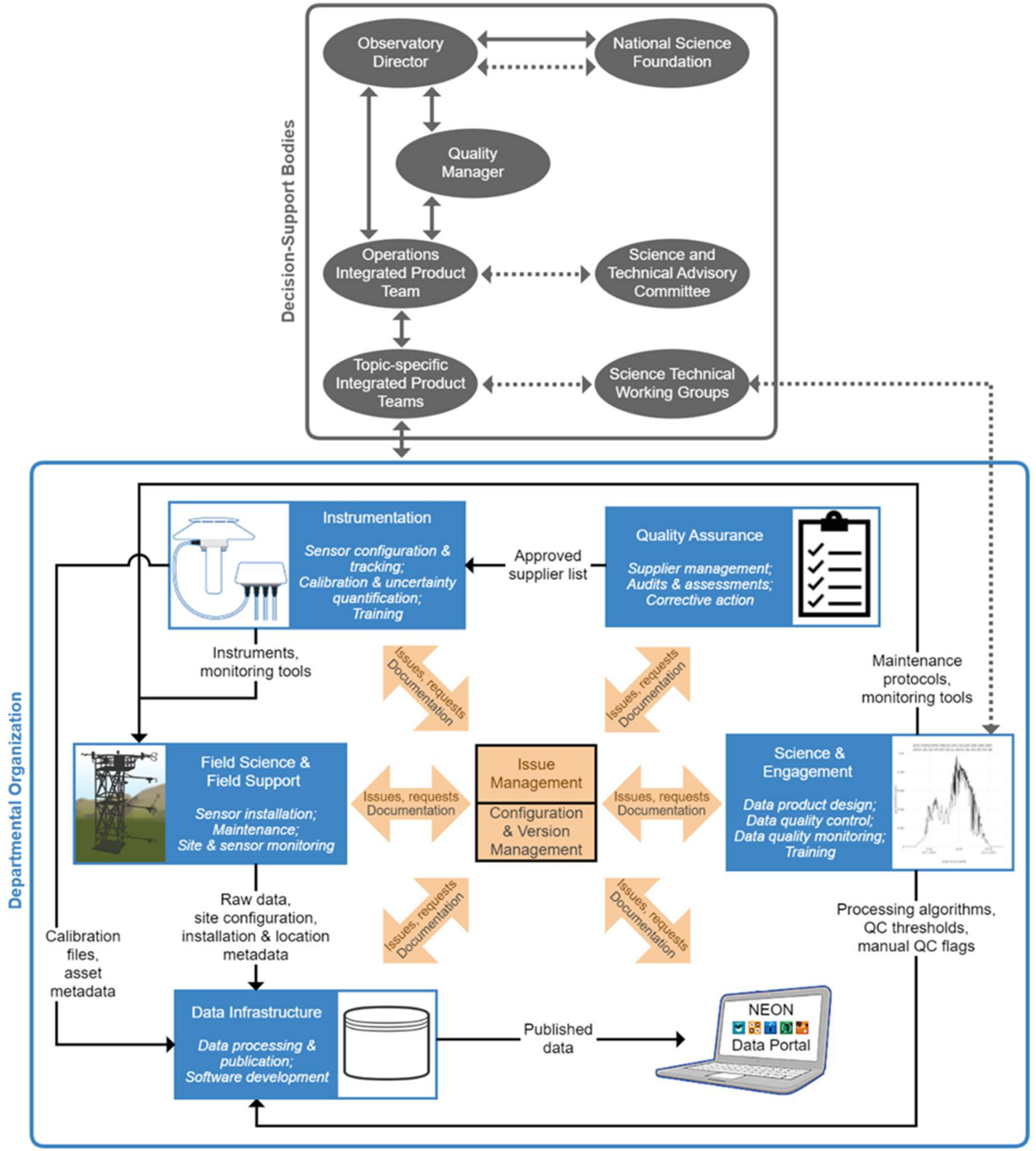
Standardized, colocated methods across sites



Novick et al. 2018

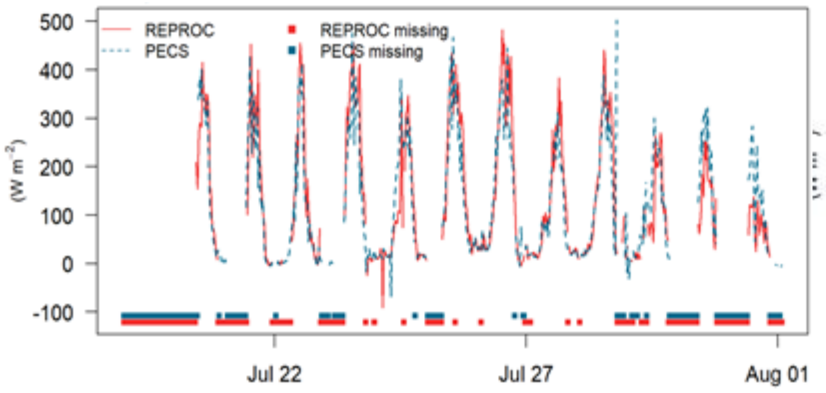
Data Quality

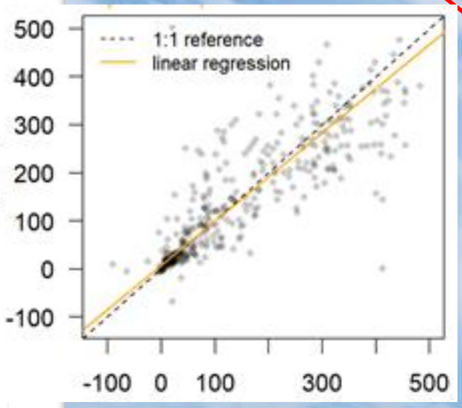




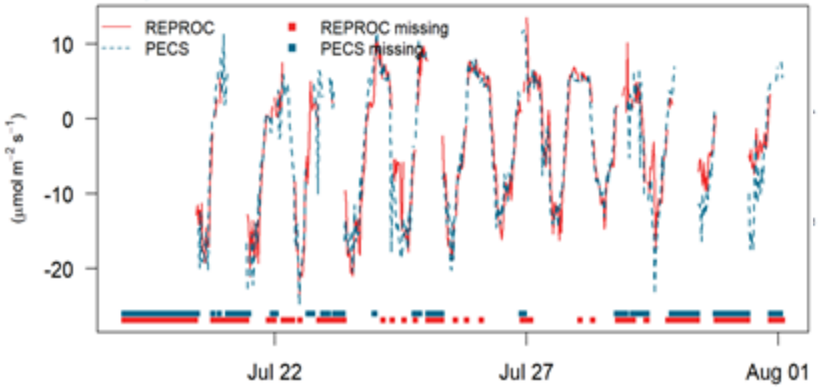
Data quality (continued)

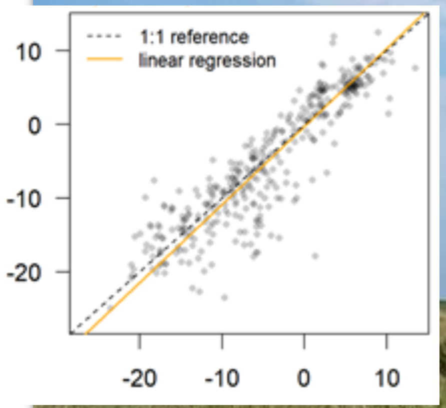
LE (latent heat flux)





FC (CO_2 flux)

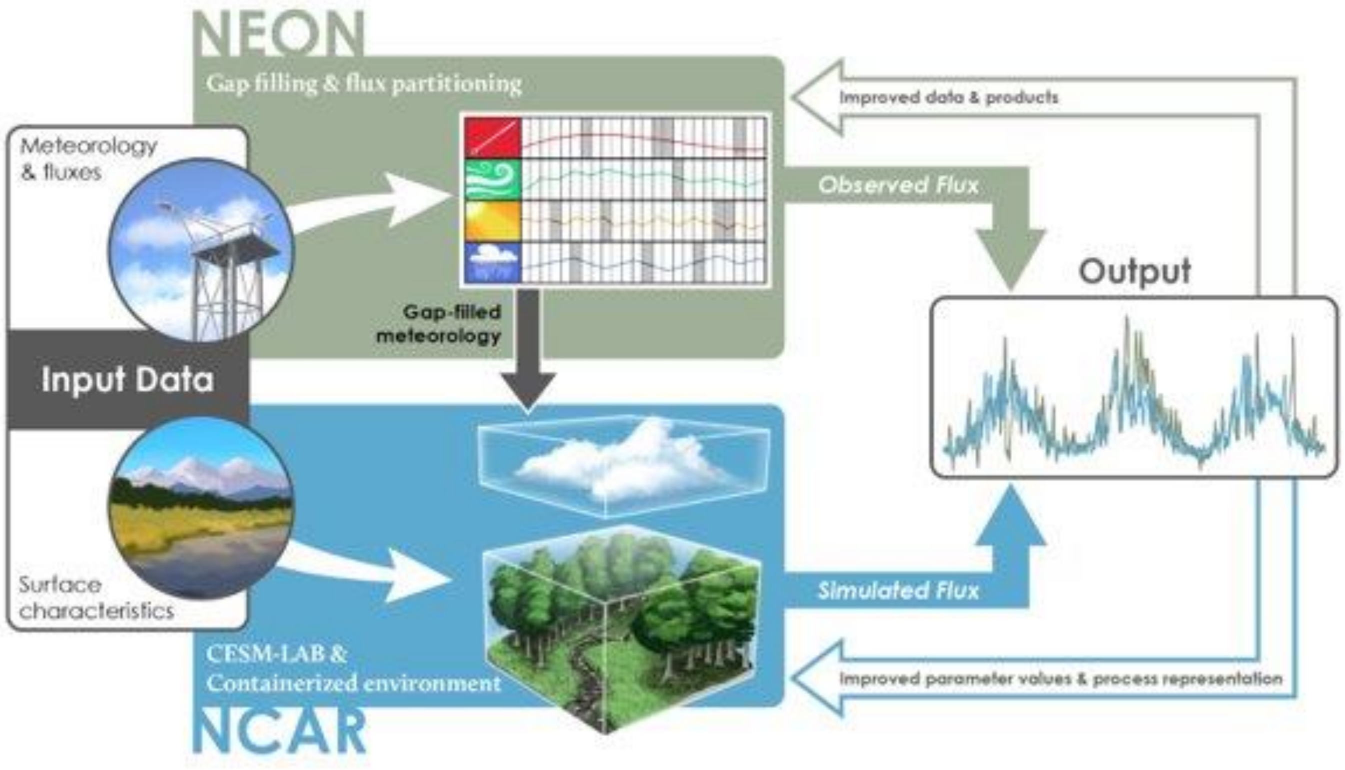




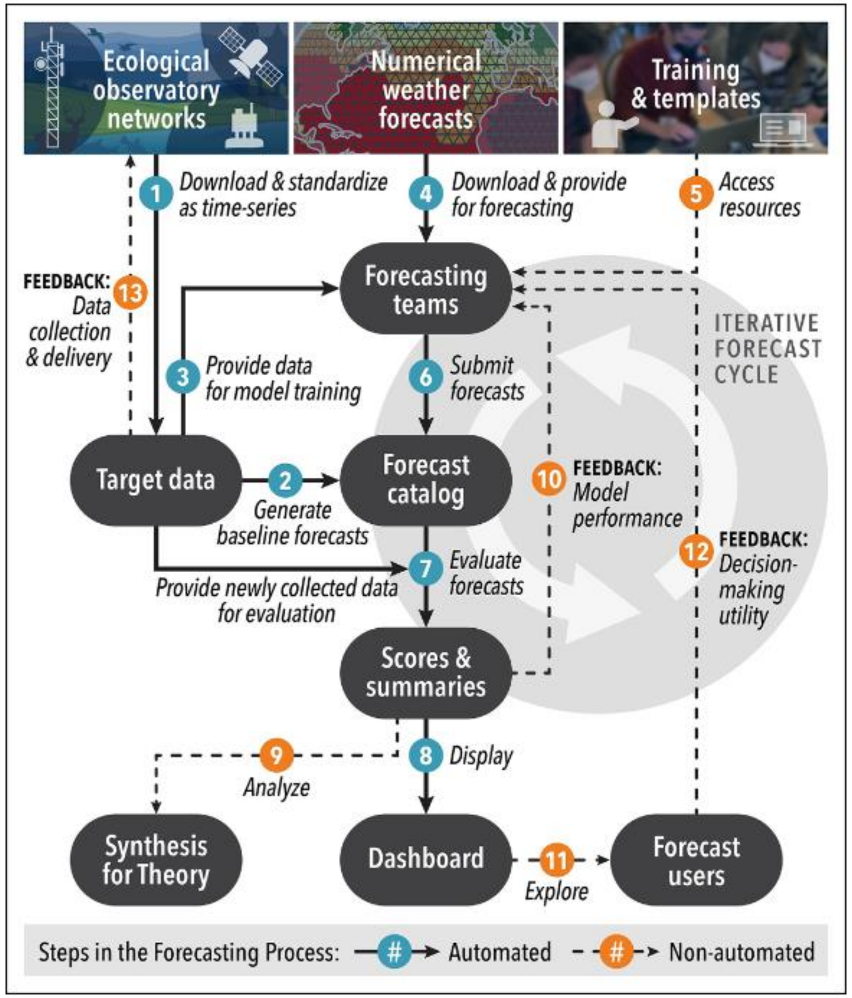
Special thanks: Housen Chu and Stephen Chan

Scaling methods: data-model integration

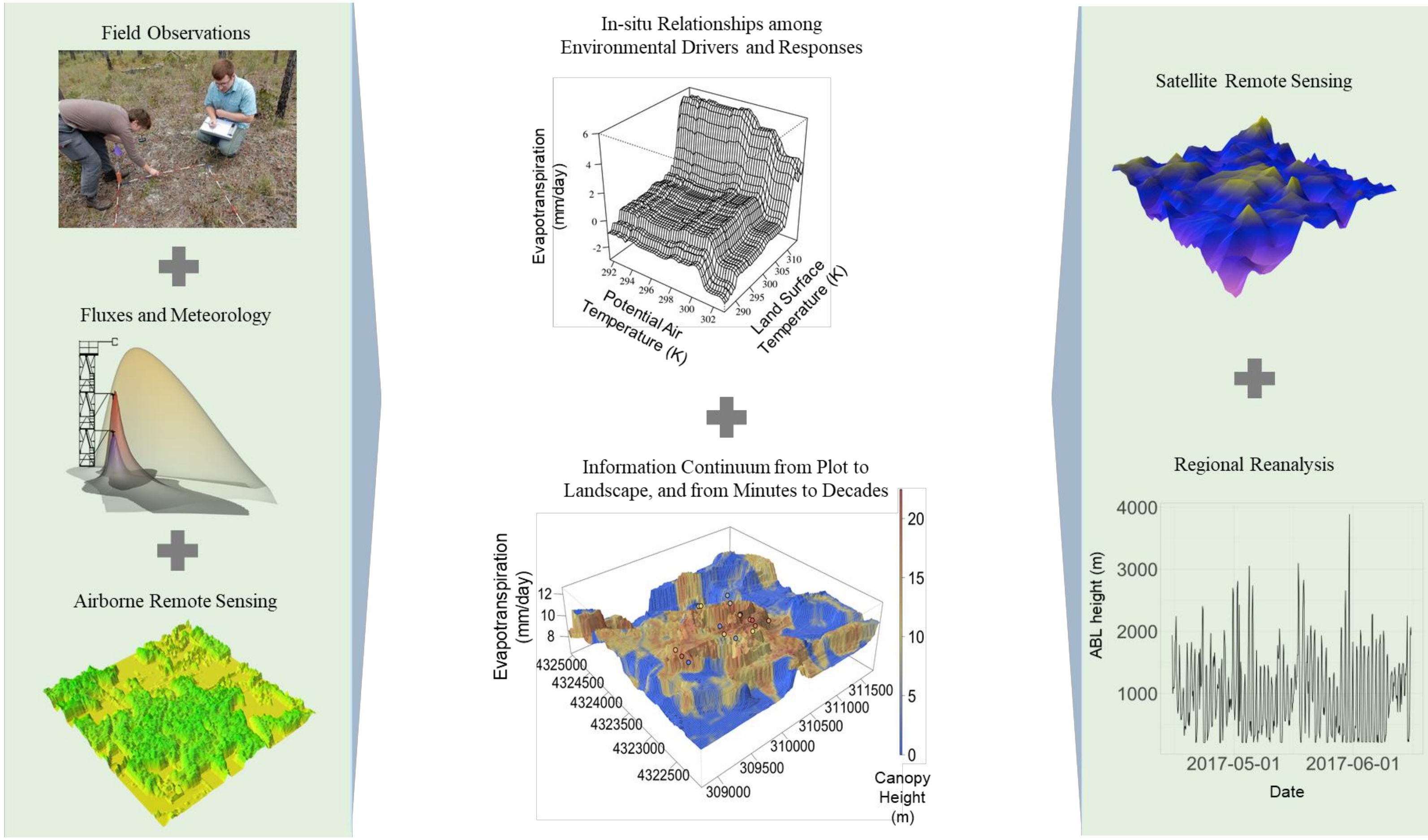
NCAR-NEON model framework



Ecological Forecasting Initiative RCN



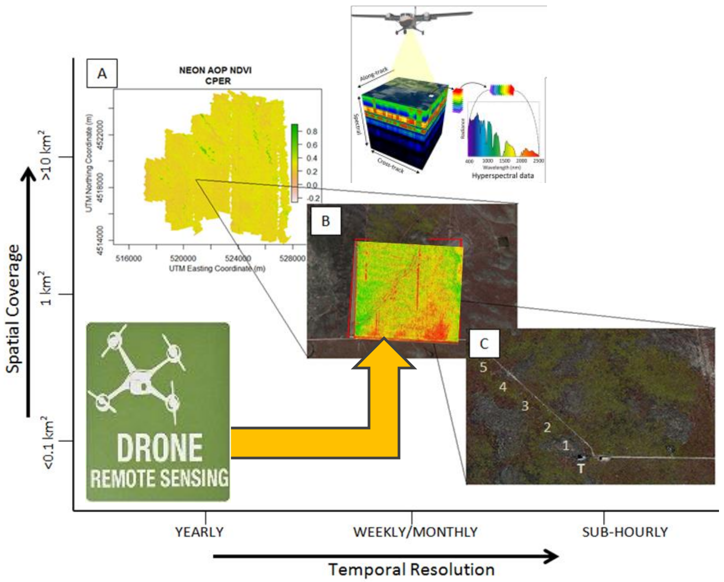
Scaling methods: data fusion and machine learning



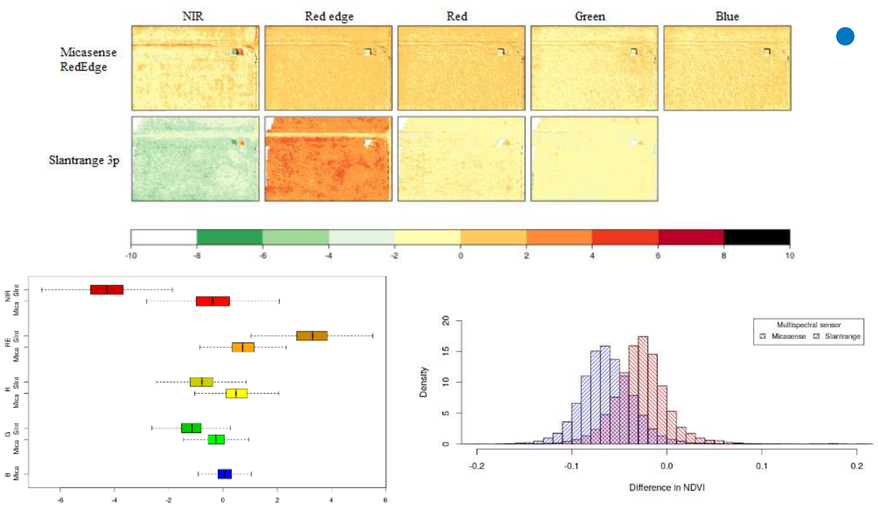
Metzger, S., Ayres, E., Durden, D., Florian, C., Lee, R., Lunch, C., Luo, H., Pingintha-Durden, N., Roberti, J. A., SanClements, M., Sturtevant, C., Xu, K., and Zulueta, R.: From NEON field sites to data portal: a community resource for surface-atmosphere research comes online, Bull. Am. Meteorol. Soc., in review.

Addressing scale gaps: new measurement technologies

Spatiotemporal gaps

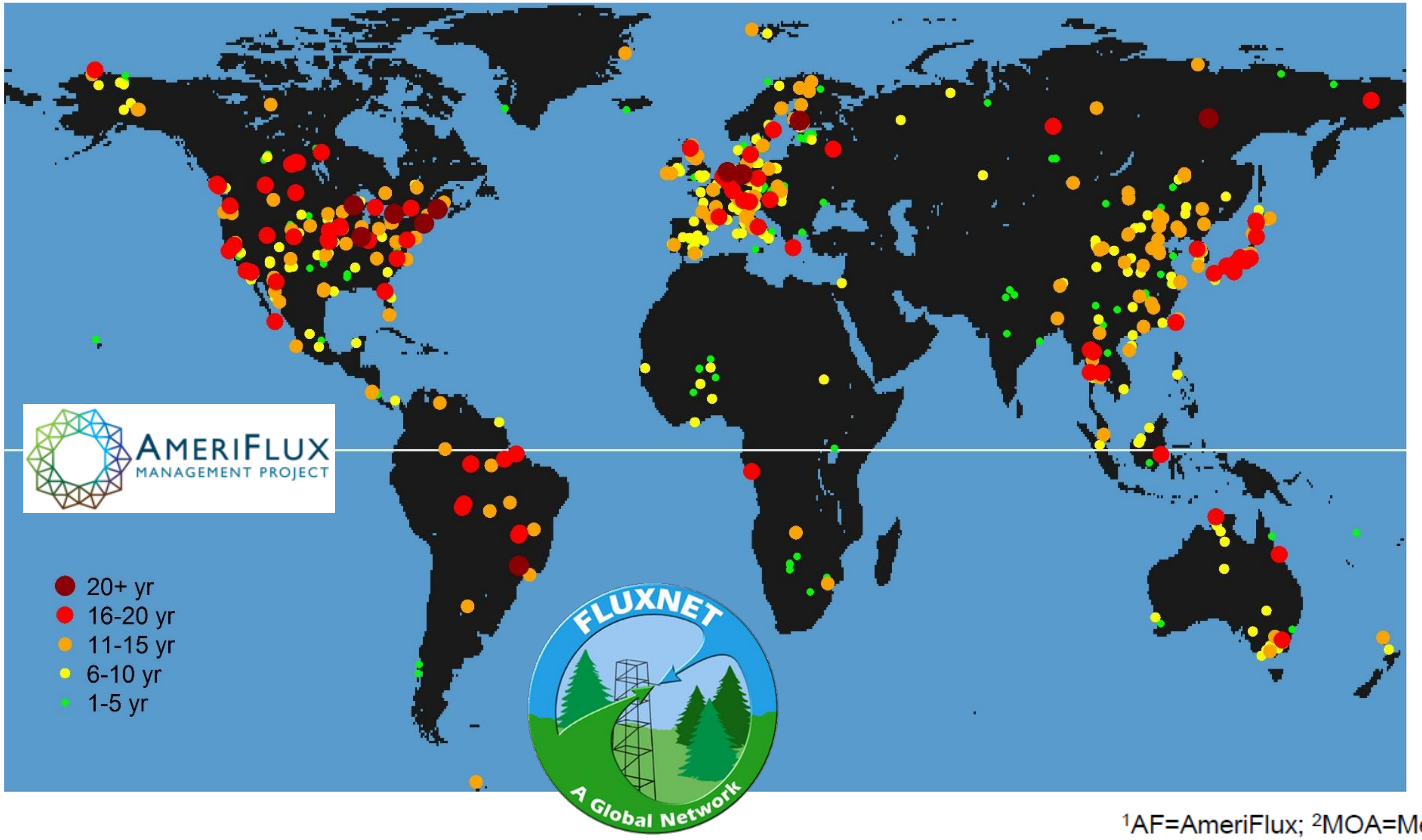


UAS multispectral vs. AOP



- NEON data products span large spatio-temporal scales, e.g. airborne remote sensing and automated tower measurements
- UAS platforms are being evaluated to:
  - provide cost effective and agile remotely sensed data products, with greater temporal resolution
  - enable target-of-opportunity measurement campaigns for extreme ecological events
  - Initial results compared to NEON AOP are promising

Addressing scale gaps: Collaboration (AmeriFlux and FLUXNET)



Our History

2016 White Paper, reciprocal steering committee members

2017 First NEON site @ AF[1], gap-filling collaboration, MOA[2]

2018 First NEON data @ AF

2019 All NEON sites @ AF, biannual data submission

2020 Reciprocal LOCs[3]

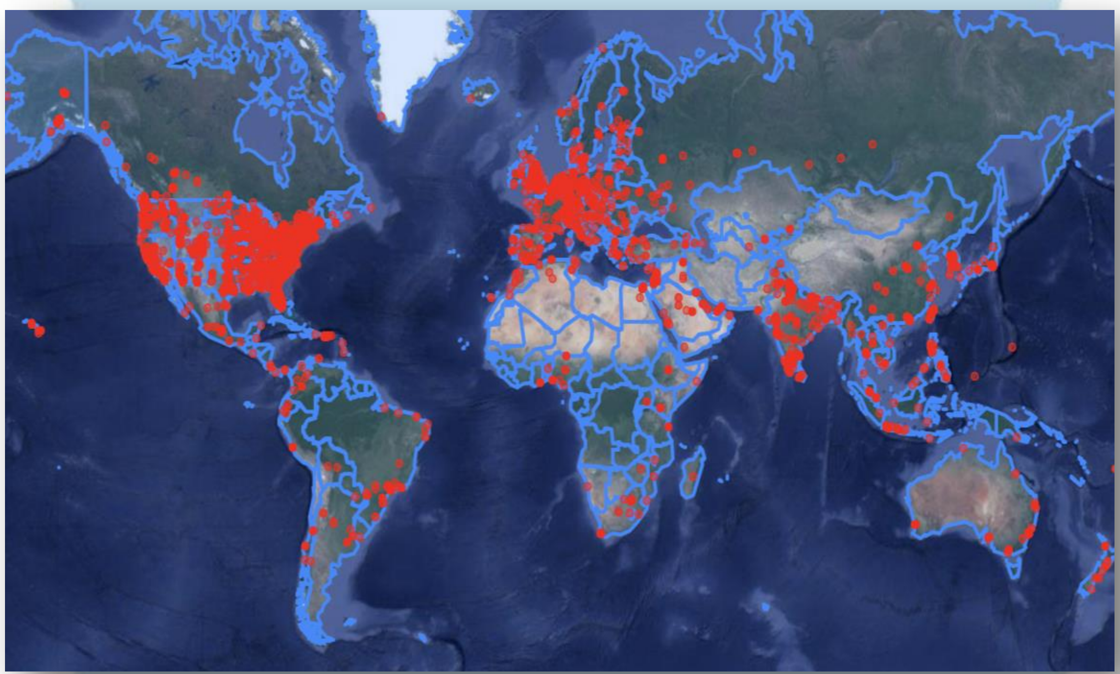
2021 FLUXNET Data Integration

2022 First NEON ONEFlux data

… To be continued…

[1]AF=AmeriFlux; [2]MOA=Memorandum of Agreement; [3]LOCs=Letters of Collaboration;

Addressing scale gaps: Collaboration

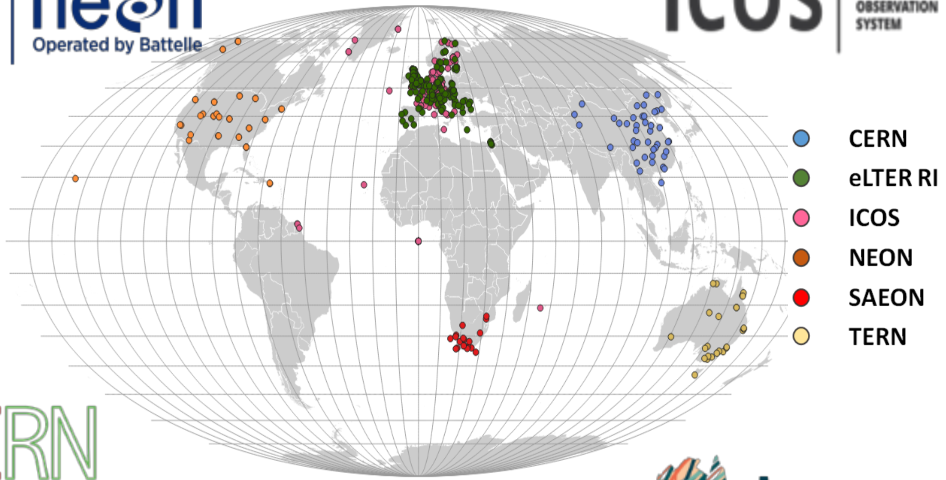


NEON is visited globally
(red dots = IP addresses)

NSF | neon Operated by Battelle

eLTER

ICOS INTEGRATED CARBON OBSERVATION SYSTEM



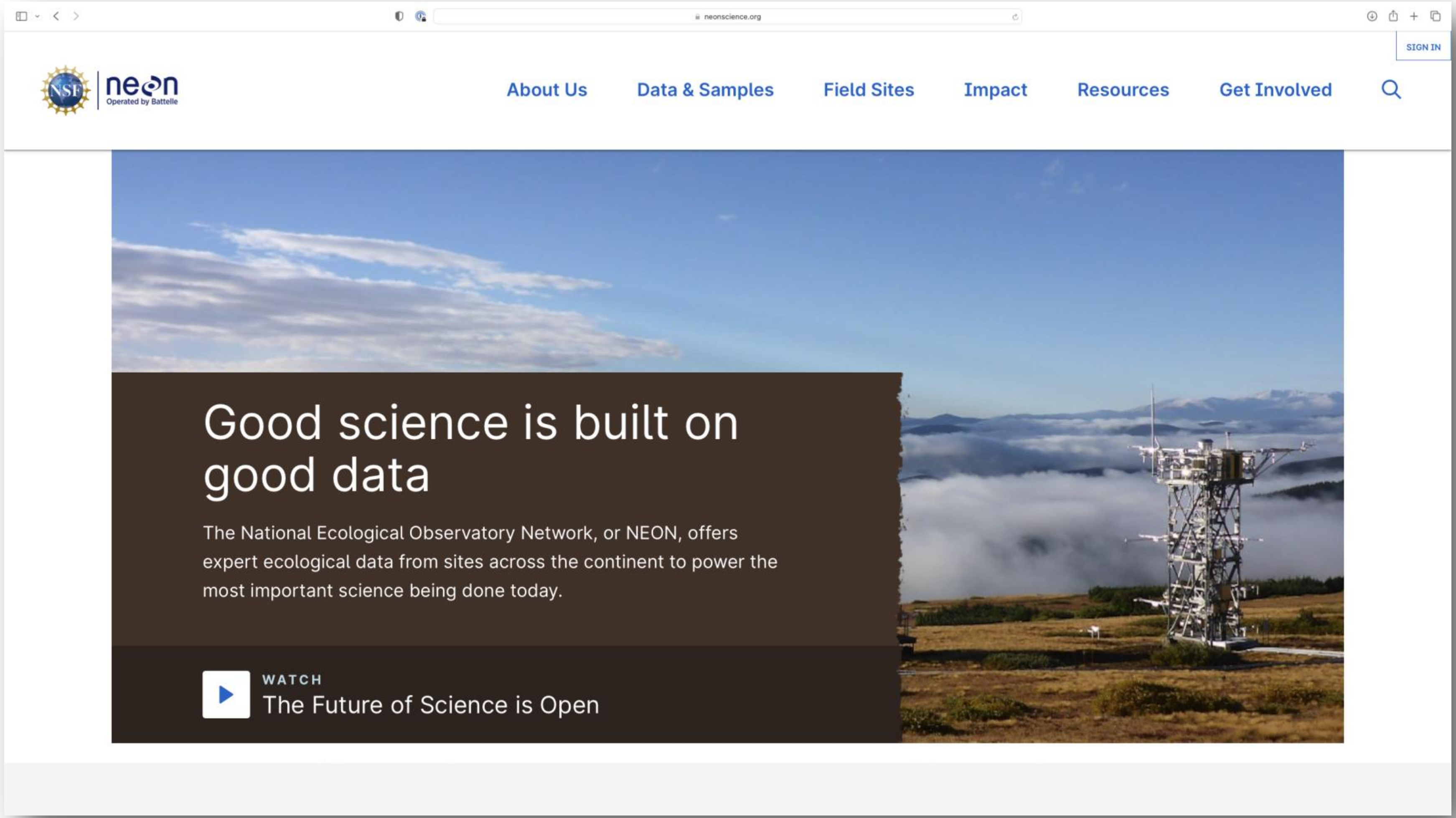
CERN

NRF SAEON South African Environmental Observation Network

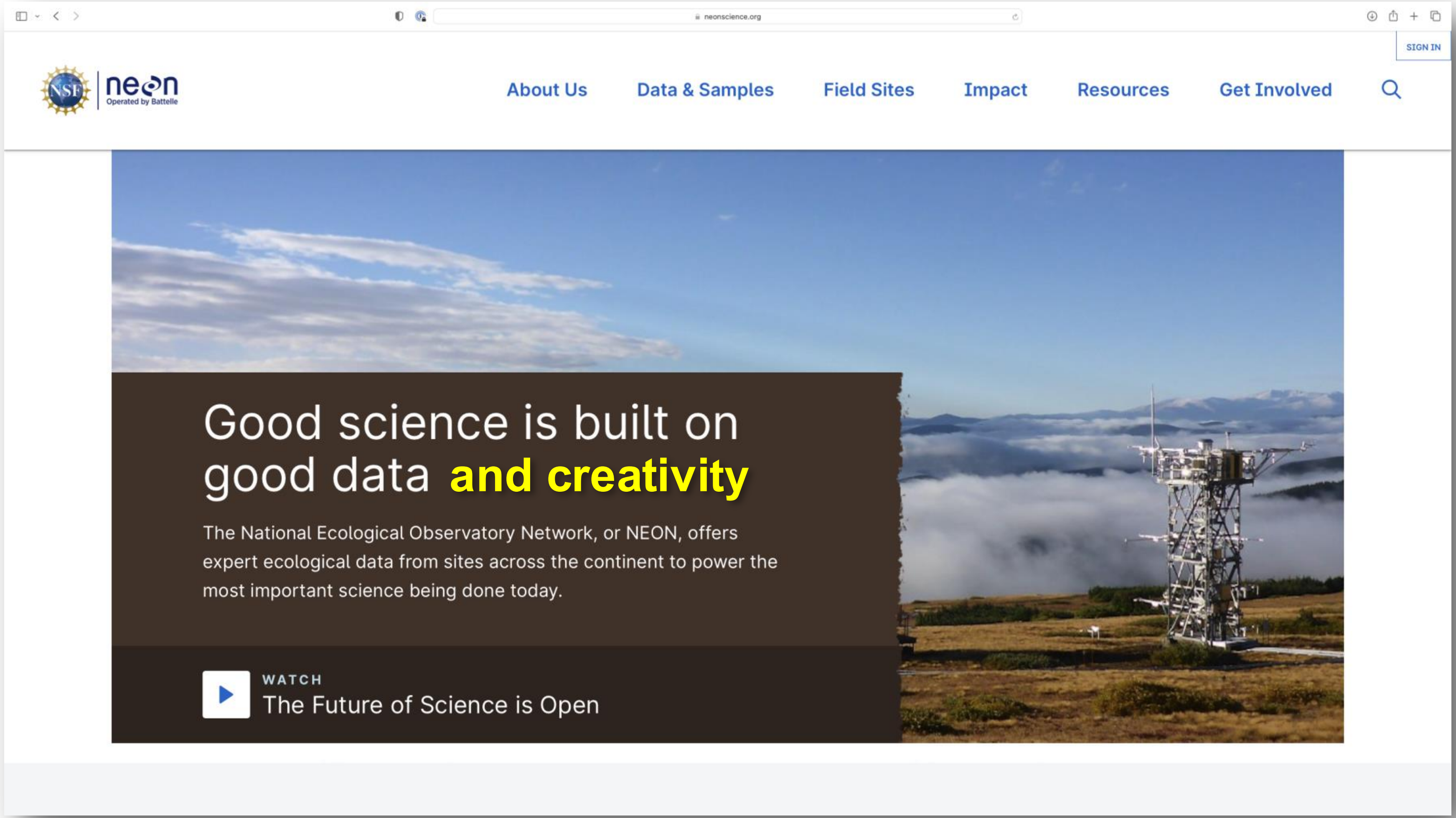
tern Ecosystem Research Infrastructure

GERI Global Ecosystem Research Infrastructure

Good science is built on good data



, . . . and creativity



Thank You!

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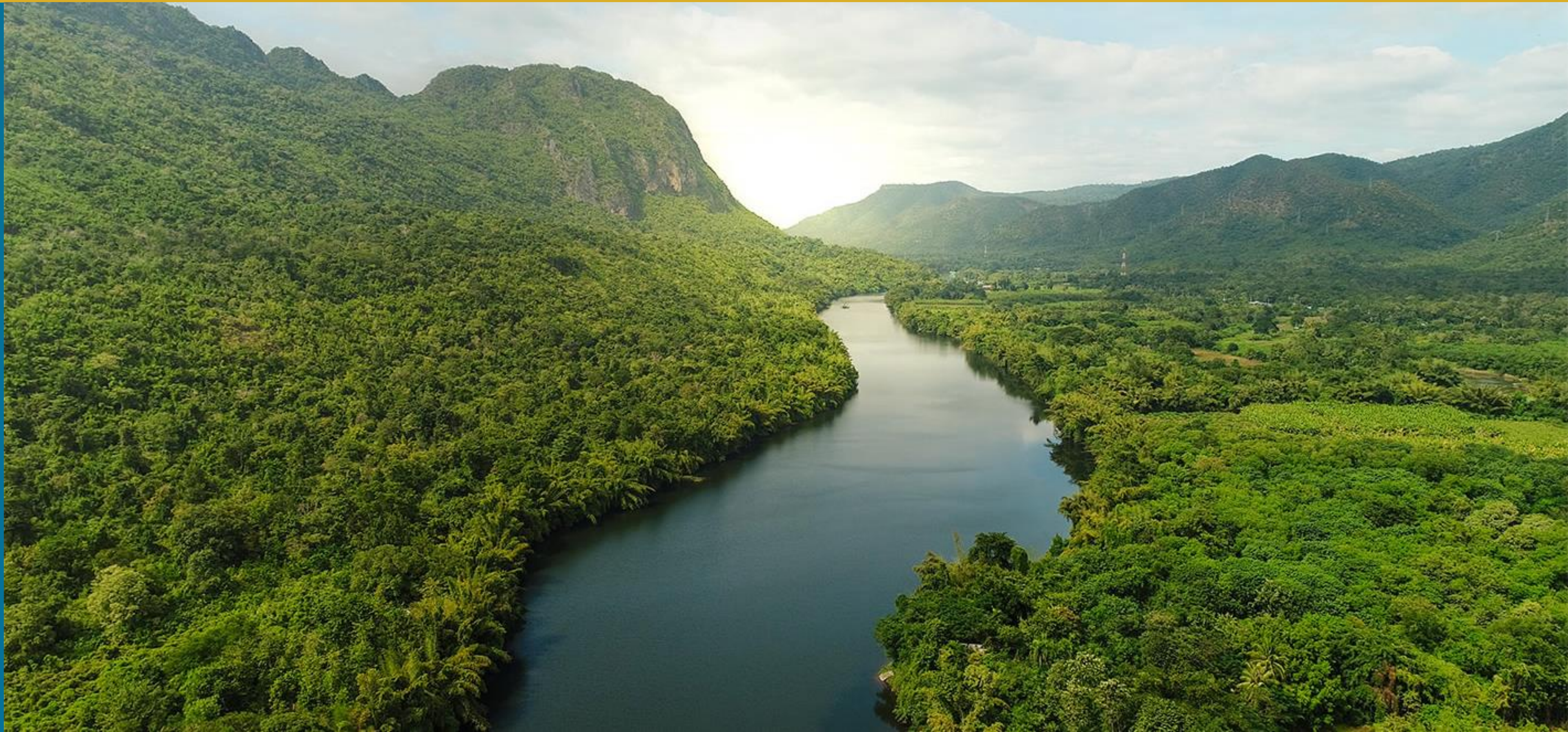
Learn more

720.746.4844 | neonscience@battelleecology.org | neonscience.org

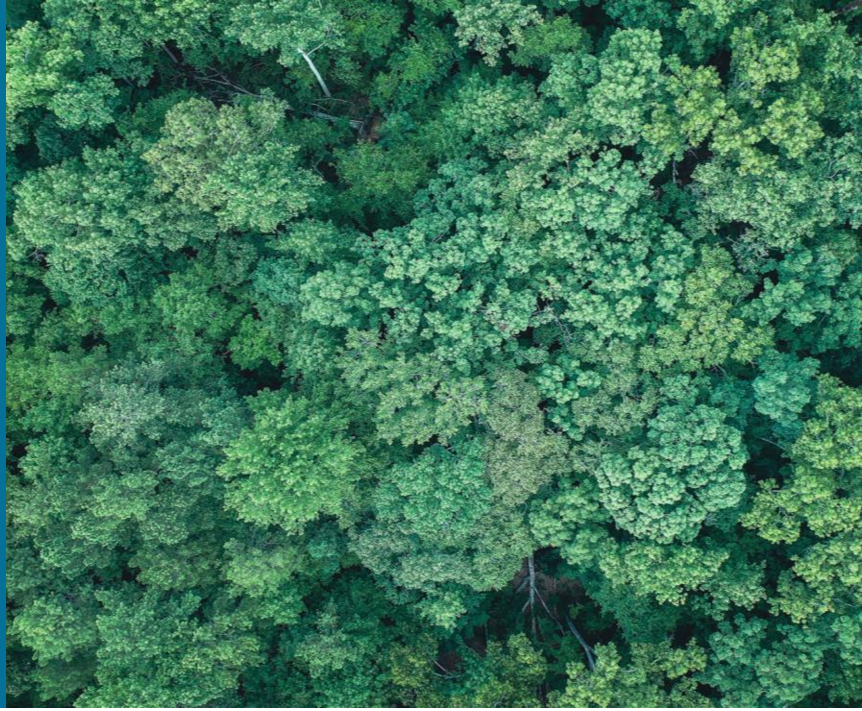
Harnessing Remote Sensing and Flux Measurements for Verified Carbon Standard (VCS) and Agricultural Land Management (ALM) Methodologies



Carolina Cardoso Lisboa, Manager, Agriculture Innovation

Verra, USA (Germany)

Agenda



- Verra Overview & the Verified Carbon Standard (VCS)
- VCS – Ag Methodologies
- Innovation and Challenges

Verra Overview

The Organization

- Non-profit founded in 2007
- Standard setting organization – environmental and social impacts
- Operate the Verified Carbon Standard
  - World's largest greenhouse gas carbon credit program
- Manage several other standards

Verified Carbon Standard

Jurisdictional & Nested REDD+

Plastic Waste Reduction Standard

Sustainable Development Verified Impact Standard

Climate, Community & Biodiversity Standards

Impact – Global Scope

1.2B+
Tonnes of greenhouse gases reduced and removed

2,100+
VCS projects around the world

95
Countries using the VCS for projects

Environmental Finance
Voluntary Carbon Market Rankings 2023 Winner

VCS: Best GHG Crediting Programme
2012, 2013, 2014, 2015, 2016, 2018, 2019, 2020, 2021, 2022, 2023

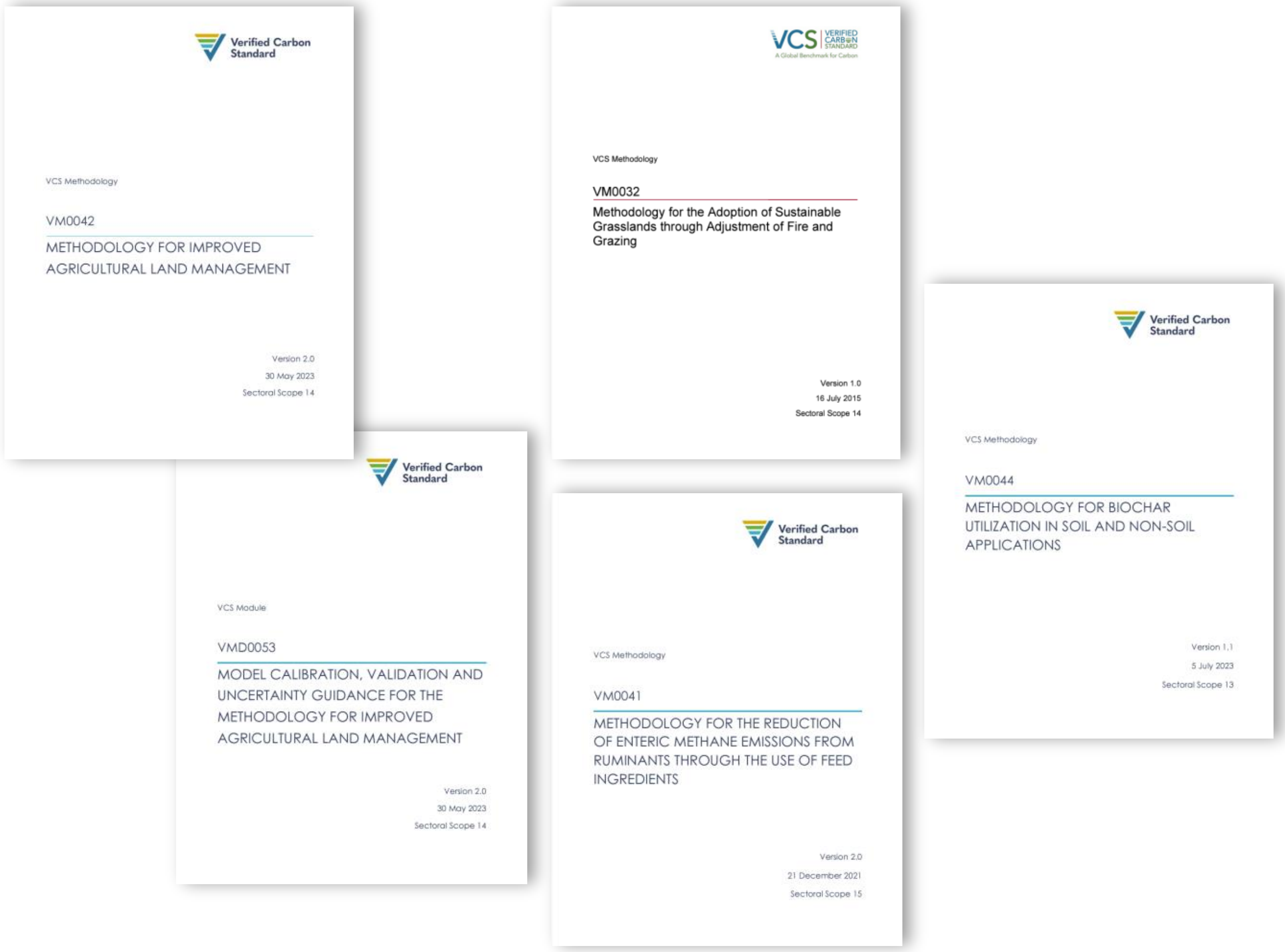
Verra Registry: Best Registry Provider
2021, 2022, 2023

VCS Ag Methodologies

Current opportunities to credit agricultural emission reduction and removal activities under the VCS

VERRA

Agriculture Methodologies (Active)



Verified Carbon Standard
VCS Methodology
VM0042
METHODOLOGY FOR IMPROVED AGRICULTURAL LAND MANAGEMENT
Version 2.0
30 May 2023
Sectoral Scope 14

VCS VERIFIED CARBON STANDARD
A Global Benchmark for Carbon
VCS Methodology
VM0032
Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing
Version 1.0
16 July 2015
Sectoral Scope 14

Verified Carbon Standard
VCS Methodology
VM0044
METHODOLOGY FOR BIOCHAR UTILIZATION IN SOIL AND NON-SOIL APPLICATIONS
Version 1.1
5 July 2023
Sectoral Scope 13

Verified Carbon Standard
VCS Module
VMD0053
MODEL CALIBRATION, VALIDATION AND UNCERTAINTY GUIDANCE FOR THE METHODOLOGY FOR IMPROVED AGRICULTURAL LAND MANAGEMENT
Version 2.0
30 May 2023
Sectoral Scope 14

Verified Carbon Standard
VCS Methodology
VM0041
METHODOLOGY FOR THE REDUCTION OF ENTERIC METHANE EMISSIONS FROM RUMINANTS THROUGH THE USE OF FEED INGREDIENTS
Version 2.0
21 December 2021
Sectoral Scope 15

The main characteristics of Ag Methodologies

Gases: N_2O, CH_4, CO_2

Sources and pools:

- Soil (SOC)
- Woody aboveground and belowground biomass
- Fertilizers (i.e., N-fertilization and Liming)
- Enteric fermentation
- Machinery

Quantification of ERRs:

- Direct measurement (*SOC: dry-combustion and CH_4: chamber measurements*)
- Empirical or processed-based models (e.g., Biogeochemical models)
- Default values (e.g., IPCC emission factors)

VERRA

Innovation and Challenges

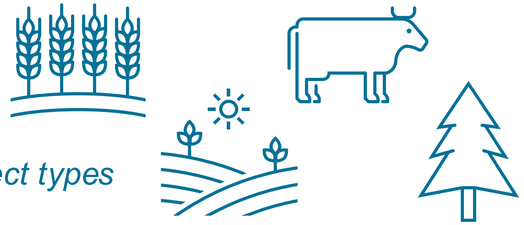
Current investment in technology to significantly increase transparency and efficiency and scale up our operations.

Innovations on GHG Quantifications

Technology Solutions

- **Digital Measurement, Reporting, and Verification (MRV) platform**

Direct Measurements
- Activity data *(e.g., surveys and digital data logs)*
- SOC stocks (Concentration and bulk density)
- CH4 and N2O fluxes *(i.e., chambers)*



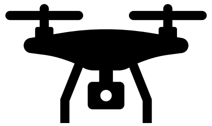
Project types

Present

(Well-stablished and implemented)

Indirect Measurements
- Activity data (e.g., image analysis)
- Indirect field measurements of GHG sources and C-pools

Satellites

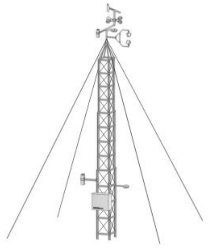


Drones

Present

(Well-advanced and under assessment)

Auxiliary Measurements
- Direct and indirect field measurements of GHG sources and C-pools
- Sensors and probes *(e.g., soil temperature and moisture)*



Eddy Covariance towers

Feasible future?

Source: Flux tower figure - https://vecta.io/symbols/321/human-science-research/46/flux-tower

Challenges to Adopt and Scale Innovation

Measurement approaches

- Uncertainty: identification of *error* sources and standard *error* propagation
- High deduction factors to be applied to ERRs
- Stratification of project area
- Standard Protocols
- Equipment costs
- Operational and maintenance needs

Data availability

- Limited access to data sources
- **F**indable, **A**ccessible, **I**nteroperable, and **R**eusable FAIR data principle
- Data Management Plan (DMP)

Organizational infrastructure

- Physical structure and high investment costs
- Technical and operational capacity

VERRA

Source: Flux tower figure - https://vecta.io/symbols/321/human-science-research/46/flux-tower

Agriculture Methodologies (Under development)

Methodology Draft Development

- Tool for quantifying organic carbon stocks using digital soil mapping: calibration, validation, and uncertainty estimation

SUMMARY OF DEVELOPMENT

The proposed tool was submitted by Perennial Climate Inc. (opens on external site) and is currently at "Step 3: Draft Methodology Development" of the *VCS Methodology Development and Review Process, 4.3* (PDF).

Stakeholders interested in collaborating during methodology development or developing projects that this methodology might enable are encouraged to contact methodologies@verra.org. Please include the Methodology Development ID# CN0137 in the subject line.

https://verra.org/methodologies/module-for-quantifying-organic-carbon-stocks-using-digital-soil-mapping-calibration-validation-and-uncertainty-estimation/

Open for Public Consultation

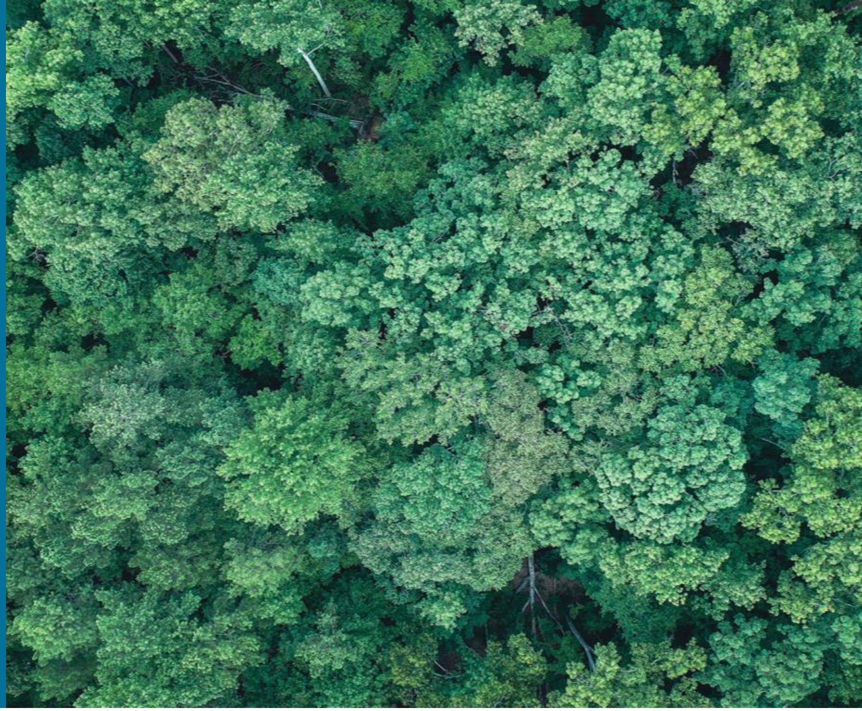
- Improved Management in Paddy Rice Production Systems

SUMMARY OF DEVELOPMENT

Verra is leading the development process for this methodology and has selected ATOA Carbon as the developer (see Section 2.1.1[2] of the *VCS Methodology Development and Review Process, v4.4* (PDF)). The proposed methodology is currently at "Step 4: Public Stakeholder Consultation" of the *VCS Methodology Development and Review Process, v4.4* (PDF).

The consultation for this proposed consolidated methodology is open from June 11, 2024, to July 12, 2024. Stakeholders are encouraged to submit feedback using the M0253 Public Comments Template (xlsx) to methodologies@verra.org.

https://verra.org/methodologies/improved-management-in-paddy-rice-production-systems/



Thank you!

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VERRA

Scaling Evergreen Forest Photosynthesis: Needle → Tower → Landscape

FLUXNET Workshop | Lawrence Berkeley National Lab | 9 July 2024

Troy Magney, Zoe Pierrat

Collaborators: Dave Bowling, Rui Cheng, Barry Logan, Christian Frankenberg, Jochen Stutz, Katja Grossmann, Jaret Reblin, Andrew Maguire

Plant OPTICS LAB

Observation Platforms To Interpret Complex ecoSystems

UC DAVIS

UNIVERSITY OF CALIFORNIA

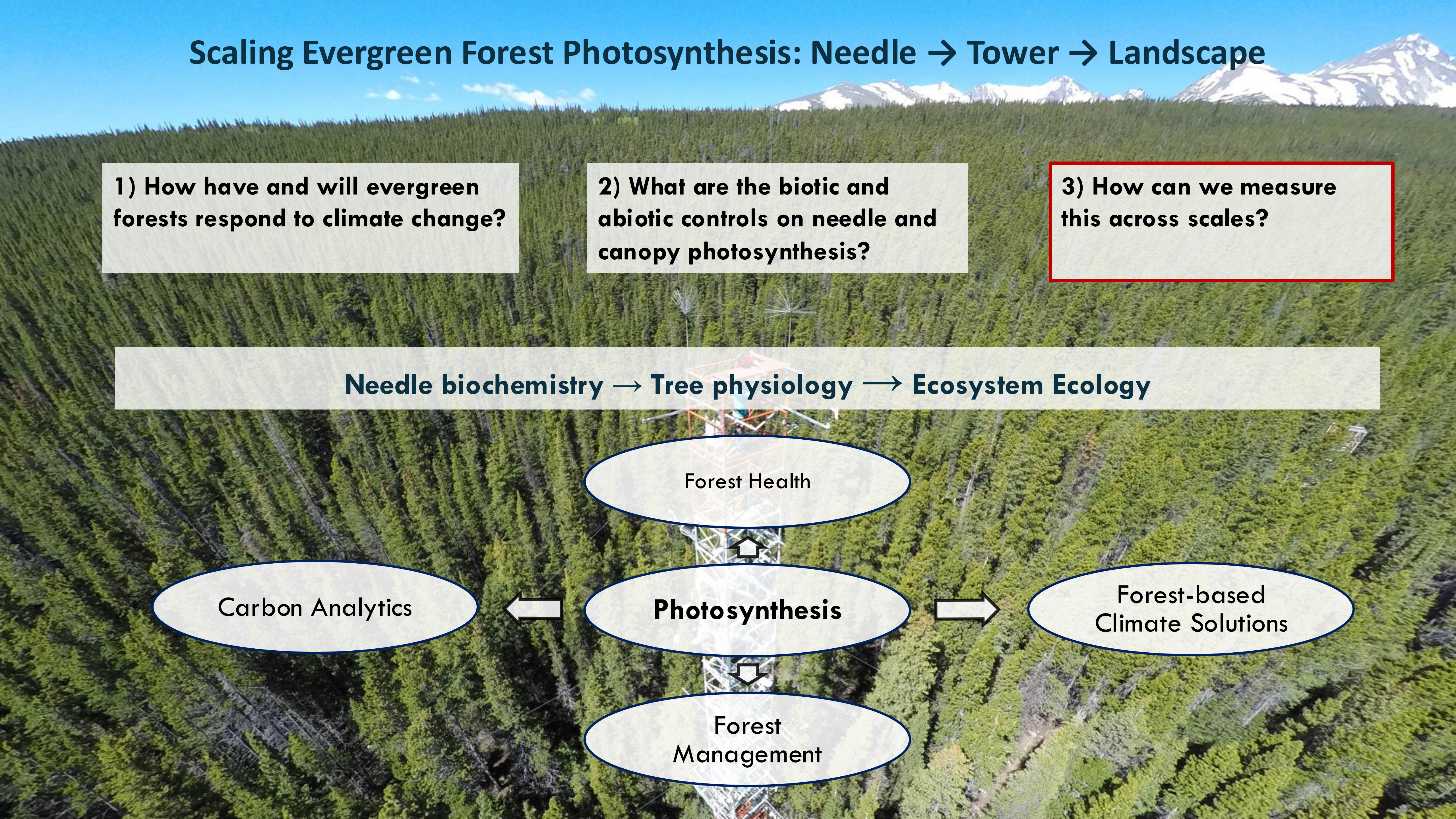
Scaling Evergreen Forest Photosynthesis: Needle → Tower → Landscape

1) How have and will evergreen forests respond to climate change?

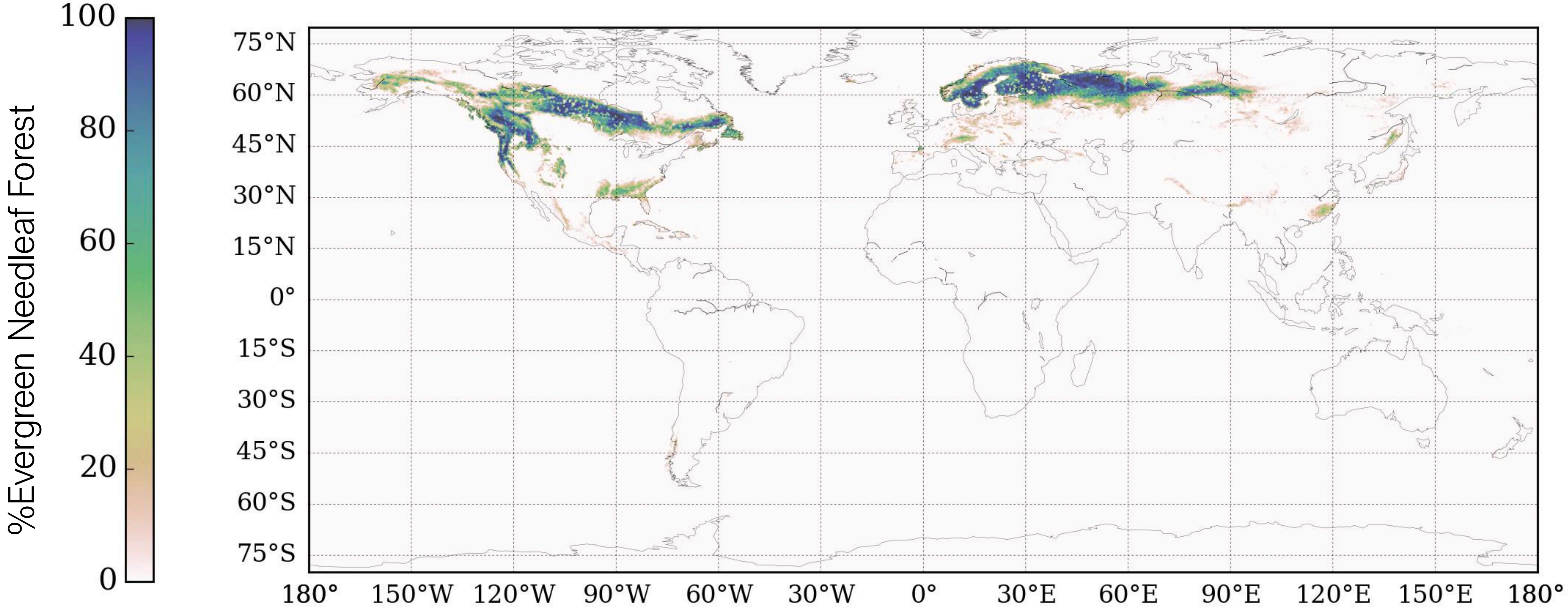
2) What are the biotic and abiotic controls on needle and canopy photosynthesis?

3) How can we measure this across scales?

Needle biochemistry → Tree physiology → Ecosystem Ecology



Evergreen Needleleaf Forests (ENF) are widespread, provide critical ecosystem services, and play a major role in the global carbon cycle

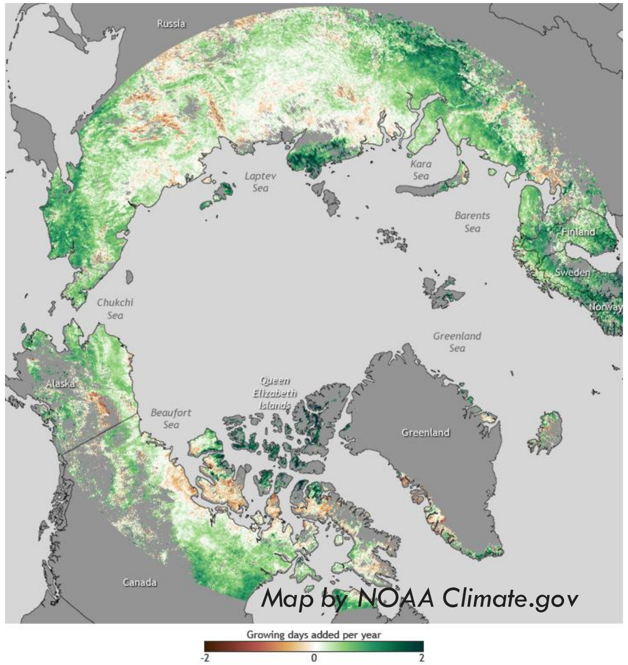


The impacts of anthropogenic climate change have made the fate of ENF highly uncertain

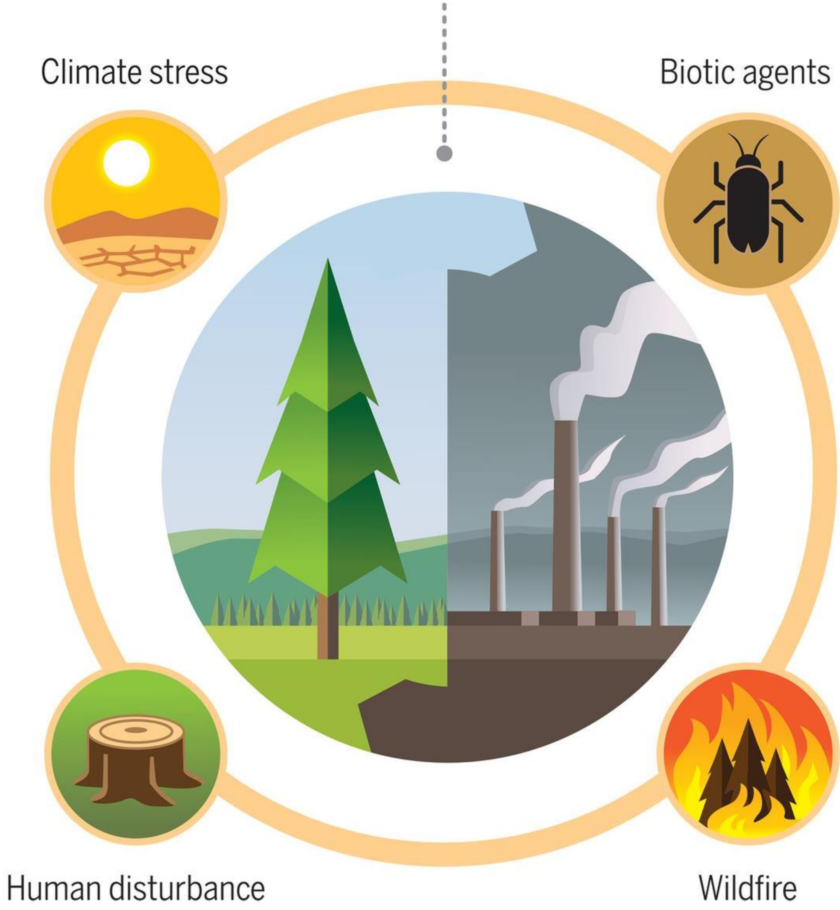
Longer growing seasons

Widespread greening

From Cindy Star/NASA's Goddard Space Flight Center



A myriad of climate related threats



Anderegg et al. 2020, Science

Insects and disease

Fire

Photosynthesis (the timing and magnitude of CO_2 uptake) plays a central role.

But it's challenging to measure across scales

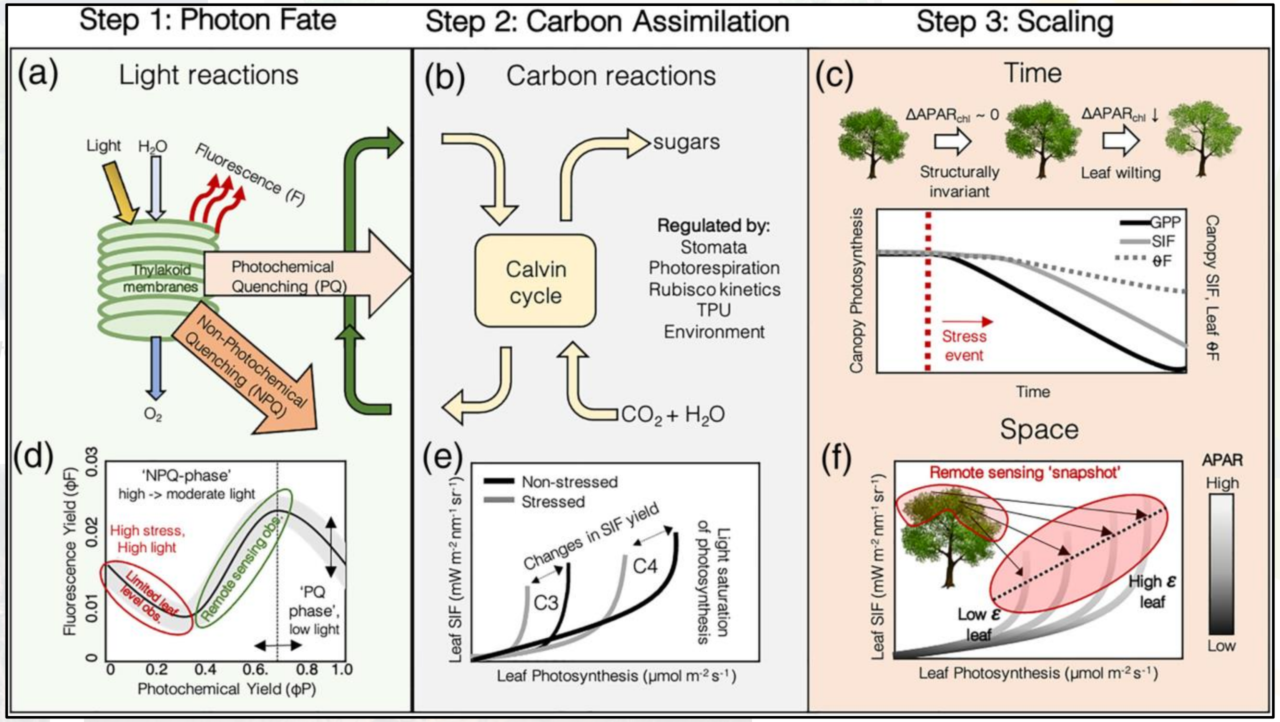
And requires a nuanced understanding of the light and carbon reactions of photosynthesis

Widespr

lated threats

Biotic agents

From Cindy Star/NASA's Goddard Space Flight Cent



Geophysical Research Letters

COMMENTARY

10.1029/2020GL091098

On the Covariation of Chlorophyll Fluorescence and Photosynthesis Across Scales

Troy S. Magney[1], Mallory L. Barnes[2], and Xi Yang[3]

Key Points:

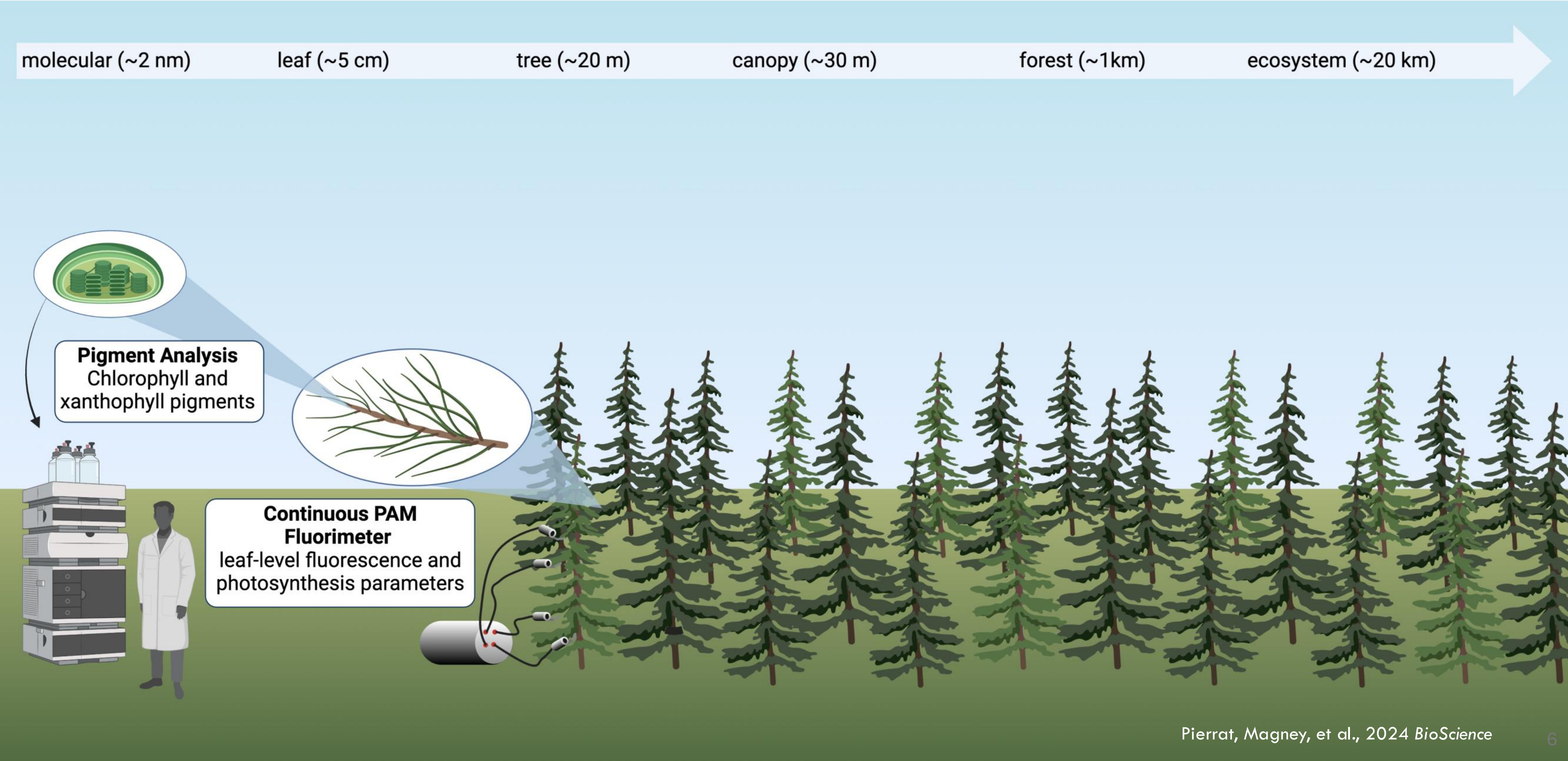
- Solar-induced fluorescence (SIF) is

Wildfire

Anderegg et al. 2020, Science

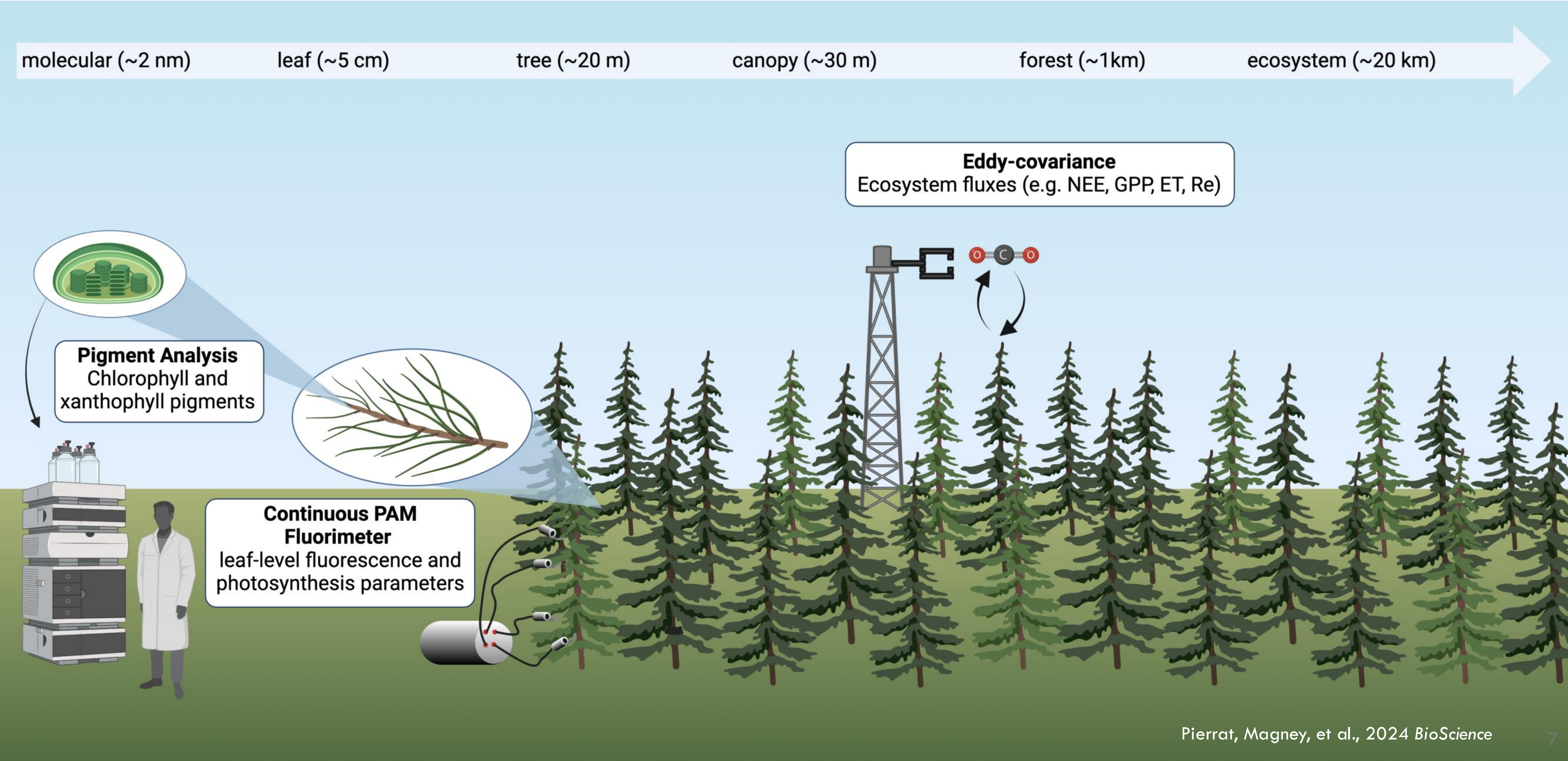
Pests

At the leaf/needle scale we can quantify ENF photosynthetic parameters using pigment analysis, PAM fluorimetry, and gas-exchange



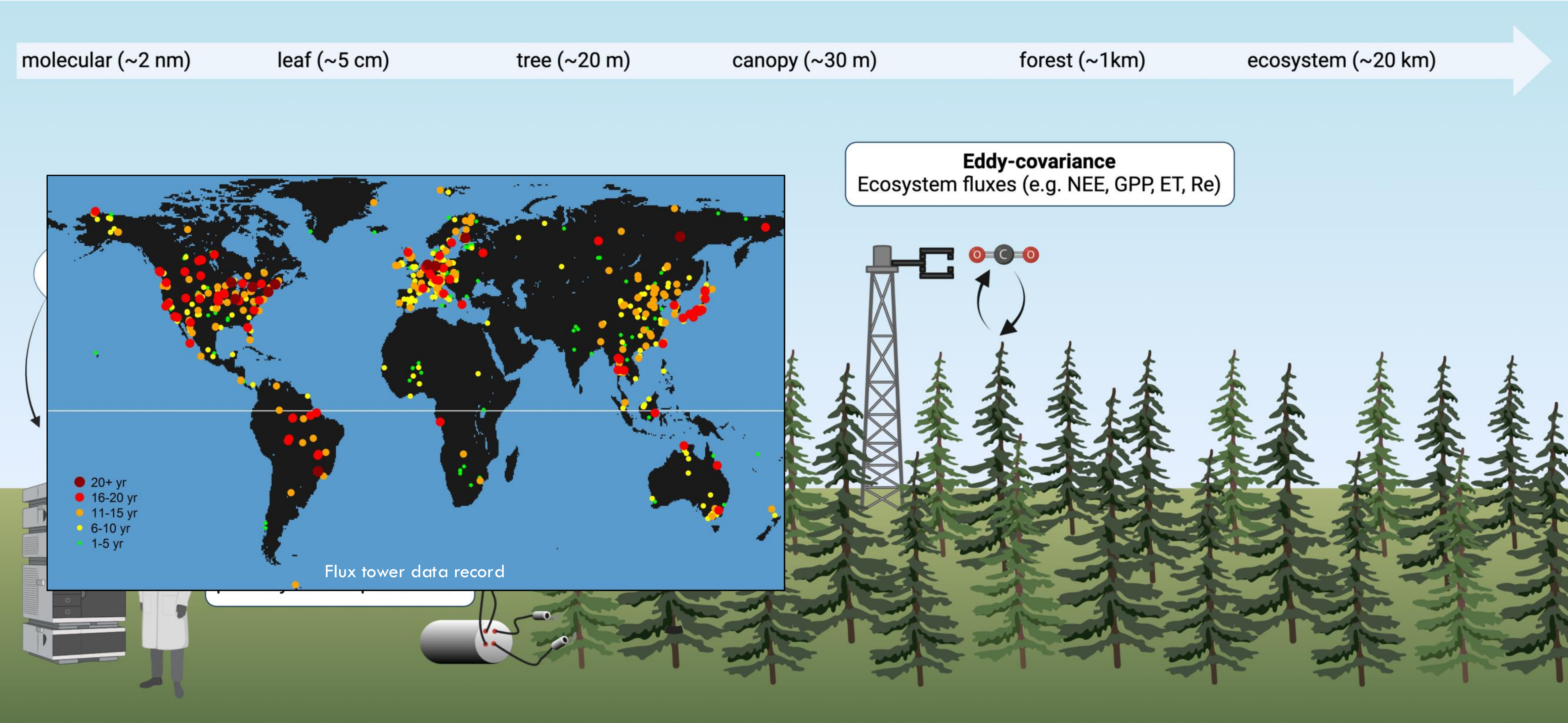
Pierrat, Magney, et al., 2024 *BioScience*

At the site/canopy-level we can use the eddy-covariance technique to derive gross-primary production (GPP)



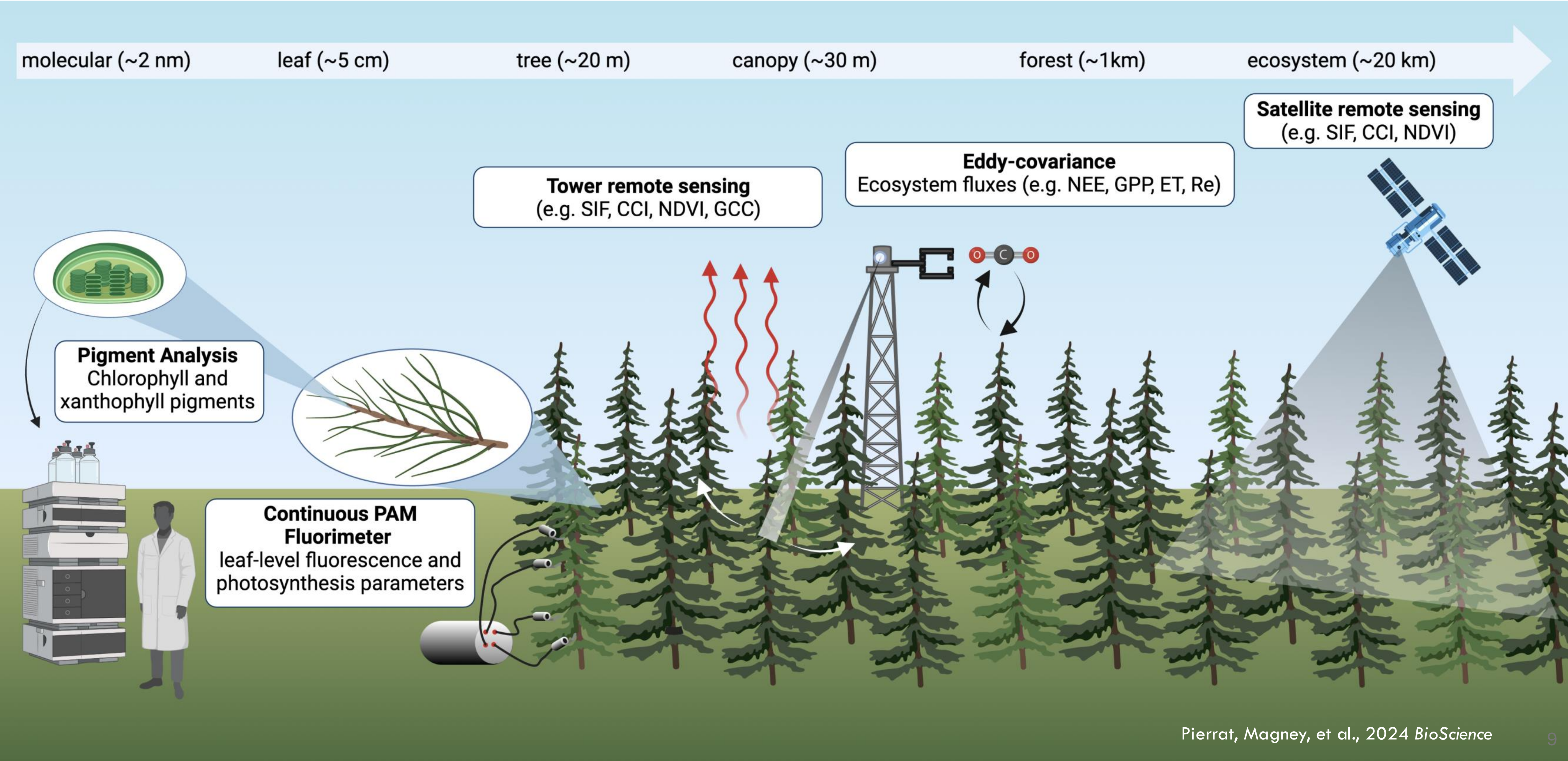
Pierrat, Magney, et al., 2024 *BioScience*

Site-level and flux tower observations are great….
but only optics can allow us to scale across space and time



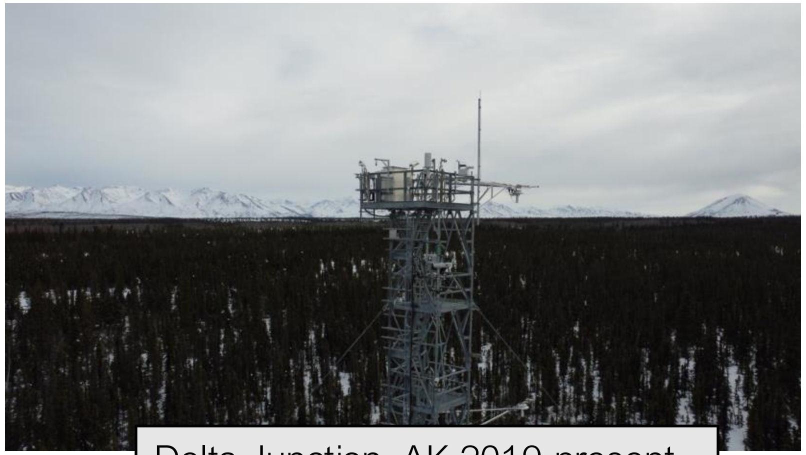
Pierrat, Magney, et al., 2024 *BioScience*

Tower and satellite-based optical metrics that are sensitive to underlying biology are an essential tool for understanding ENF

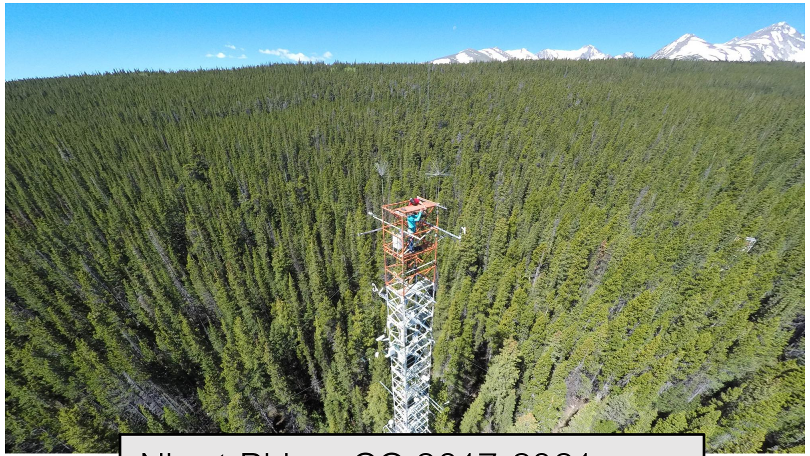


Pierrat, Magney, et al., 2024 *BioScience*

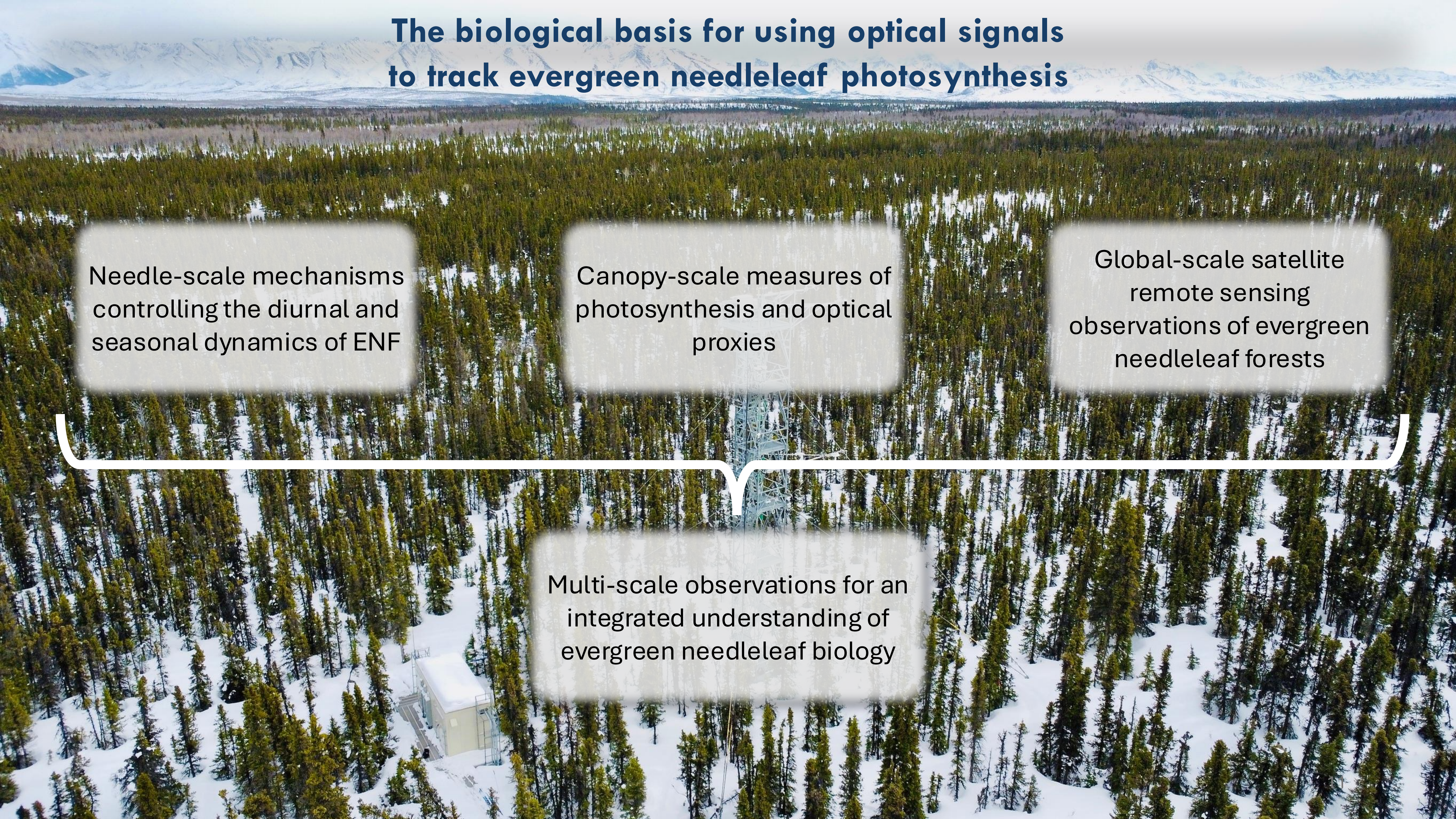
We can test this approach across ENF forests by collecting multi-scale data across a latitudinal gradient

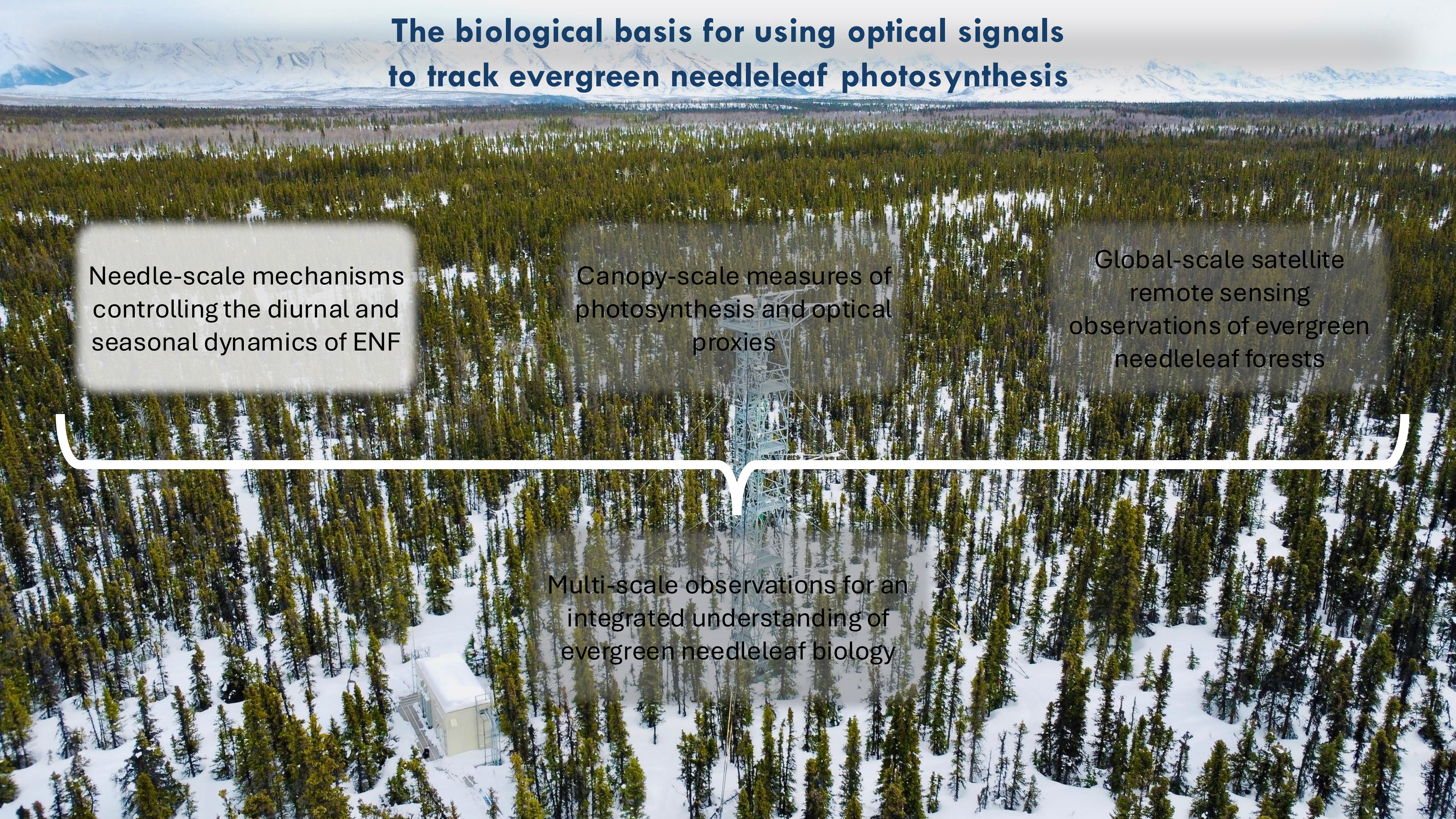

Delta Junction, AK 2019-present


Old Black Spruce, Sask. 2018-present


Niwot Ridge, CO 2017-2021


Ordway Swisher, FL 2019-present


The biological basis for using optical signals
to track evergreen needleleaf photosynthesis
Needle-scale mechanisms controlling the diurnal and seasonal dynamics of ENF
Canopy-scale measures of photosynthesis and optical proxies
Global-scale satellite remote sensing observations of evergreen needleleaf forests
Multi-scale observations for an integrated understanding of evergreen needleleaf biology


The biological basis for using optical signals to track evergreen needleleaf photosynthesis
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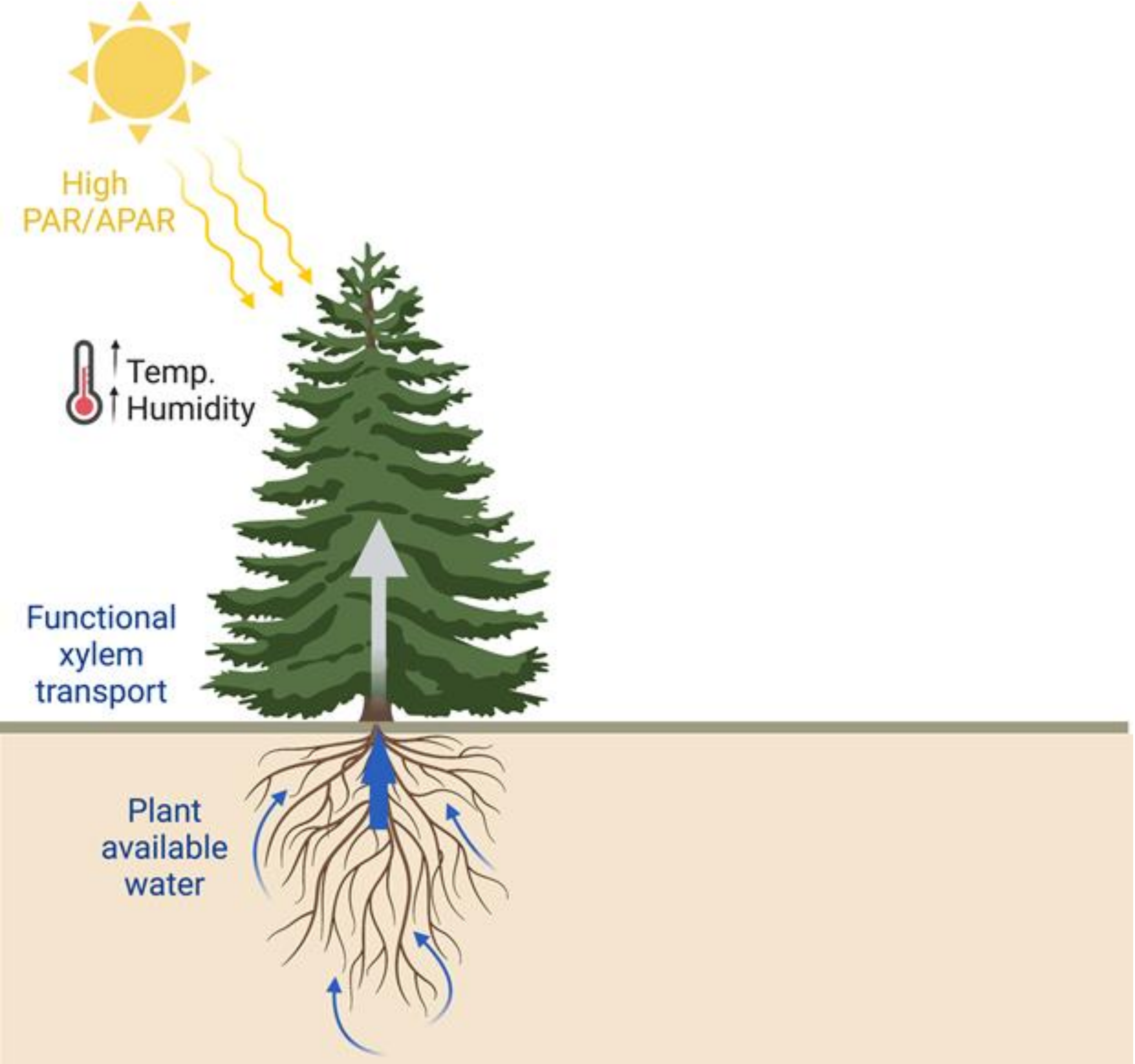
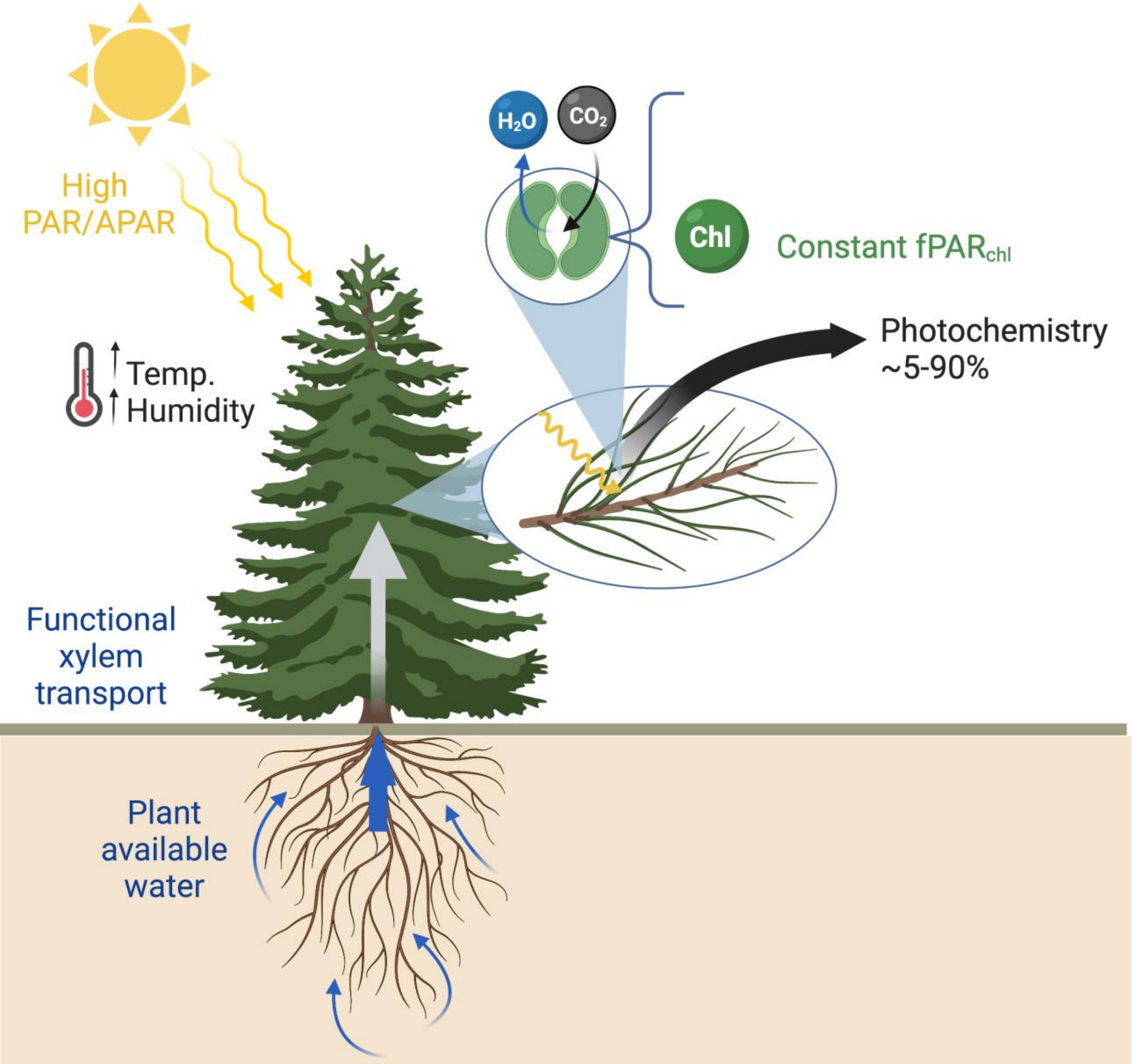
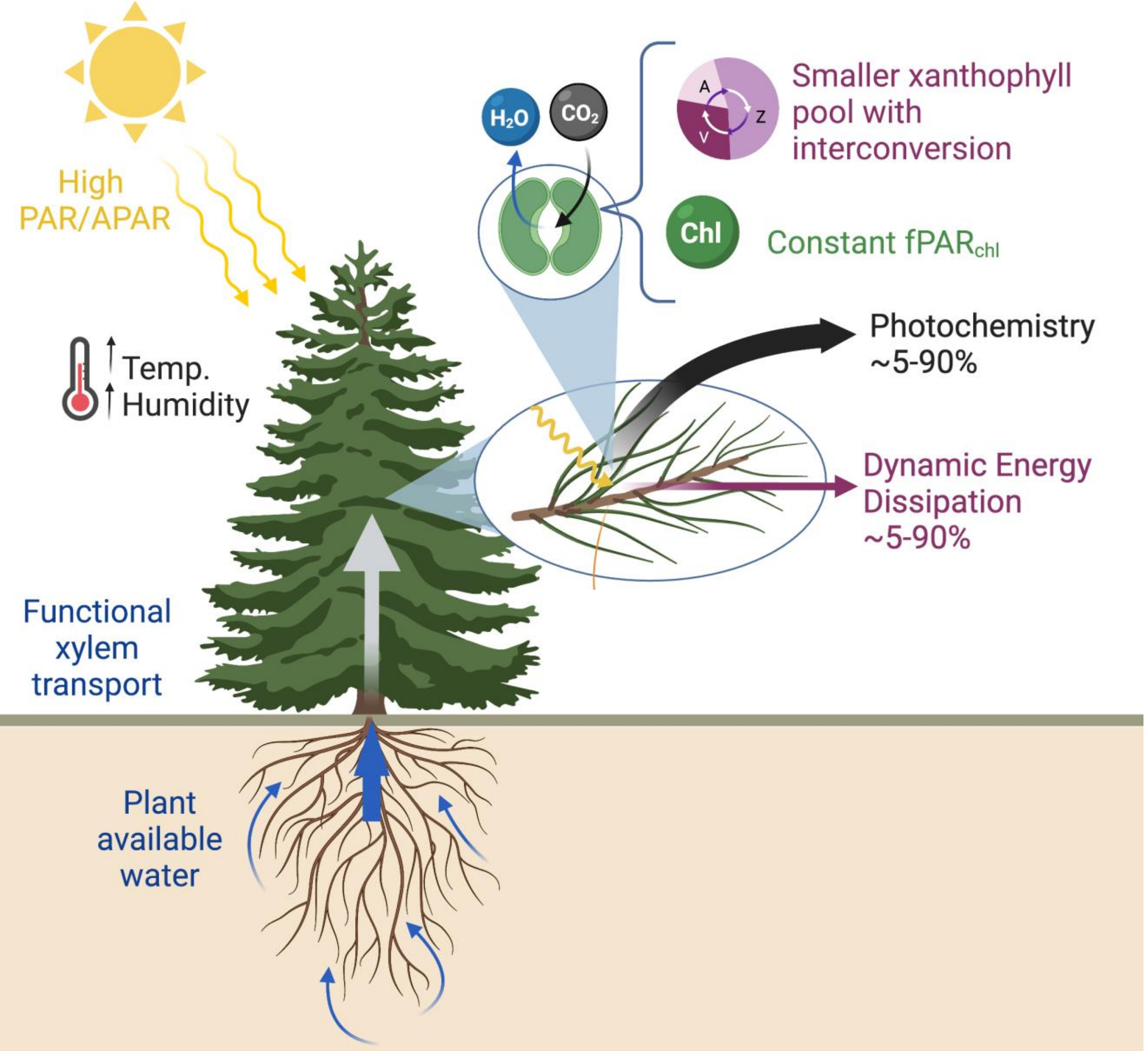
Environmental conditions regulate light harvesting at the needle scale



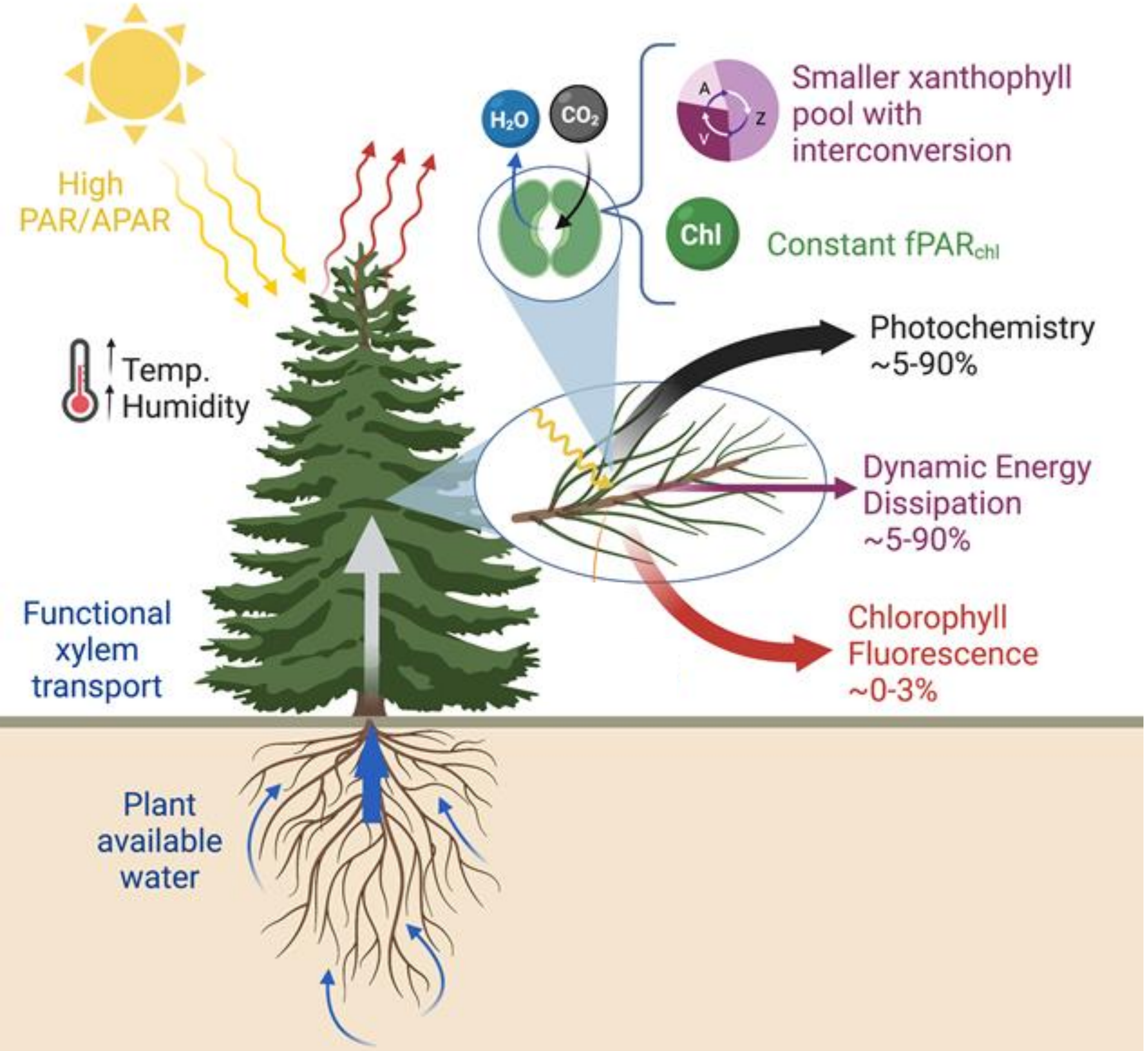
Evergreen species retain Chl year-round, but seasonally regulate light partitioning



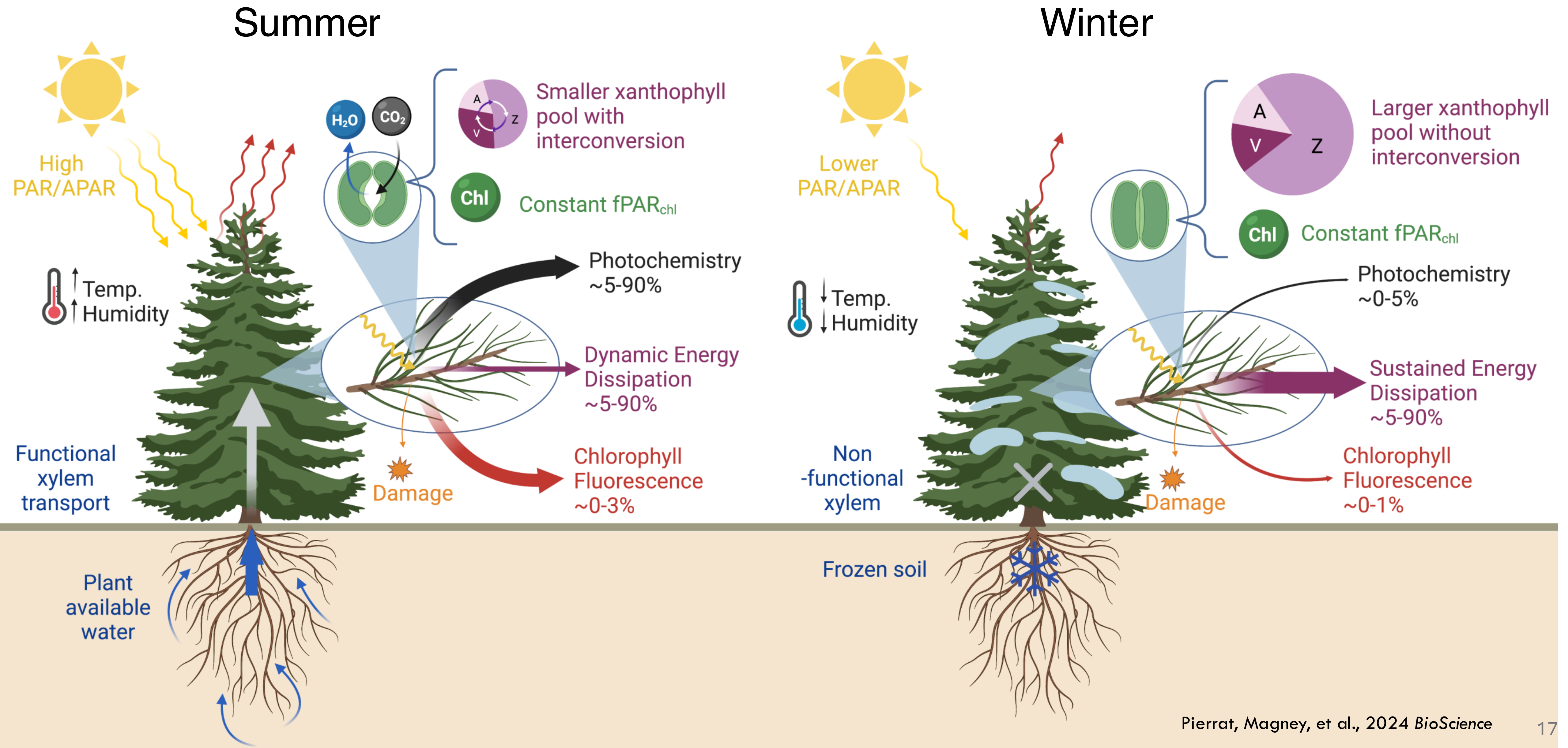
Plants can protect themselves from excess sunlight by safely dissipating the energy as heat (i.e., thermal energy dissipation)



Energy can also be re-emitted as fluorescence which is essentially an excited electron falling back down to its ground state

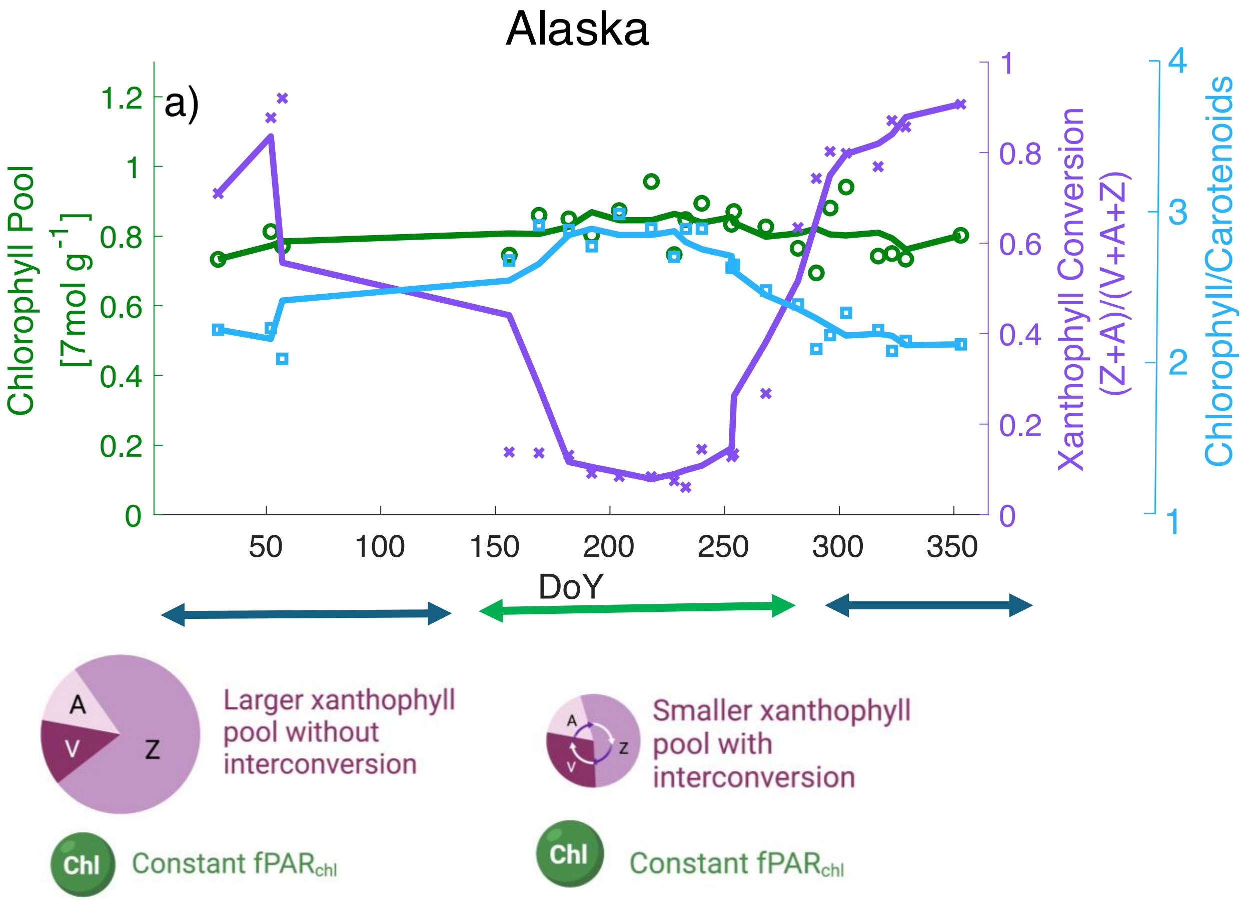


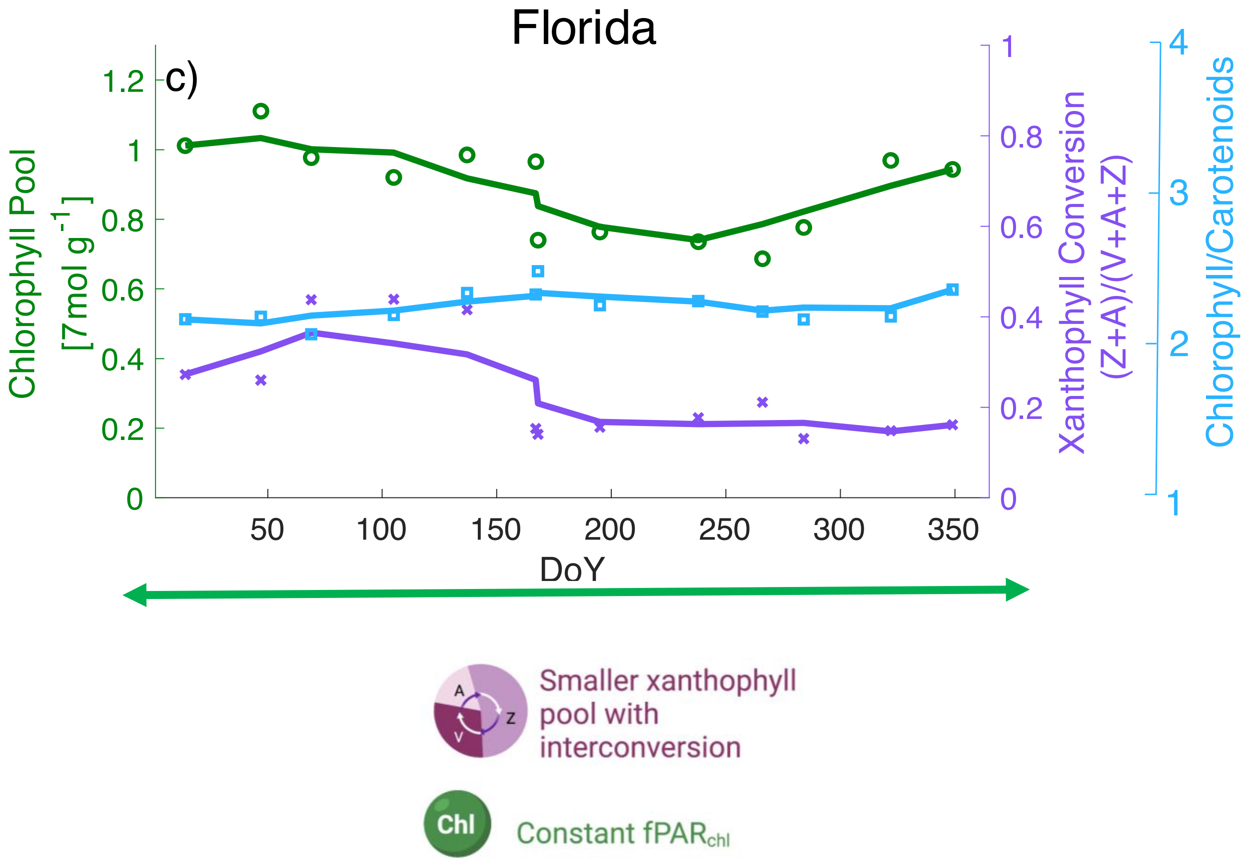
In many ENF, these processes also have a seasonal dependence due to harsh winters with sub-zero temperatures



Pierrat, Magney, et al., 2024 *BioScience*

We observe changes in pigments that reflect seasonal heat-dissipation dynamics

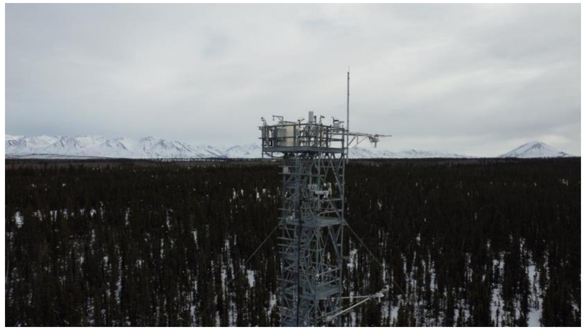


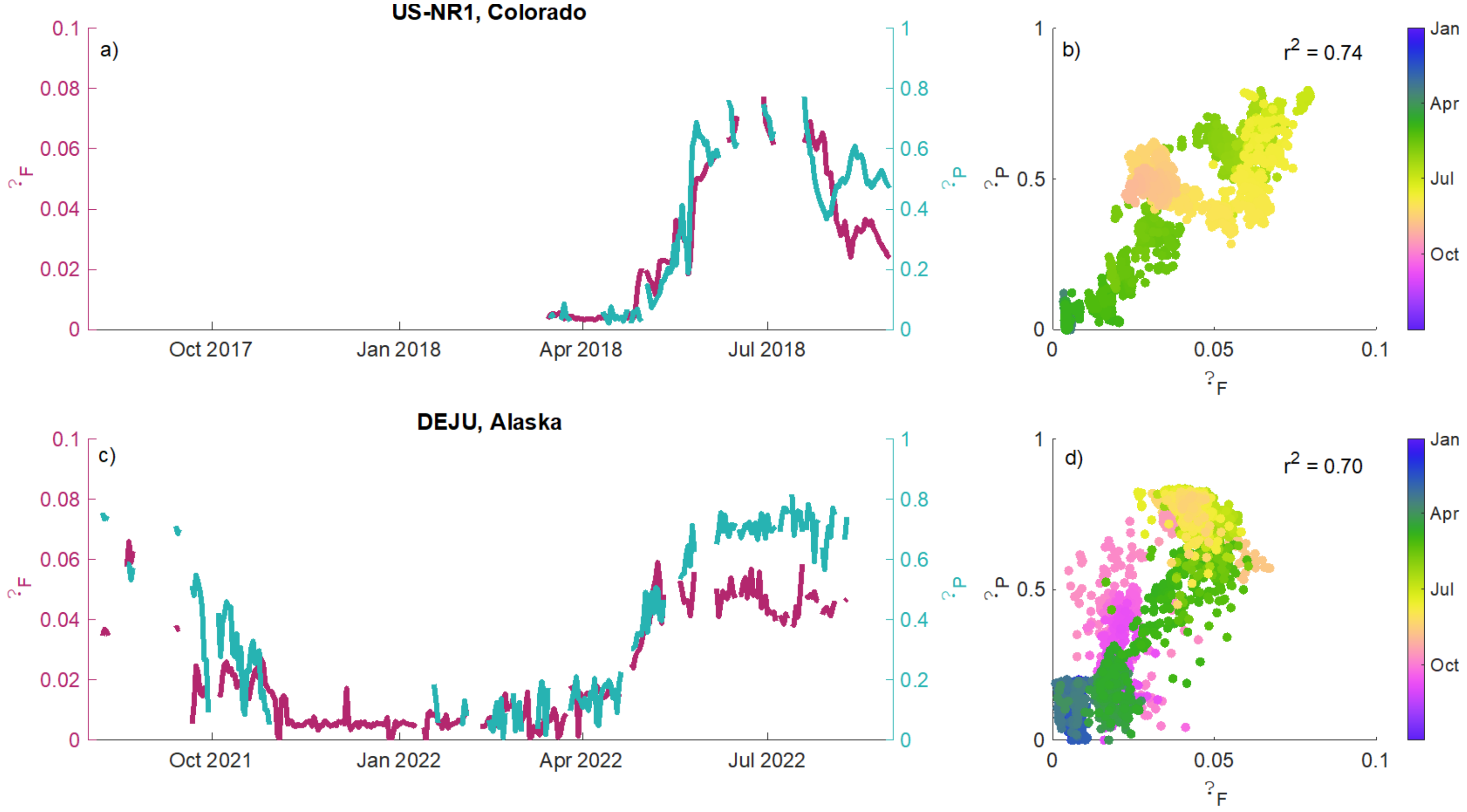


Pierrat, Magney, et al., 2024 *BioScience*

We also observe seasonal co-variation between yields of fluorescence and photosynthesis at the needle scale

ΦF = fluorescence yield
ΦP = photochemical yield

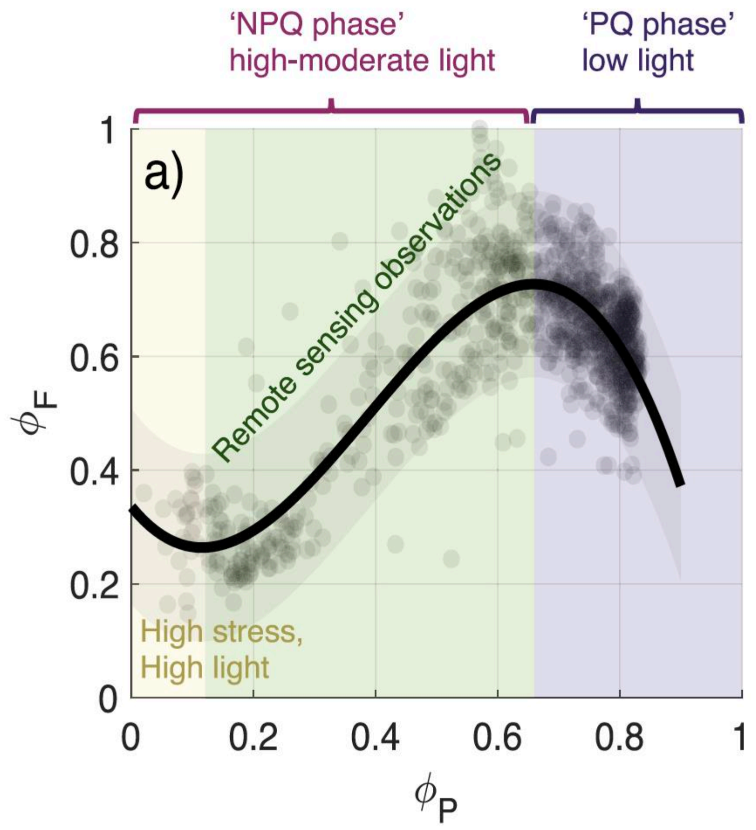


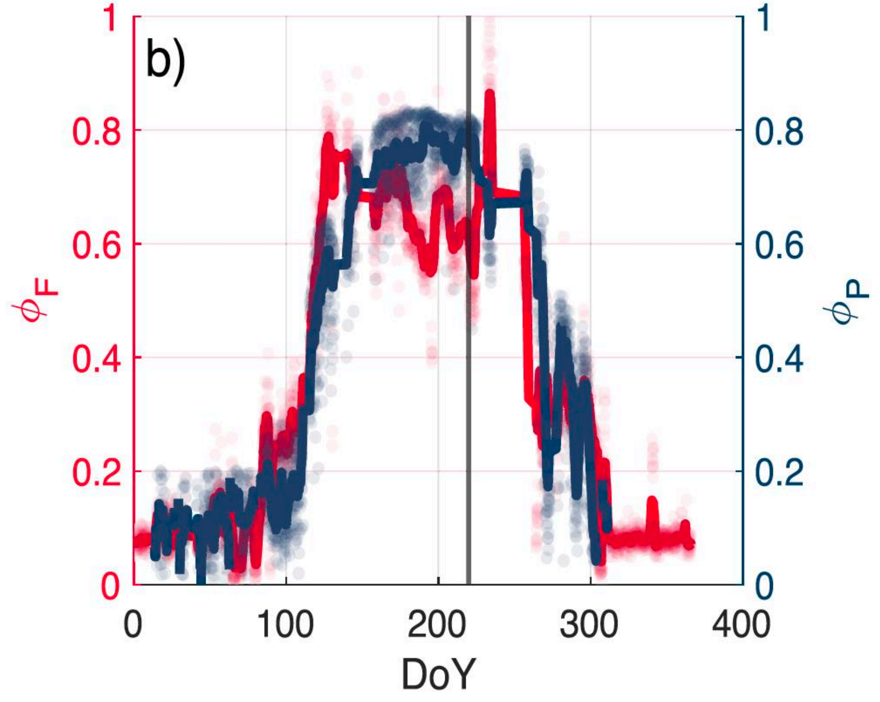


Pierrat, Magney, et al. *in press, Ecology*

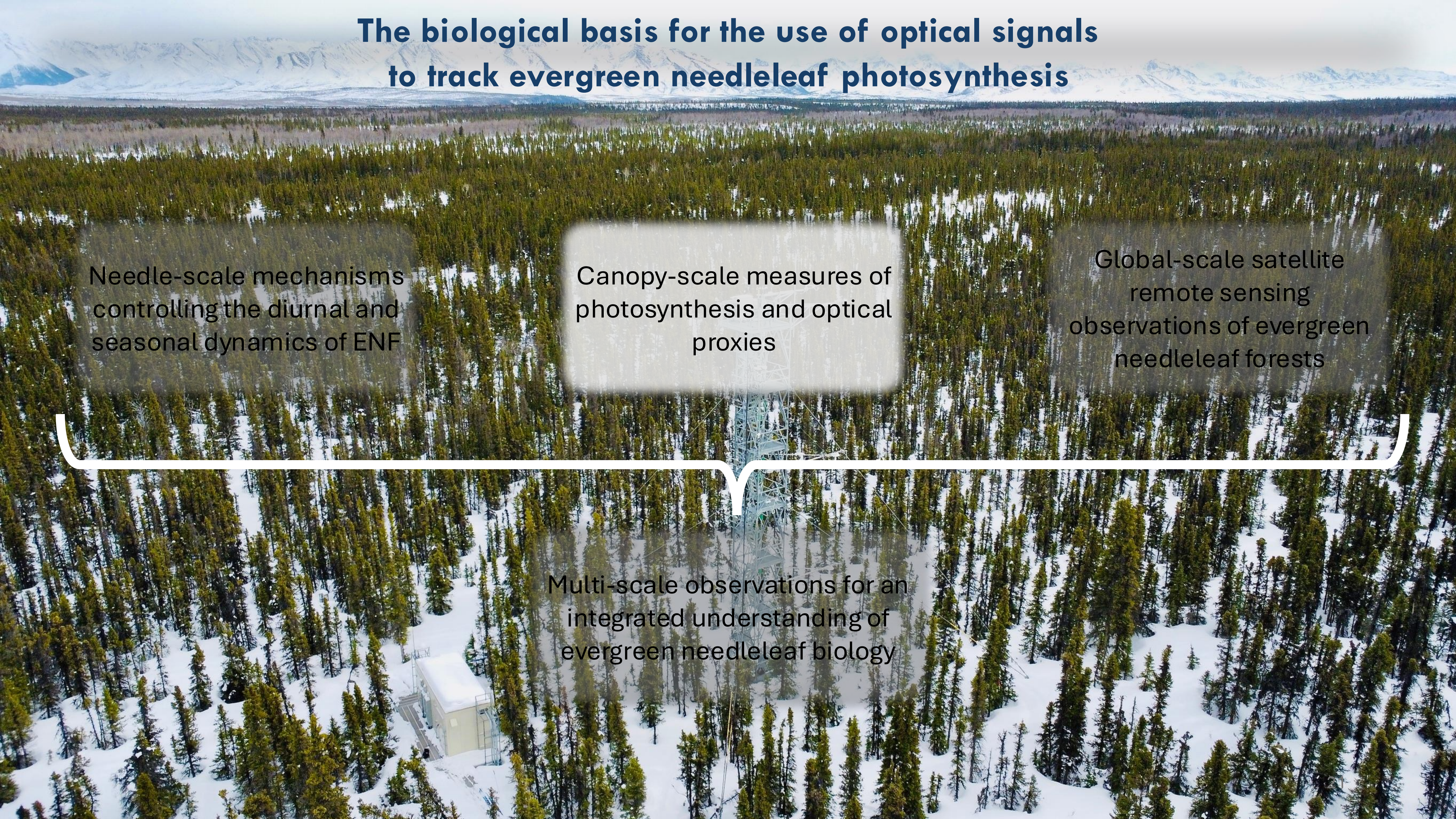
Remote sensing observations primarily occur during the 'NPQ' phase of the ΦF vs. ΦP relationship

Delta Junction, Alaska





Pierrat, Magney, et al., 2024 *BioScience*
Pierrat, Magney, et al., *in press,* Ecology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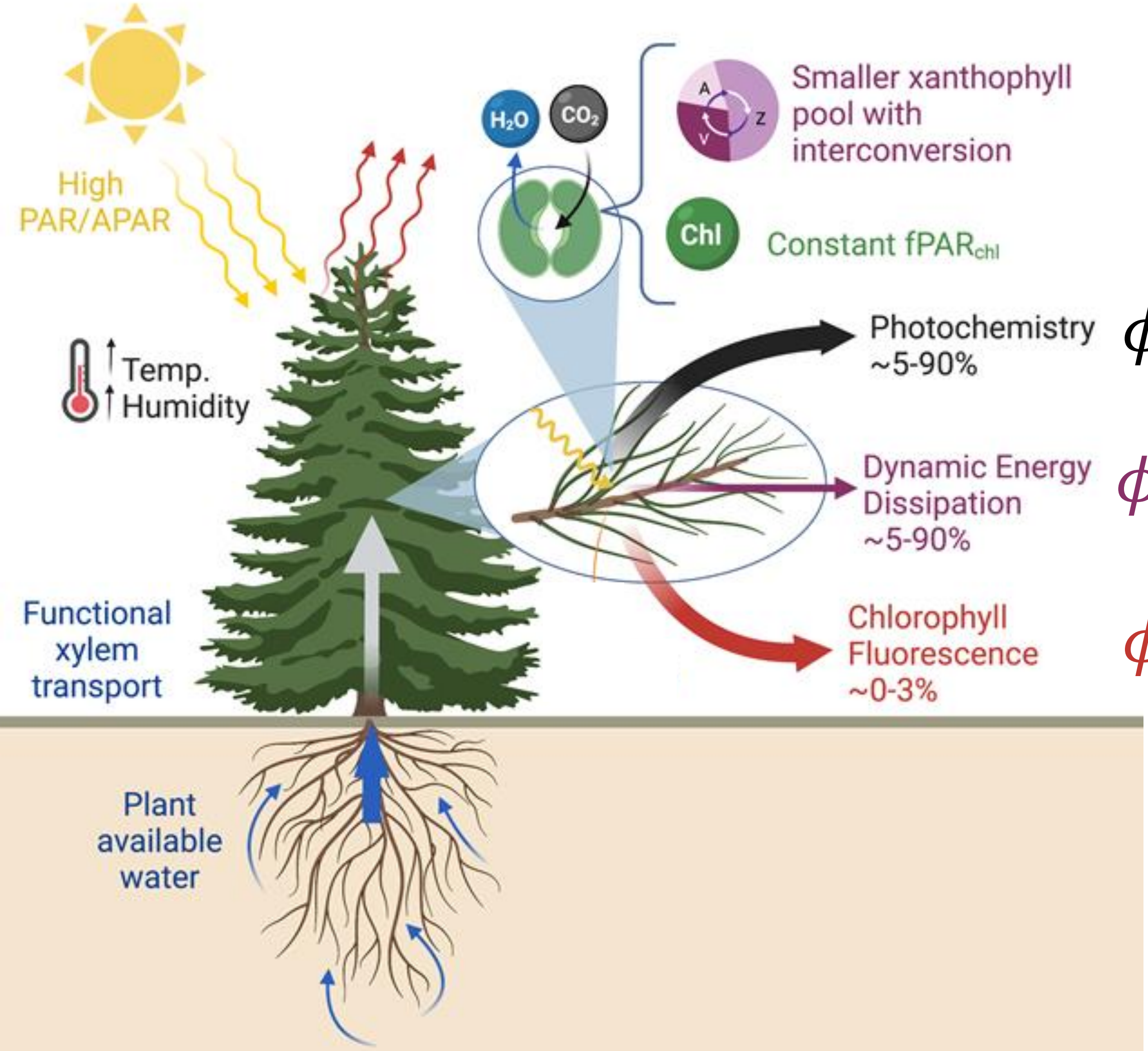
Gross Primary Productivity (GPP) depends on both the amount of absorbed light, and the partitioning among these different pathways



ϕ_P

ϕ_N

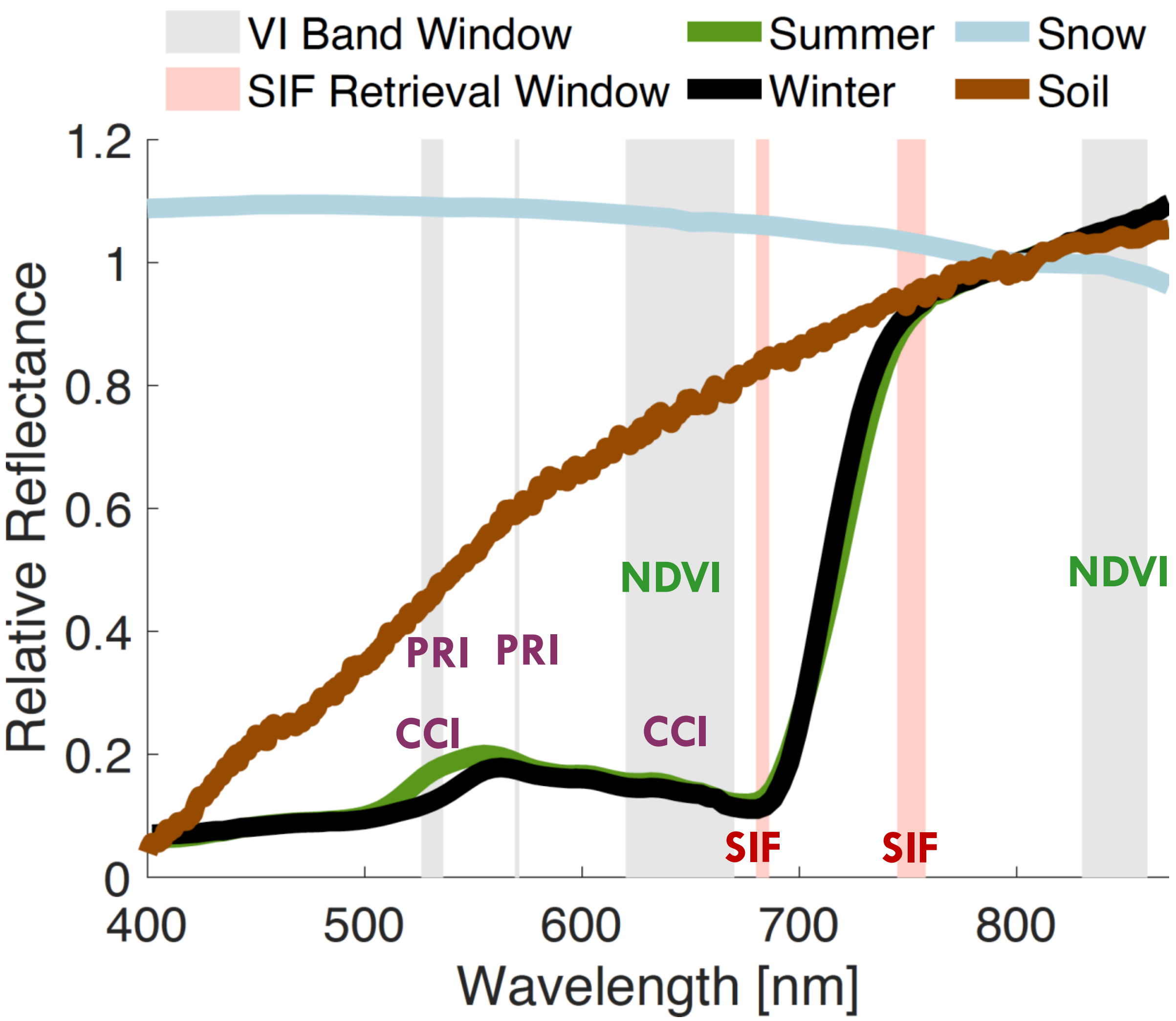
ϕ_F

$$1 = \phi_P + \phi_N + \phi_F$$

$$GPP = APAR_{Chl} * \phi_P$$

$$GPP = APAR_{Chl}(1 - \phi_N + \phi_F)$$

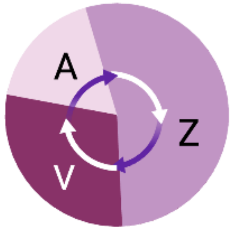
Optical metrics are sensitive to either the amount of absorbed light ($APAR_{chl}$) or energy partitioning



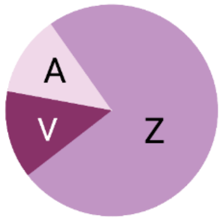
Pierrat, Magney, et al., 2024 *BioScience*

$$GPP = APAR_{Chl}(1 - \phi_N + \phi_F)$$

Normalized Diff. Veg. Index (NDVI)
Canopy Greenness



Photochemical Reflect. Index (PRI)
Dynamic Xanthophyll Interconversion



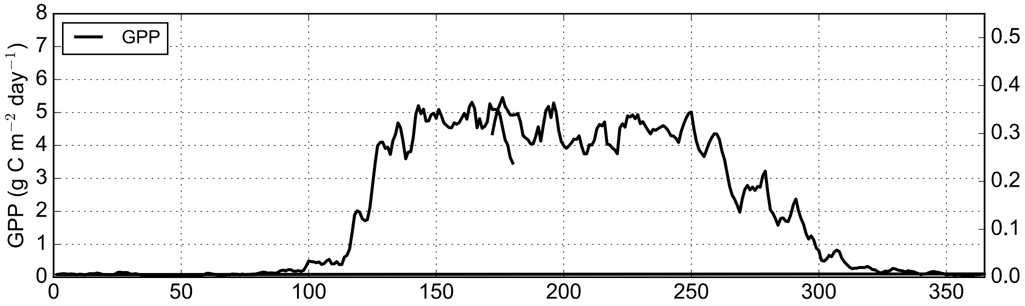
Chlorophyll:Carotenoid Index (CCI)
Sustained Xanthophyll Retention

Solar Induced Fluorescence (SIF)
Chlorophyll a fluorescence

A seasonal cycle at Niwot Ridge, Colorado

$$GPP = APAR_{Chl}(1 - \phi_N + \phi_F)$$

Niwot Ridge, CO



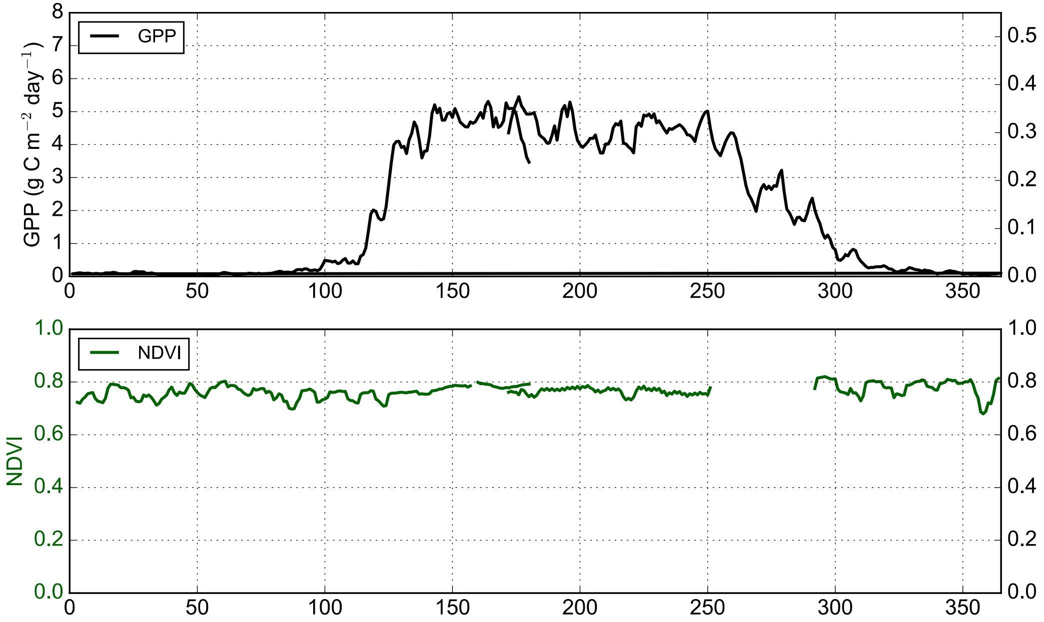
Day of Year

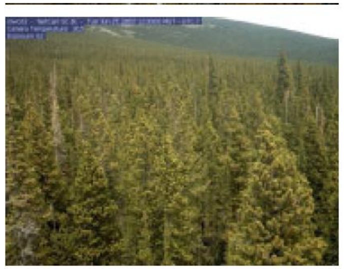
Magney et al., *PNAS*, 2019

NDVI is constant because negligible change in Chl and structure

$$GPP = APAR_{Chl}(1 - \phi_N + \phi_F)$$

Niwot Ridge, CO





Day of Year

Normalized Diff. Veg. Index (NDVI)

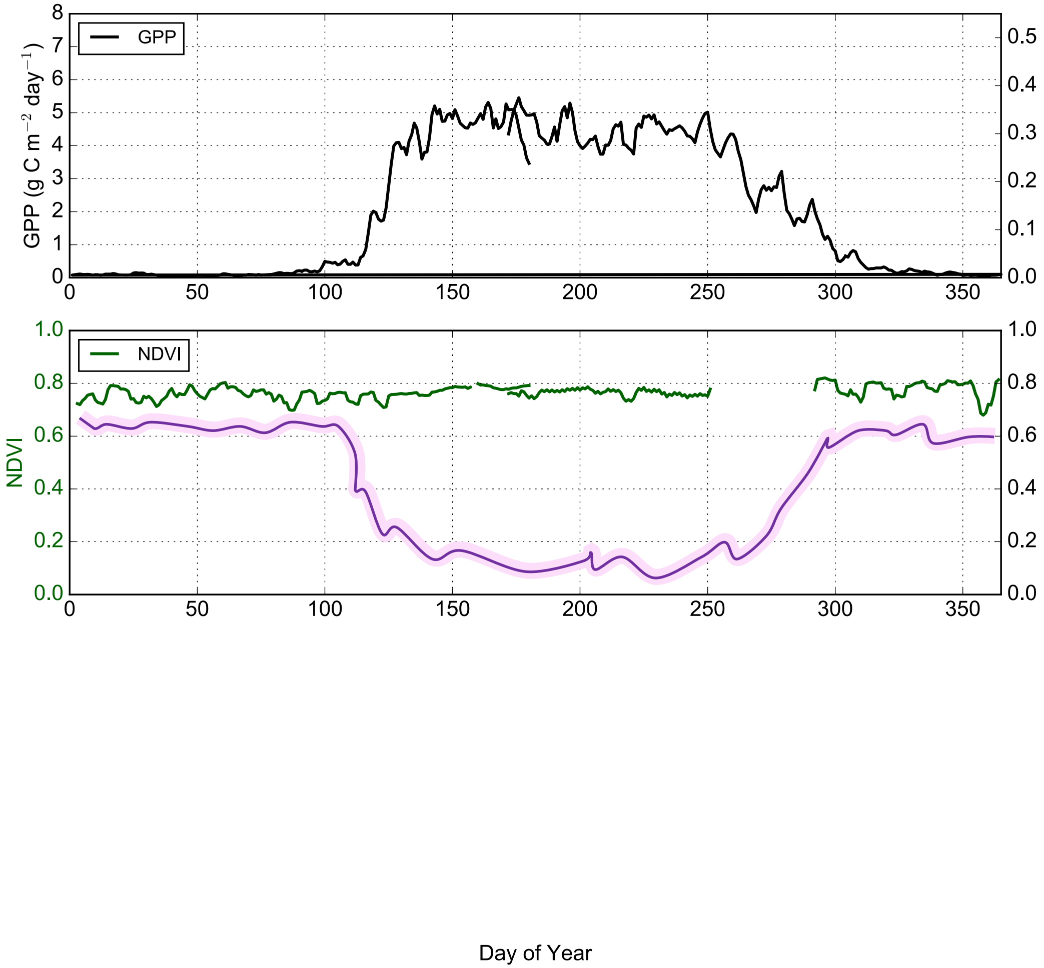
Canopy Greenness

Magney et al., *PNAS*, 2019

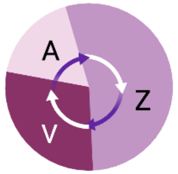
Pigment based indices can tell us about photoprotective mechanisms

$$GPP = APAR_{Chl}(1 - \phi_N + \phi_F)$$

Niwot Ridge, CO



Normalized Diff. Veg. Index (NDVI)
Canopy Greenness



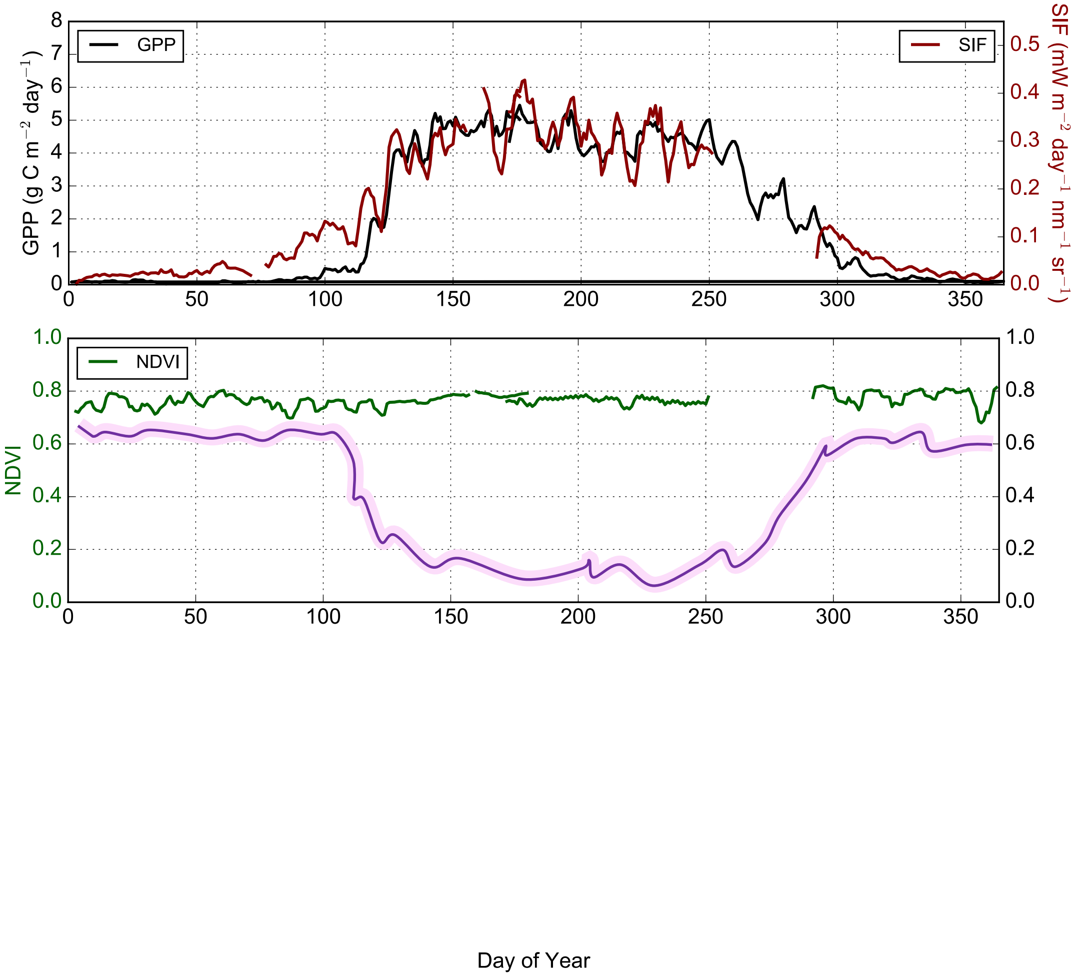
Photochemical Reflect. Index (PRI)
Integrated plant stress

Magney et al., *PNAS*, 2019

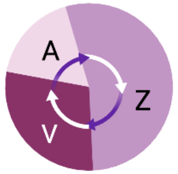
Solar-induced fluorescence is sensitive to both absorbed light and photochemistry

$$GPP = APAR_{Chl}(1 - \phi_N + \phi_F)$$

Niwot Ridge, CO



Normalized Diff. Veg. Index (NDVI)
Canopy Greenness



Photochemical Reflect. Index (PRI)
Integrated plant stress

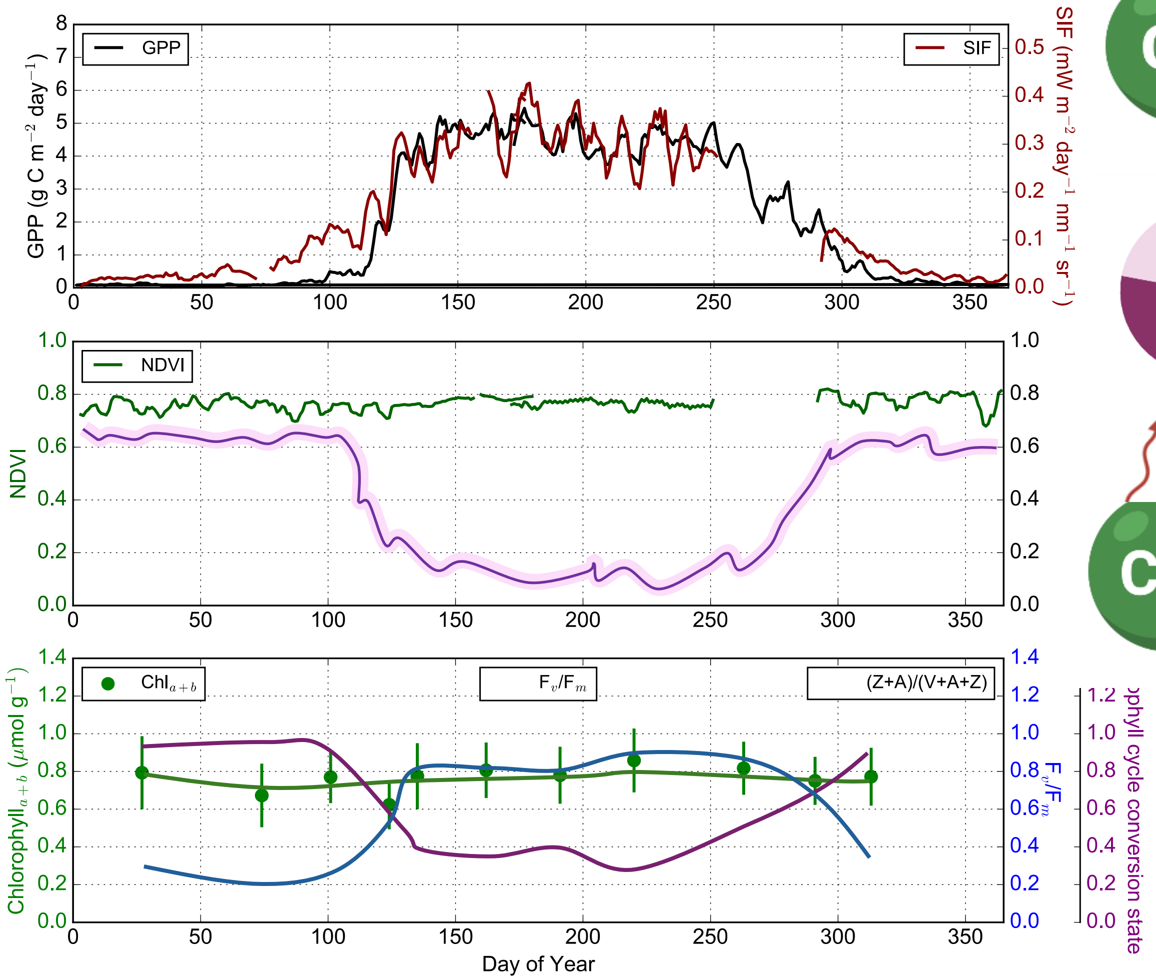
Solar Induced Fluorescence (SIF)
Chlorophyll a fluorescence

Magney et al., *PNAS*, 2019

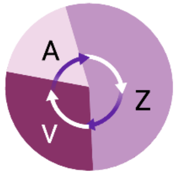
Covariation in the seasonality of field measured pigments and photochemistry

$$GPP = APAR_{Chl}(1 - \phi_N + \phi_F)$$

Niwot Ridge, CO



Normalized Diff. Veg. Index (NDVI)
Canopy Greenness



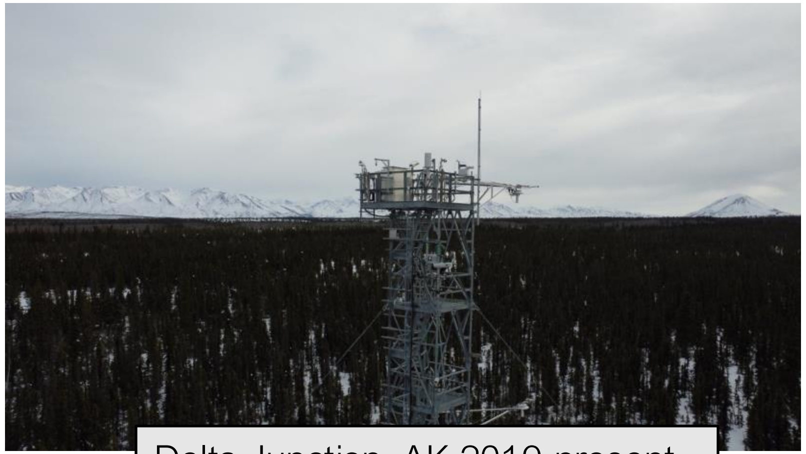
Photochemical Reflect. Index (PRI)
Integrated plant stress

Solar Induced Fluorescence (SIF)
Chlorophyll a fluorescence

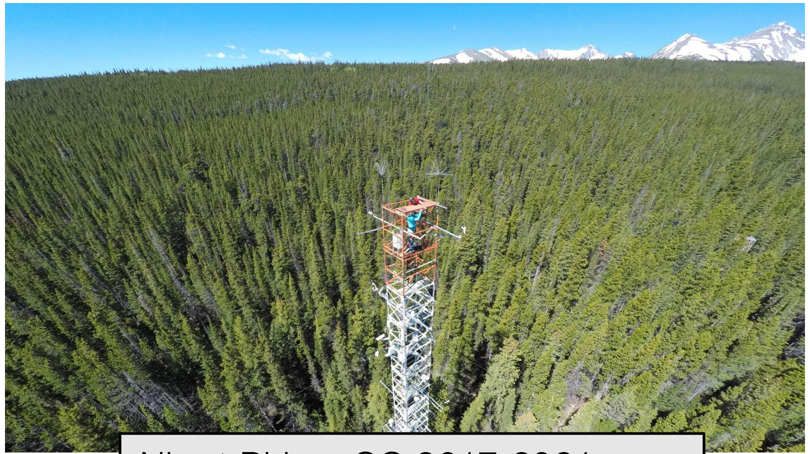
Seasonal cycles of needle pigments and photochemistry (in situ)

Magney et al., *PNAS*, 2019

Let's test this approach across four evergreen sites

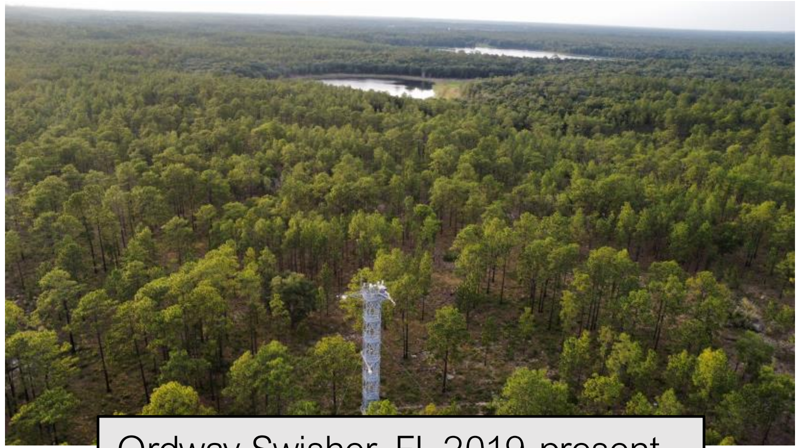


Delta Junction, AK 2019-present



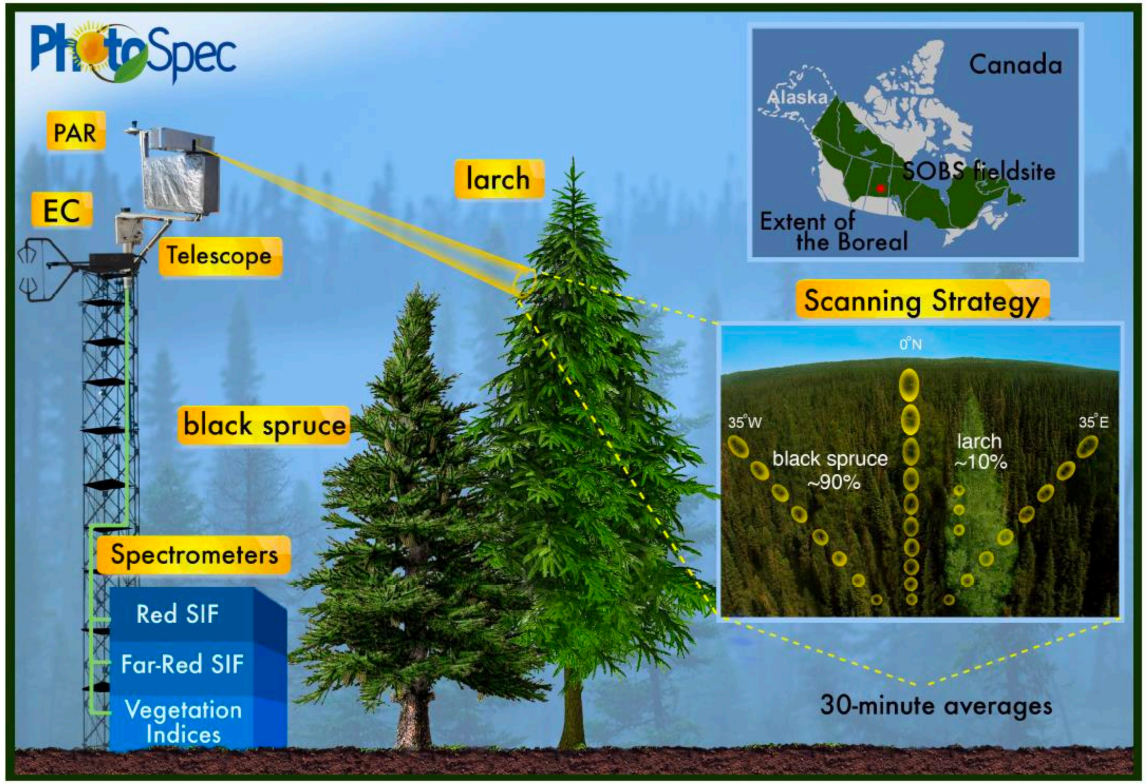
Niwot Ridge, CO 2017-2021

Old Black Spruce, Sask. 2018-present

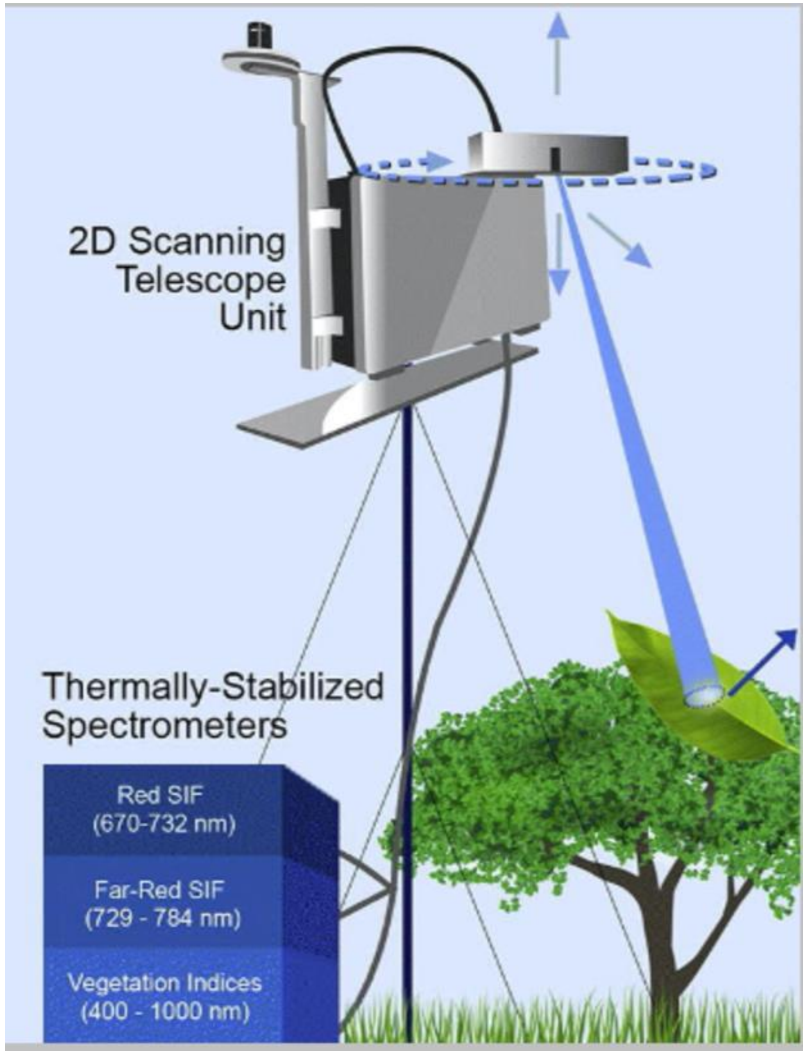


Ordway Swisher, FL 2019-present

We use a scanning-tower spectrometer, PhotoSpec, for continuous tower-based measurements (~20 second retrievals)

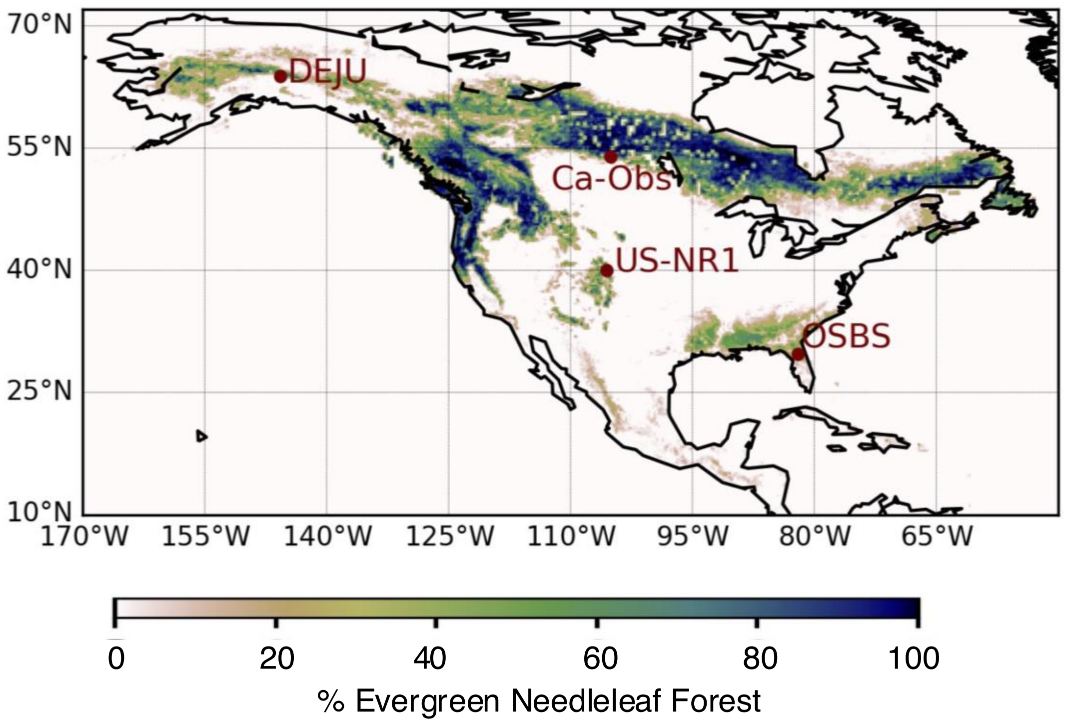


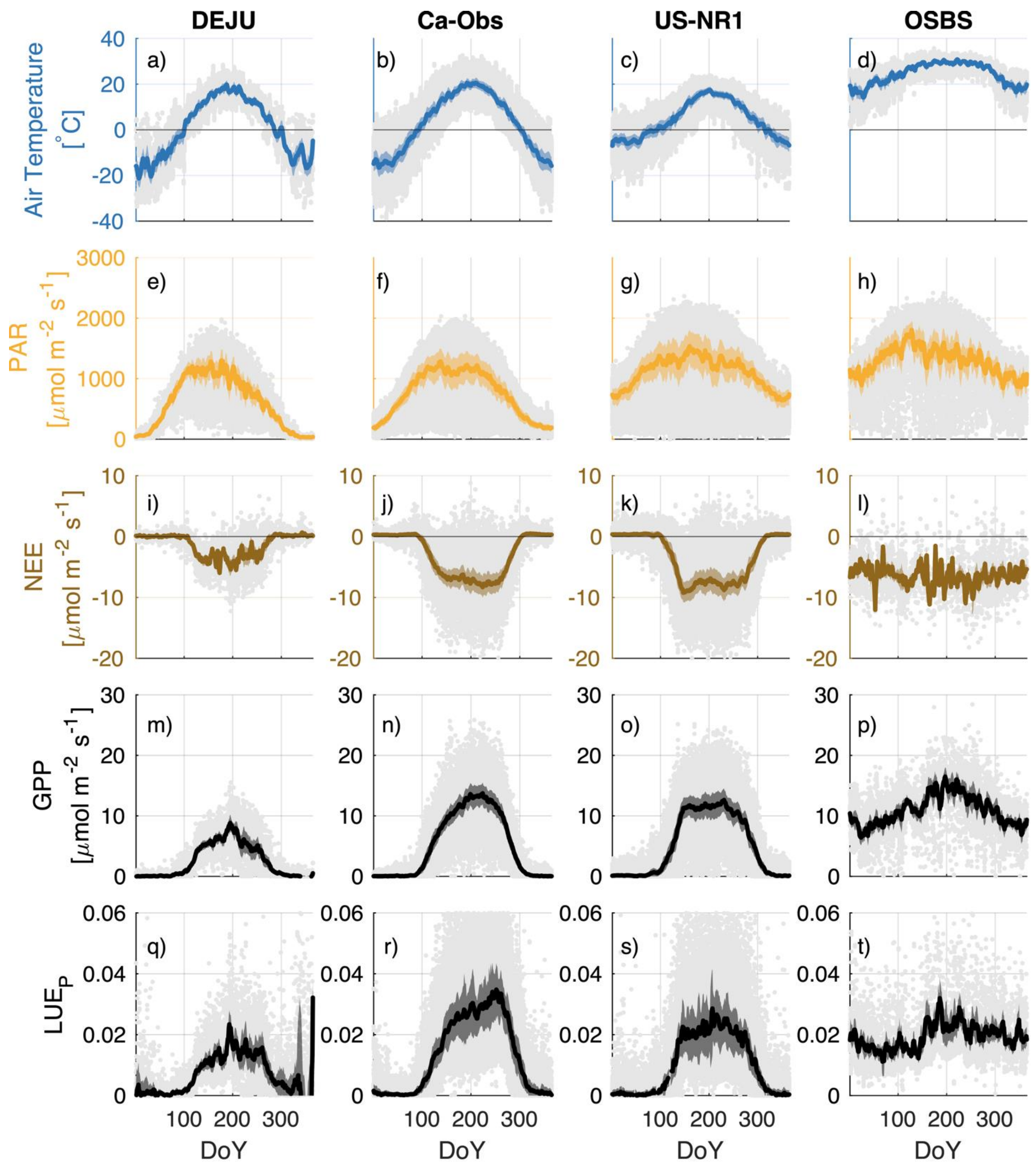
Pierrat, Magney, et al. 2022 *JGR-Biogeosciences*



Grossmann et al., 2018 *RSE*

Temperature and light drive the seasonal cycle of photosynthesis

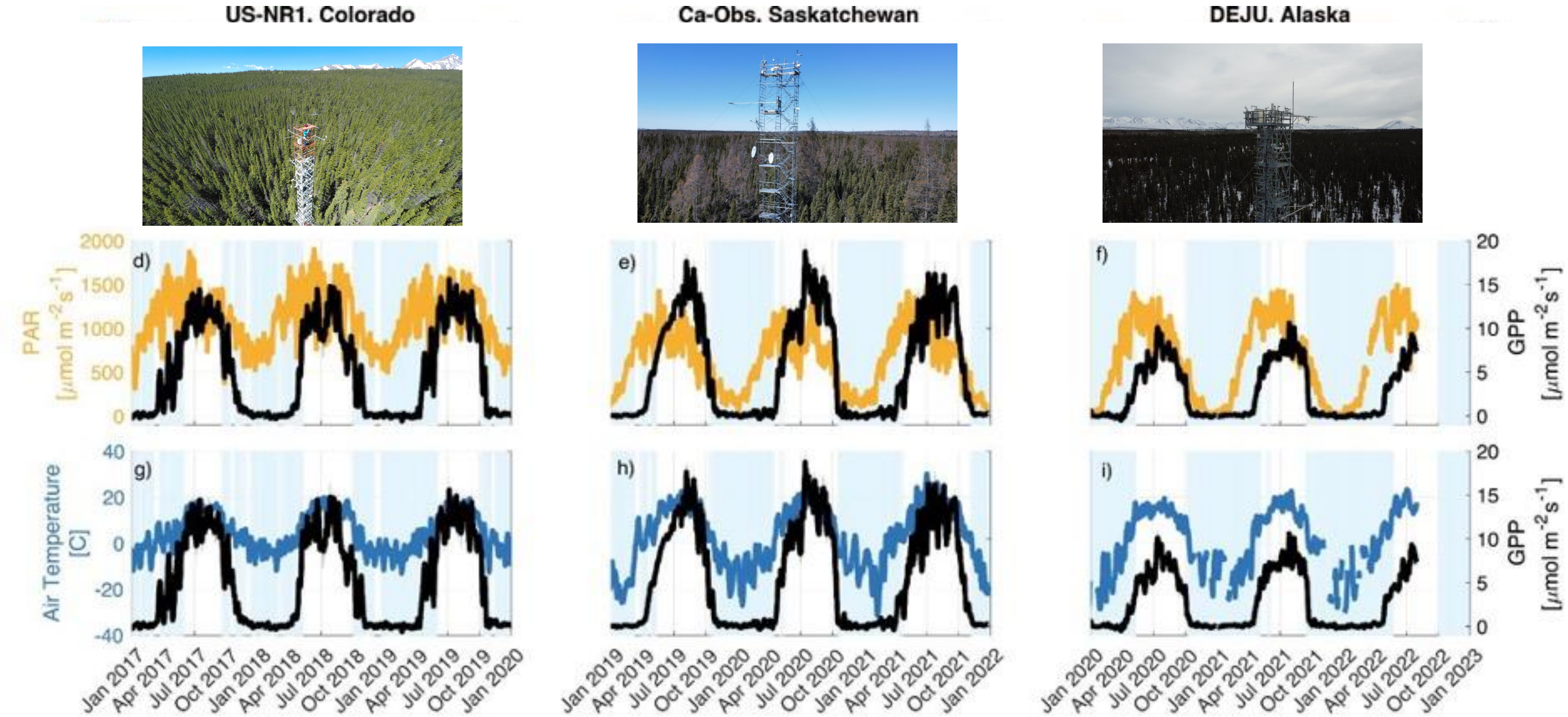




Pierrat, Magney, et al. 2024 *BioScience*

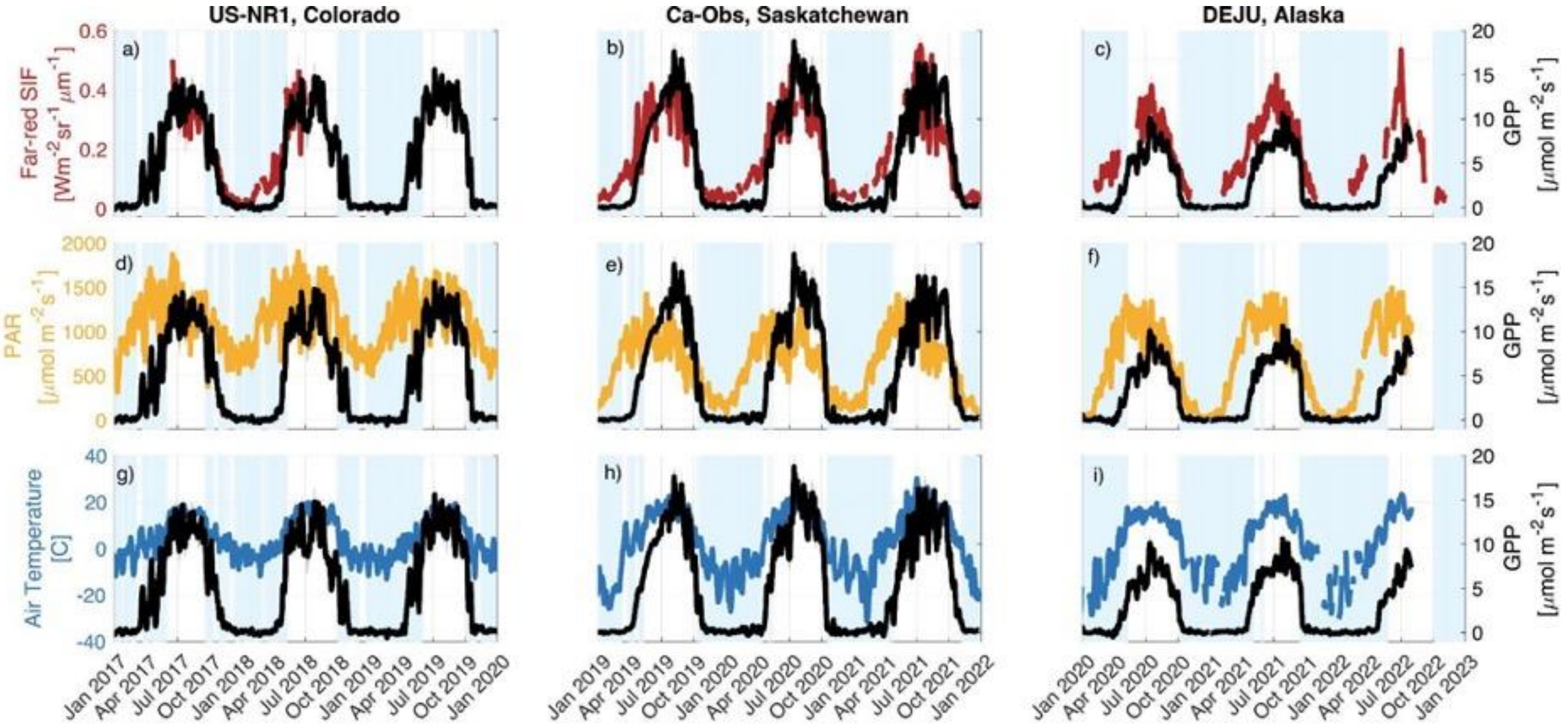
Photosynthesis (GPP) begins prior to snowmelt

Snow on canopy is indicated by blue vertical lines



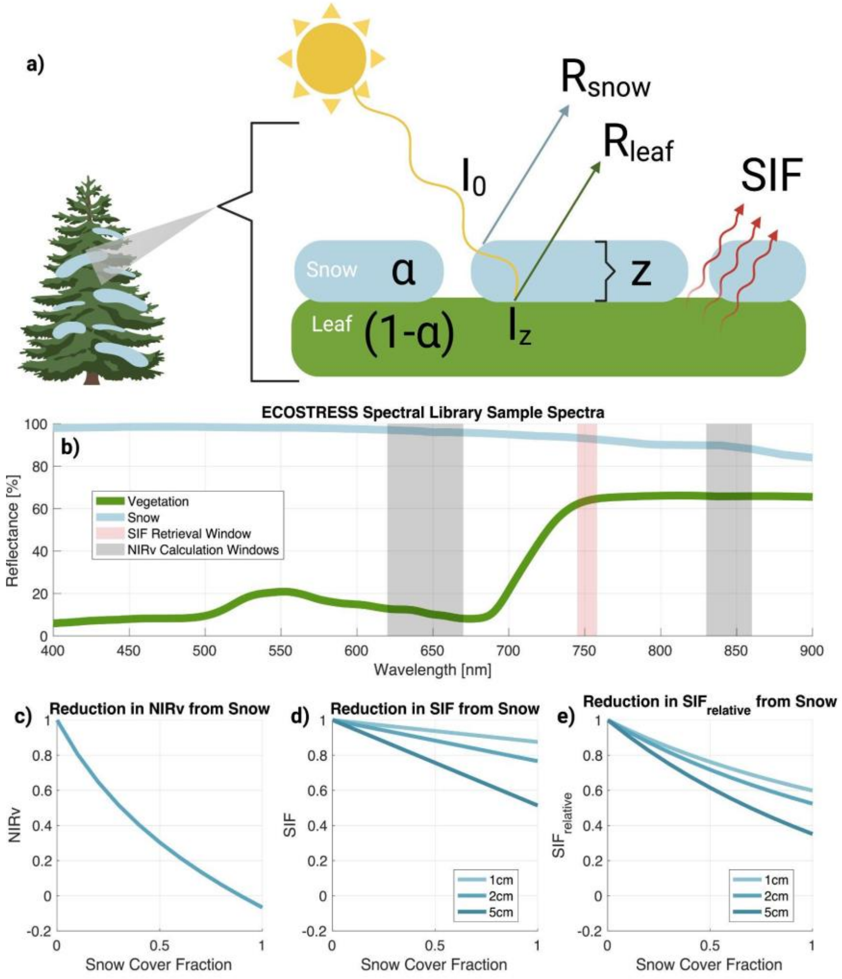
Pierrat, Magney, et al. *in press, Ecology*

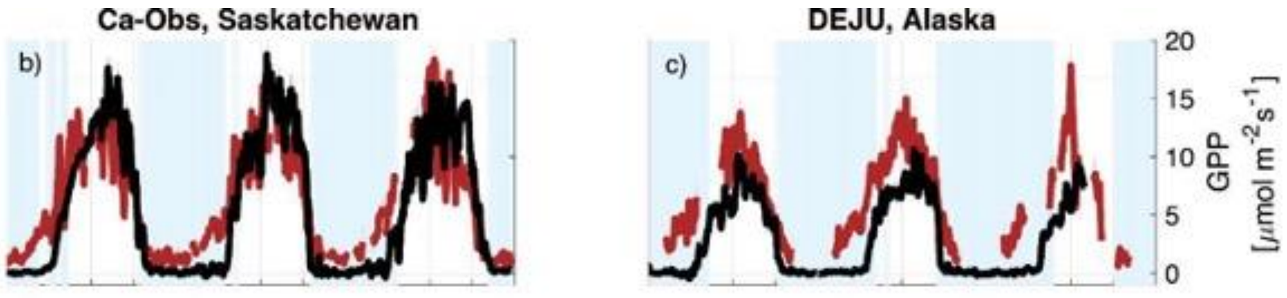
SIF has a light response to increasing PAR
Beginning prior to GPP onset



Pierrat, Magney, et al. *in press, Ecology*

How can we 'correct' for the light driven increase in SIF? And the impact of snow?



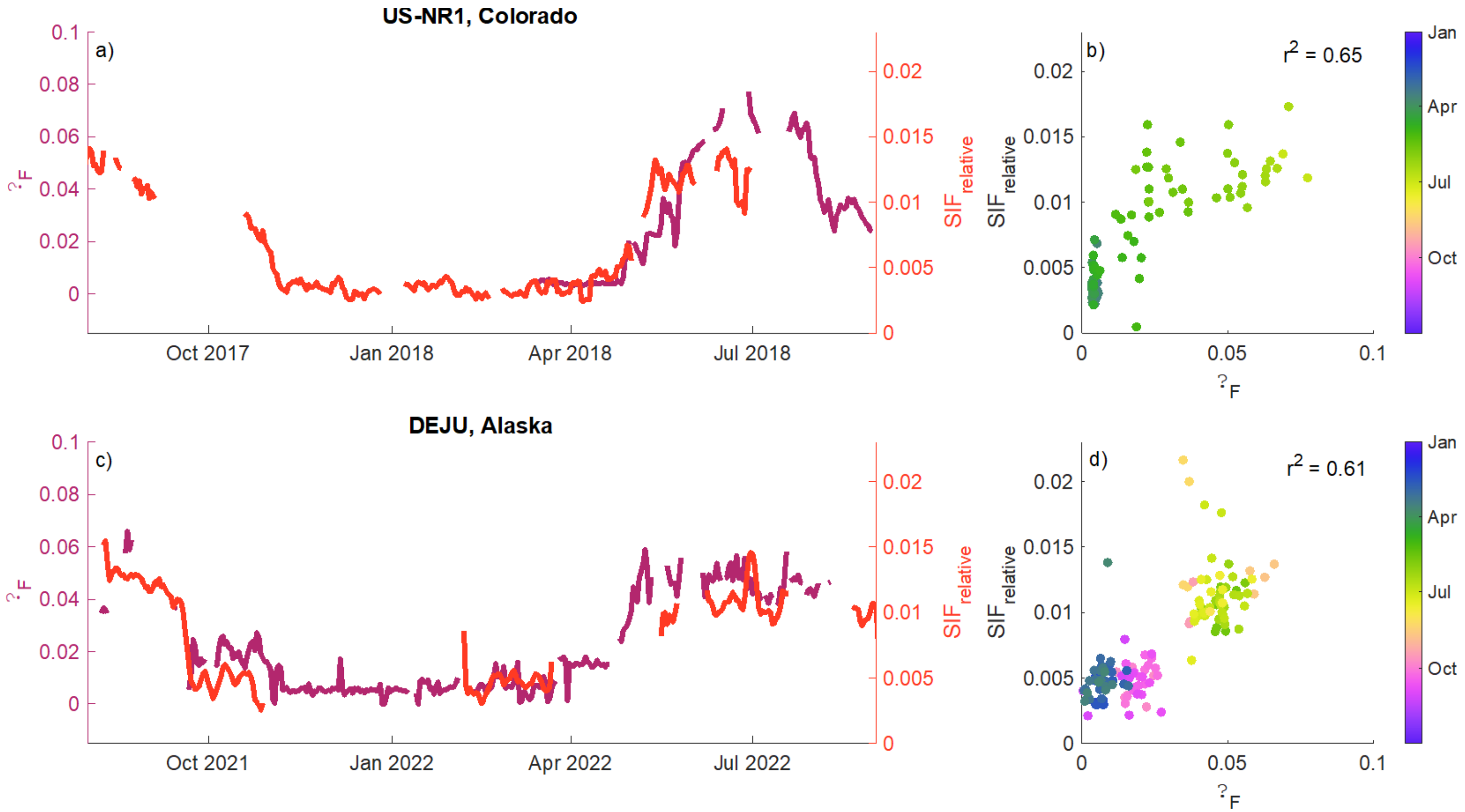


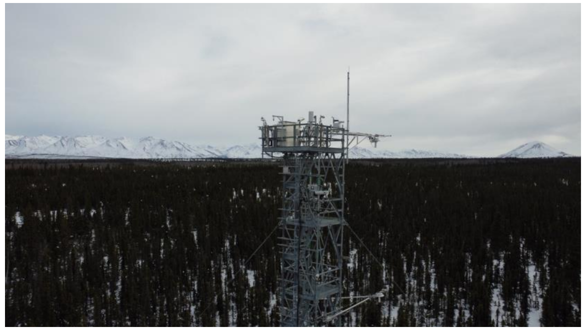
$$\text{Relative SIF} = \frac{\text{SIF}_{(751\text{-}771\ nm)}}{\text{reflected radiance}_{(751\text{-}771\ nm)}}$$

Pierrat, Magney, et al. *in press, Ecology*

How does the needle scale compare to the tower scale?

Comparing fluorescence yield (ΦF) with $SIF_{relative}$



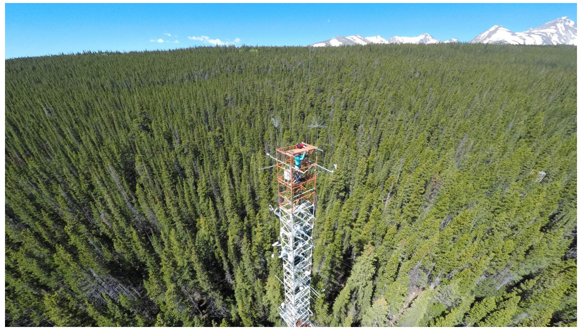


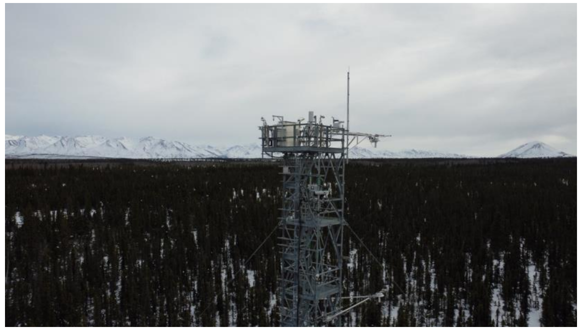
$SIF_{relative}$ = SIF / reflected radiance in the retrieval window

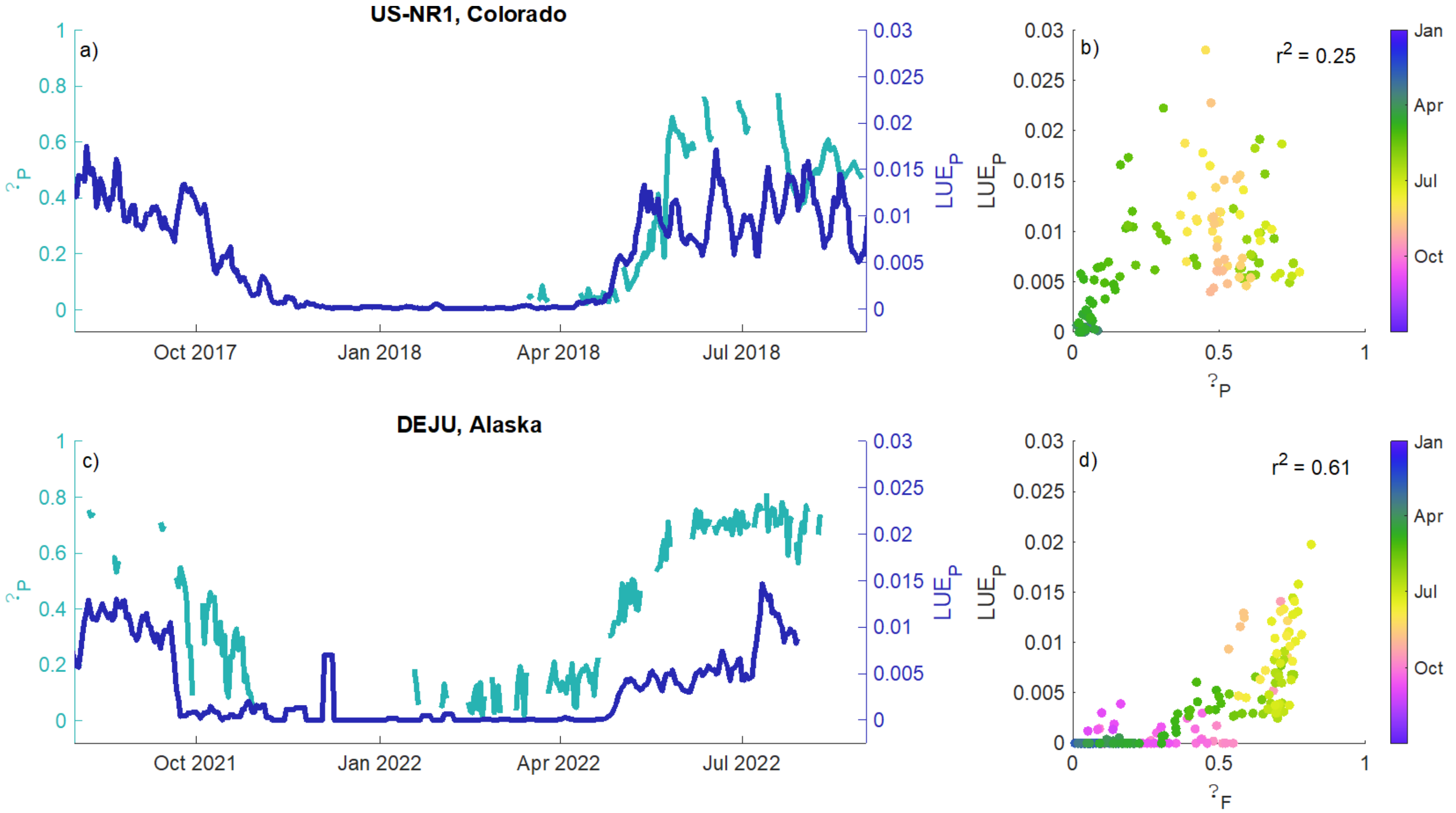
Pierrat, Magney, et al. *in press, Ecology*

How does the needle scale compare to the tower scale?

Comparing photochemical yield (ΦP) with light-use efficiency (LUE_P)



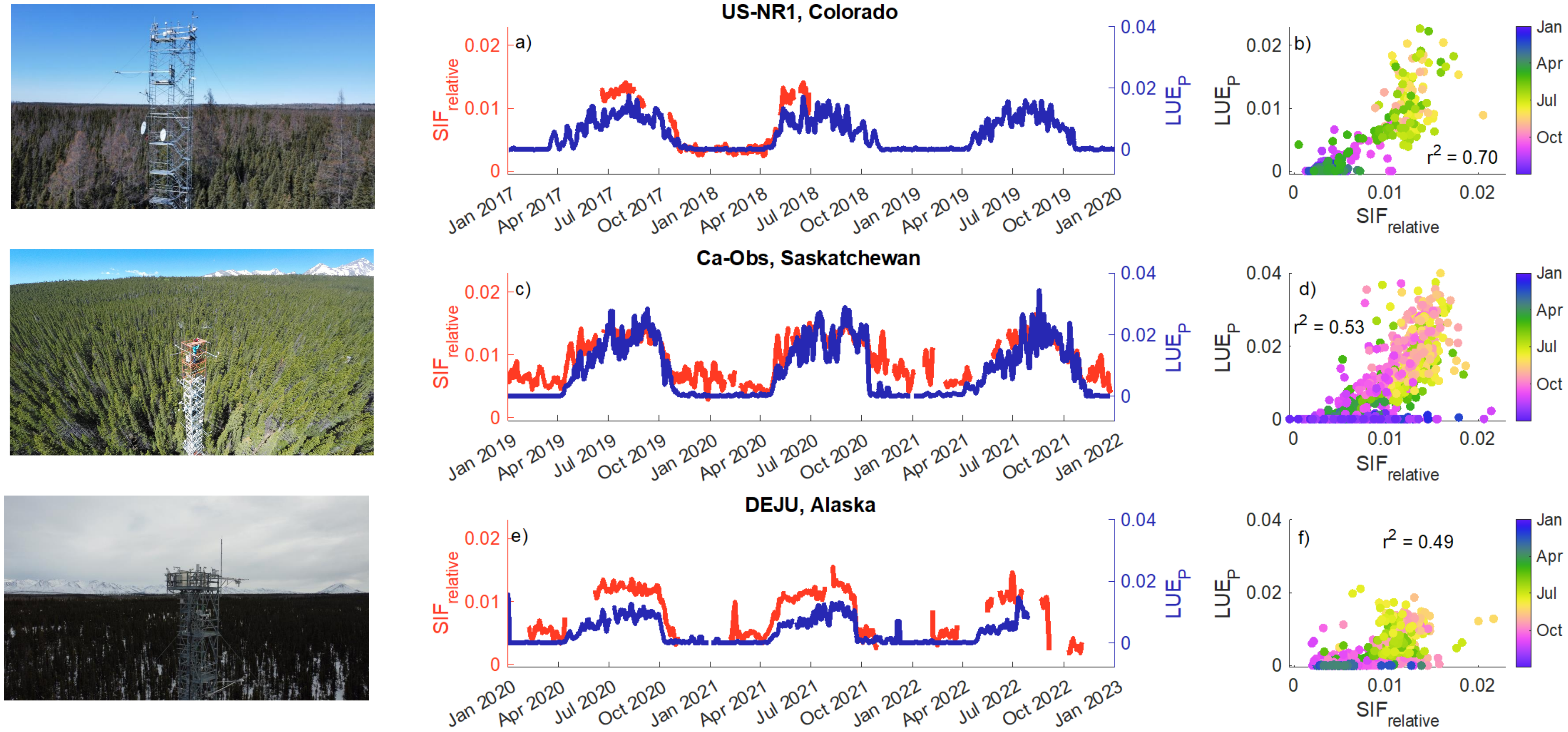




LUE_P = GPP/absorbed light (APAR)

Pierrat, Magney, et al. *in press, Ecology*

Taken together, $SIF_{relative}$ matches well with LUE_P at all 3 sites



Pierrat, Magney, et al. *in press, Ecology*

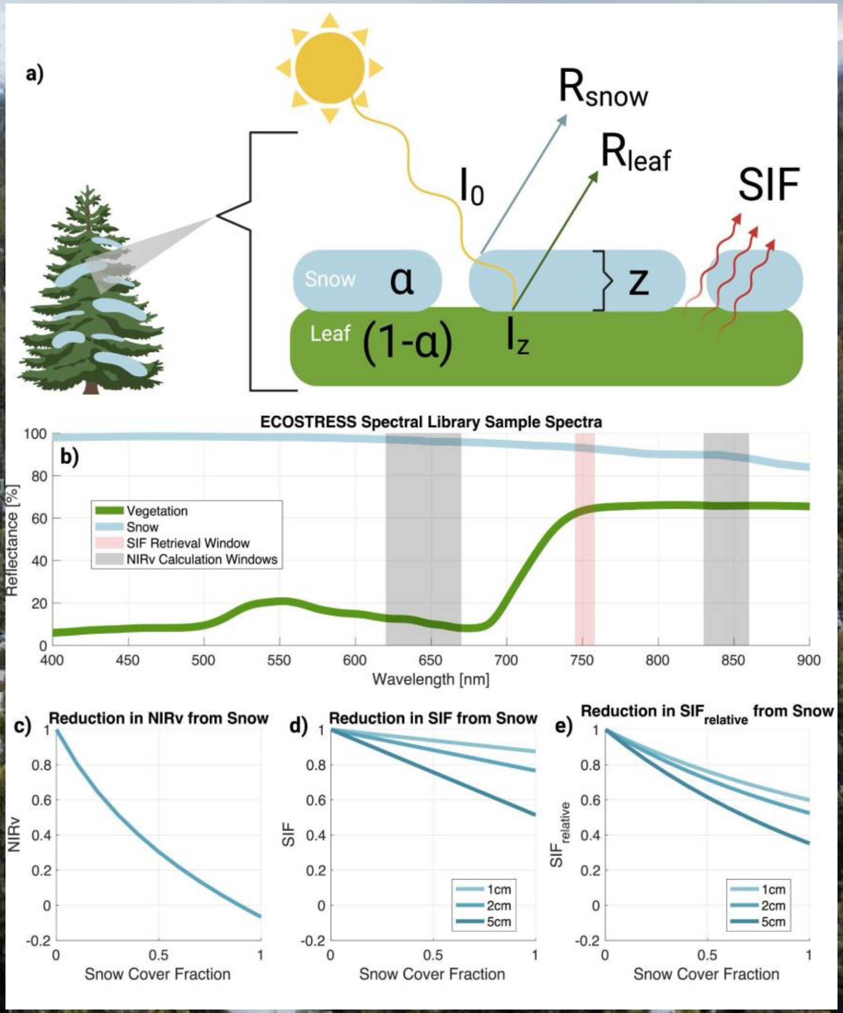
Correcting for SIF using $SIF_{relative}$ better tracks GPP onset

Satellites have not been able to see this previously because of snow background

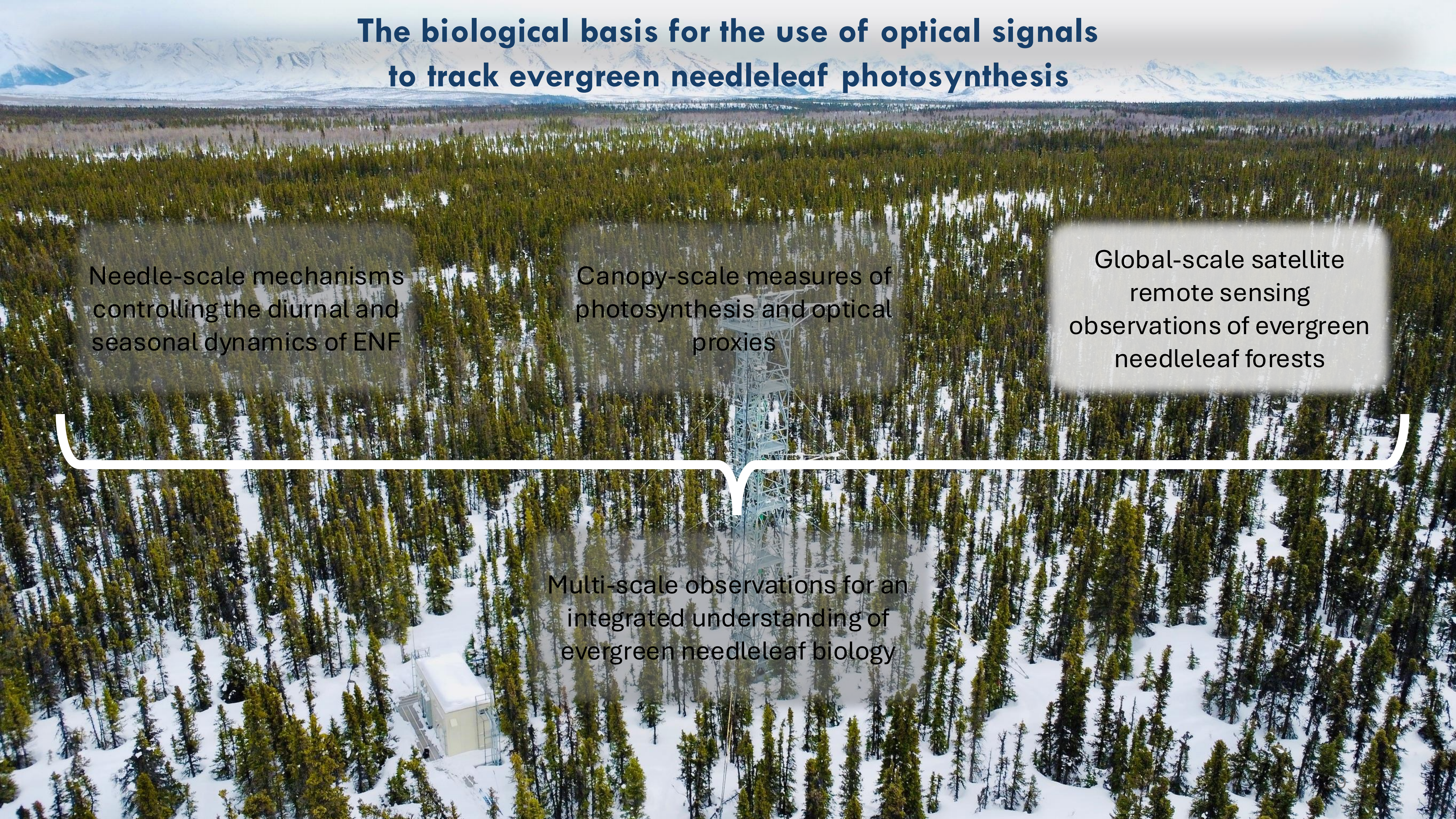
But now we can correct for snow using a physiologically sensitive index ($SIF_{relative}$)

To confirm this 'wakening' at a range of scales (needle -> tower -> satellite)

And hopefully gain a better understanding on the seasonal timing of photosynthesis in ENFs



Pierrat, Magney, et al. *in press, Ecology*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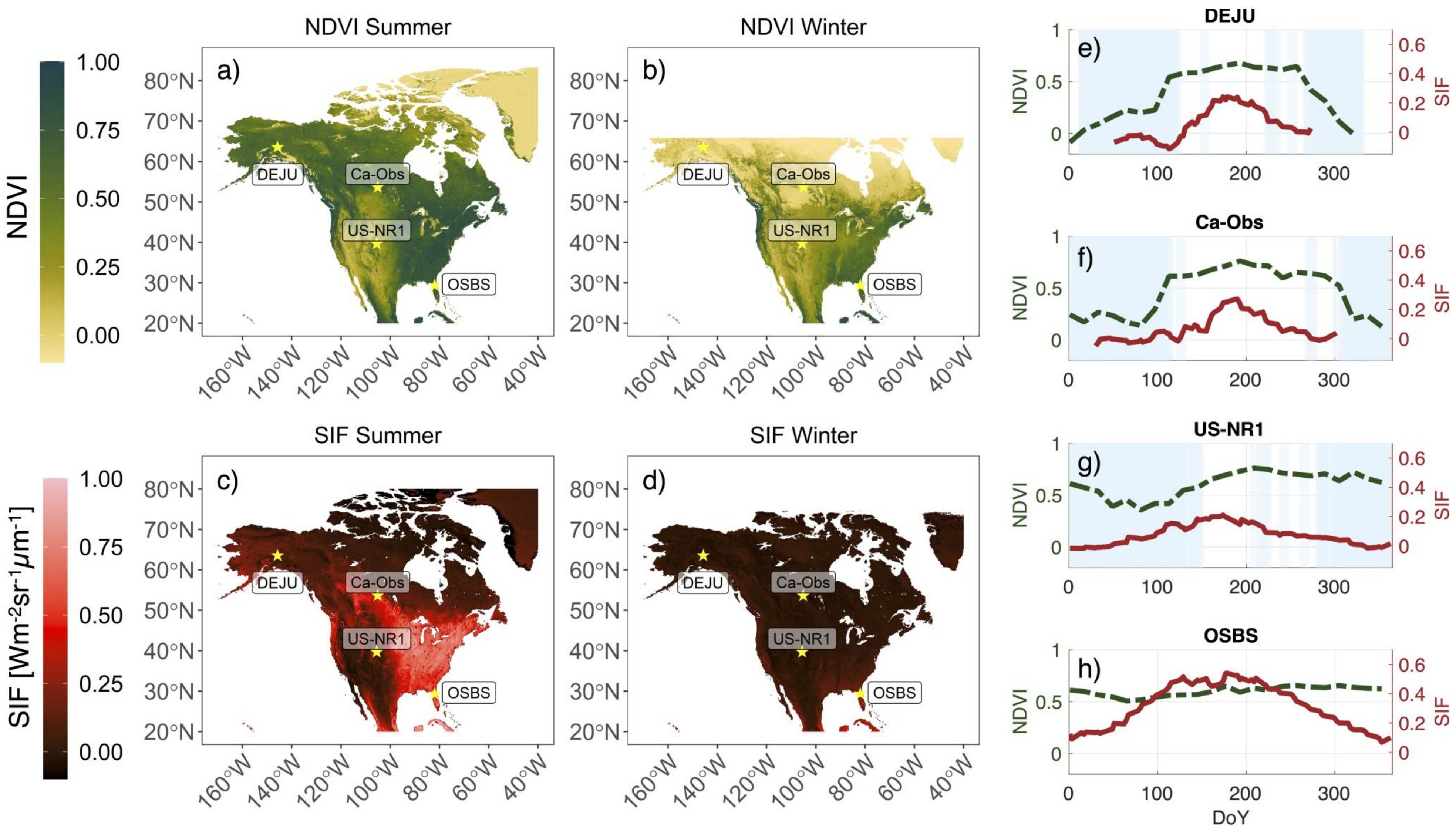
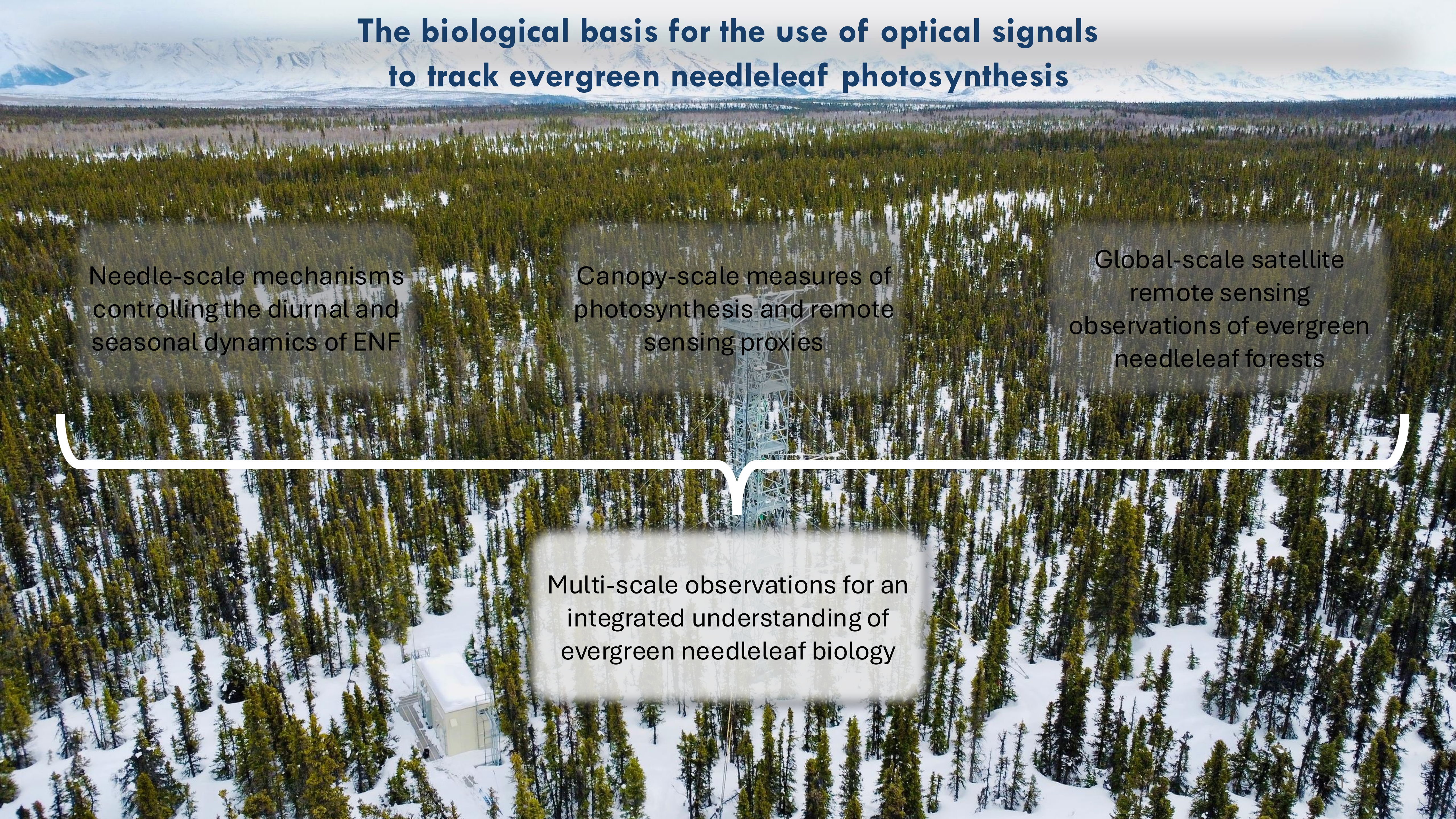
Satellite remote sensing expands the spatial range but there remains a need for mechanistic ground-based validation



Cheng, Magney, et al. 2022 *Environmental Research Letters*

Pierrat, Magney, et al. 2024 *BioScience*



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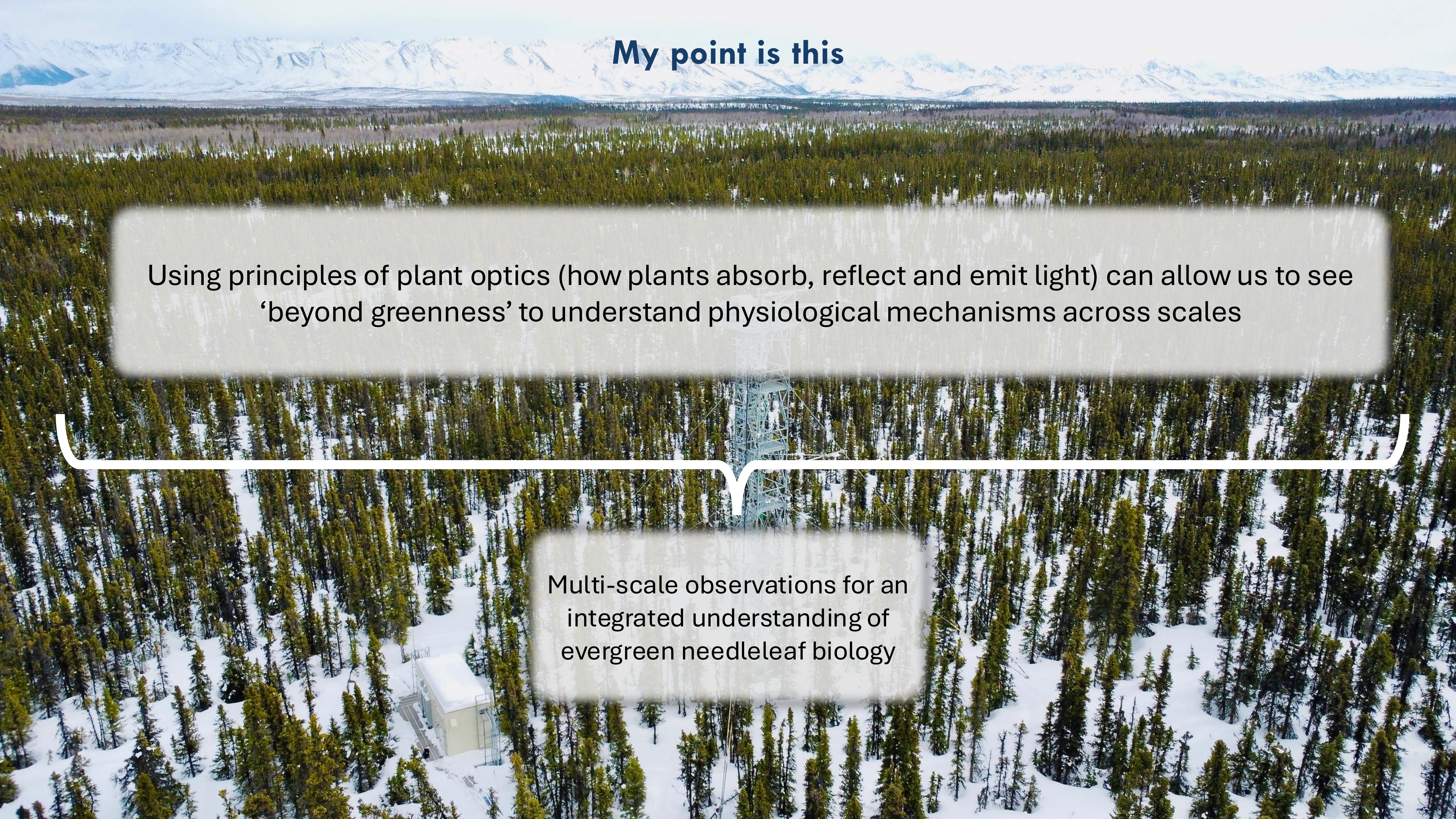
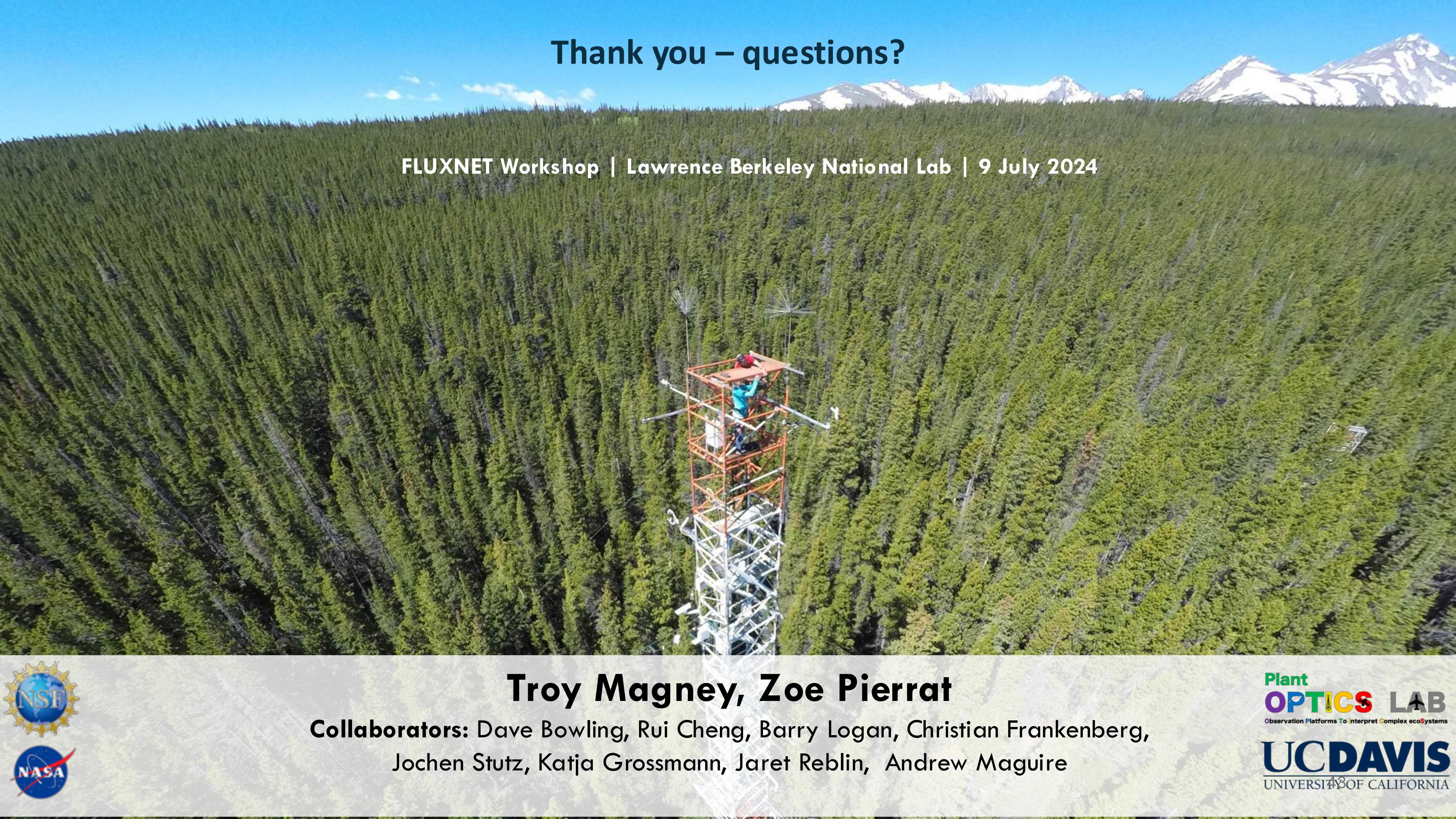
My point is this



Thank you – questions?



FLUXNET Workshop | Lawrence Berkeley National Lab | 9 July 2024

Troy Magney, Zoe Pierrat

Collaborators: Dave Bowling, Rui Cheng, Barry Logan, Christian Frankenberg, Jochen Stutz, Katja Grossmann, Jaret Reblin, Andrew Maguire

Plant OPTICS LAB
Observation Platforms To Interpret Complex ecoSystems

UC DAVIS
UNIVERSITY OF CALIFORNIA

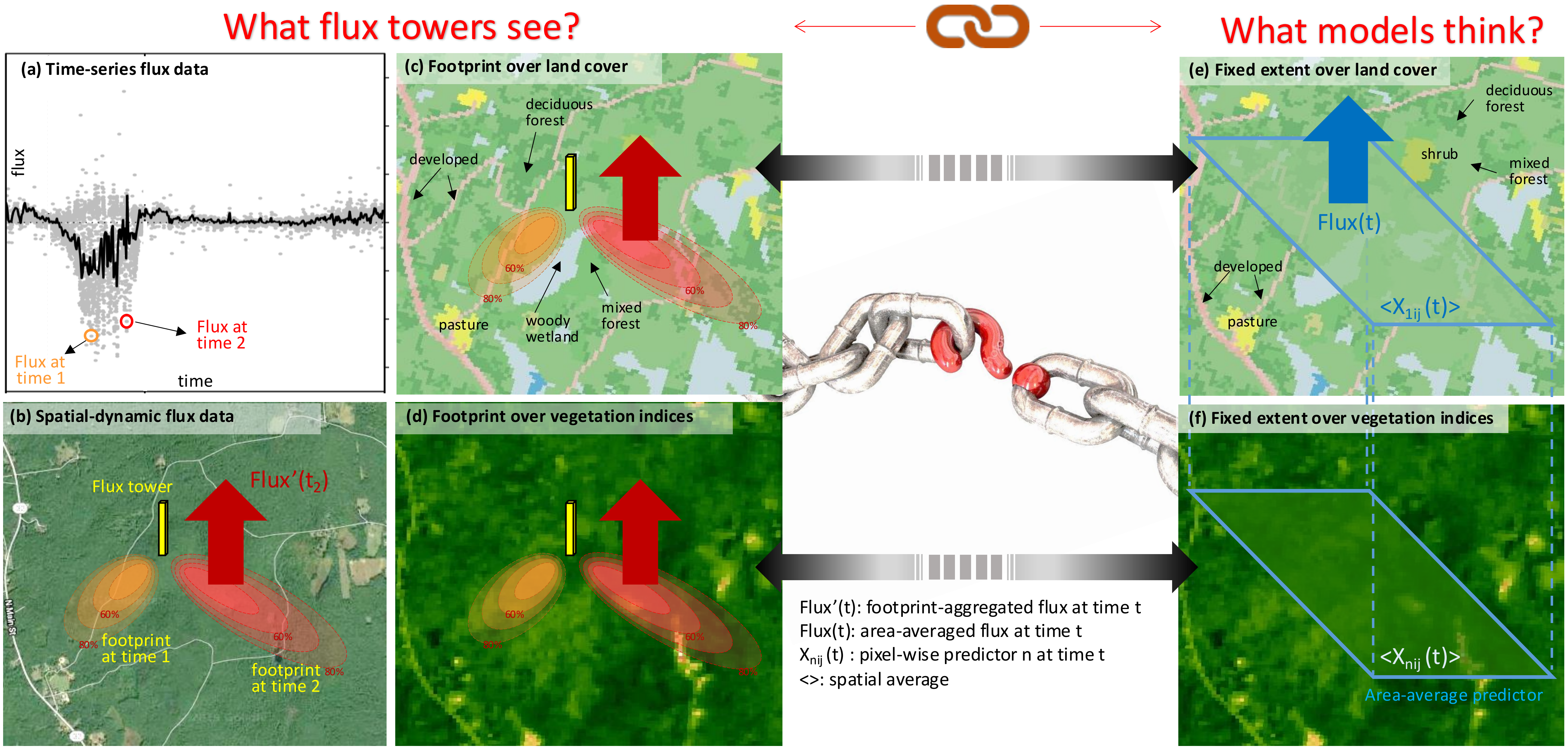
Bridge the link between flux towers and models to enable upscaling

Housen Chu[1],
Xiangzhong Luo[2],
Zutao Ouyang[3],
Patty Oikawa[4],
Thomas Fenster[4,5],
Camilo Rey-Sanchez[6],
Iryna Dronova[7], Alex Valach[8]
AmeriFlux Management Project and Site Teams

1 Lawrence Berkeley National Laboratory
2 National University of Singapore
3 Auburn University,
4 California State University – East Bay
5 University of California, Davis
6 North Carolina State University
7 University of California, Berkeley
8 Berner Fachhochschule BFH, Bern, Berne, Switzerland

AMERIFLUX

Background



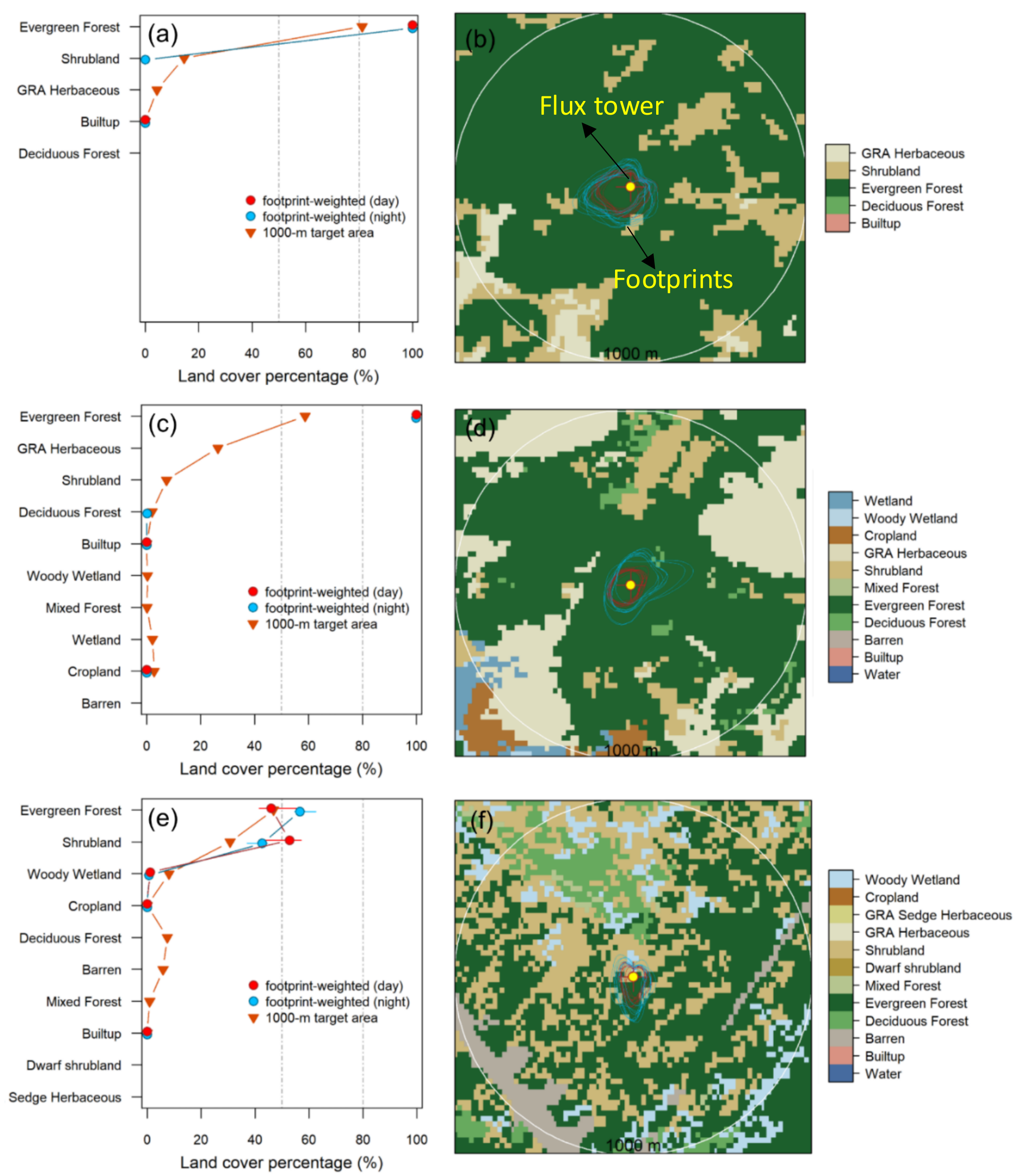
(Chen et al., 2012; Gockede et al., 2008; Rebmann et al., 2005; Wang et al., 2016)

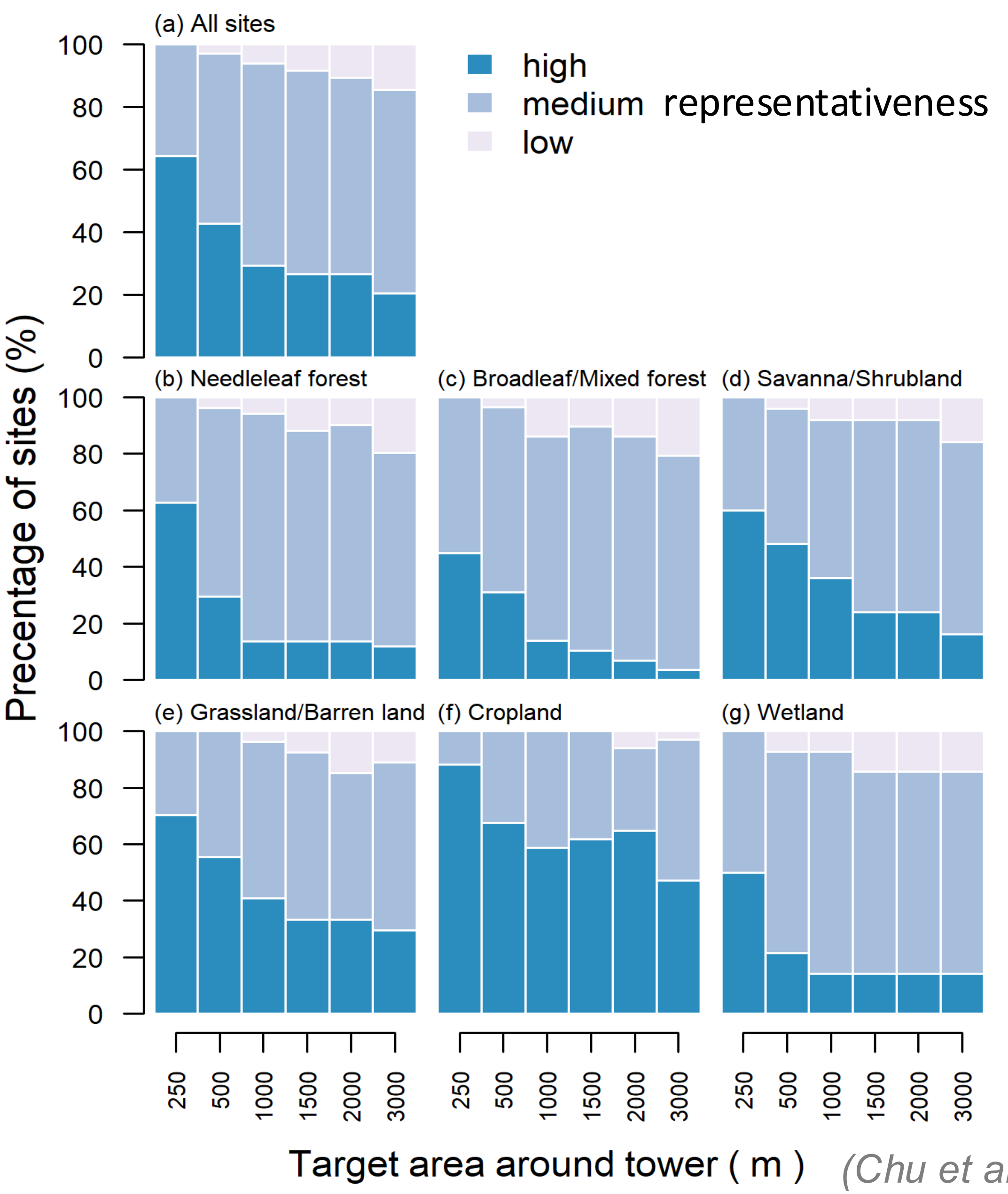
Representativeness based on land cover composition

High

Medium

Low





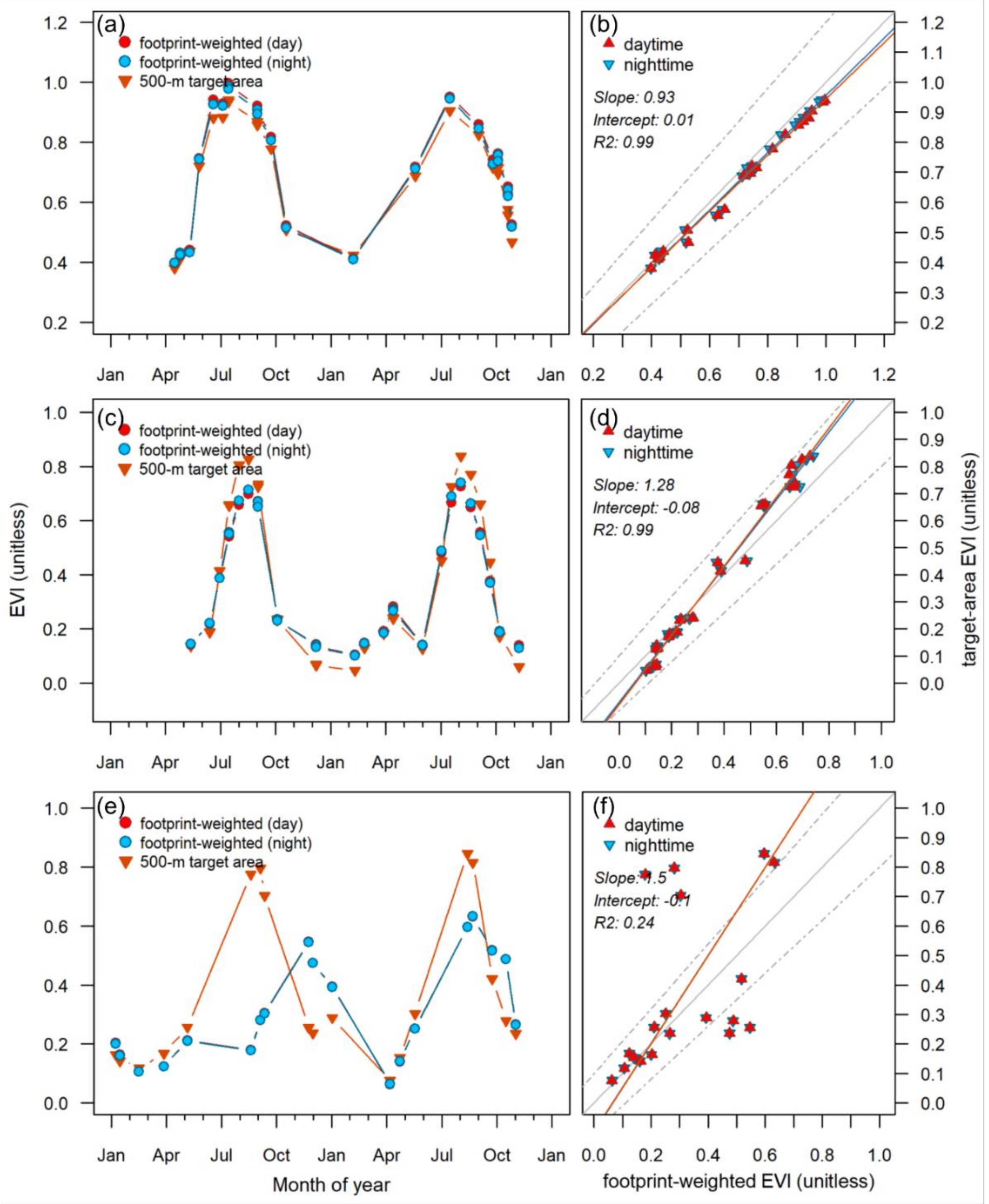
(Chu et al. 2021)

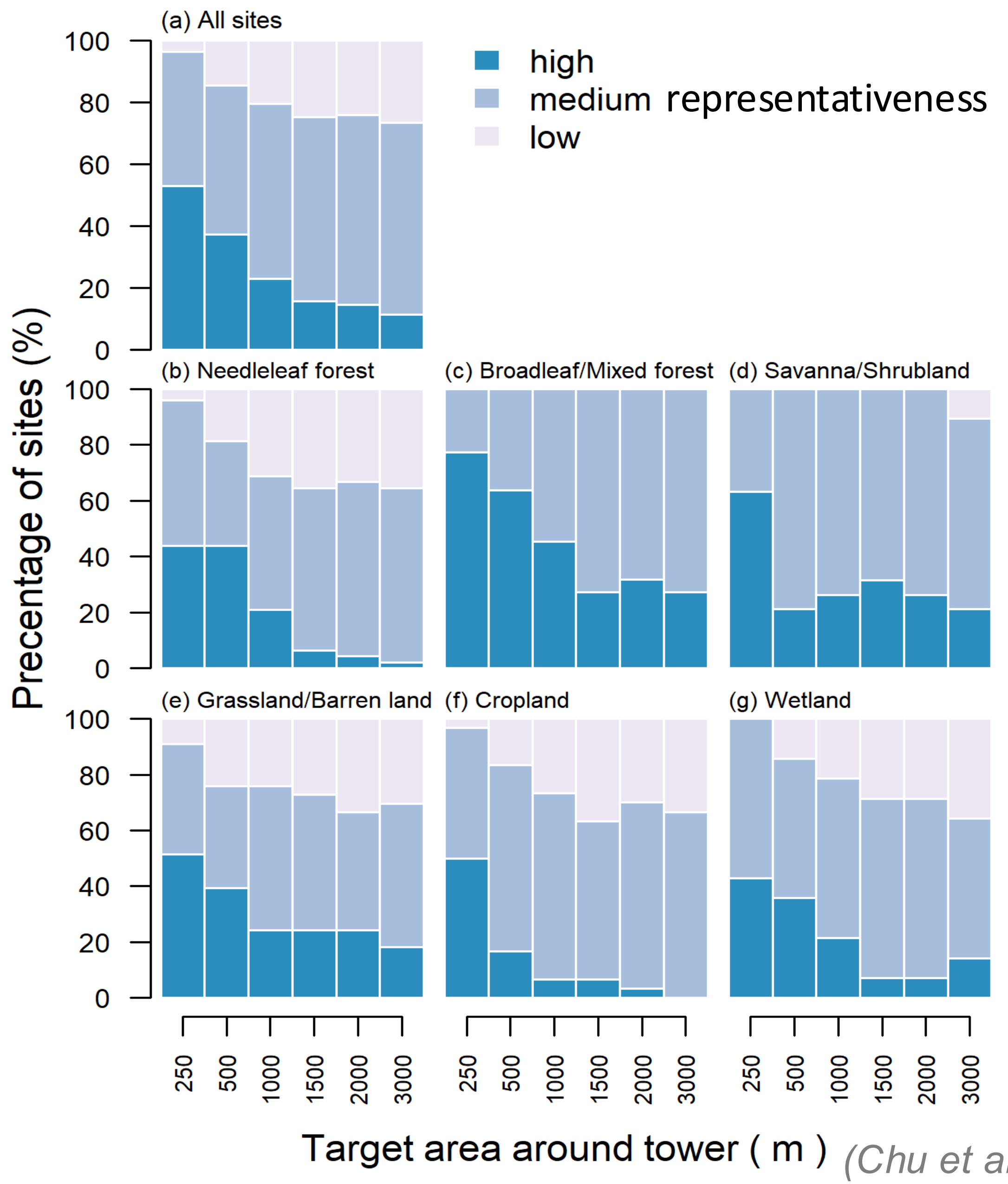
Representativeness based on EVI

High

Medium

Low



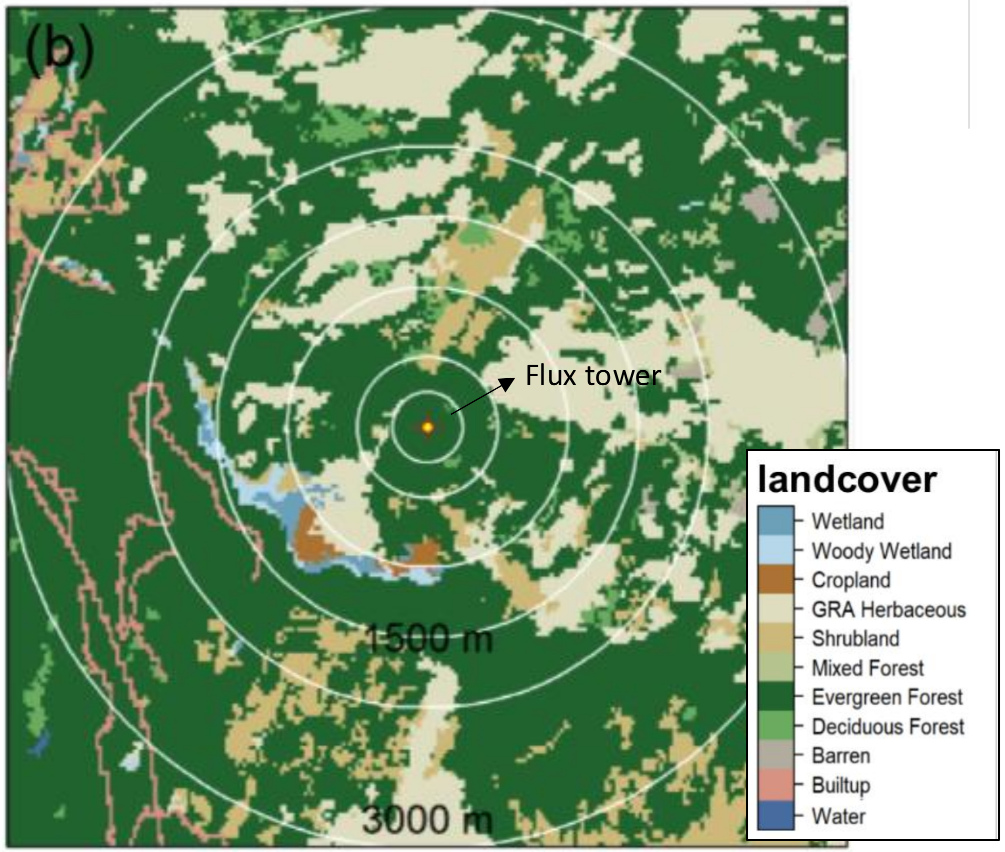


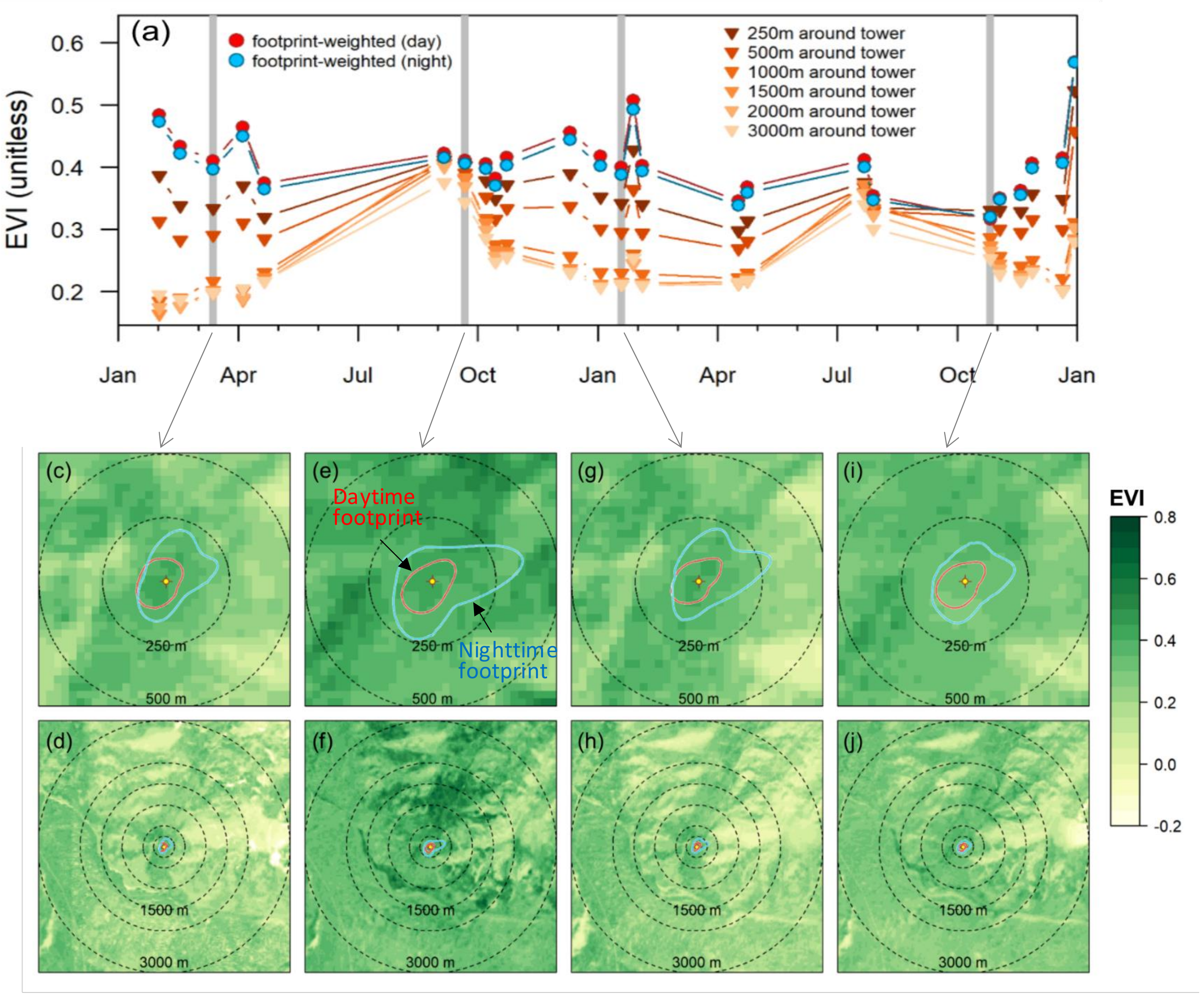
(Chu et al. 2021)

Example case – limited representativeness

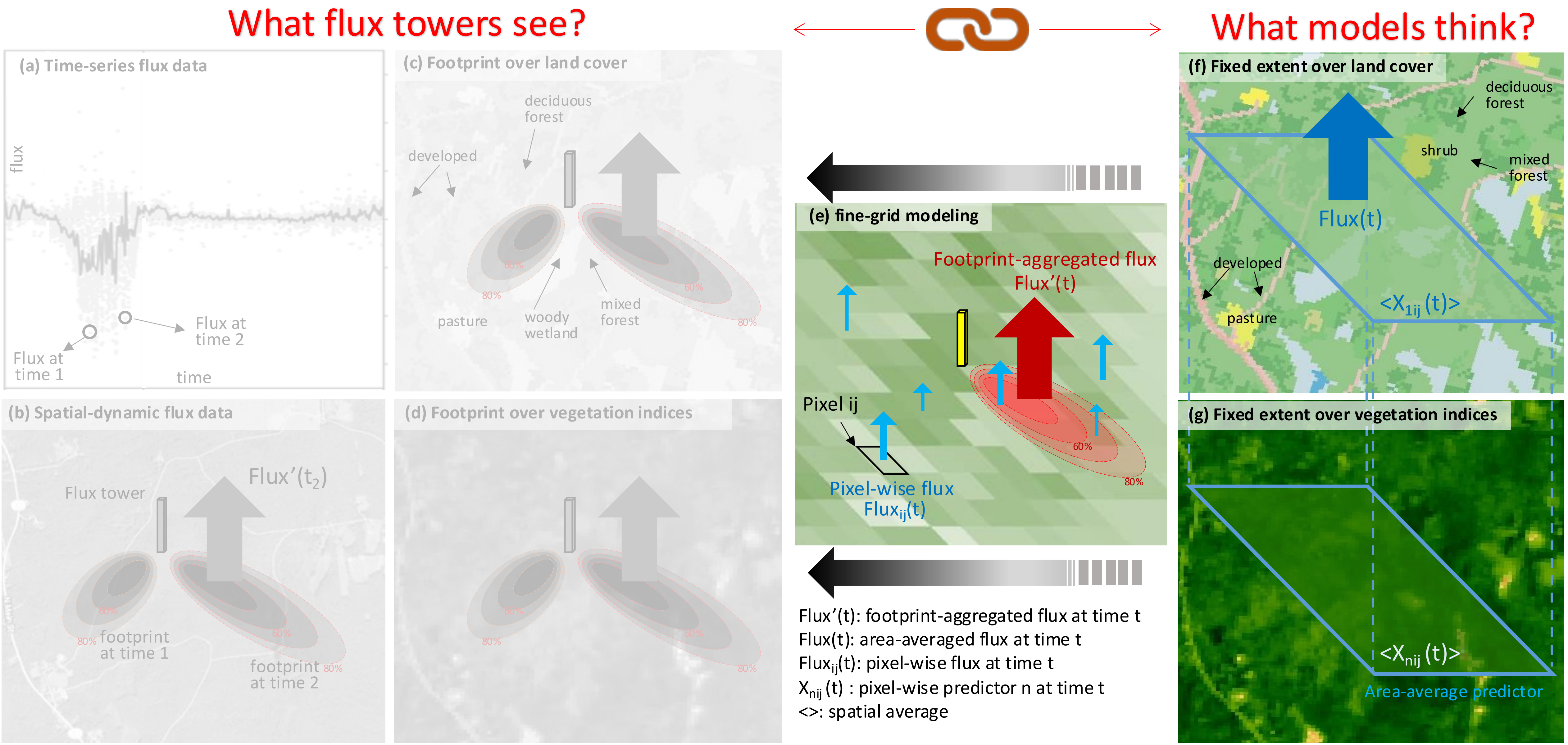
US-Vcp site

An evergreen forest located within a forest-shrub-grassland landscape





A fine-grid modeling approach

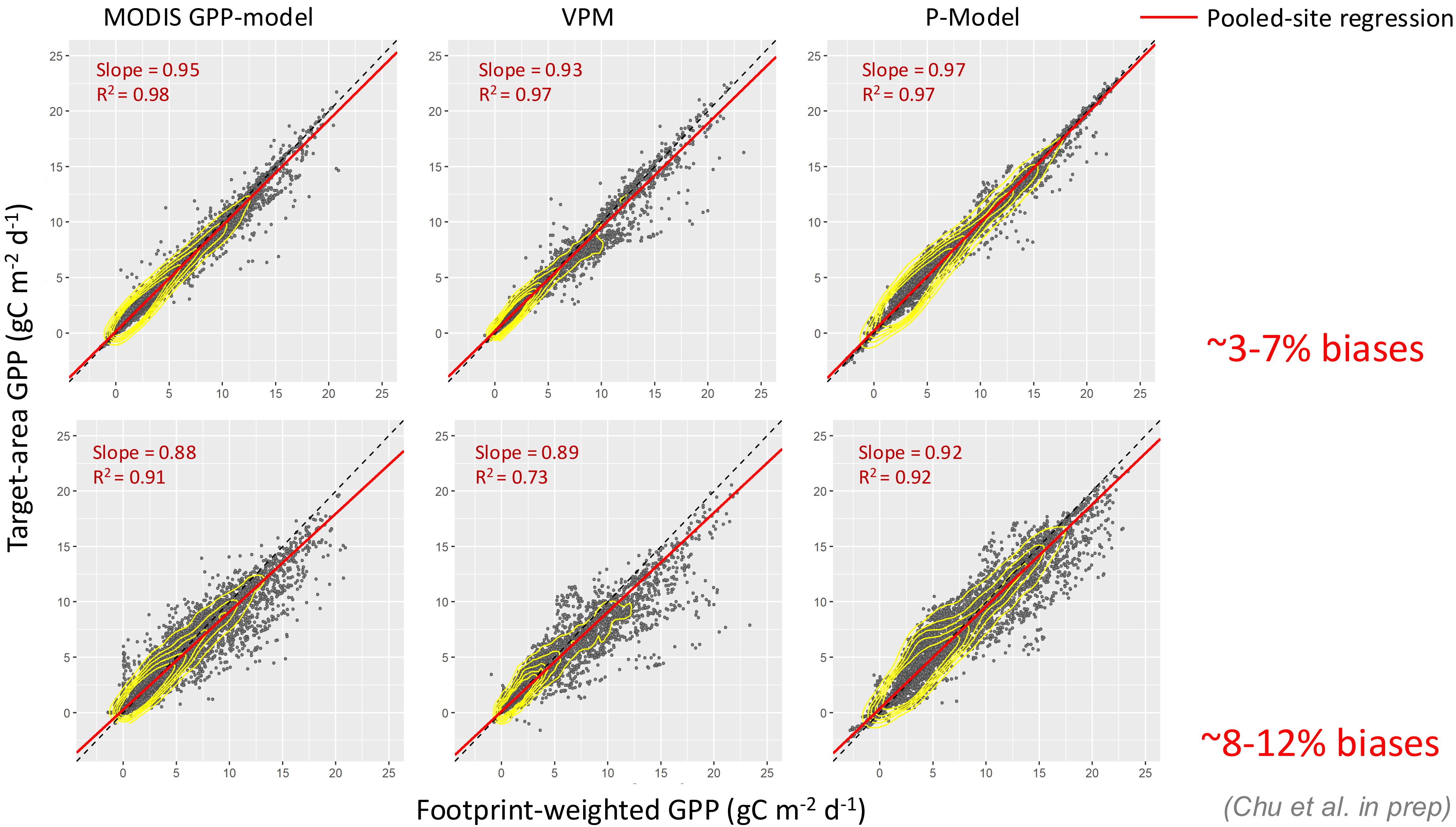


(Chen et al., 2010; Fu et al., 2014; Ran et al., 2016)

Footprint-weighted vs Target-area GPP (all sites)

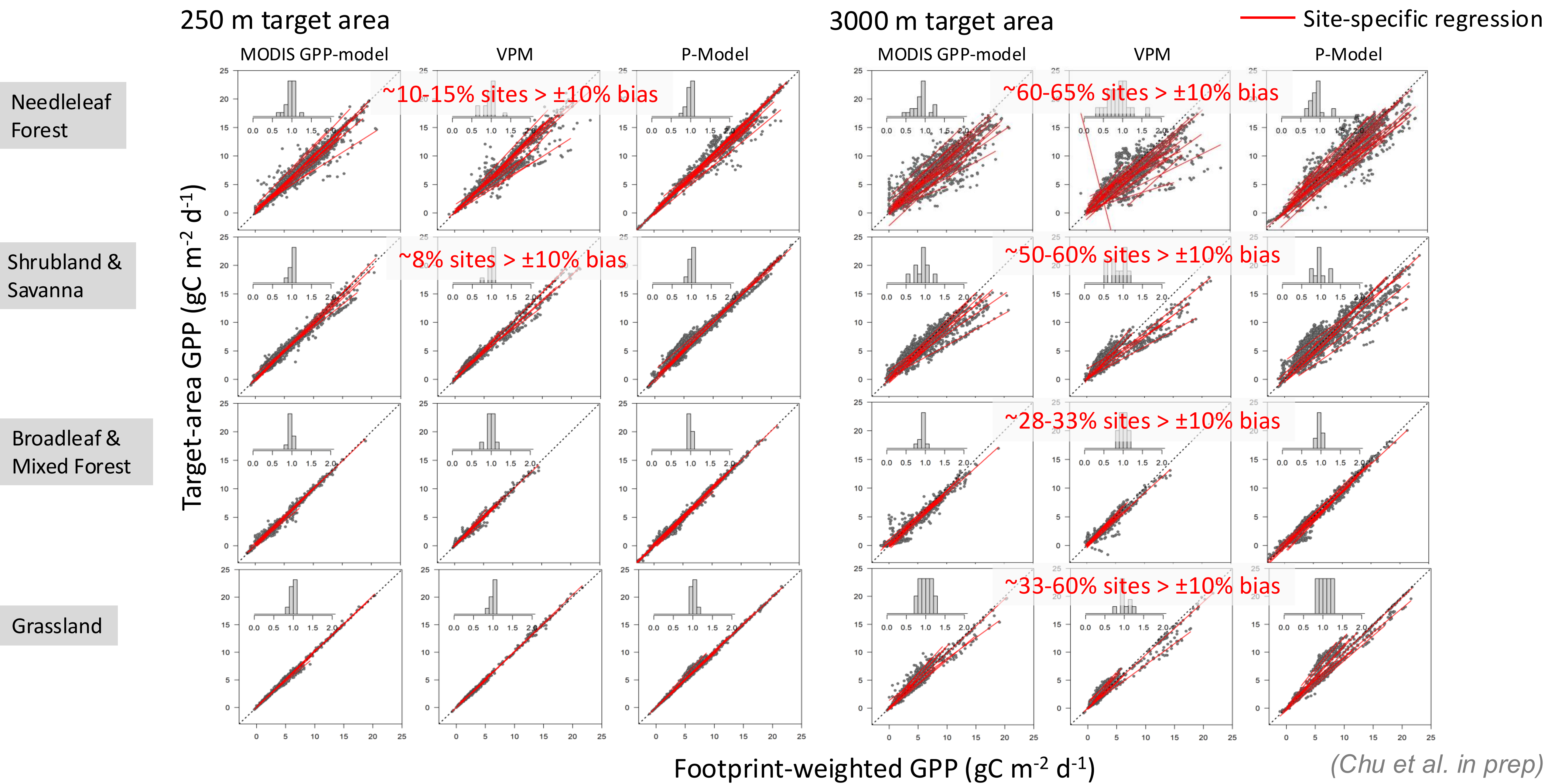
250 m target area

3000 m target area



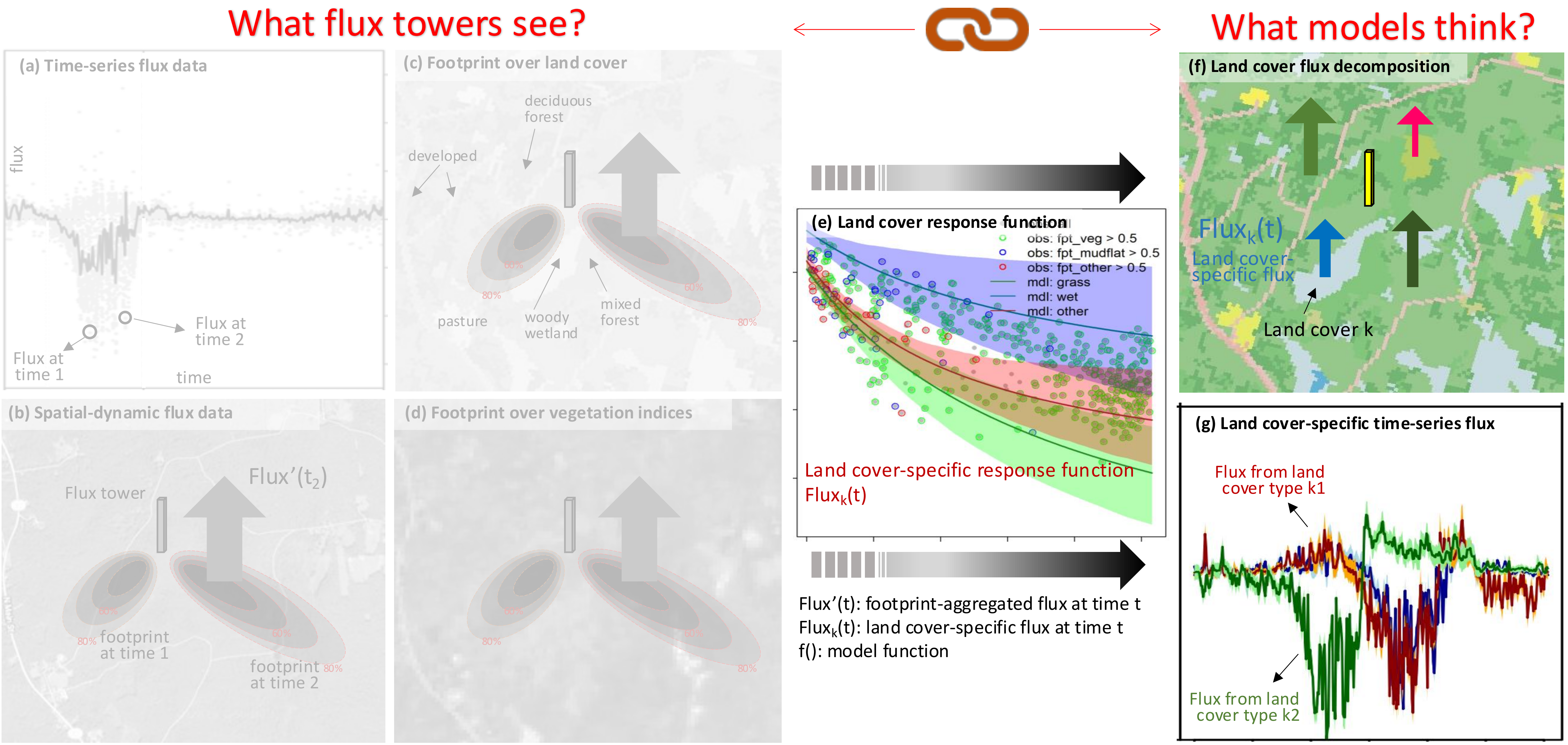
(Chu et al. in prep)

Footprint-weighted vs Target-area GPP (by ecosystem types)



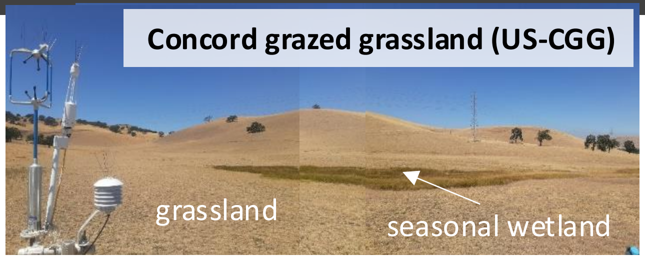
(Chu et al. in prep)

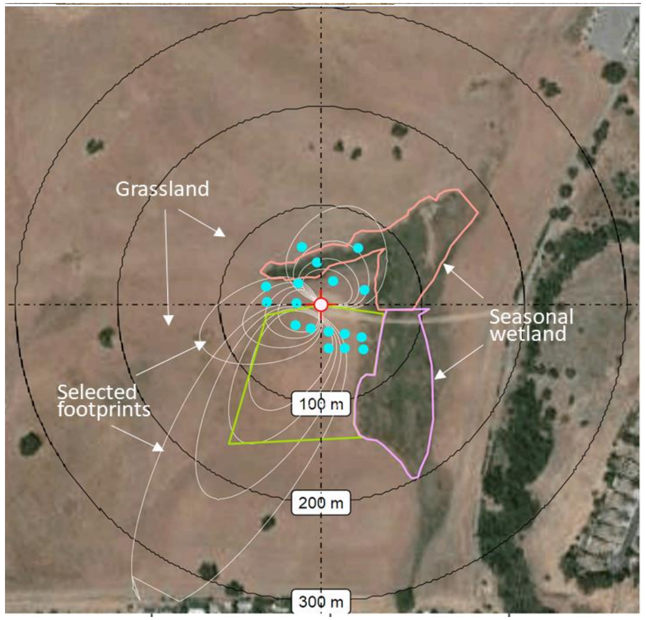
A footprint-informed decomposition approach

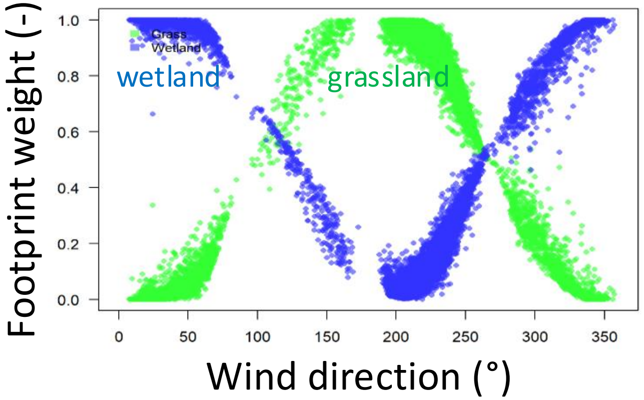


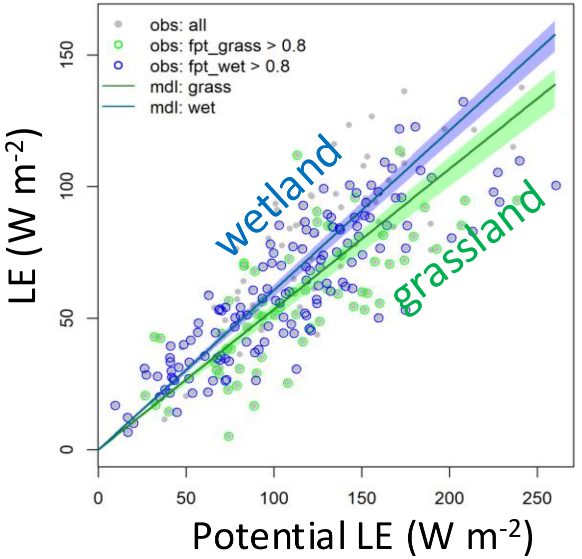
(Wang et al., 2006; Xu et al., 2017; Duman et al. 2018; Levy et al., 2020)

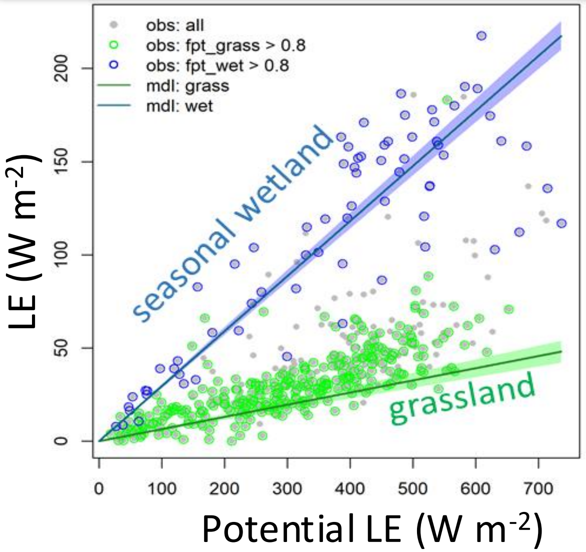
Simple case

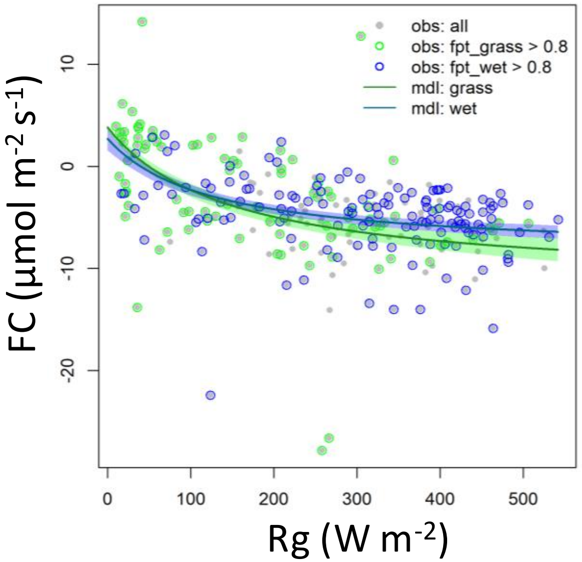


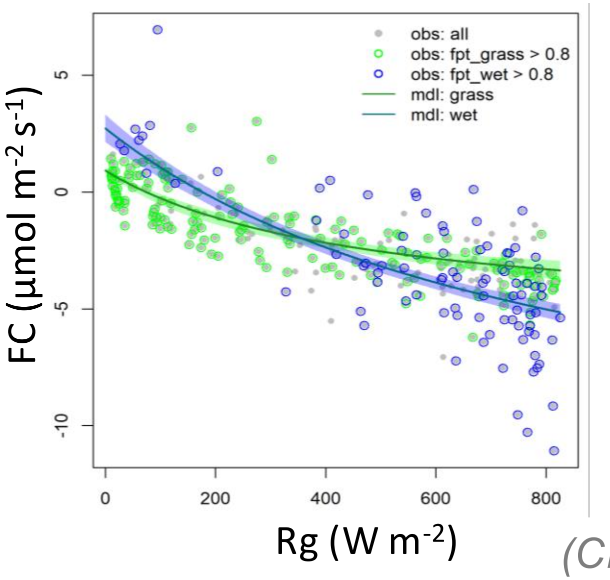






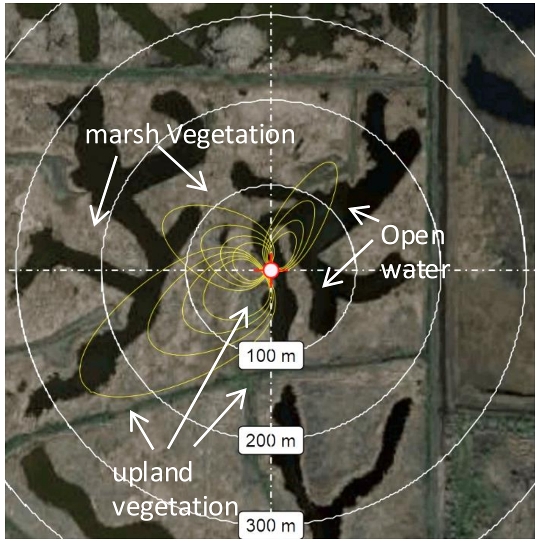


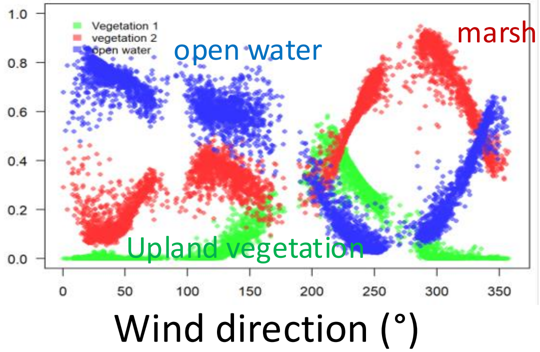




(Chu et al. in prep)

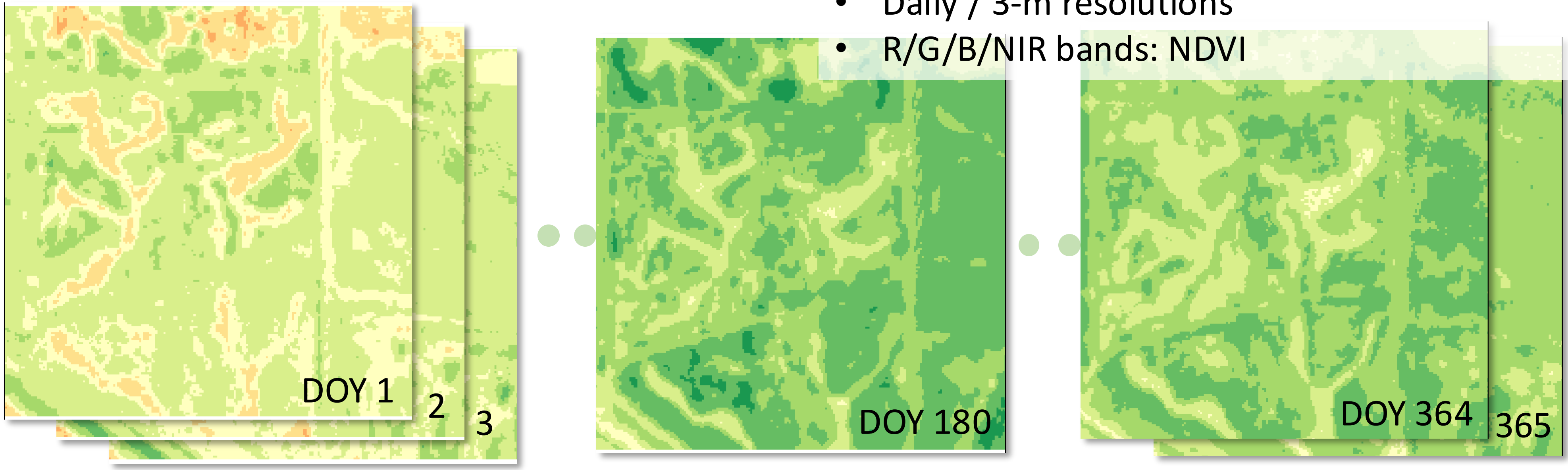
Complicated Case





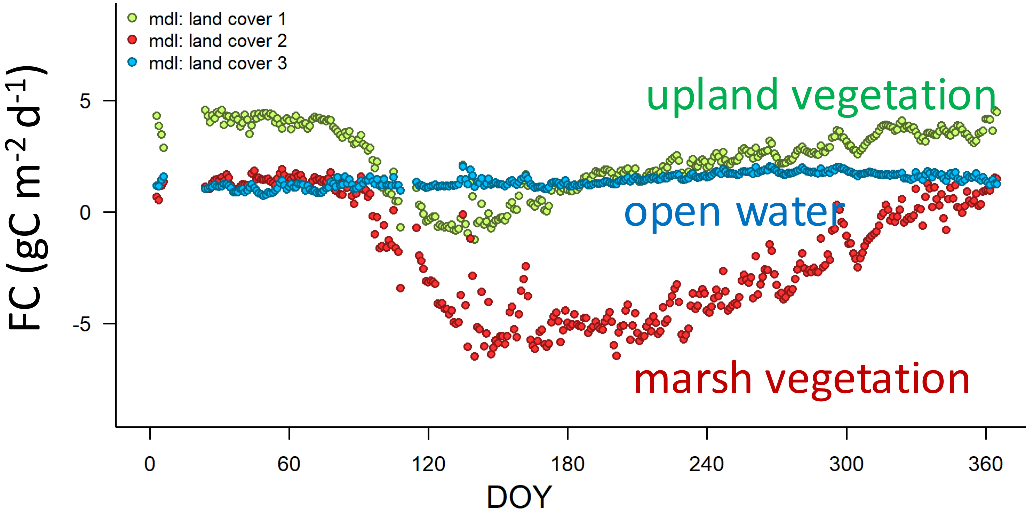
Planet Fusion Product

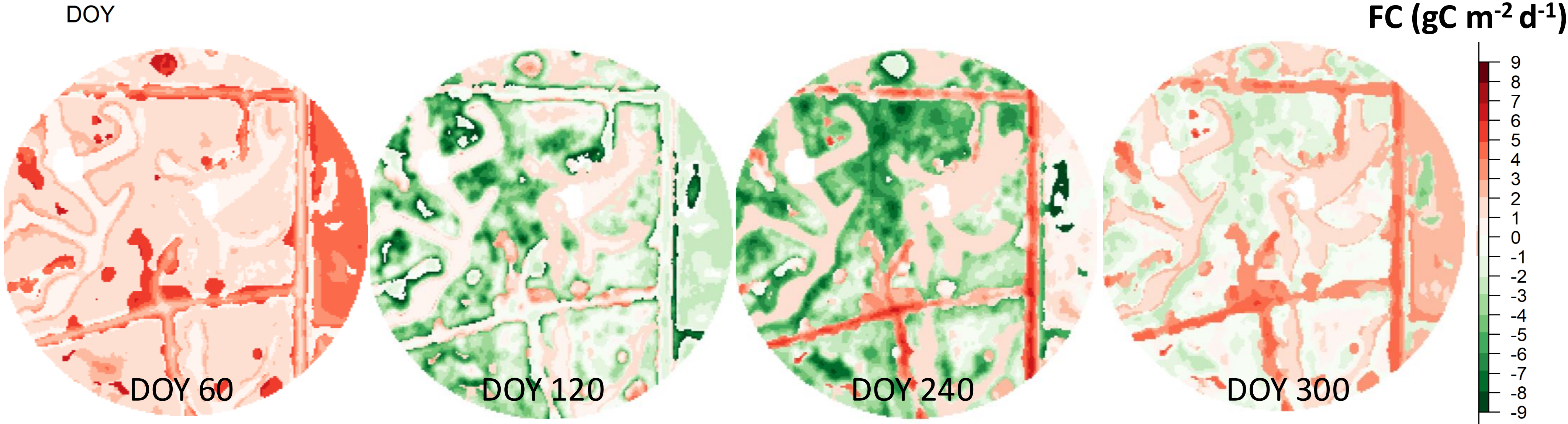
- PlanetScope CubeSats – based
- Calibrated, geo-referenced, gap-filled
- Daily / 3-m resolutions
- R/G/B/NIR bands: NDVI



(Chu et al. in prep)

Spatiotemporal Constraints





(Chu et al. in prep)

Summary

Footprint representativeness of AmeriFlux sites

- Large-scale eddy-covariance flux datasets need to be used with footprint-awareness
- Using a fixed-extent target area across sites can bias model-data integration
- Most sites do not represent the dominant land-cover type at a larger spatial extent
- A representativeness index provides general guidance for site selection and data use

Footprint-informed decomposition approaches

- Few, mostly done at single-site studies
- Variation in Core models
  - Biophysical model (Duman et al., 2018, Wang et al., 2006)
  - Remote-sensing model (Ran et al., 2016, VPM)
  - Statistical model (Levy et al., 2020, e.g., linear additive model; Xu et al., 2017a multi-linear model)
  - Land surface model (Wang et al. 2022; CLM-Microbe)
  - Machine learning (Xu et al., 2017b; Metzger, 2018, Environmental Response Function)
  - Hybrid approach (Wiesner et al. 2022)
- Additional constraints/inputs
  - Chamber flux measurements (Rey-Sanchez, et al., 2018)
  - Lysimetric measurements (Joy & Chávez 2021)
  - Spatial drivers/characteristics – remote sensing (Xu et al., 2017b)

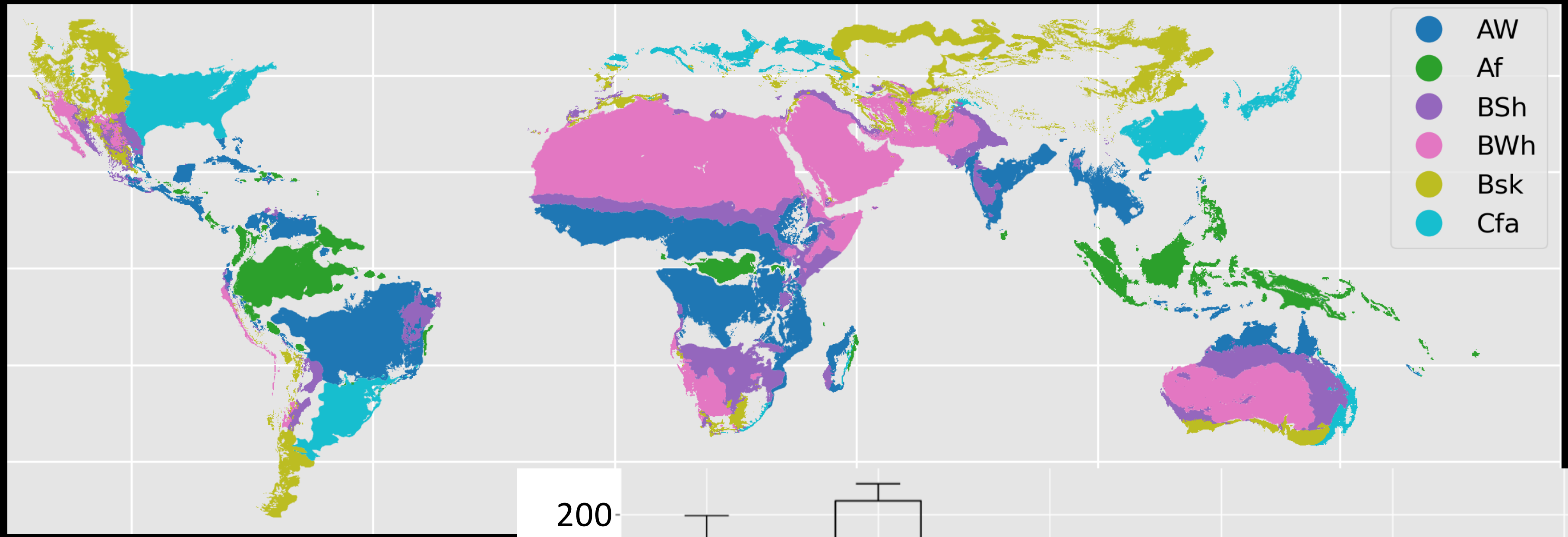
Foundation Models for Vegetation Growth and Carbon Sequestration

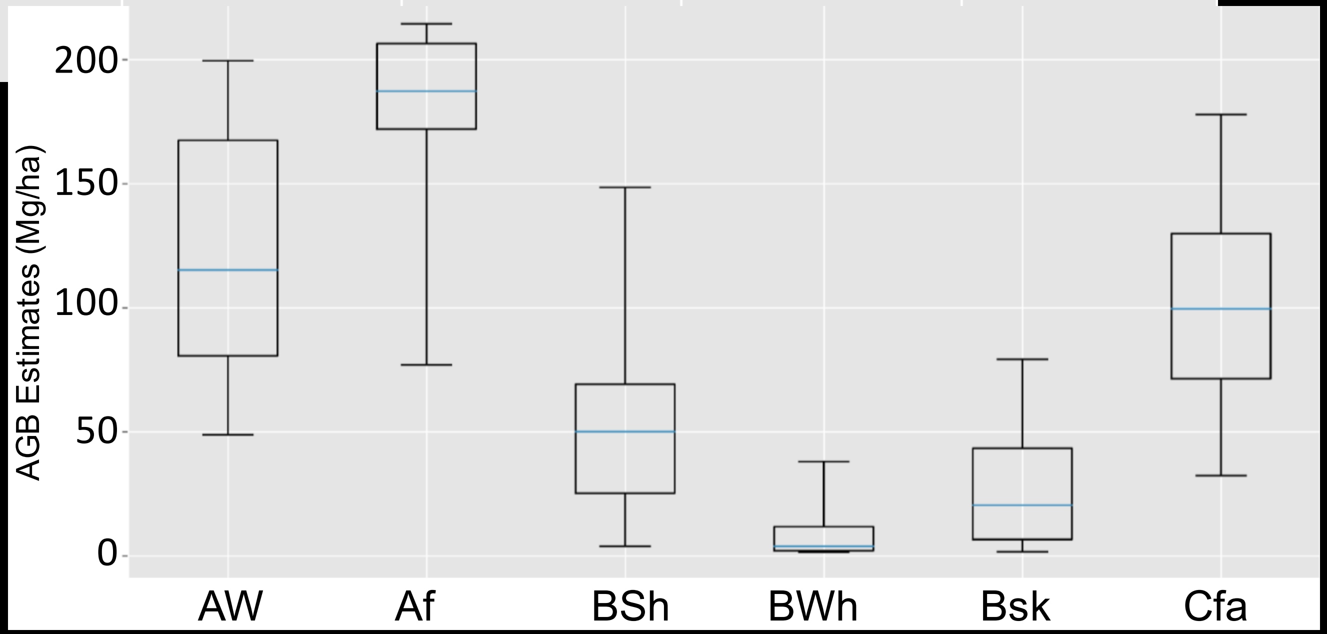
Levente Klein
IBM Research, NY

Carbon Sequestration

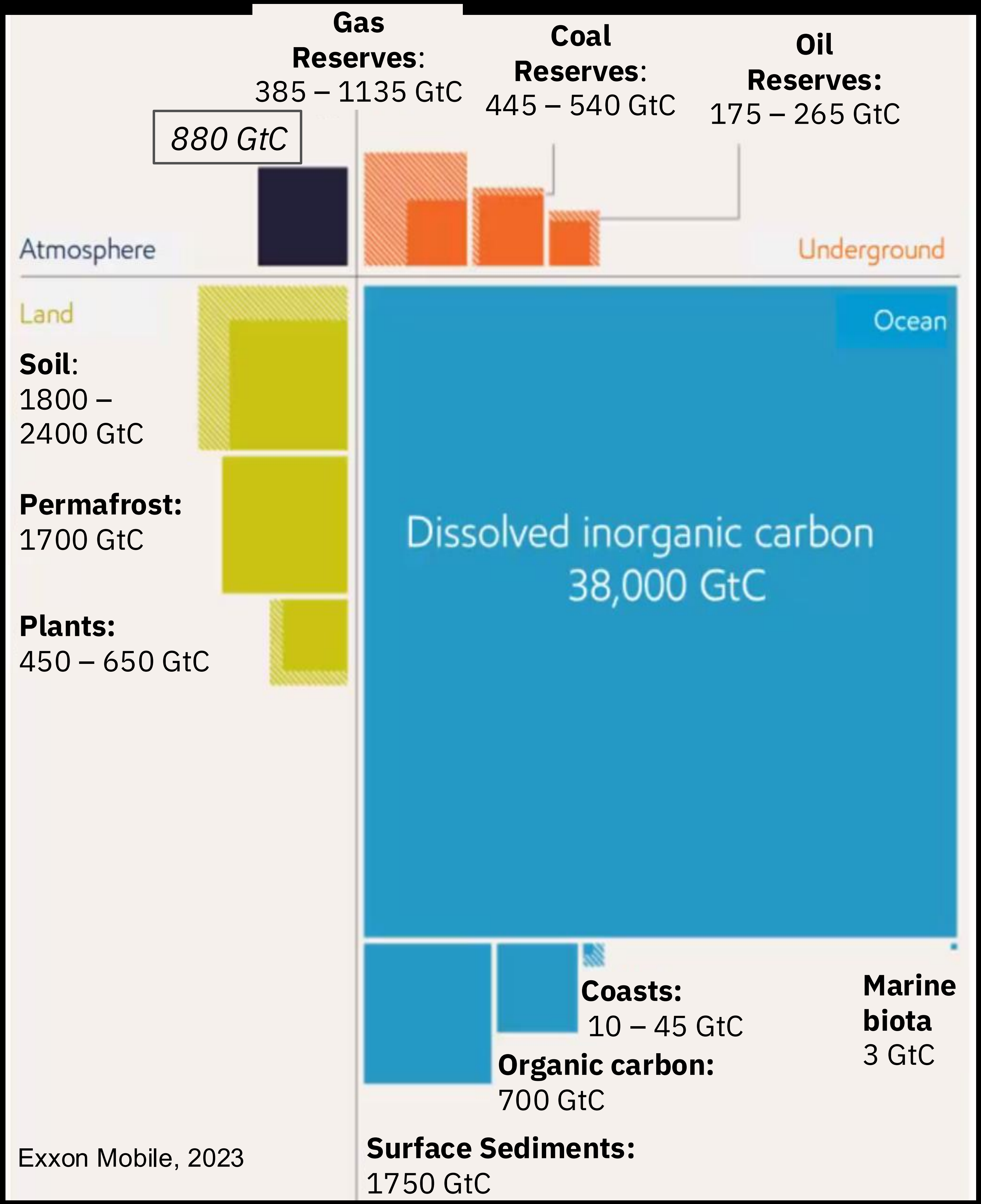
Maintaining and, ultimately, increasing **vegetation coverage** is likely the **most impactful** approach to **globally capture carbon**.

Biomass is a crucial **parameter** for **quantifying carbon** stored in vegetation, and **estimating it poses challenges**.





Biomes
AW: Tropical wet
Af: Tropical rainforest
Bsh and **Bsk**: Semiarid
BWh: Arid,
Cfa: Humid subtropical



Exxon Mobile, 2023

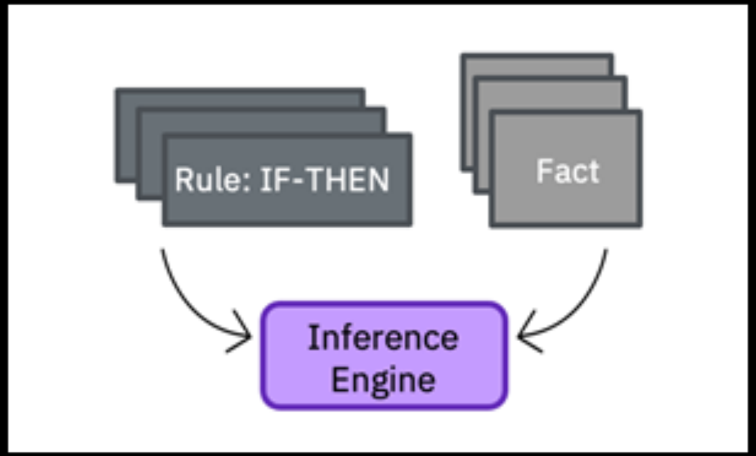
Nathaniel, J., Klein, L. J., Watson, C. D., Nyirjesy, G., & Albrecht, C. M. (2022). Aboveground carbon biomass estimate with Physics-informed deep network. *arXiv preprint arXiv:2210.13752*.

The evolution of AI and the emergence of Foundation Models

80s | Big data

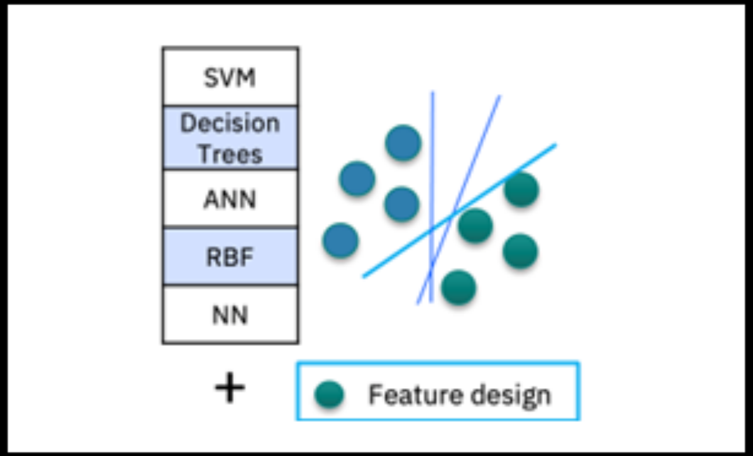
80s to ~2010 | Massive data + Compute

2010 -2017+ | Self-supervision at scale + Massive data + Compute



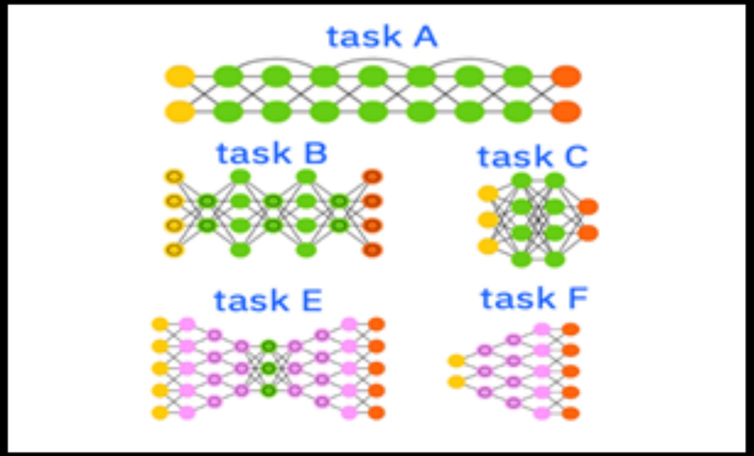
Expert Systems

Hand-crafted symbolic representations



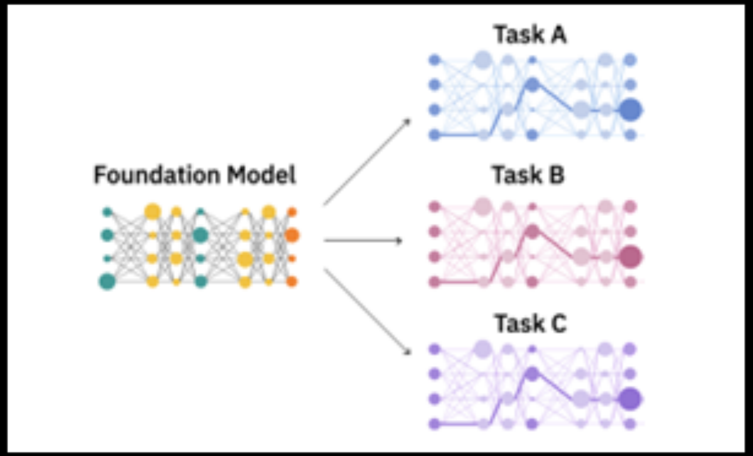
Machine Learning

Task-specific hand-crafted feature representations



Deep Learning

Task-specific learnt feature representations



Foundation Models

Generalizable & adaptable learnt representations

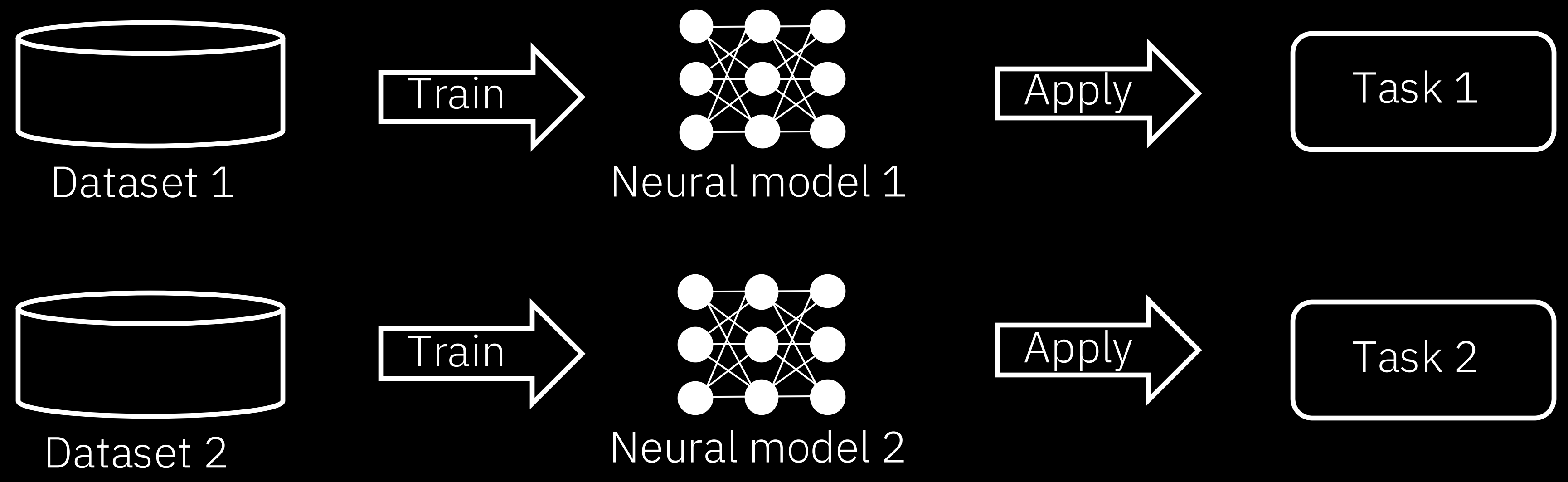
AI Algorithms, techniques and tools

AI models as platforms

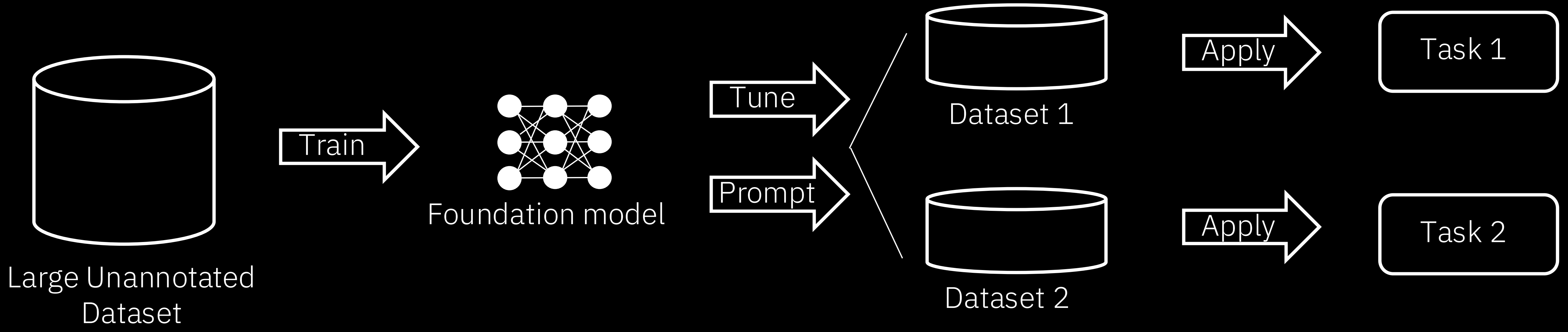
A fundamental shift

What are foundation models?

Conventional Machine Learning Systems



Foundation Model Systems



Geospatial use cases (samples)


Detecting wildfires


Detecting floods


Classifying trees

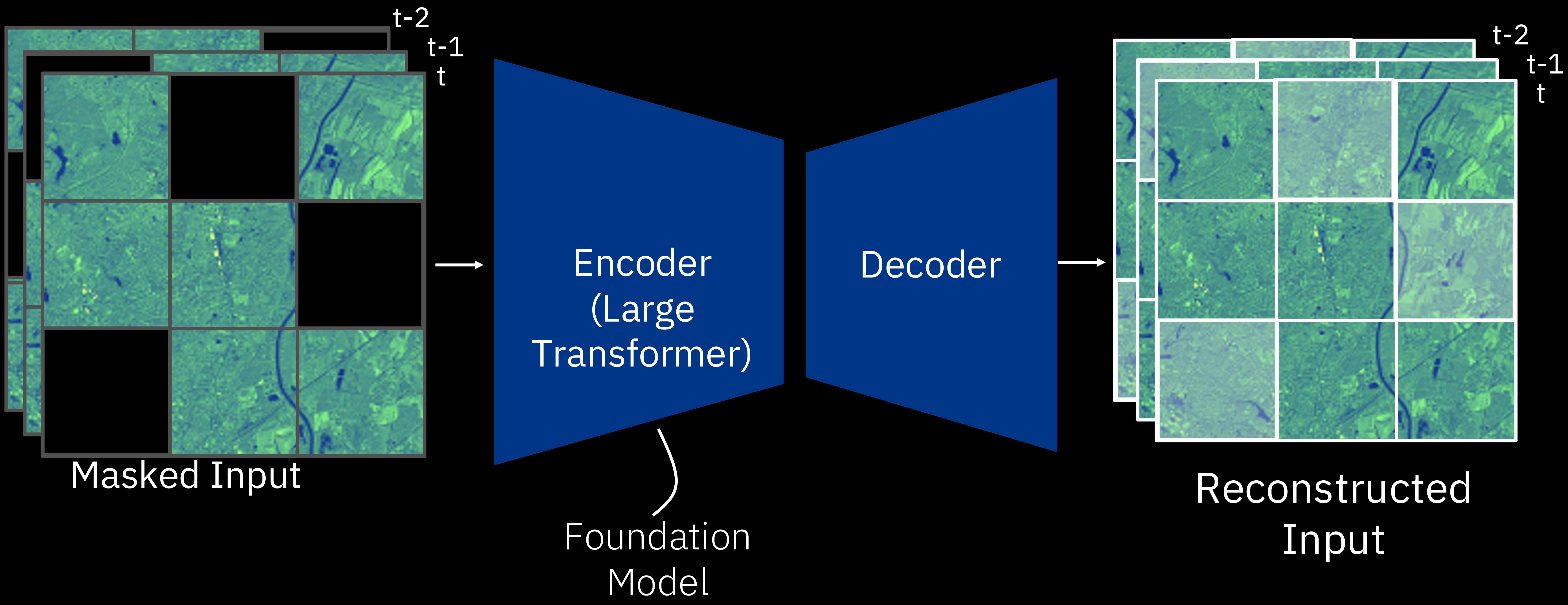

Monitoring GHGs

ESG use cases (samples)

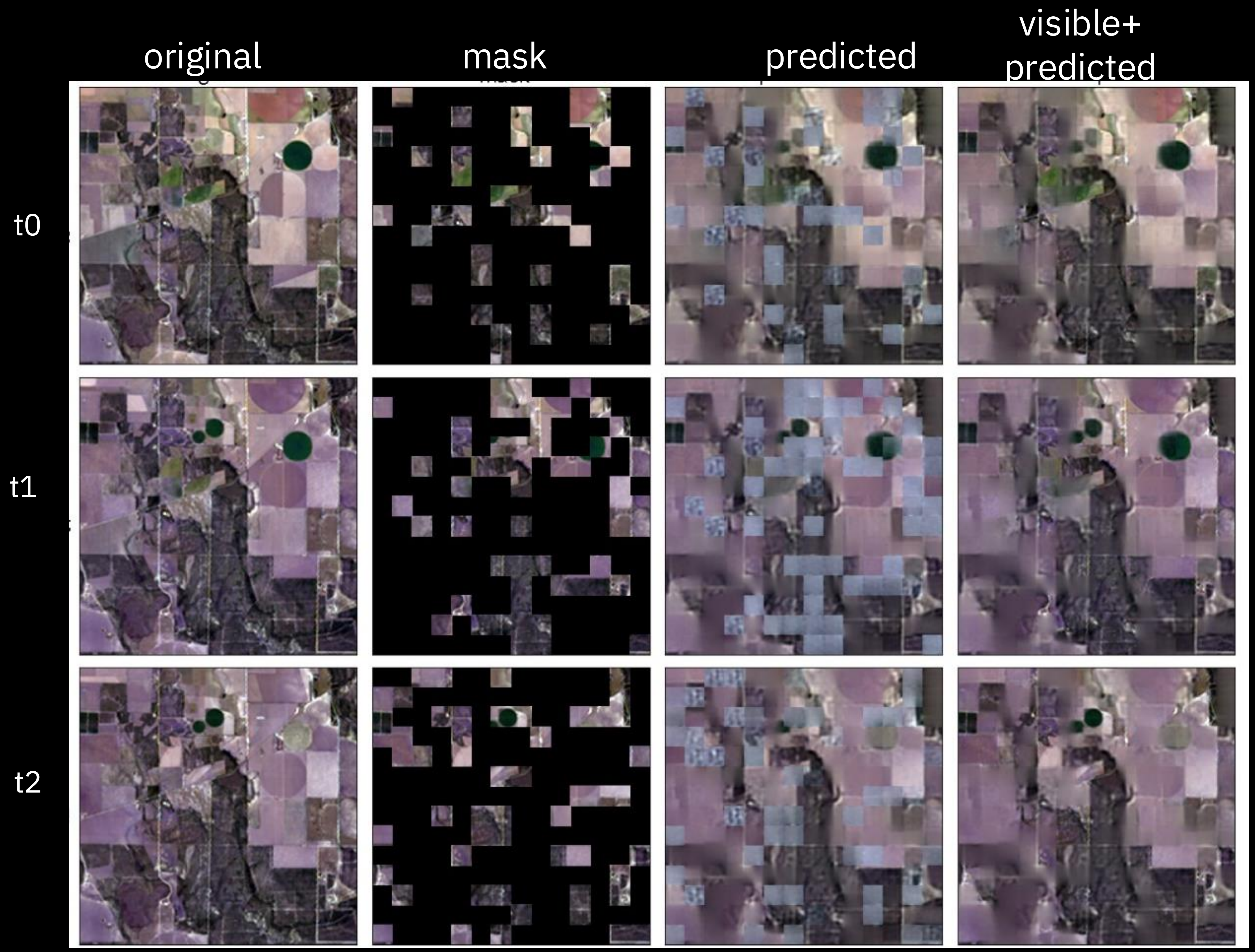

Scope 3 Emissions


Q&A Chatbot for ESG

Self-supervised Learning to Pre-train Foundation Models

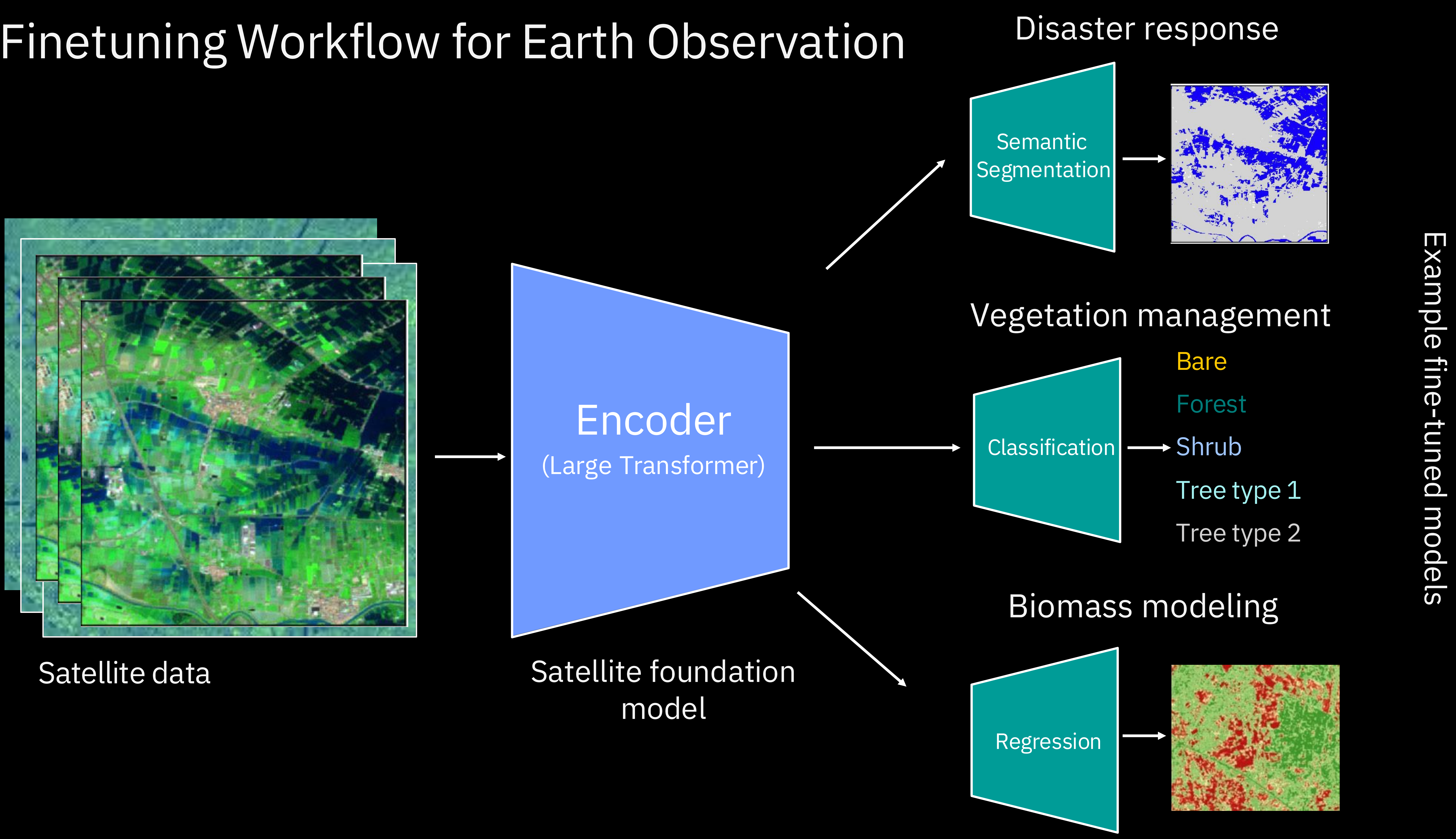


Pretraining Results with 100M Foundation Model



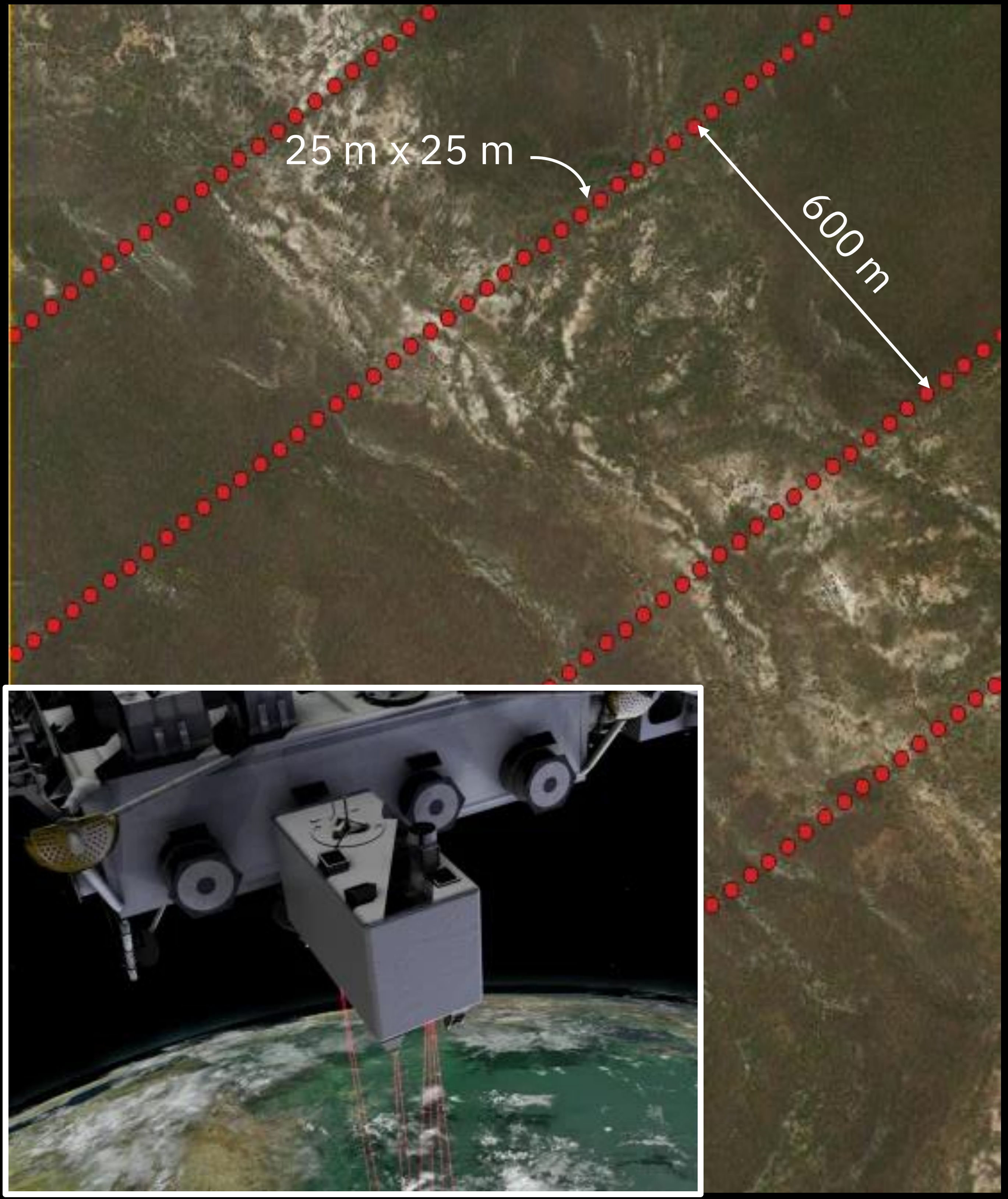
- Excellent spatial and temporal reconstruction performances
- Training MSE loss of 0.0283, and validation loss of 0.0364 with 75 % masking
- All the pre-training runs were conducted in the IBM watsonx platform using up to 64 NVIDIA A100 GPUs.

Finetuning Workflow for Earth Observation

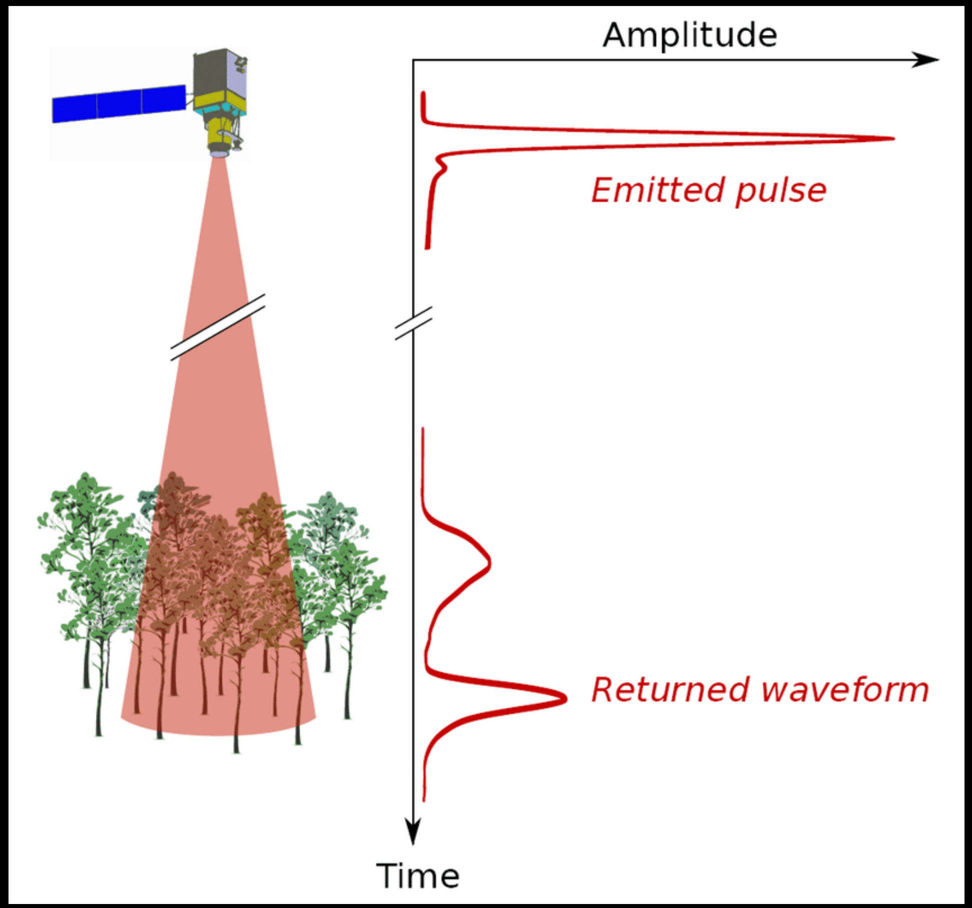


Above Ground Biomass Estimation

LIDAR Observations
from International Space Station

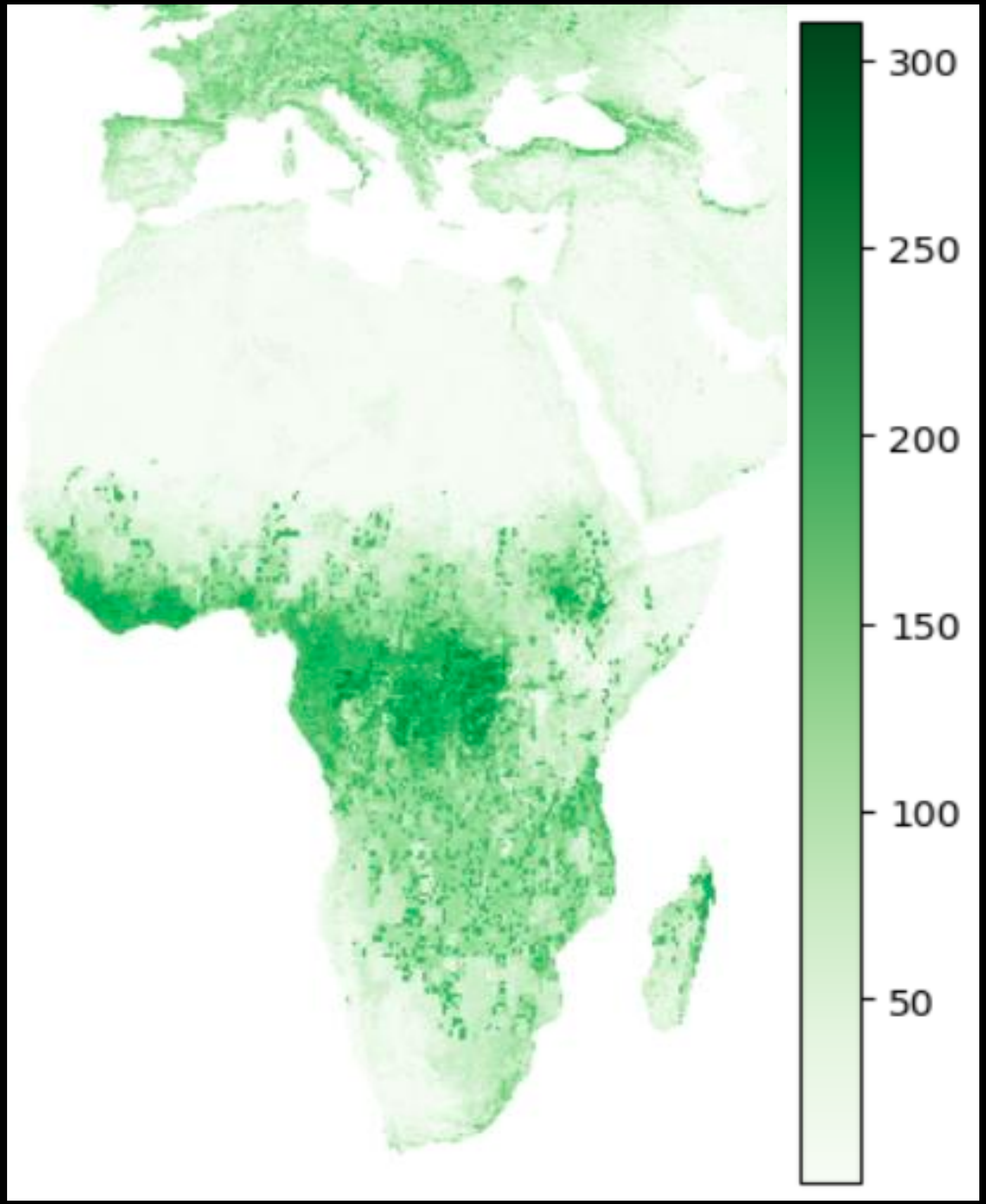


LIDAR Signal



Approach
- Sparse LIDAR data as ground truth for Prithvi fine-tuning
- Prithvi to estimate tree height from high-resolution satellite images

Natural Carbon Stock Estimation



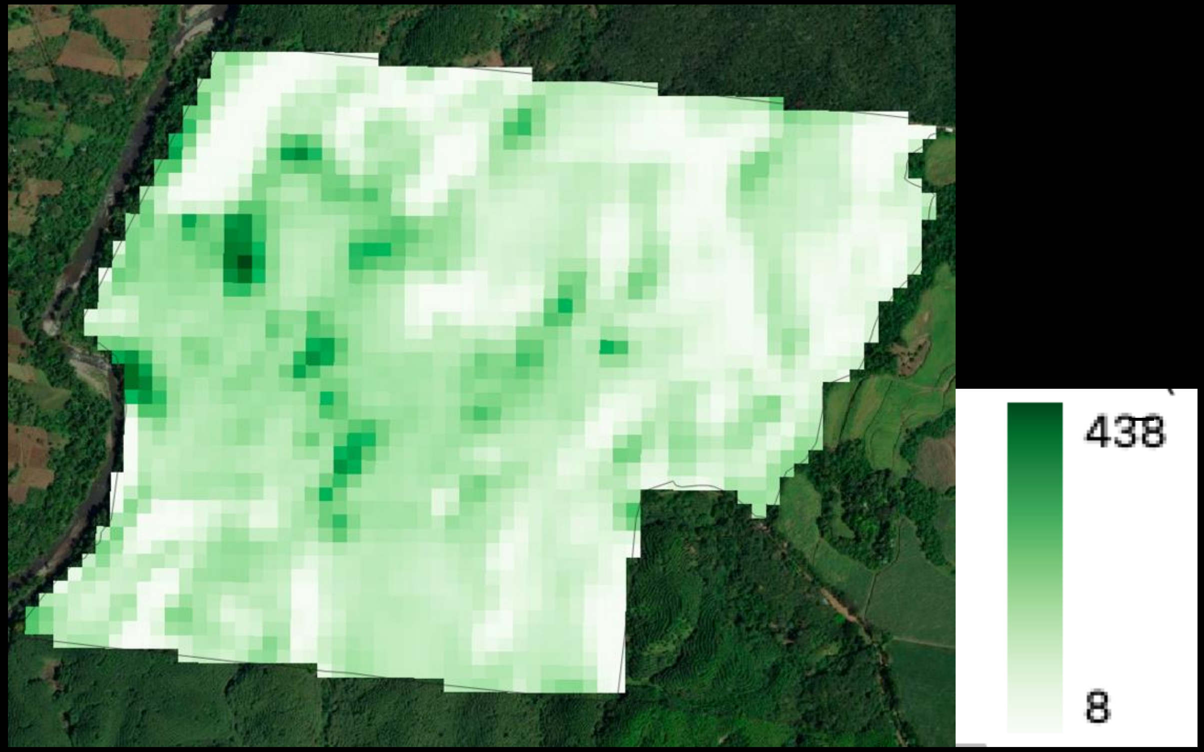
Above Ground Carbon Biomass [Mg C/ha]

CO2-e, Carbon and Above Ground Biomass

source	Total Carbon (ton CO2-e)
2019 Verra report*	38,125.06
IBM model (adjusted for area as per Verra)	35,854.44

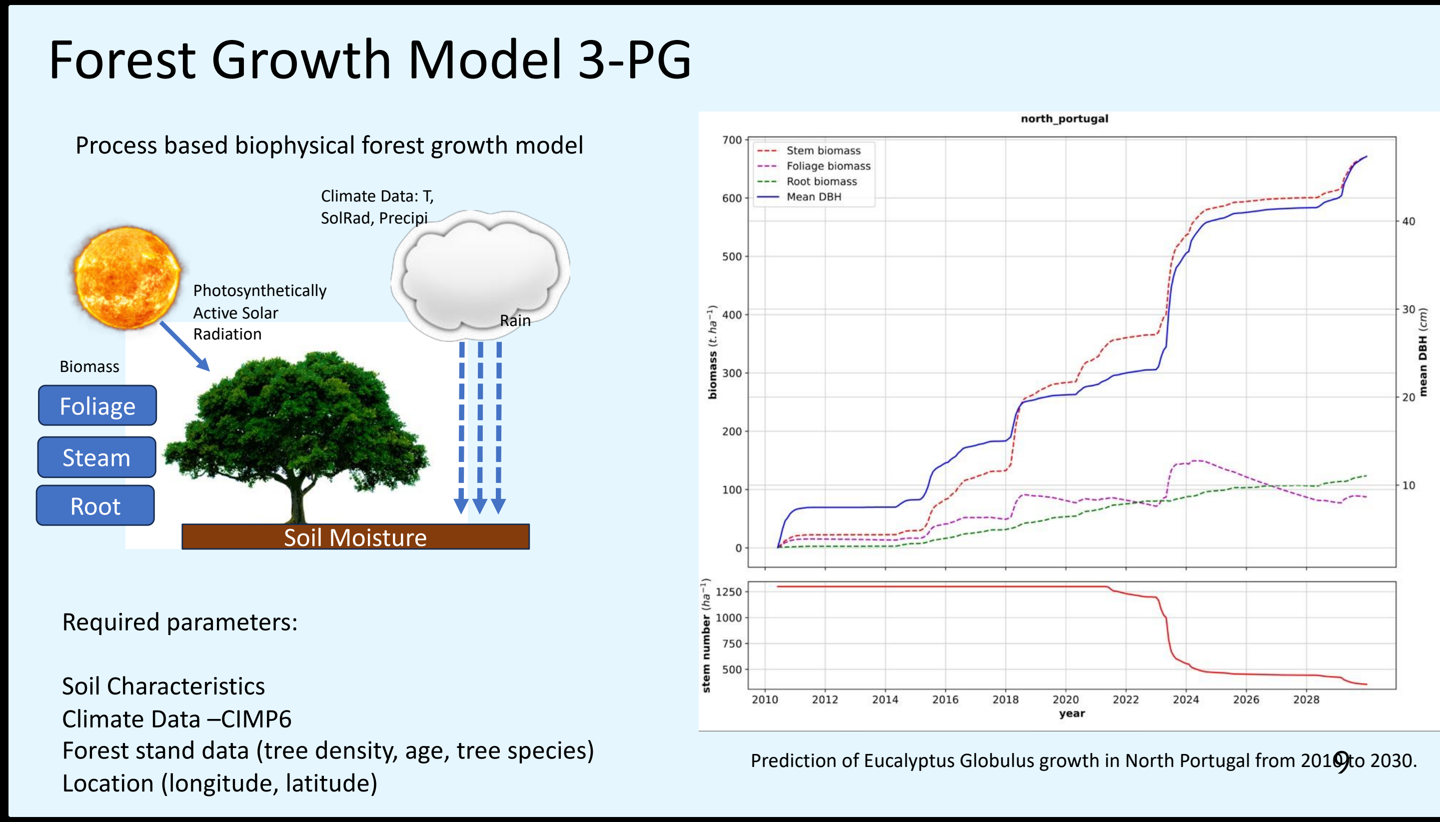
source	AGB (ton)
2019 Verra report*	16,875
IBM model (adjusted for area as per Verra)	15,870

source	Mean AGBD (t/ha)
2019 Verra report*	119.3
IBM model	111.8



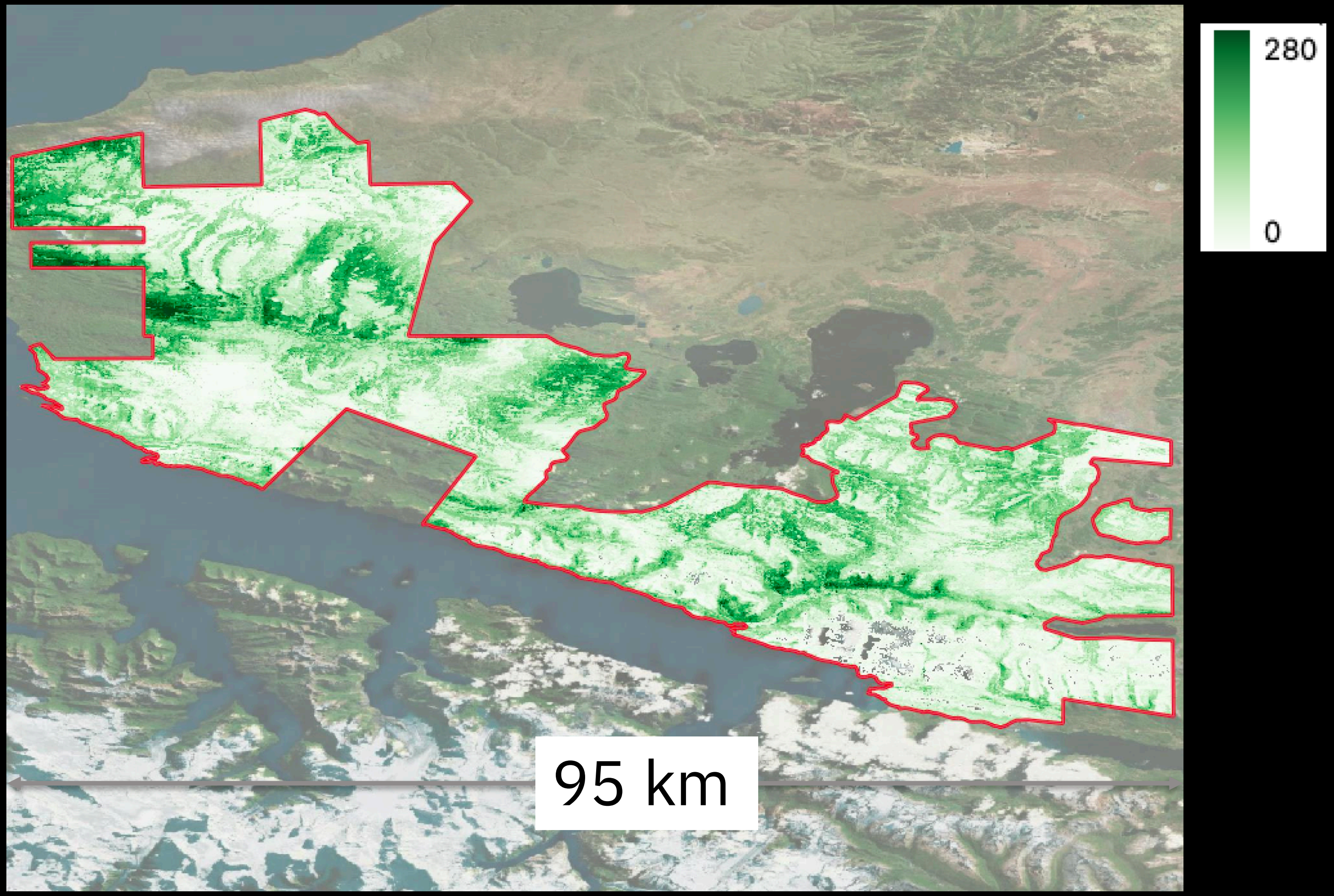
Above Ground Biomass and Carbon Calculation

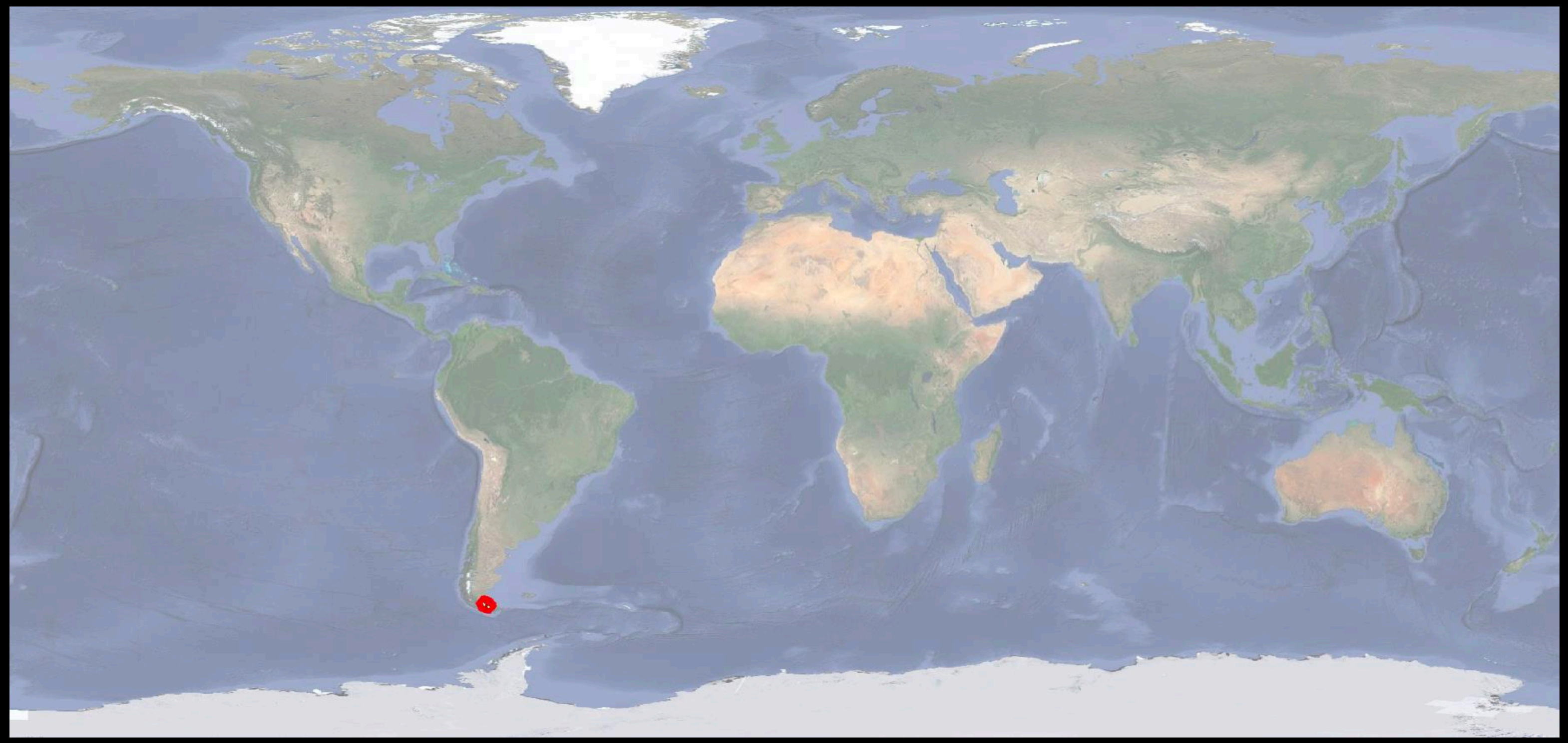
- Computed as a fraction of total carbon
- Ratio of Below to Above Ground biomass is 0.22
- Carbon is 50% total biomass
- Carbon = (0.27) * CO2-e

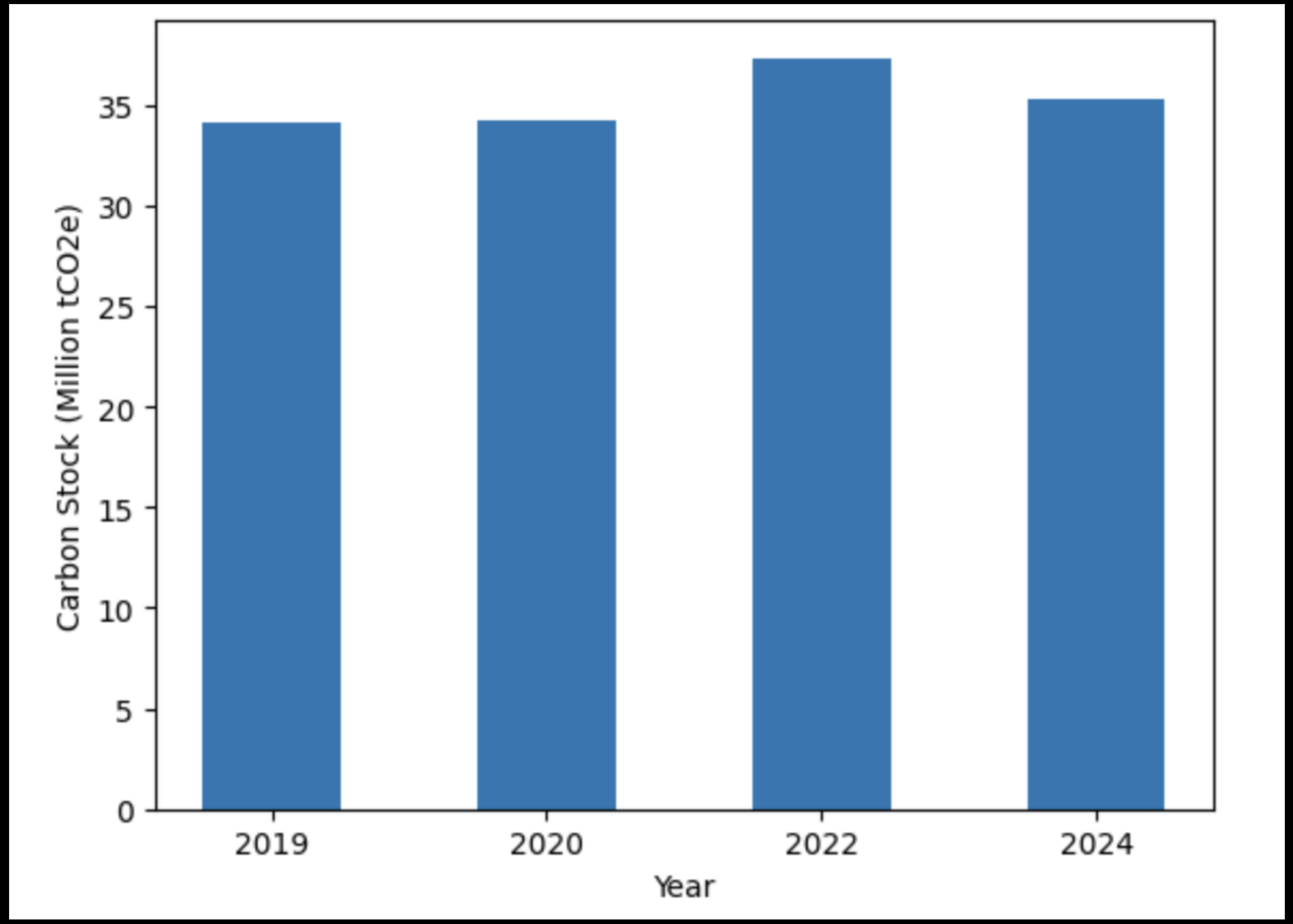


Above Ground Biomass

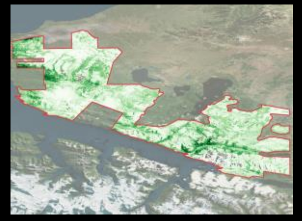
AGBD (t/ha)







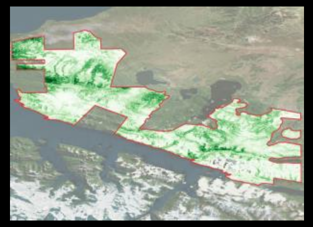
Total Carbon Stored in Vegetation



2019

2020

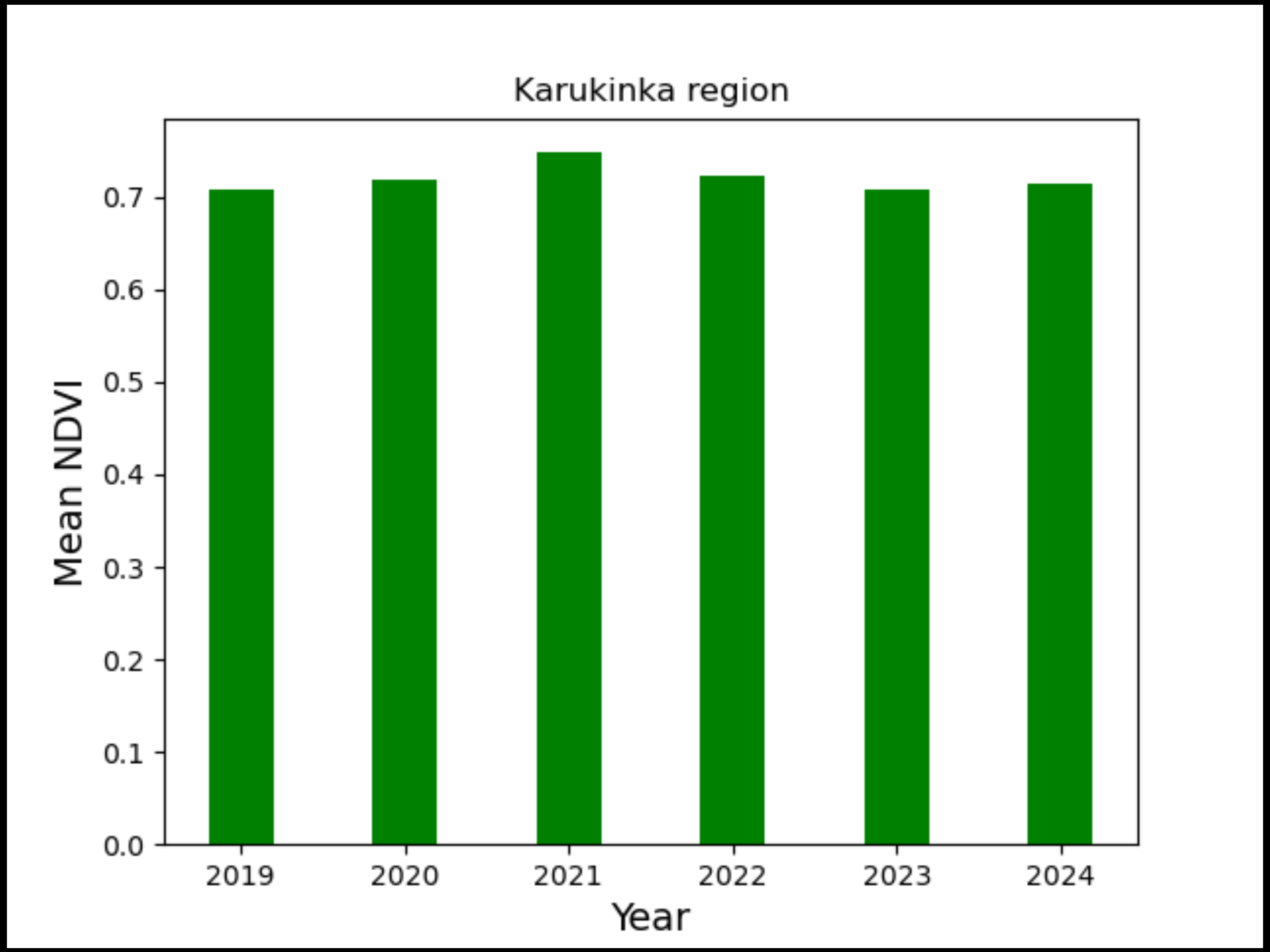
2022



2024

Carbon Sequestration; Carbon Pool Growth

Forest Greenness has year to year fluctuations



2019

2020

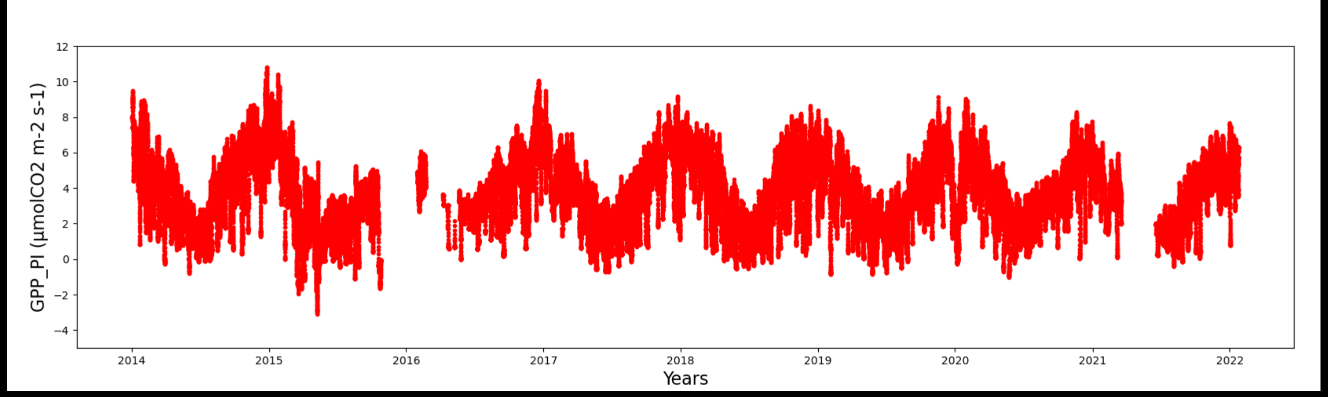
2021

2022

2023

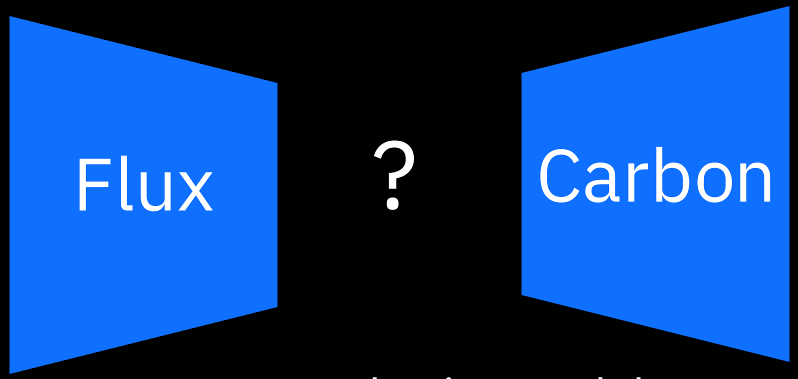
2024

Chile, a mixed forest but not in the sense of deciduous vs evergreen but in the sense of broadleaf vs conifer trees. They are all evergreen species. GPP values decreasing, year to year-how to relate to carbon flux?



Ameriflux, **CL-SDF: Senda Darwin Forest**

Training data: synthetic flux data to capture growth across ecoregions



- Physics Model
- AI model
- Physics Informed AI model

Outlook

Foundation Model provide self supervised models that are generalizable across large geographic regions. For local measurements, the model require finetuning of parameters.

Finetuning the model for year-to-year change in carbon sequestered require filed measurements (tree parameters, LiDAR or Flux Tower data)

Integration of AI/biophysics models that capture vegetation growth require either more data or specialized domain expertise.

Sam Upton and Jake Nelson's presentation can be found here:

http://bgc-jena.mpg.de/~jnelson/UpscalingWorkshop2024

Upscaling workshop
Jul 9-10, 2024

BERKELEY LAB

Beyond Boundaries: The Future of Land Surface Fluxes through Hyper-Resolution Remote Sensing across Space, Time, and Spectrum

Youngryel Ryu, Ph.D.

서울대학교
SEOUL NATIONAL UNIVERSITY

Acknowledgements

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KOPRI
극지연구소

AL SENSING AI LAB
Seoul National University

VERI TAS LUX MEA

과학기술정보통신부

KARI
한국항공우주연구원
Korea Aerospace Research Institute

농촌진흥청

JAXA

SCHMIDT FUTURES

MOTIVATION

Model evaluation against X by X pixels centered on flux tower over Y days

meteorological data and GPP estimates for 2001. Every 8 days, a window of the MODIS daily GPP (7 by 7 pixels) is retrieved at the exact location of these towers, and we make a direct comparison between the MODIS GPP and tower measurements of vegetation GPP (figure 7). This protocol is

Running et al., (2004) BioScience

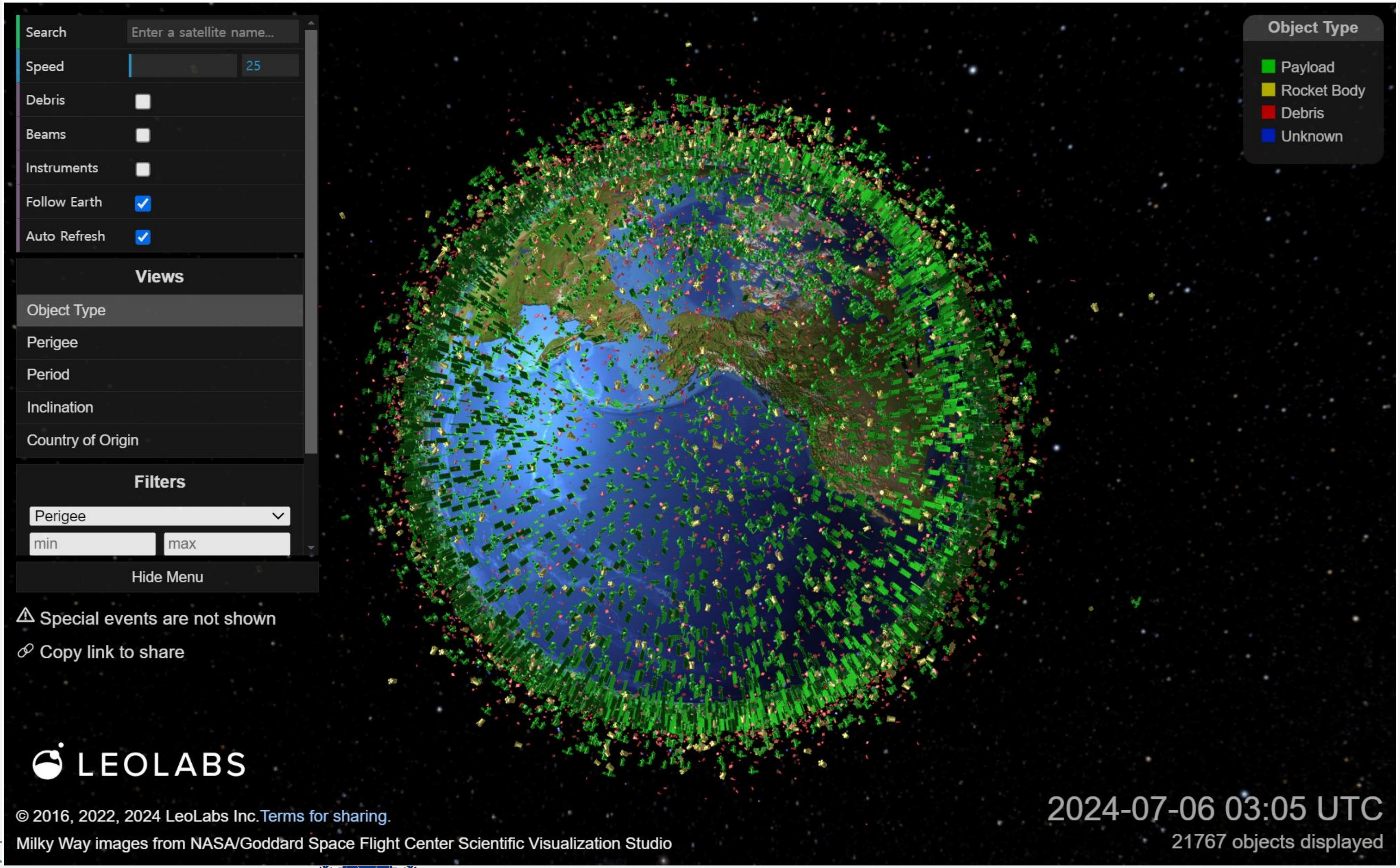
We extracted average values for the central 3 km × 3 km area within the 7 km × 7 km cutouts to better represent the flux tower footprint

Xiao et al., (2010) RSE

We further evaluated the performance of BESS in comparison with two benchmark products, FLUXCOM and GLASS, at a monthly step against FLUXNET tower pixels (Fig. 3). All three products were resampled to a 0.05° spatial resolution. Overall, all three products agreed well

Li et al., (2023) RSE

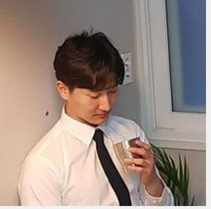
Opportunities



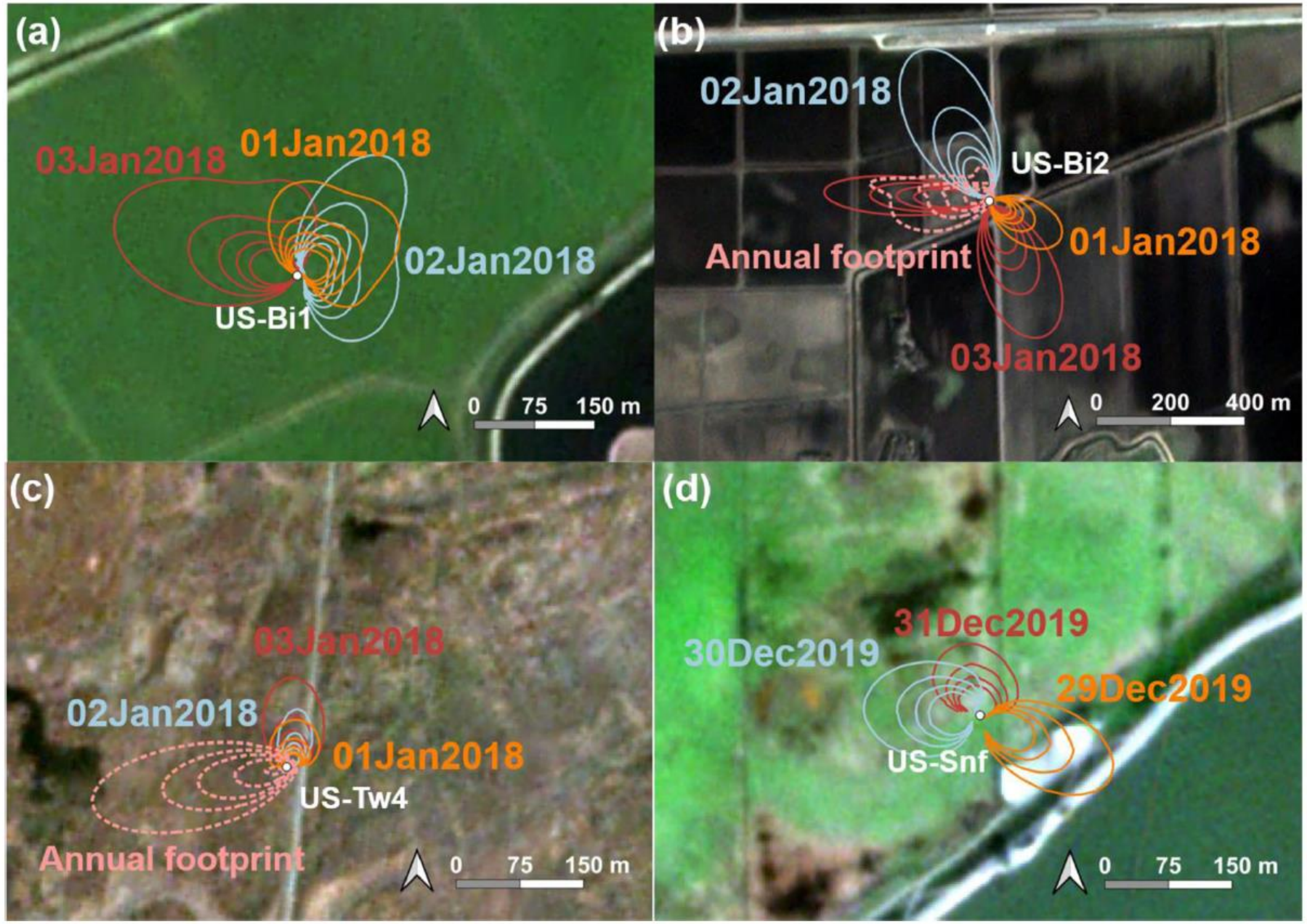
ECOLOGI
Seoul National University

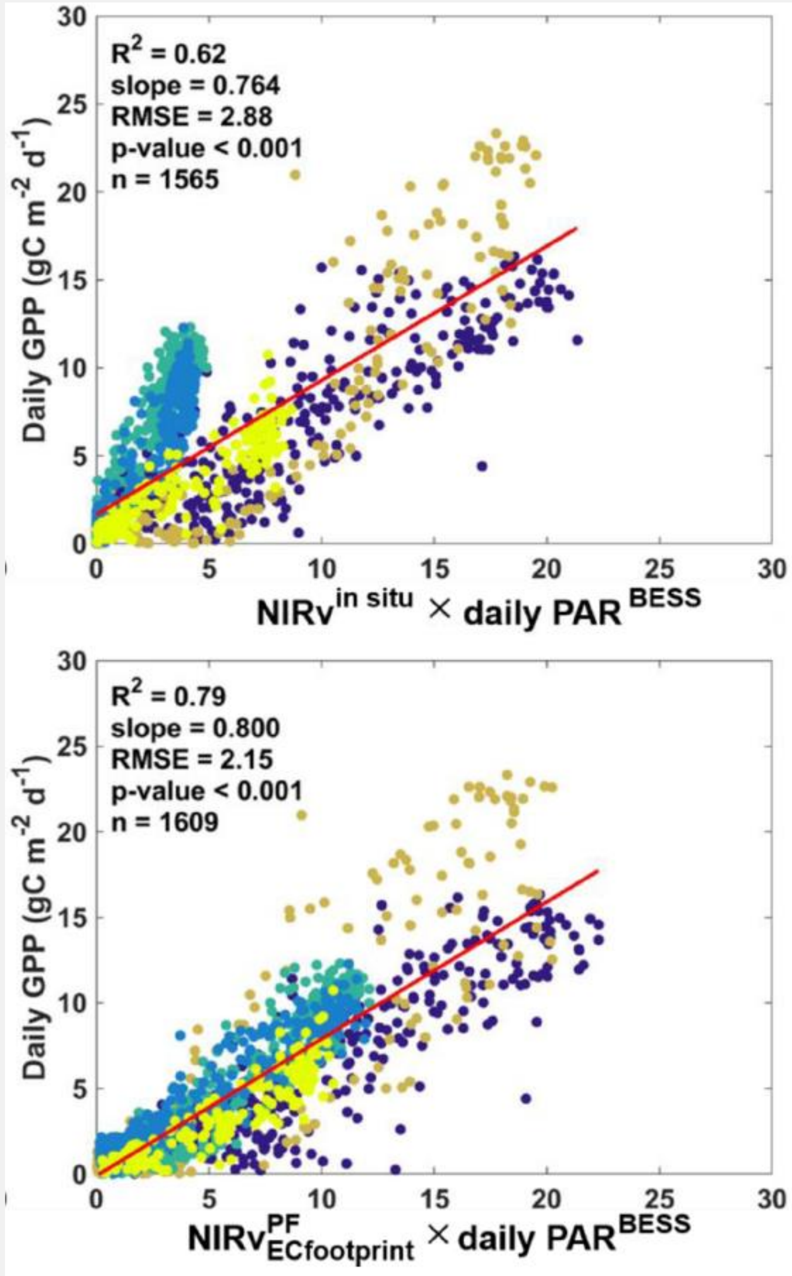
https://platform.leolabs.space/visualization

SPACE



Pixels into the flux footprint - 3 m, daily Planet Fusion





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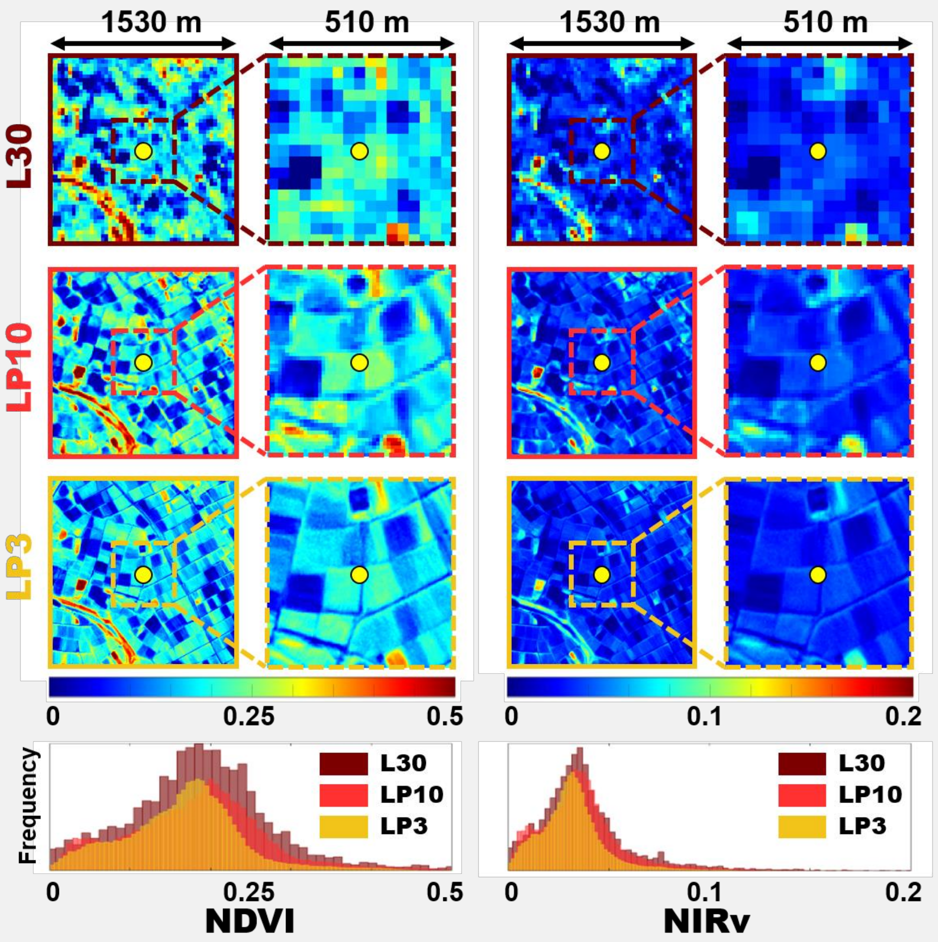
Kong et al., (2022) Agricultural and Forest Meteorology

Super resolution Landsat learned from Cubesats

- GAN (generative adversarial network) was applied to make 30 m Landsat into 3 and 10 m images by learning finer spatial patterns from Cubesats
- It can open a new opportunity to map photosynthesis at highly fragmented landscapes back to several decades



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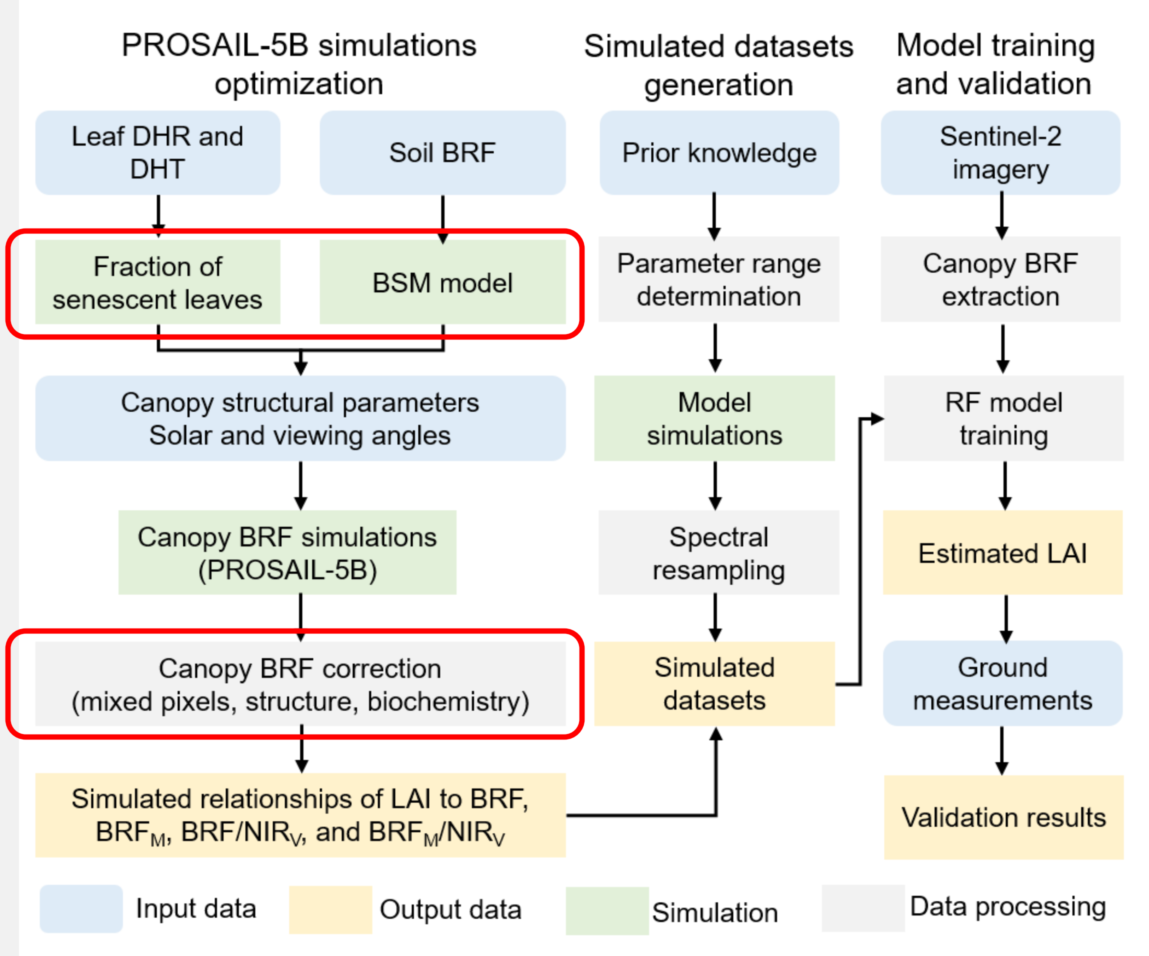
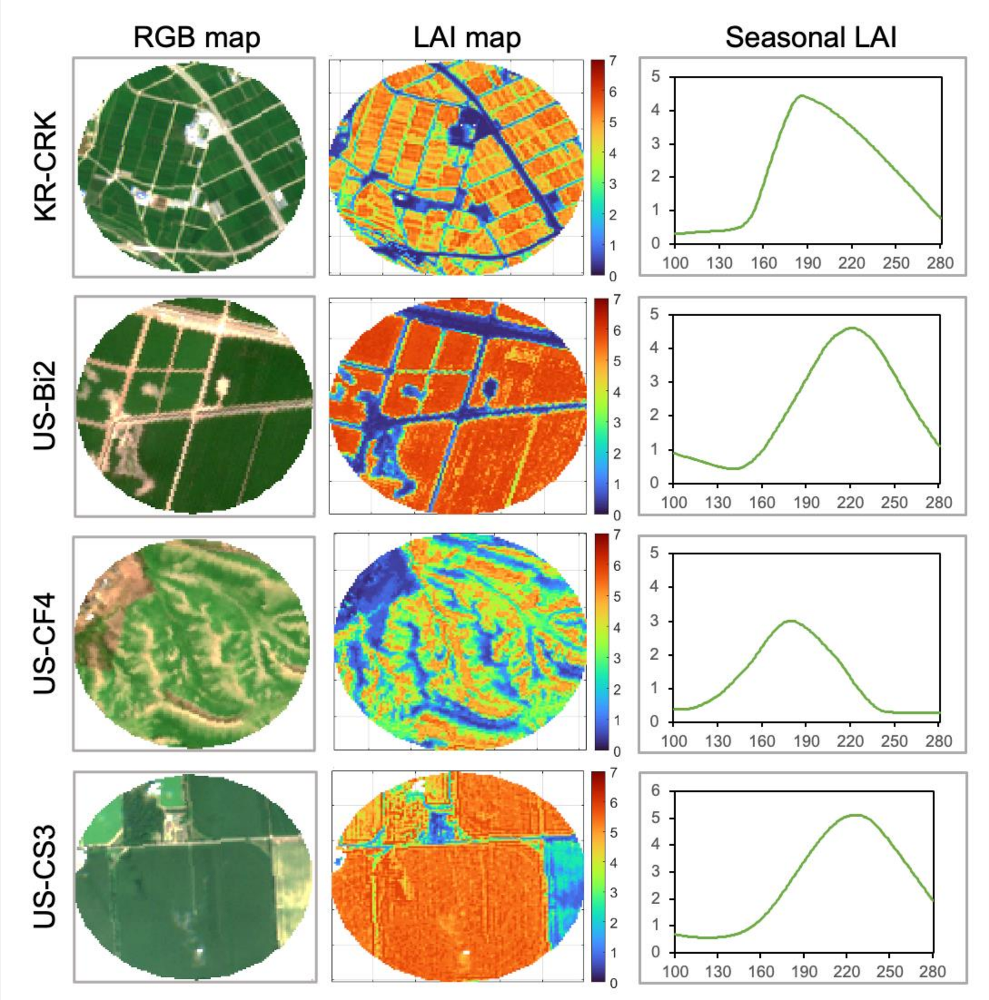
Seoul National University

Kong et al., (2023) ISPRS Photogrammetry and Remote Sensing

10 m LAI from Sentinel2 towards global land

-correcting canopy structure, biochemistry, soil background effects-





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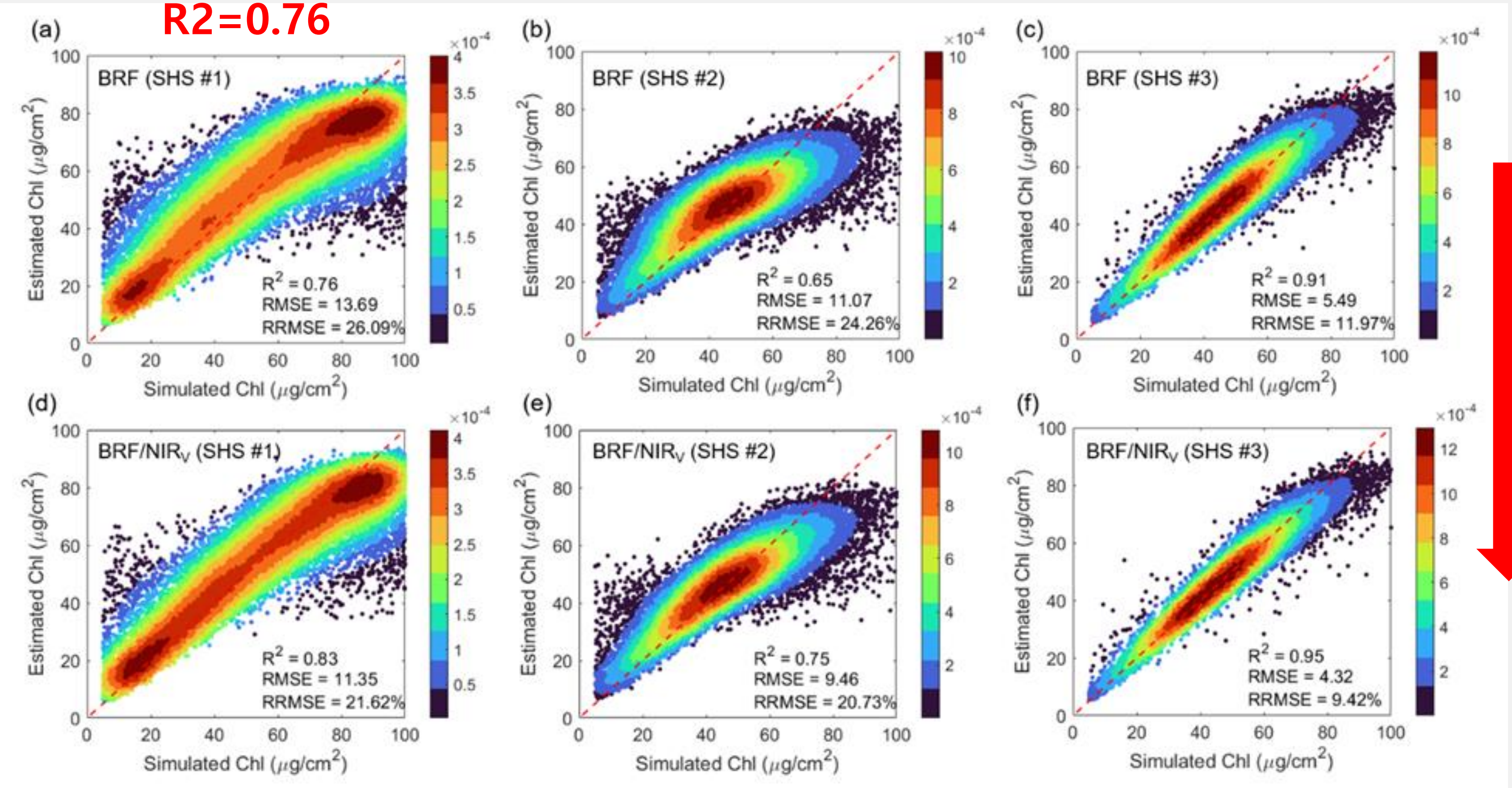
Wan et al (2024a) Remote Sensing of Environment

10 m Chl from Sentinel-2 towards global land

Different distributions in parameters

BRF/NIRv to mitigate canopy structure effects

R2=0.76



R2=0.95

BRF

Vs

BRF/NIRv

PROSAIL-5B inversion

Train the model with RF

Forced w/S2 BRF and NIRv

Generate 10 m Chl maps

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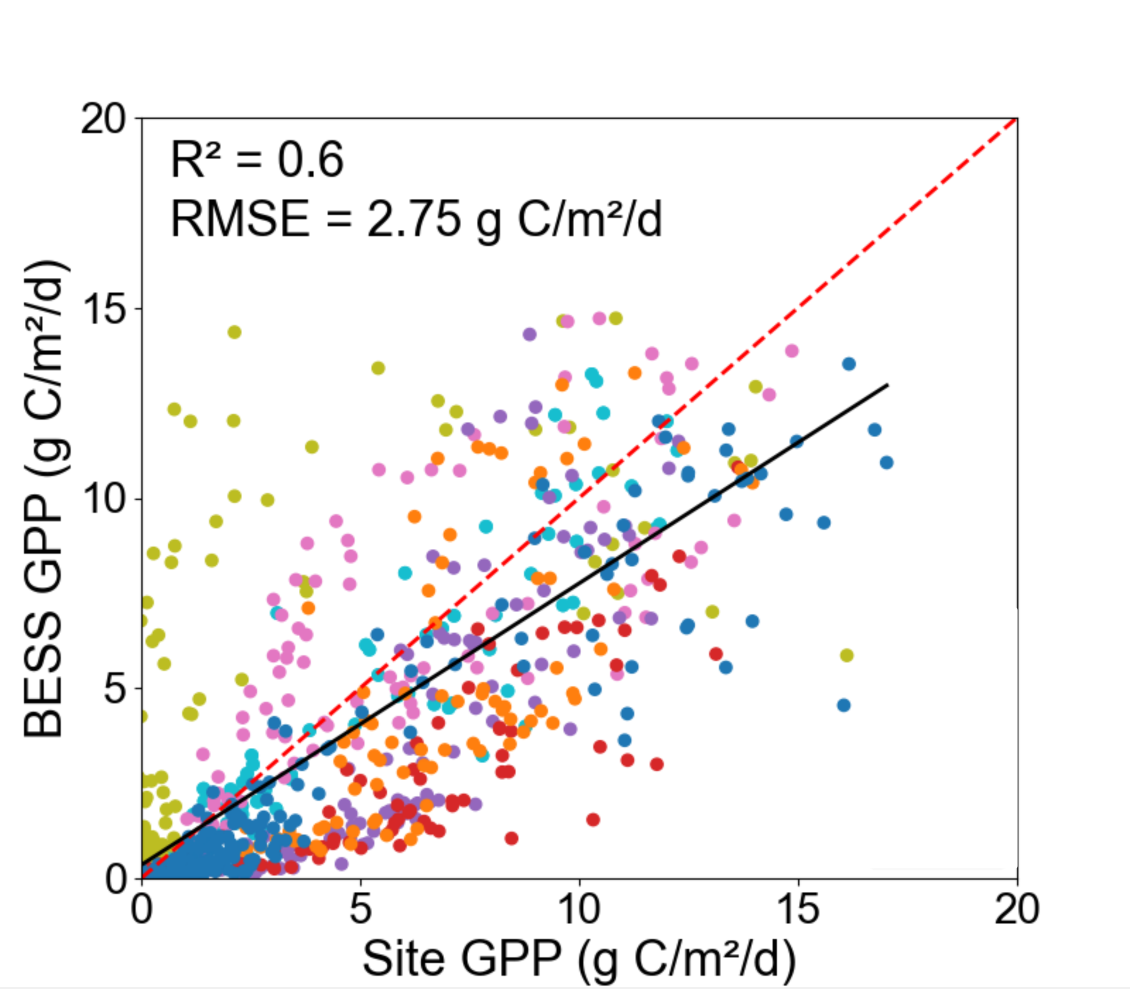
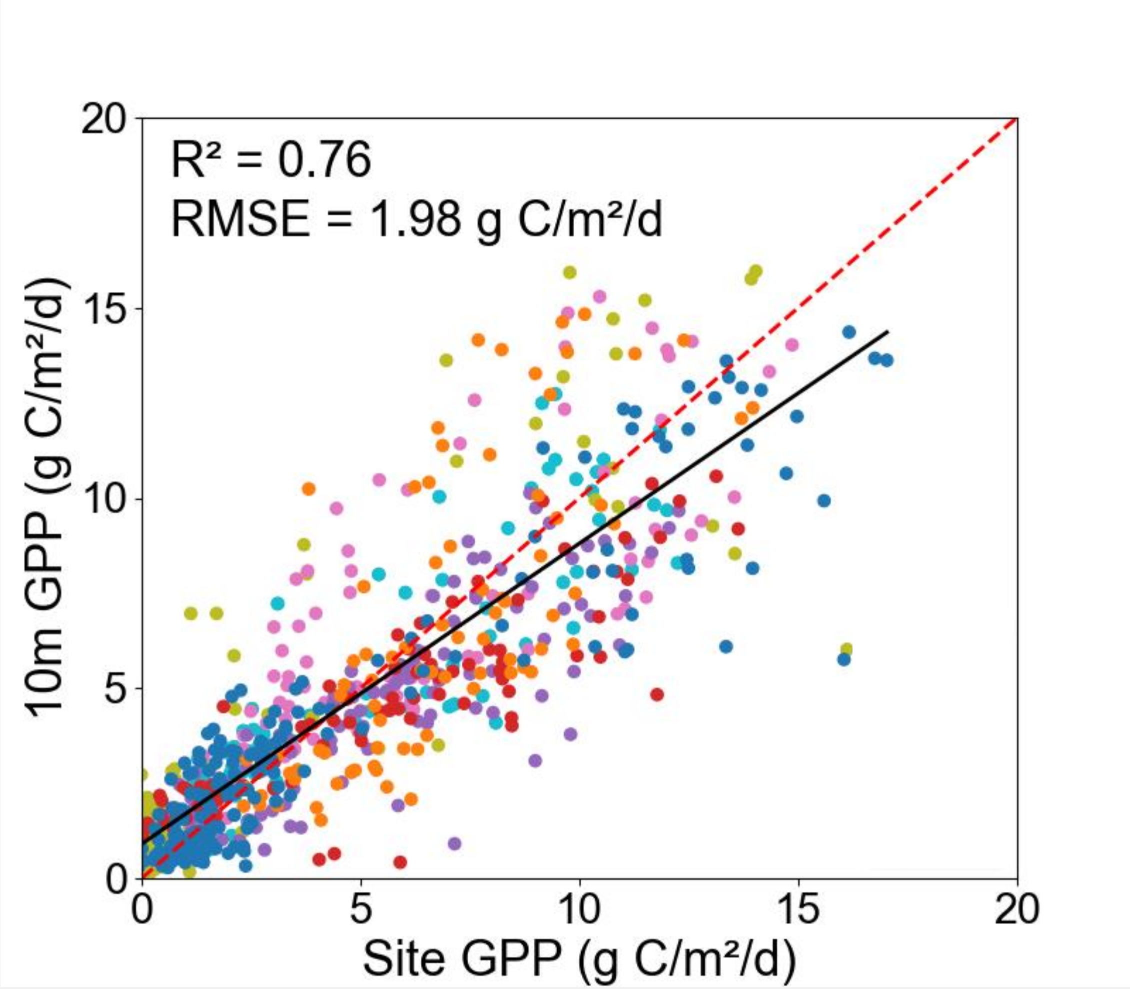
Seoul National University

Wan et al (2024b) Remote Sensing of Environment

0.05 degree vs 10 m BESS GPP in Korea

-Ready to run BESS at 10 m-





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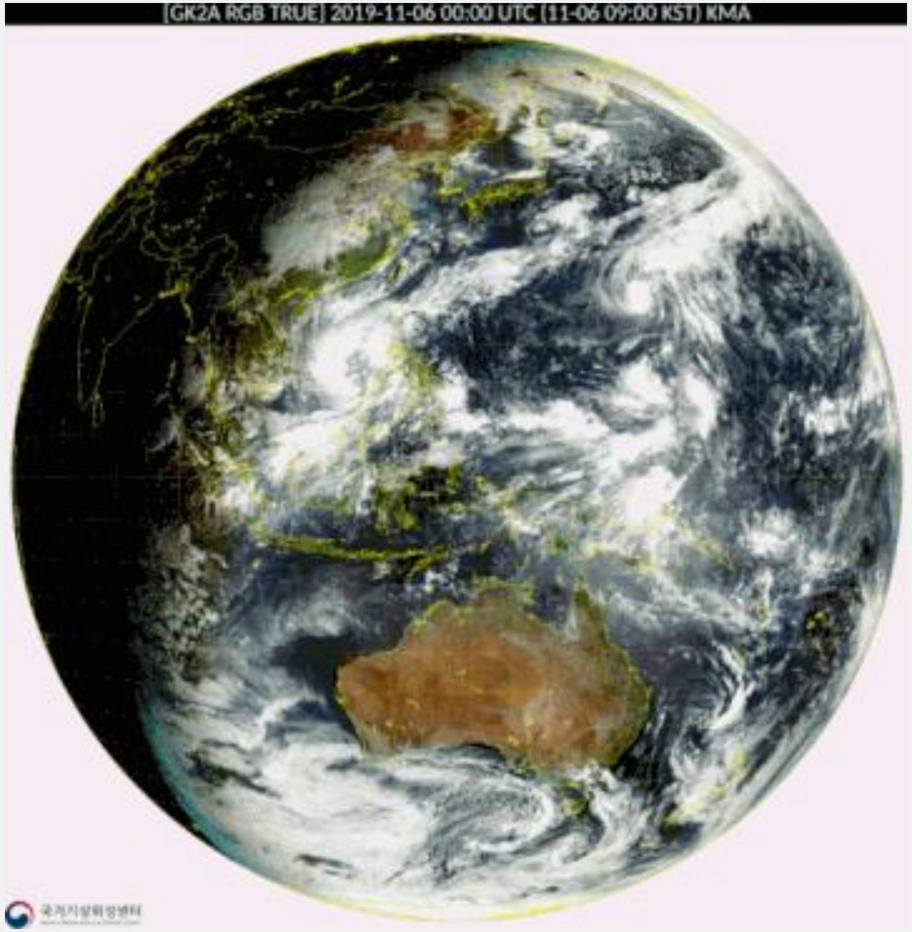
Zhang et al (in preparation)

TIME

Every min sensing on the Earth disc



- Opens new opportunity to monitor diurnal variations of GPP
- But solar zenith angle variations are so large
- Sensor view angle is not nadir except for Equator
  - Strong BRDF effects!

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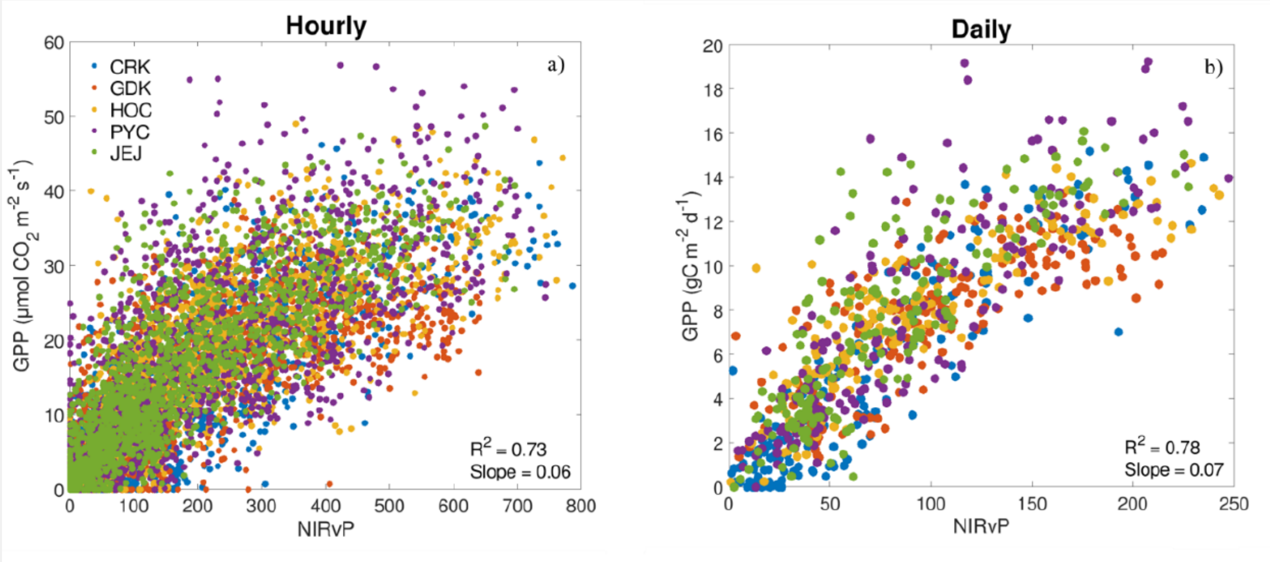
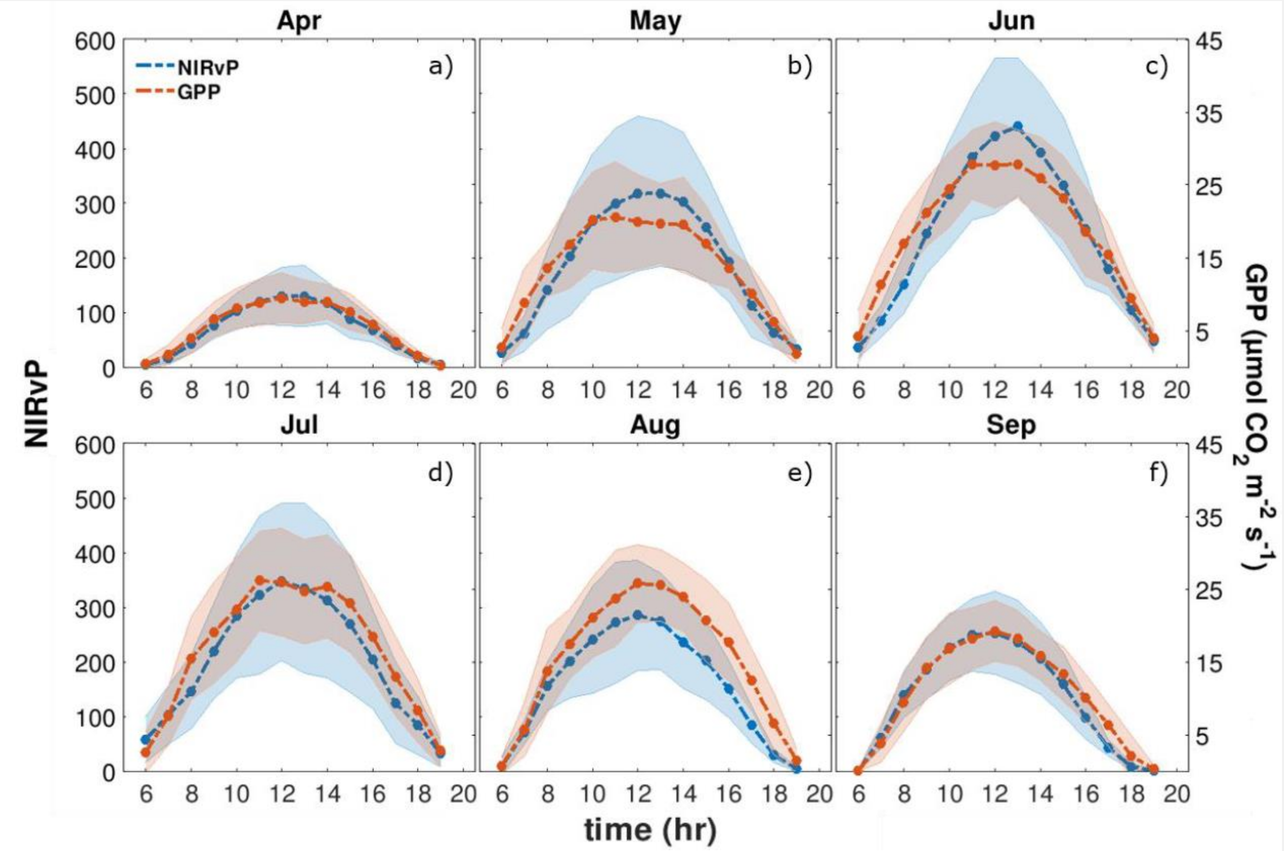
Diurnal variations of GPP from GEO-NIRvP

Five flux towers in South Korea
: 3 DBF, 1 MF, 1 CRO





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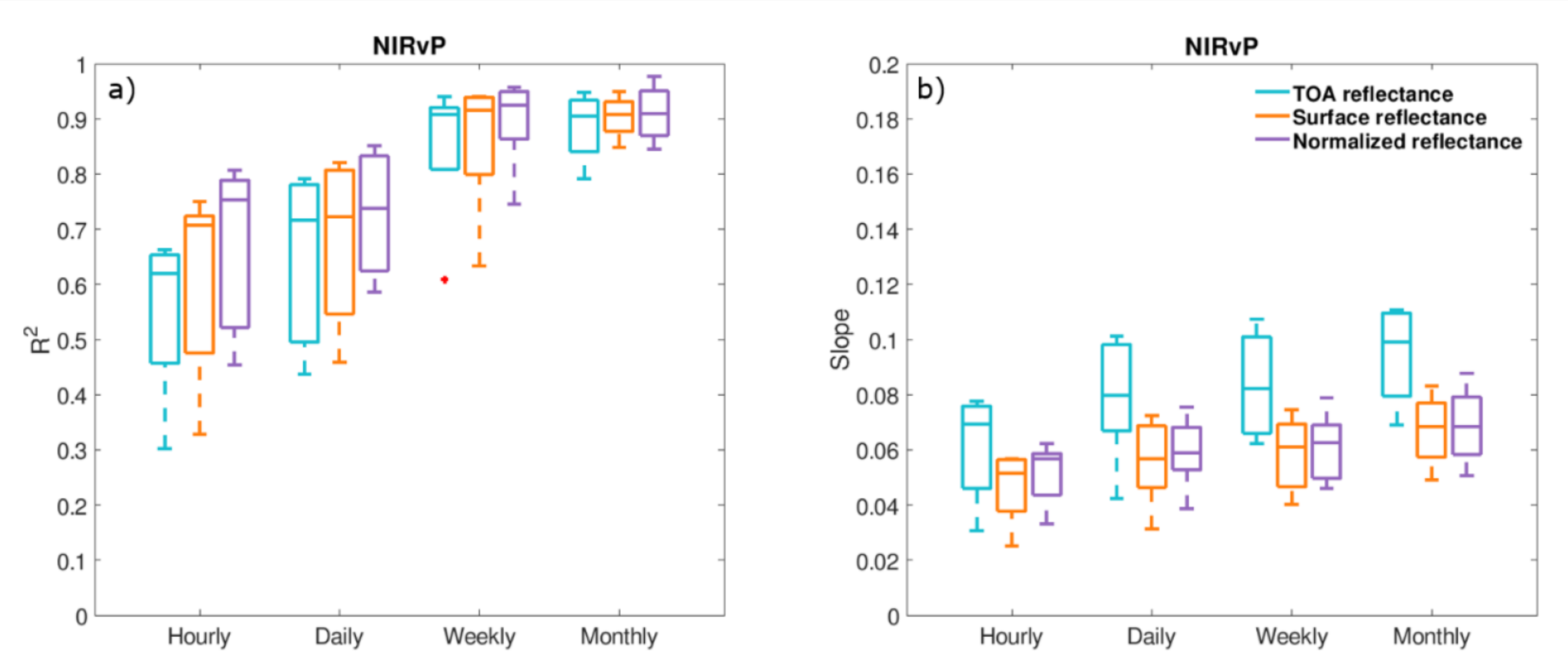
Jeong et al., (2023) Remote Sensing of Environment

Atmos & BRDF corrections matter in NIRvP~GPP relationships!



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Jeong et al., (2023) Remote Sensing of Environment

Hourly SIF mapping: GEO-SIF

- XGBoost model
- Adjusted GK2A view geometry into OCO3 view geometry through BRDF

SIF = f (Blue, Green, Red, NIR reflectance, SW, VPD)

↑ OCO-3 (SIF)

↑ GK-2A (Blue, Green, Red, NIR reflectance)

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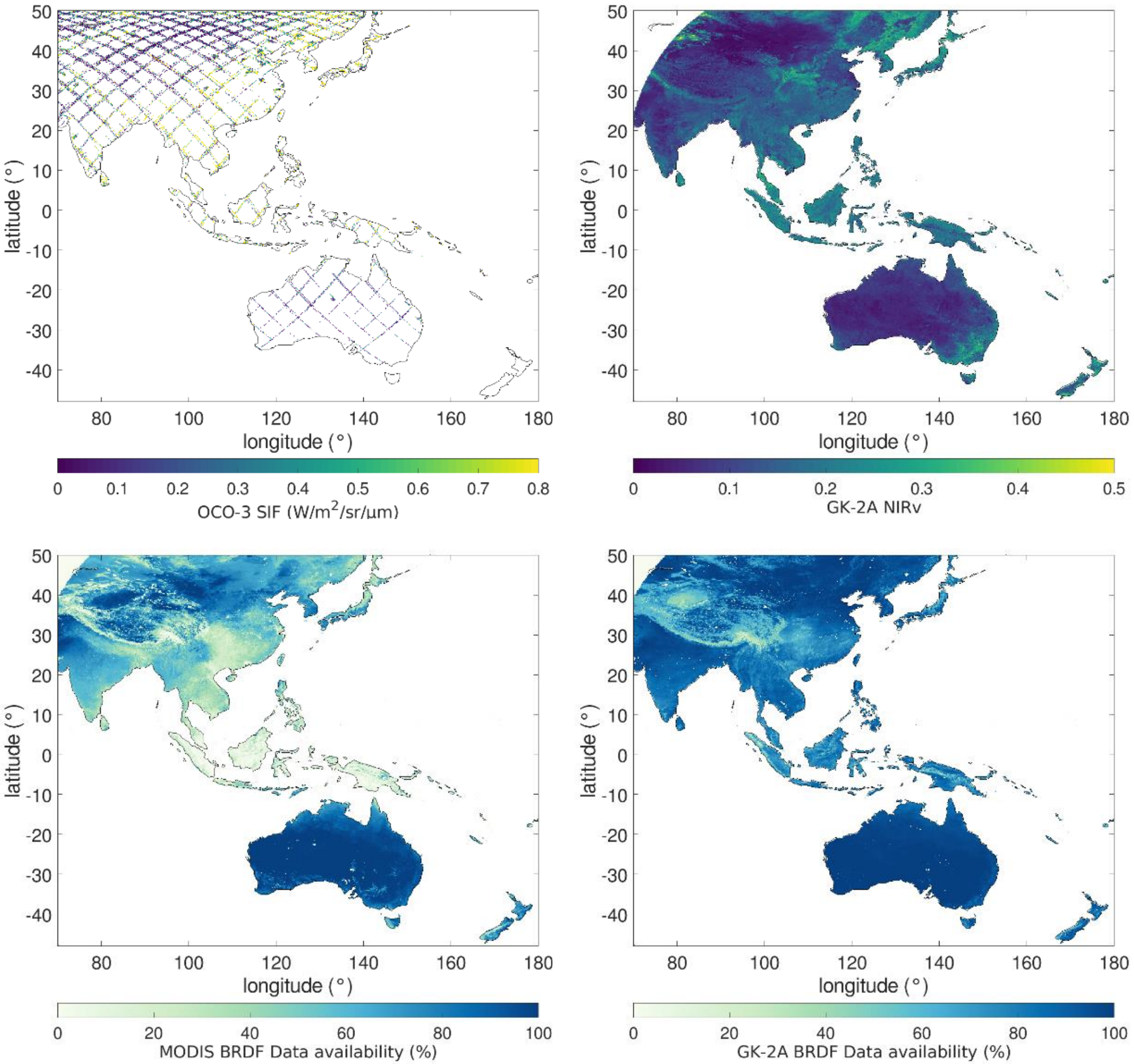
Jeong et al (2024a) Remote Sensing of Environment

Much more data in GK2A



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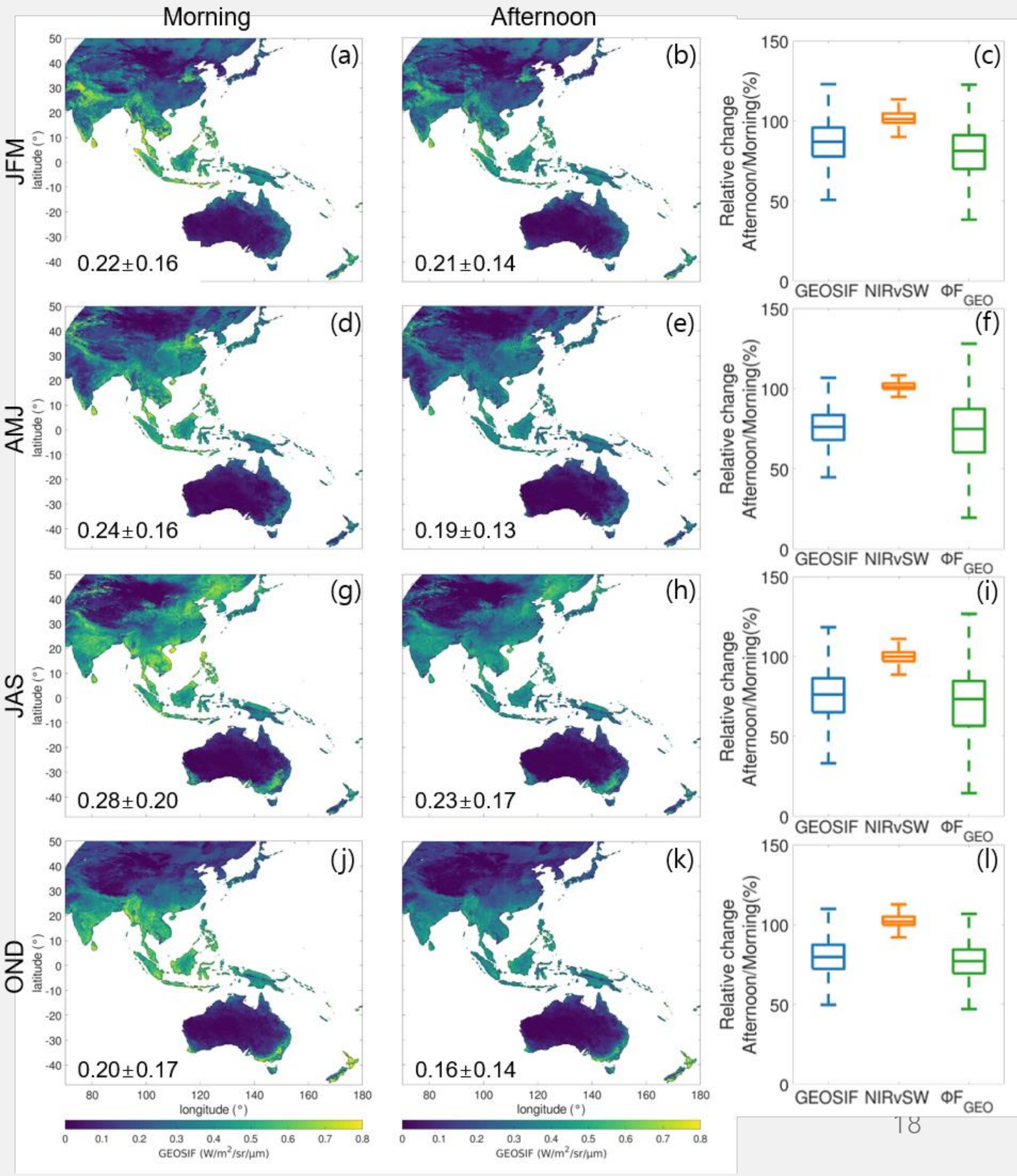
- Overall, morning showed higher SIF and SIFyield than afternoon

- NIRvP showed little difference between morning and afternoon!



Jeong et al (2024a) Remote Sensing of Environment

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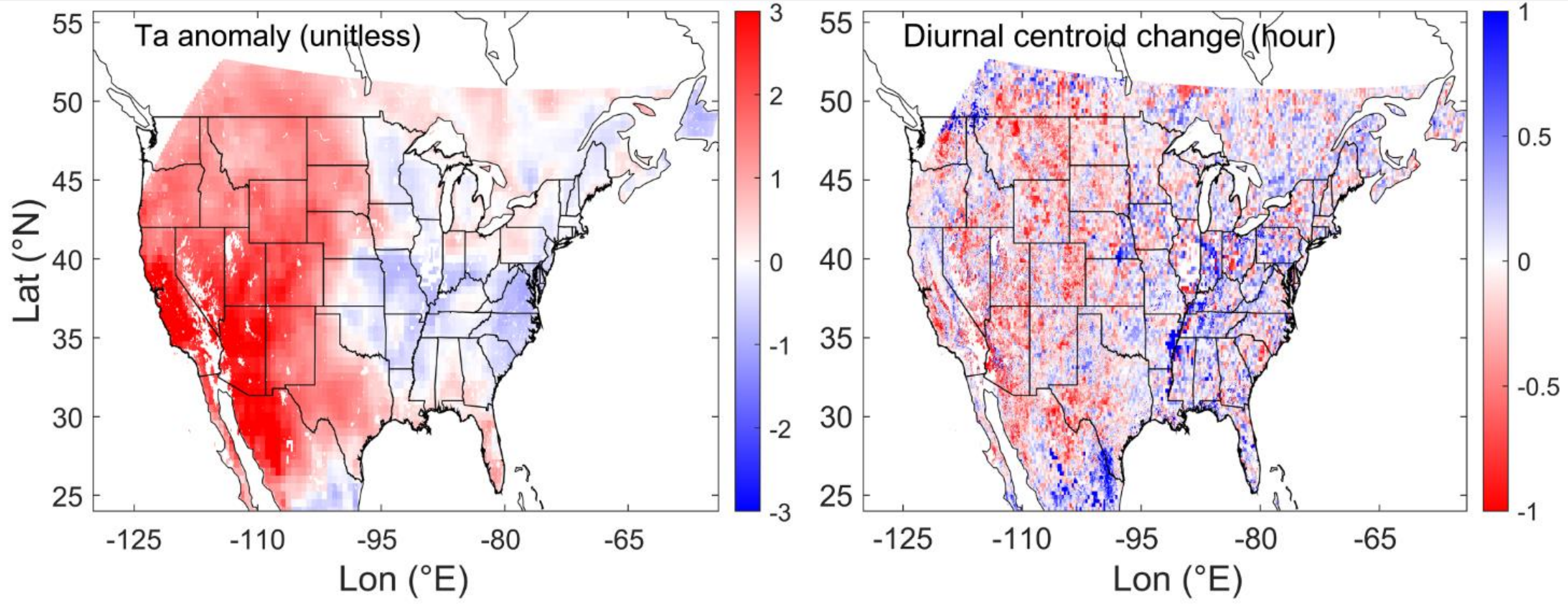
Geostationary satellite detects midday depression in dryland photosynthesis



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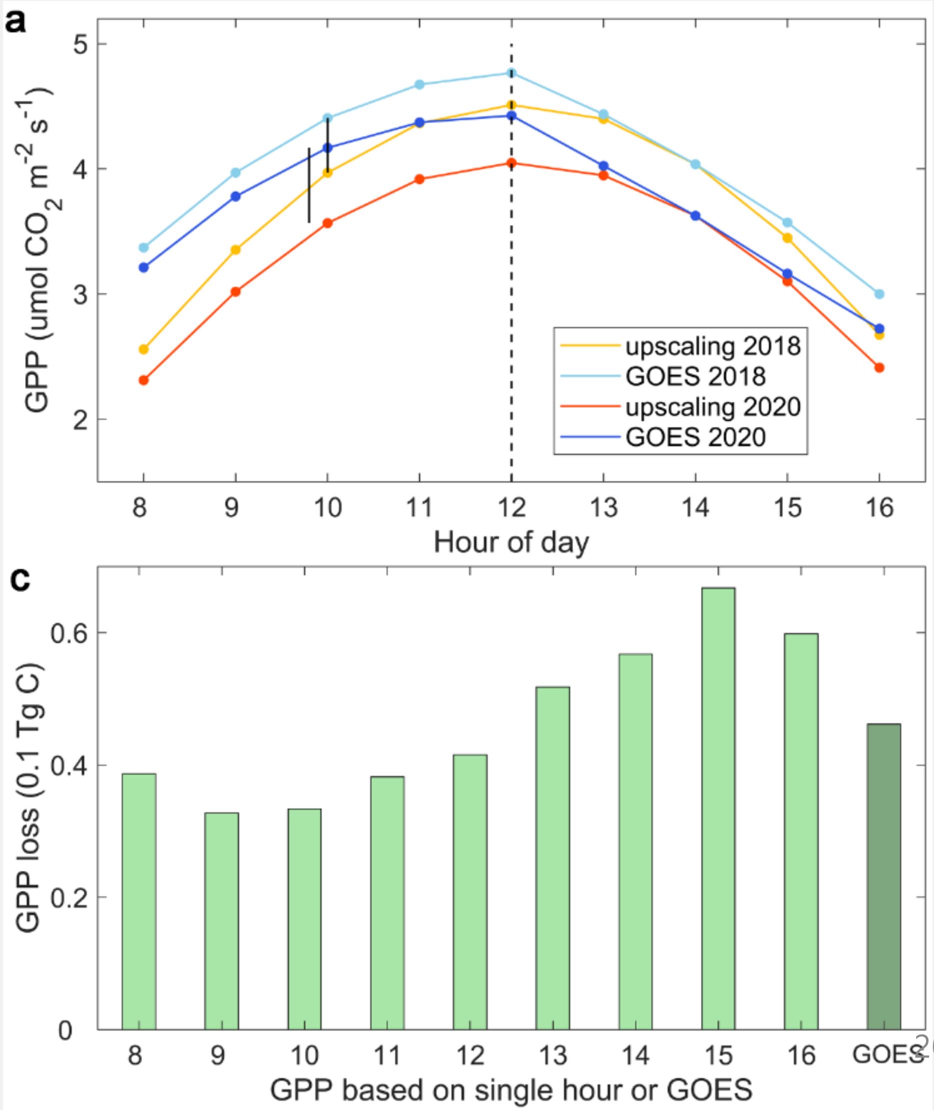
Li et al., (2023) Science Advances

Temporal upscaling from snapshot leads biases in daily sum estimates

- 2020 Western US heatwave induced strong diurnal asymmetry of photosynthesis in dryland
- Diurnal monitoring of photosynthesis from geostationary satellite could minimize the bias in daily sum estimates



Li et al., (2023) Science Advances

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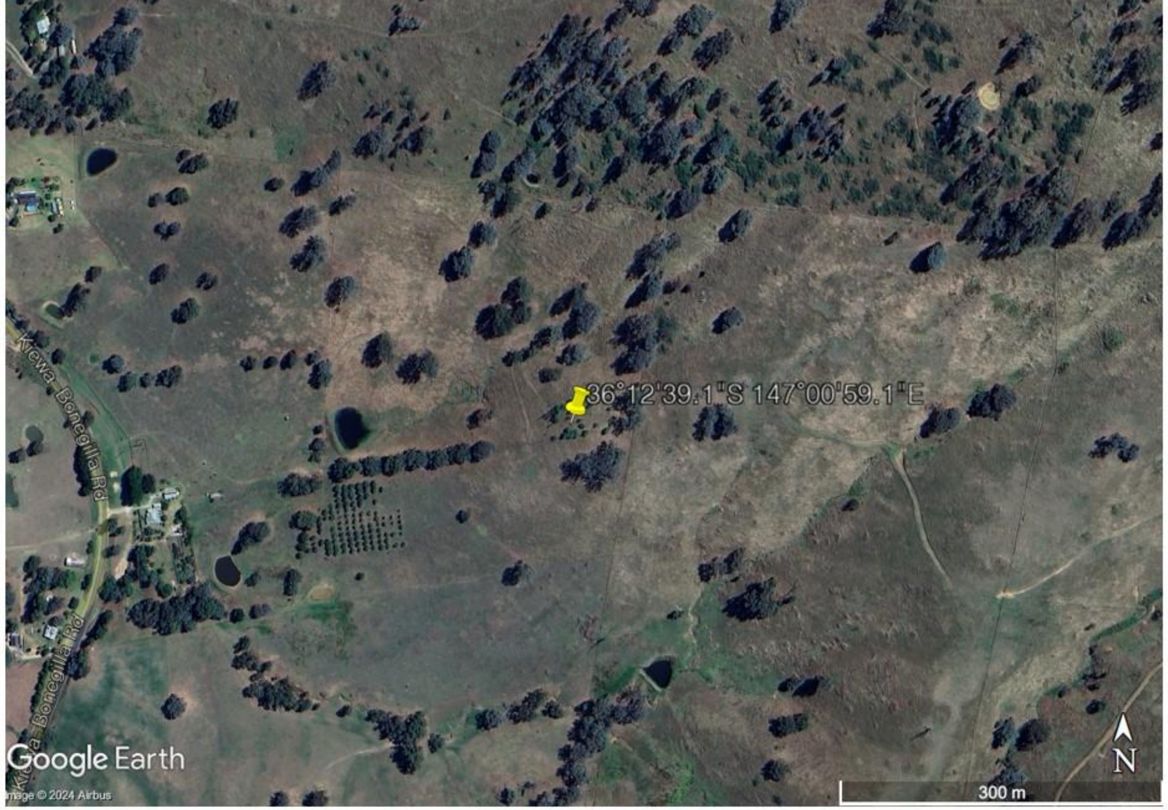
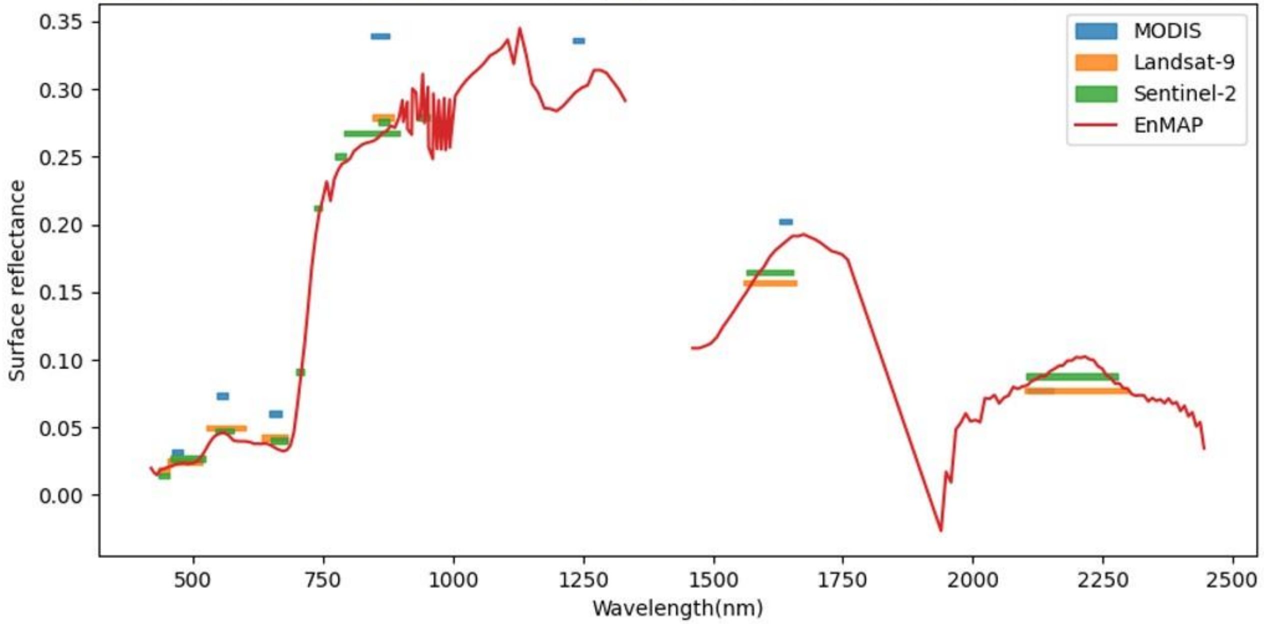
SPECTRUM

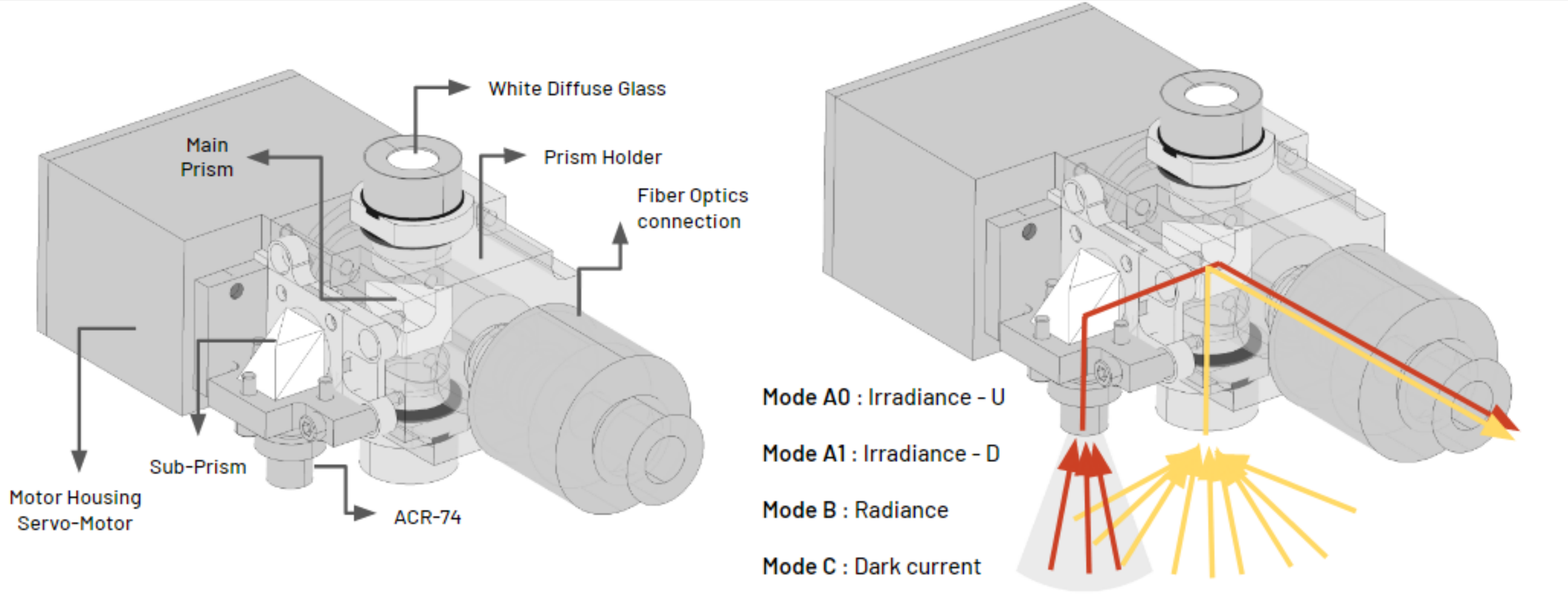




- Heterogeneous
  - Landscape
  - Spectral bands
  - Spectral resolutions
  - Spatial resolution
  - Temporal revisit frequency
- Tower based hyperspectral network is much needed

Ryu (in review) JGR-B

Upgraded rotaprism system that integrates BHR and BRF in VNIR, SIF and SWIR



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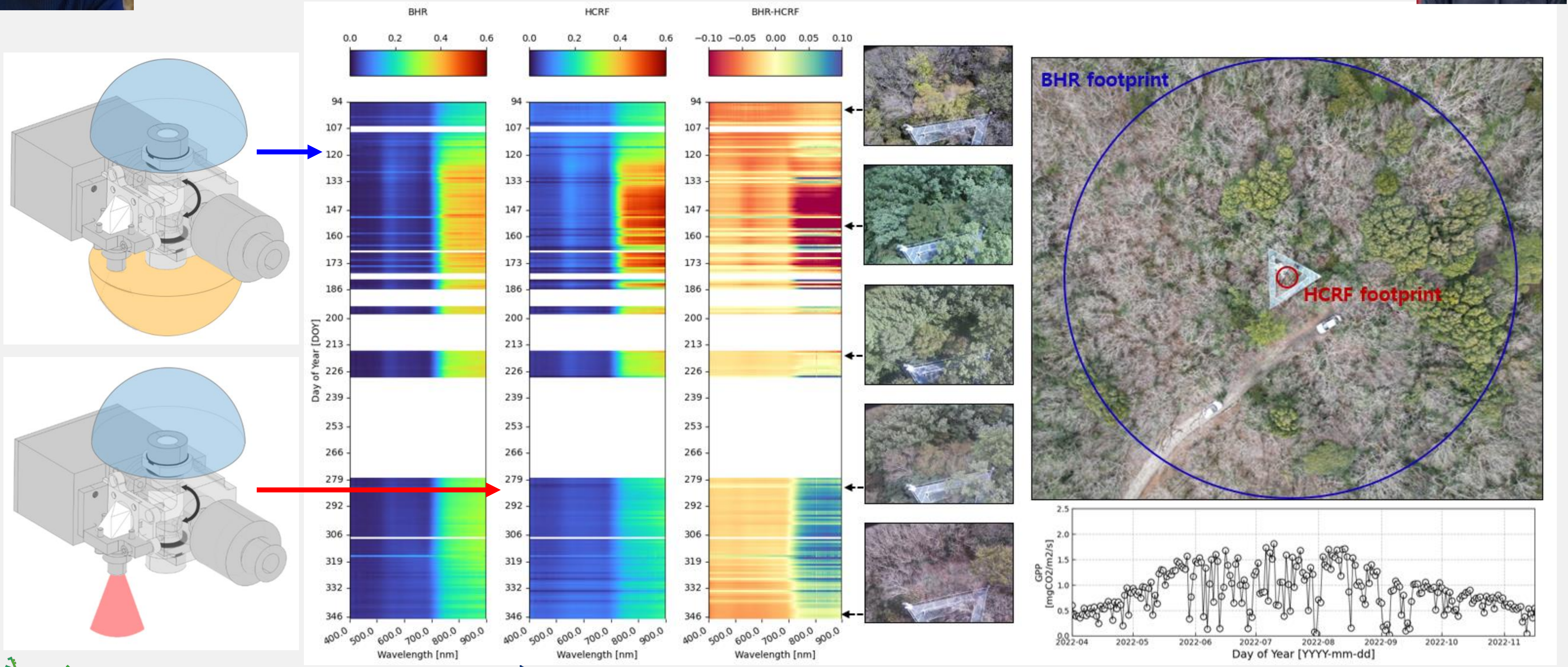
Lee et al (to be submitted)

Different view geometries



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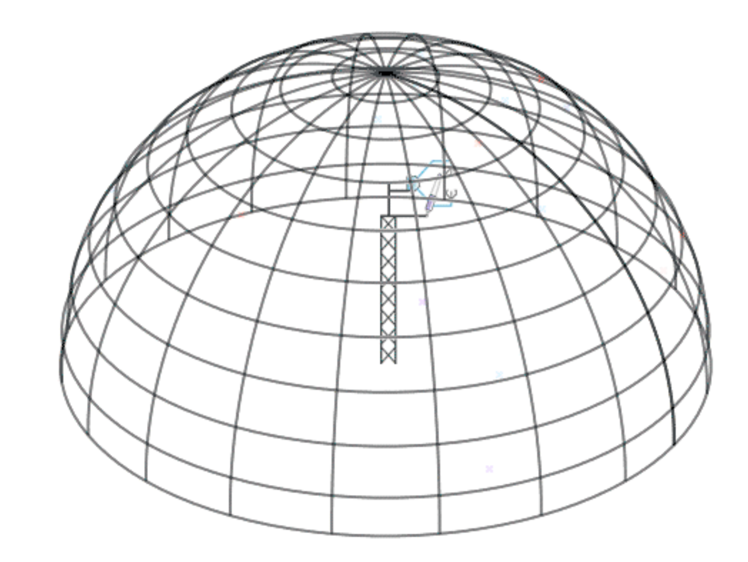
Lee et al (to be submitted)

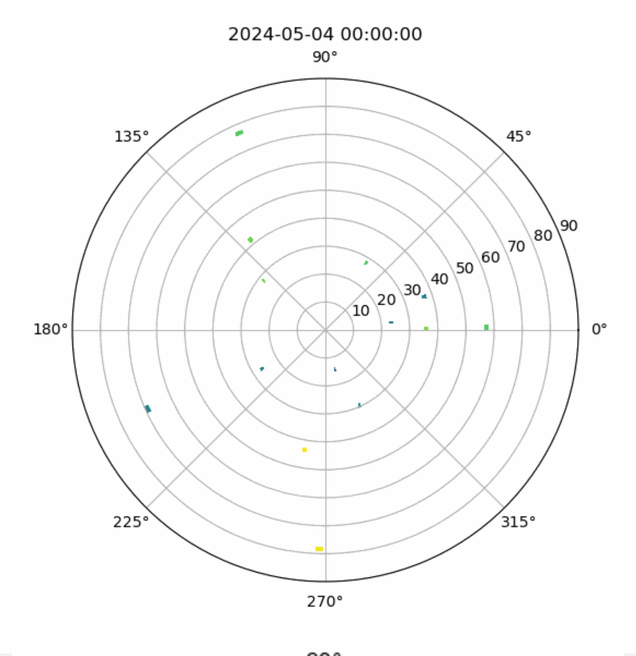
Hyperspectral systems in six flux towers

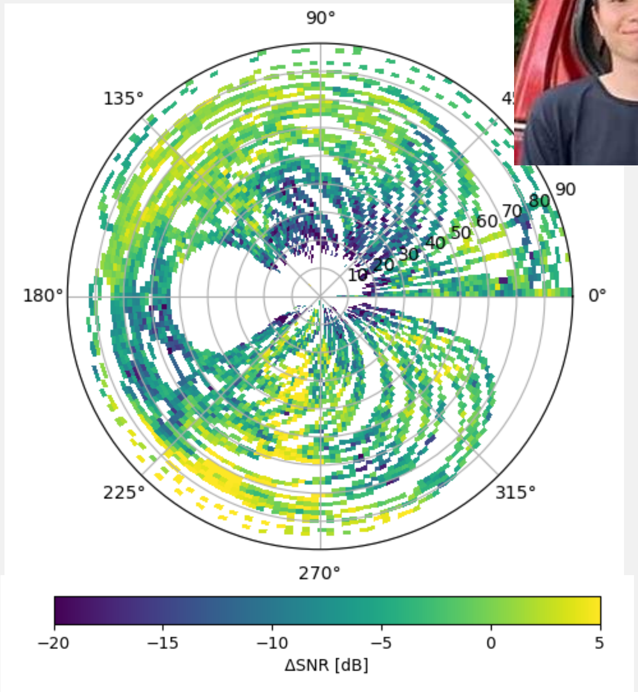
GNSS-based L-VOD

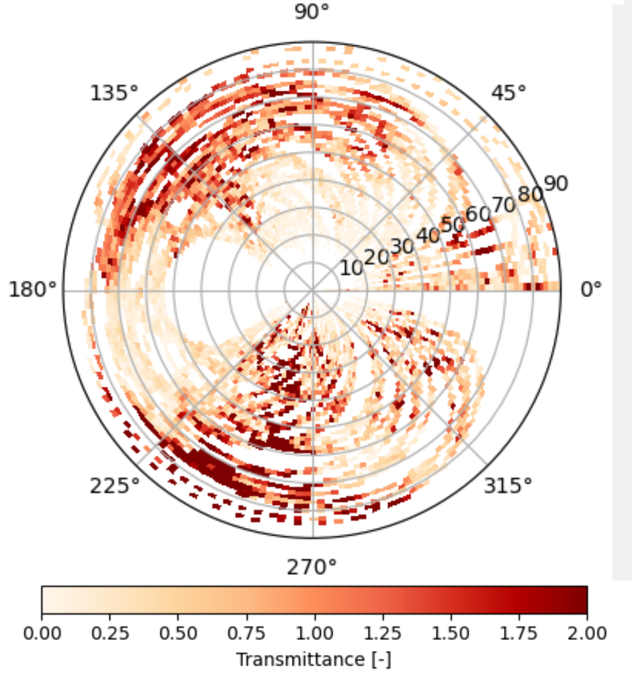
2024-05-04 00:00:00

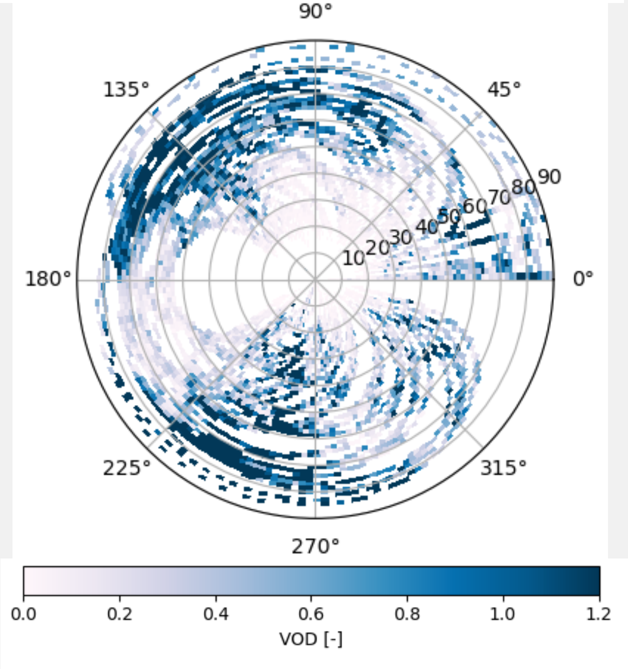
Satellite Num: 21

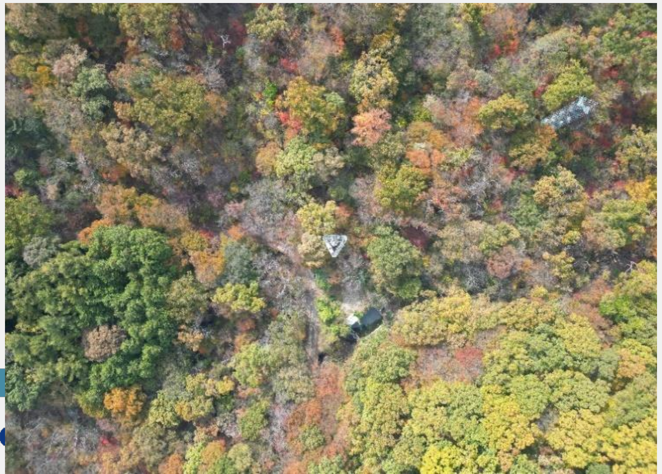






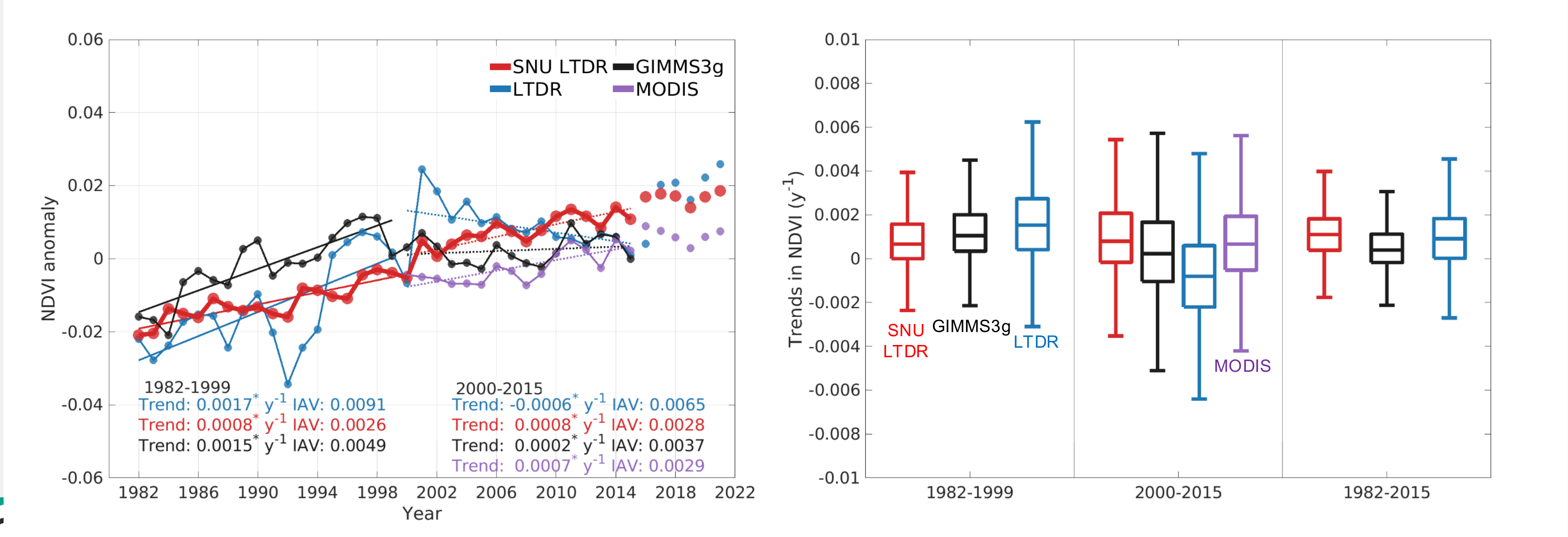






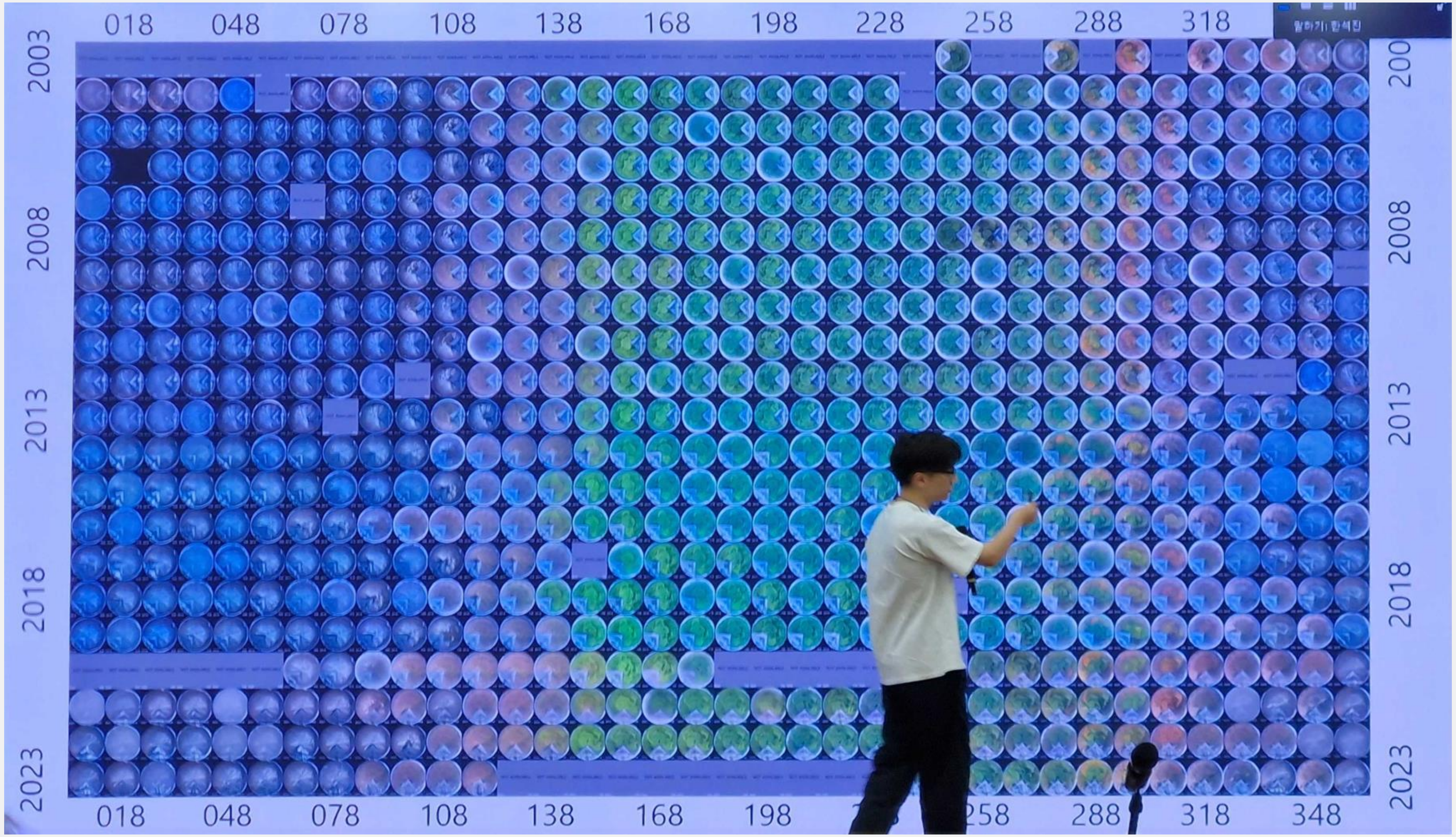
We really need long-term spec data

- Many papers reported saturation of CO2 effects/WUE/… after 2000, but it depends on the long-term VI data
- We found a persistent greening over the four decades



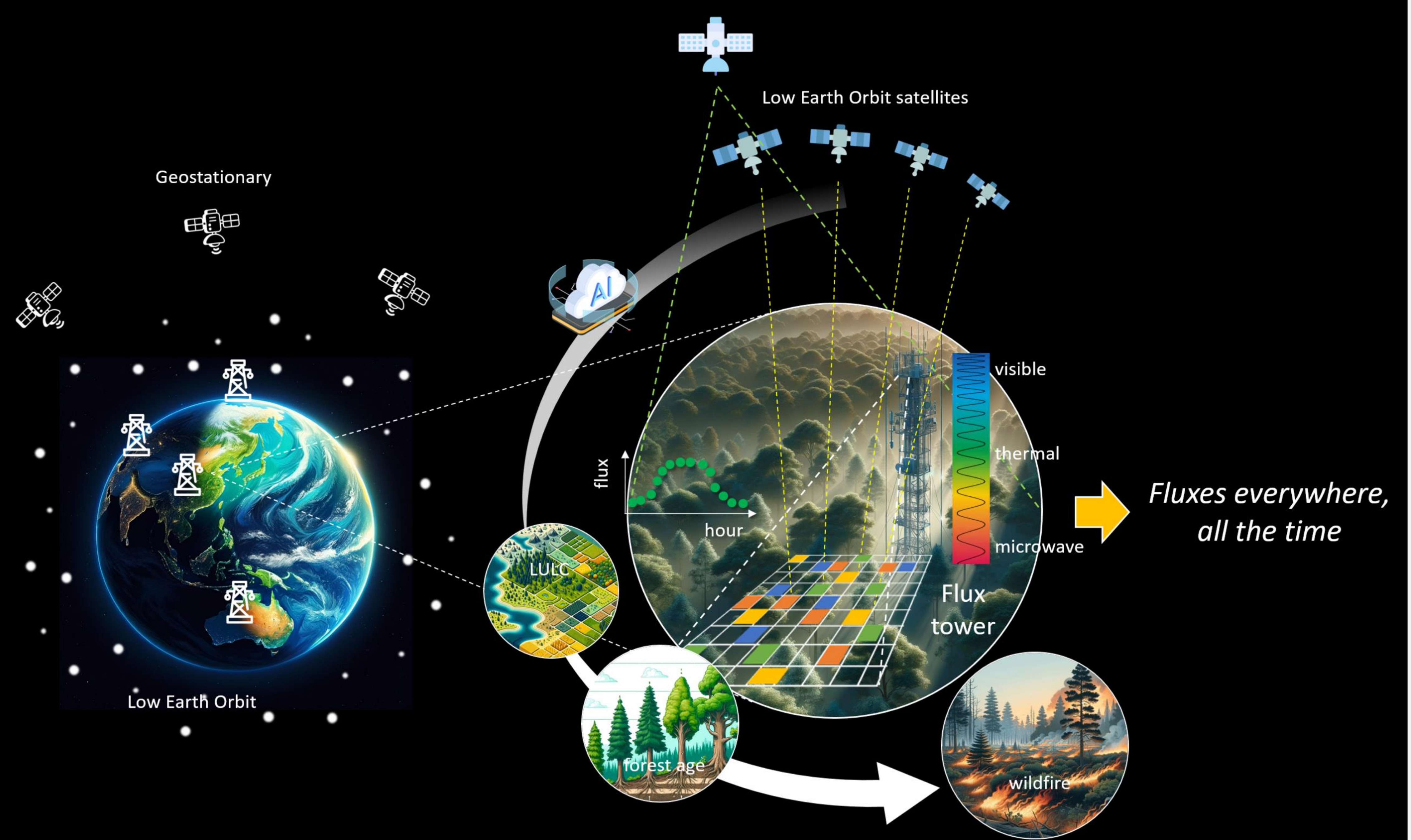
Amazing example: 20 years PEN records

-Kenlo Nishida Nasahara and Taiga Sasagawa from U Tsukuba-



From Geostationary satellite workshop at SNU (29 June 2024)

Ryu (in review) JGR-Biogeoscience



Take home message

- Strengthen collaborations between flux and remote sensing communities

- Install hyperspectral systems in flux towers

- Build long-term records of spectral observations
  - Shared protocols
  - Calibration, calibration, calibration….

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Seoul National University

AtmoFacts

Quantify emissions. Visualize impacts.

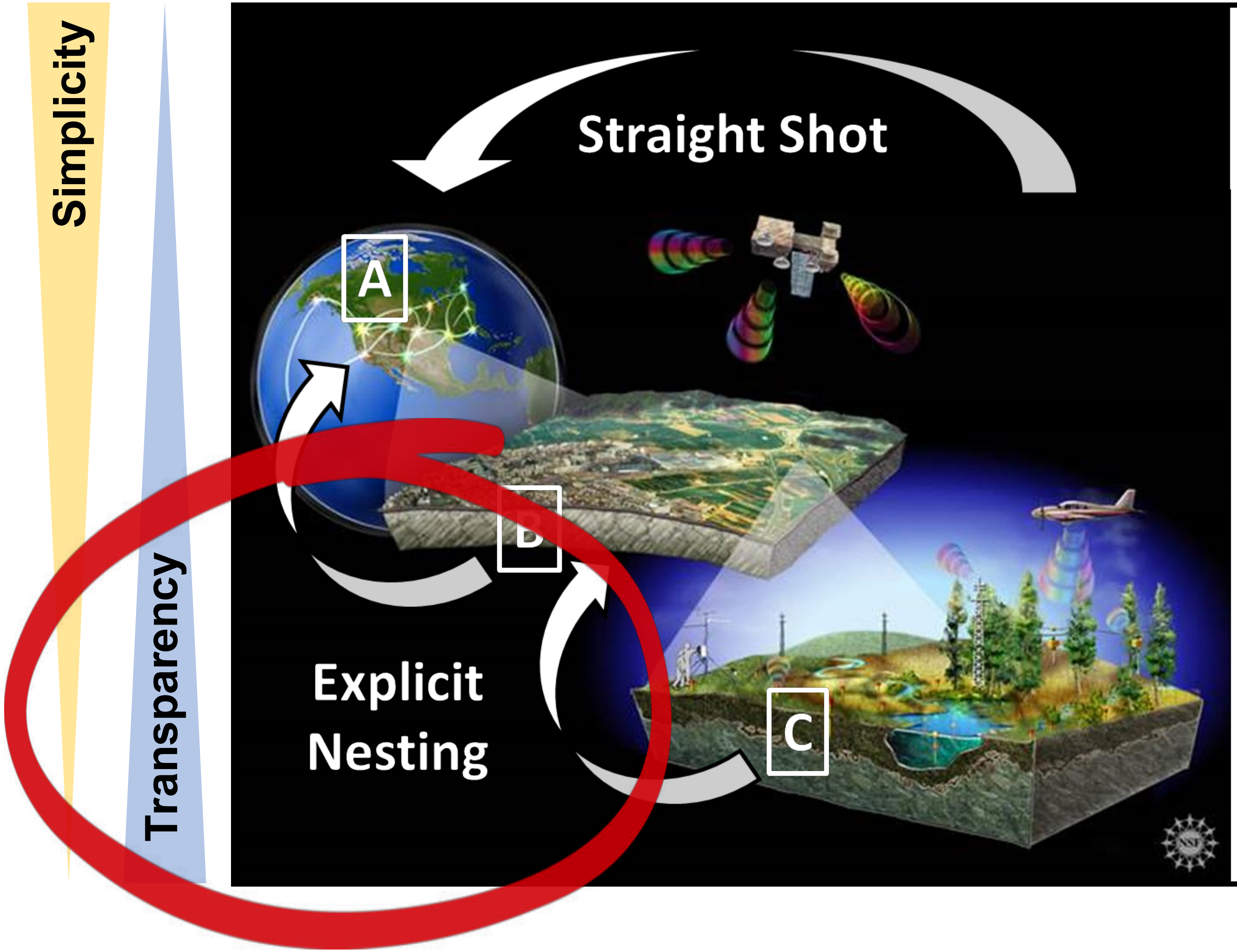
Linking Realms from Ground to Orbit

Matching Fluxes *x* States Across Scales

Stefan Metzger, Ph.D.
smetzger@atmofacts.com

Acknowledgement: NSF Award Number: 2313772 "Closing the energy balance gap at scale"

What are we scaling for?



Societal Relevance

A Continental-to-global accountability and coordination of net-zero pledges, climate solutions, earth stewardship, e.g., UNFCCC nationally determined contributions.

B Regional-to-continental information continuum for public awareness, policy-making from reliable stream of ground truth for satellites, climate solution testbed.

C Local-to-regional practices across heat, water, carbon and pollution management sectors: heat islands, irrigation, emissions measurement, reporting and verification.

Eddy-covariance (EC) in the Measurement, Reporting, Verification feature set

Feature	Spatialized EC	Classical EC	Slow EC	Atmospheric inversion	RS + model proxies	In-situ proxies, manual	Activity-based
Quantifies individual sources and sinks					✓	✓	✓
Spatial acuity and representativeness					✓		
Measures >95% emissions / removals (e.g., LCFS*)				✓			
Measures >80% emissions / removals				✓			
Measures atmospheric emissions and removals				✓			
Continuous, real time				✓			
Economic <\$1K km^{-2} y^{-2}				✓	✓	✓	✓
All climate forcers				✓			

* LCFS = California Air Resources Board Low Carbon Fuel Standard

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Continuous, real time		✓	✓	✓			
Economic <$1K km^{-2} y^{-2}			✓	✓	✓	✓	✓
All climate forcers		✓	✓	✓			

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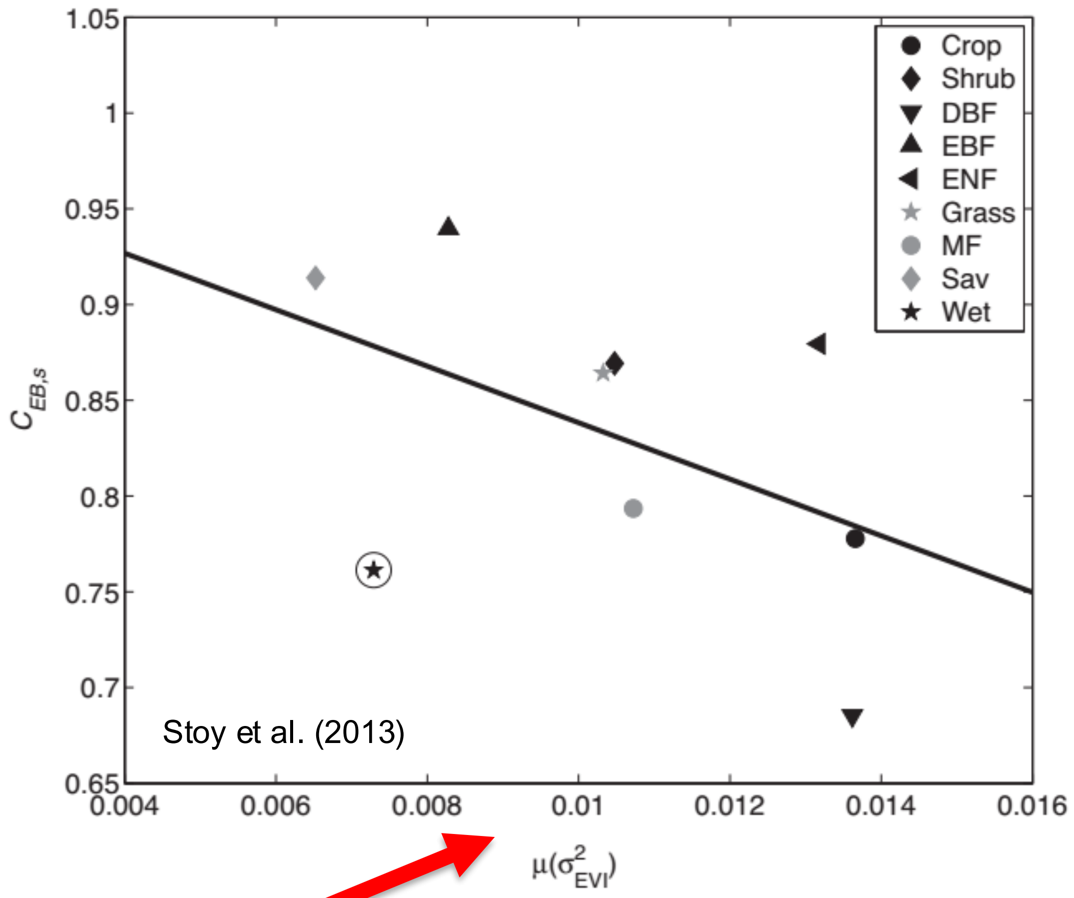
Economic <$1K km^{-2} y^{-2}	✓		✓	✓	✓	✓	✓
All climate forcers	✓	✓	✓	✓			

* LCFS = California Air Resources Board Low Carbon Fuel Standard

AtmoFacts

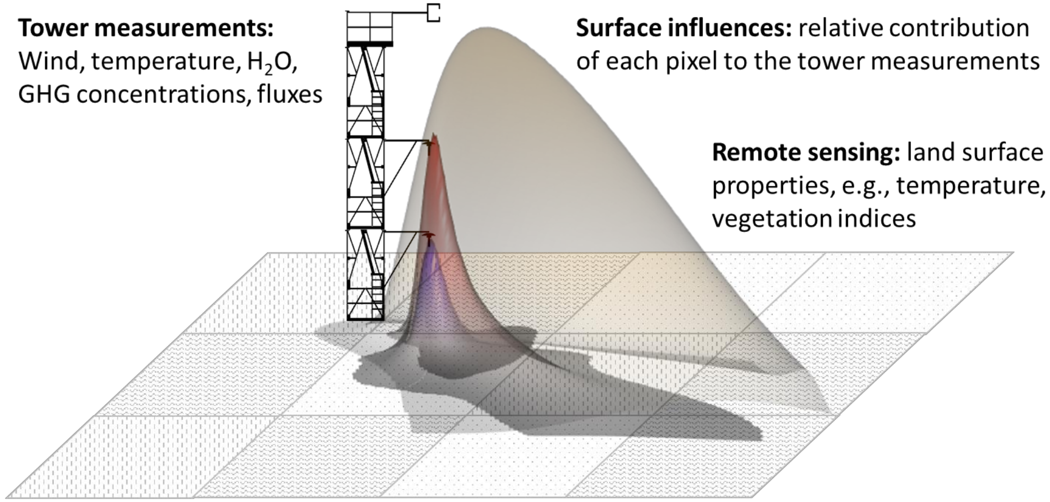
Account for missing fluxes by satisfying the micrometeorology

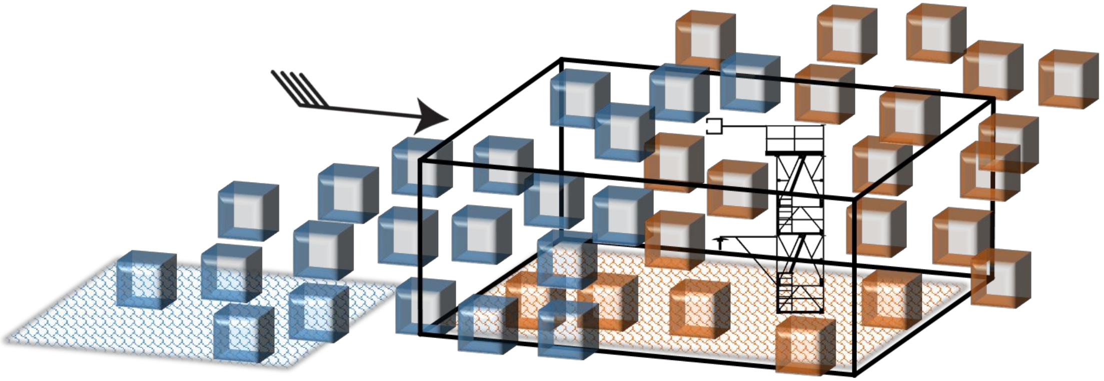


20% - 40% missing flux

From observational puzzle to continuity of energy and mass

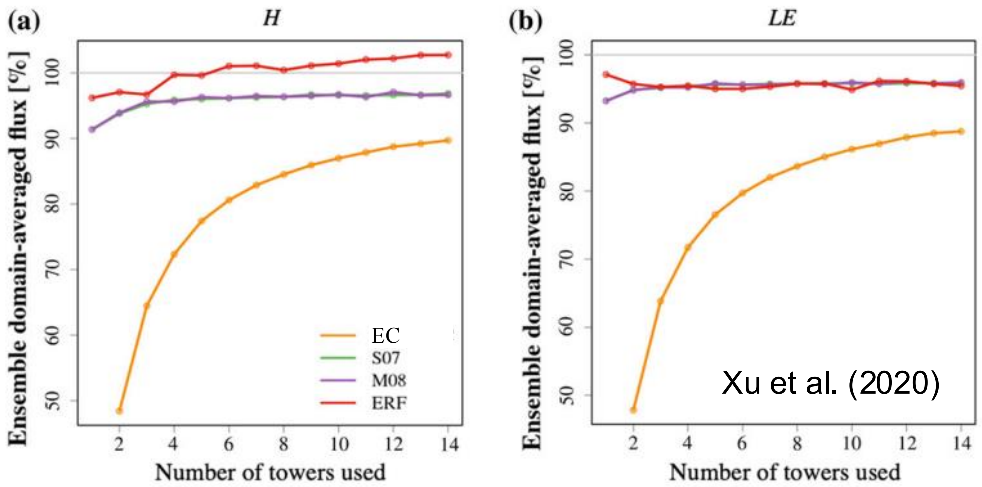
Classical EC



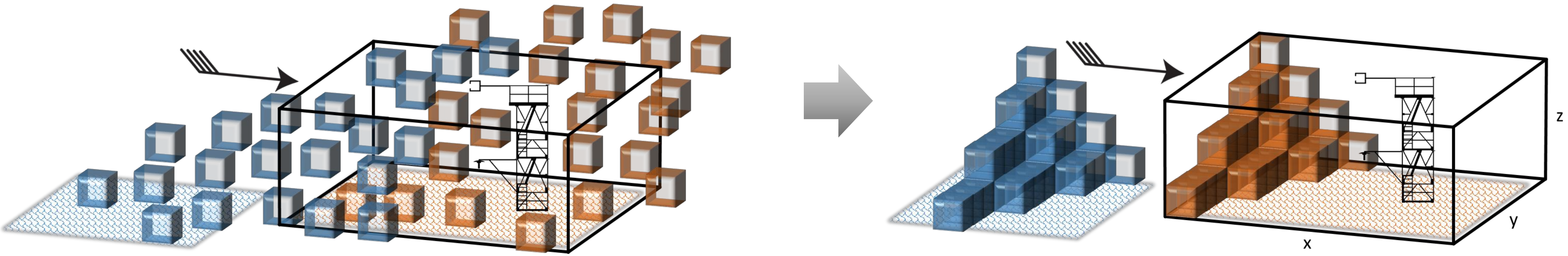


Adopted from: Metzger (2018)

From observational puzzle to continuity of energy and mass



Classical EC **Spatialized EC**



Adopted from: Metzger (2018)

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Continuous, real time	✓	✓	✓	✓			
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All climate forcers	✓	✓	✓	✓			

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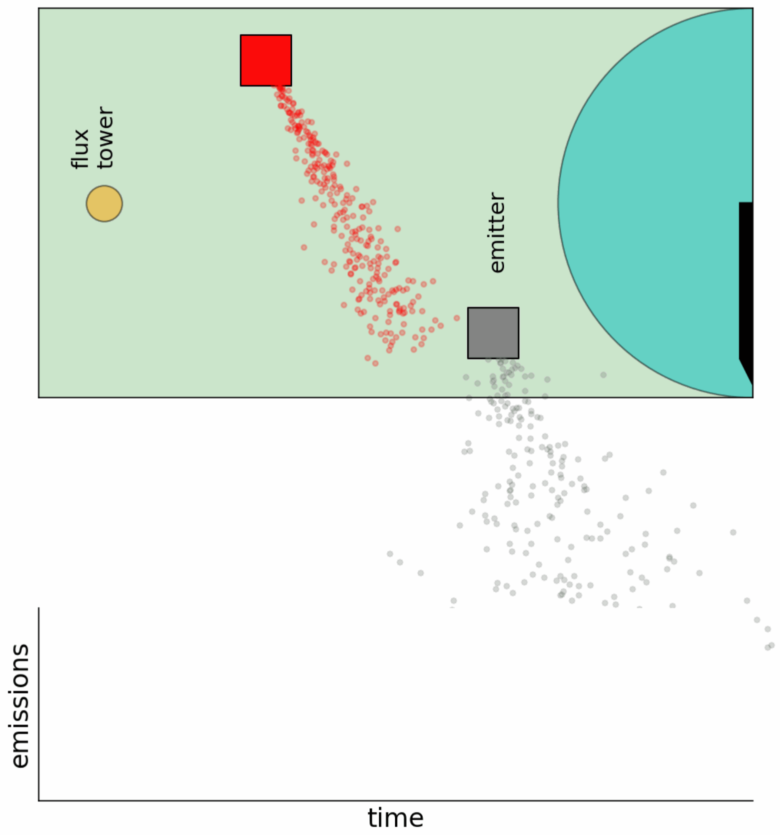
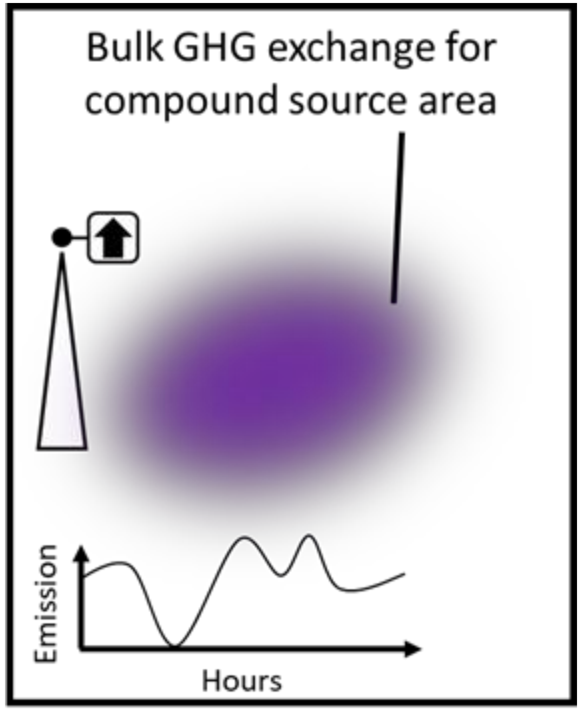
Quantify individual sources and sinks

Classical 30-min mixing



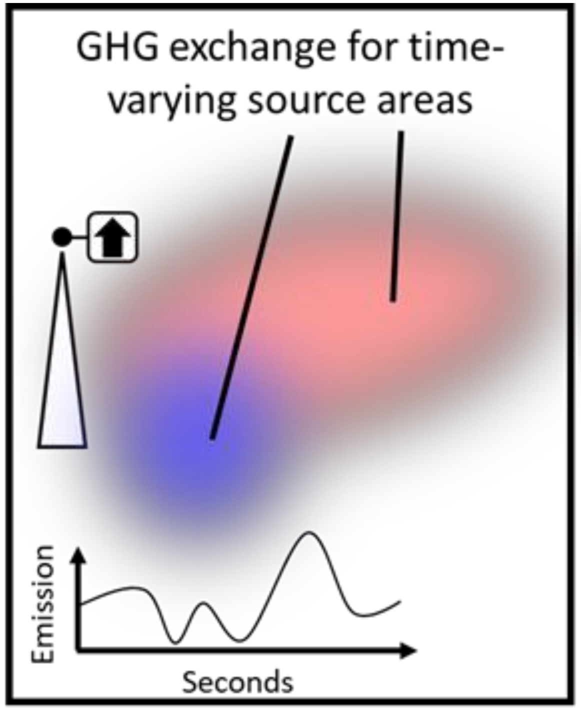
Spatialized EC runs high-resolution fluxes backwards on the wind

Classical 30-min mixing



- 1 x 30-min data point
- 7+ decades tradition
- Information averaging
- Ambiguous attribution

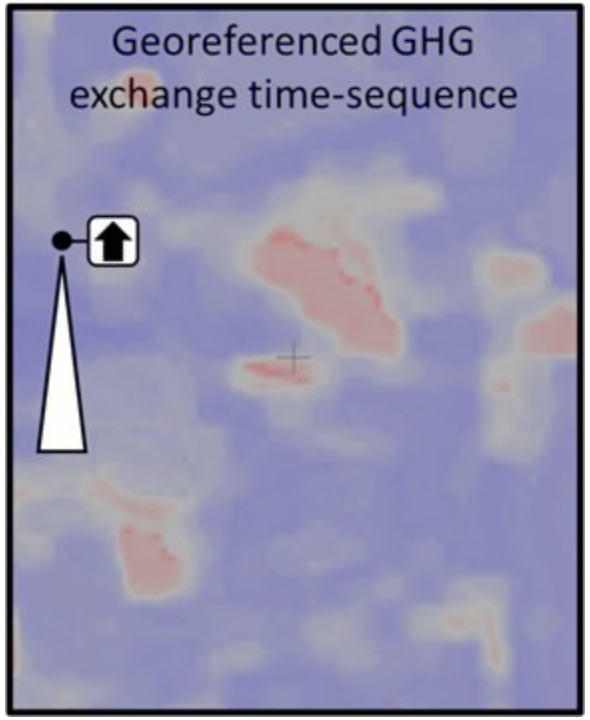
Flux tower 20 Hz data



- 10,000s x 20 Hz points in time

7+ decades innovation: time-frequency decomposition, dispersion modeling, physics-guided AI;
10 - 100 X statistical power

Spatialized EC 30-min un-mixing



- 10,000s x 30-min pixels in space
- NKOTB, dozens applications
- Information transcription
- **Unambiguous attribution**

Eddy-covariance (EC) in the Measurement, Reporting, Verification feature set

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Economic <$1K km^{-2} y^{-2}	✓		✓	✓	✓	✓	✓
All climate forcers	✓	✓	✓	✓			

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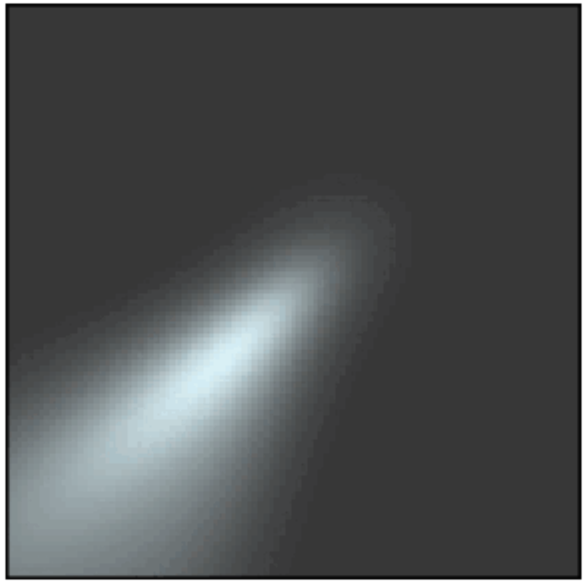
High-resolution attribution and scale extension for direct flux towers

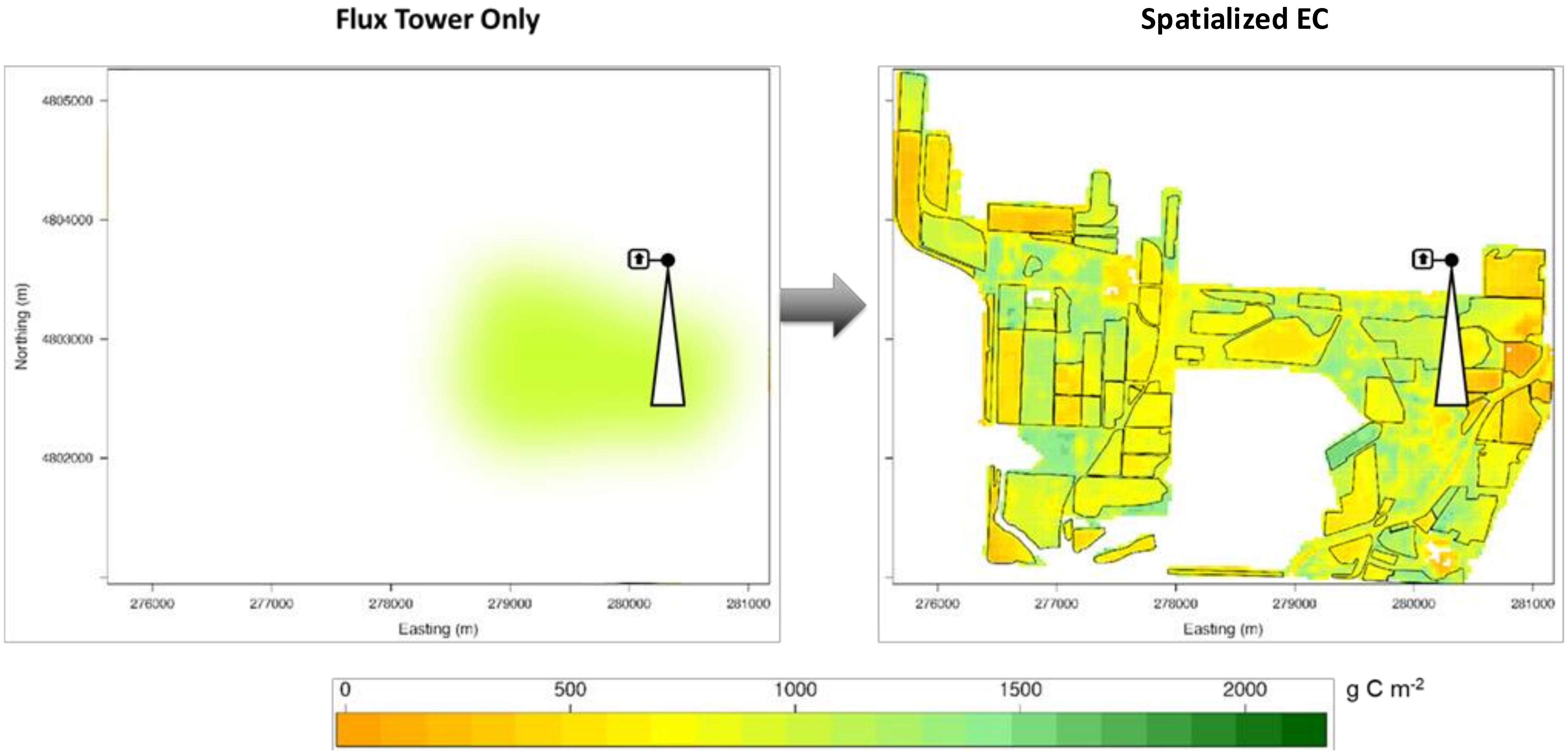
A NEON Mobile Deployment Platform flux tower at a Colorado field

Classical Flux Tower



Credit: US-PFa tower data (desai@aos.wisc.edu), Flux Mapper (smetzger@atmofacts.com)

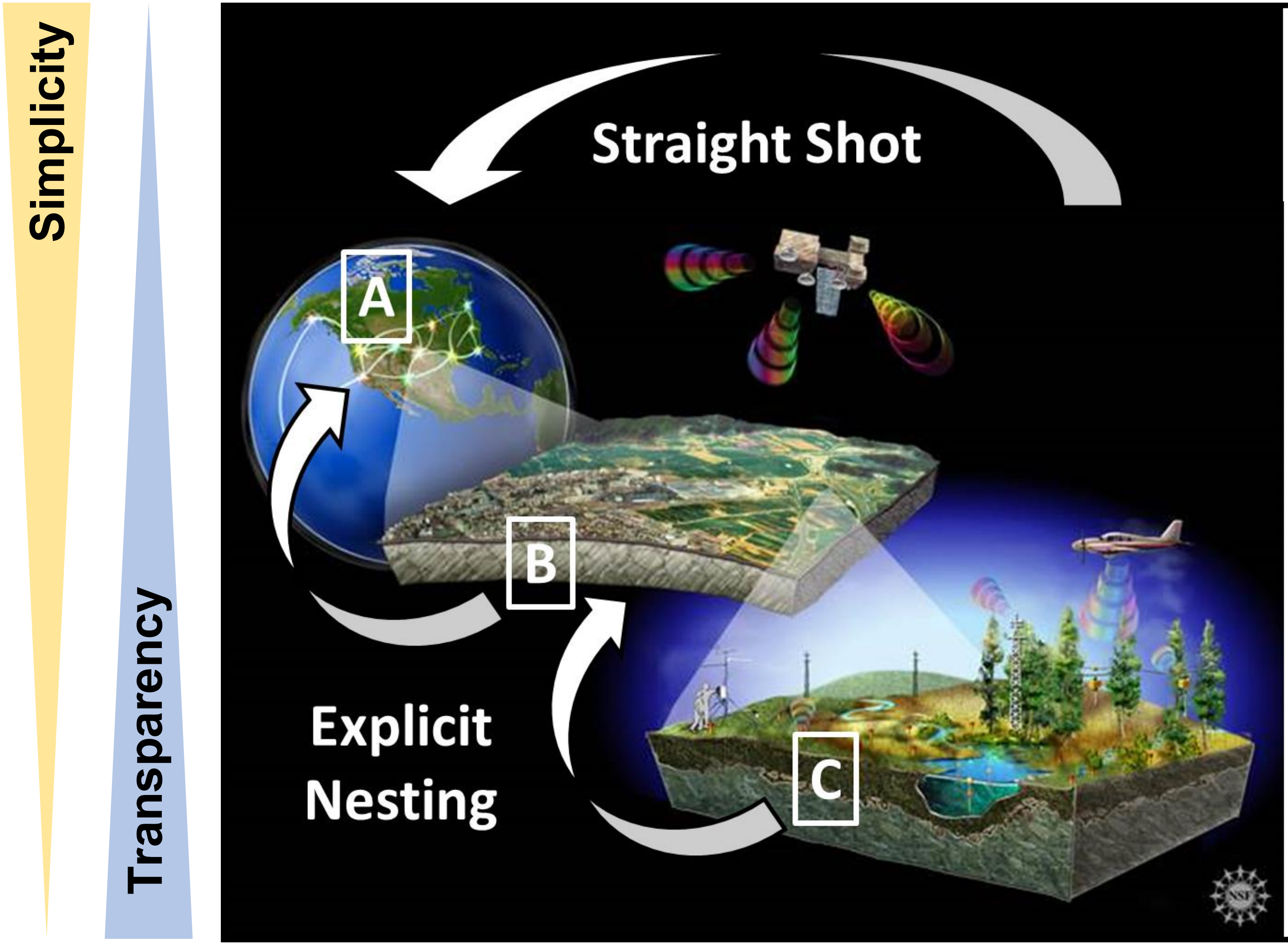
Real-world case study – dairy farm flux tower



Adopted from: Wiesner et al. (2022)

AtmoFacts

"Right-scaling" recipe



"Recipe"

- Sensible choice among "straight shot" and "explicit nesting" to meet the demands of the task at hand.
- "Straight shot" affords simplicity but struggles with scale-emergent properties such as continuity of energy and mass.
- "Explicit nesting" propagates spatial and temporal controls separately, makes data intuitive to use and serves as "Flux Tower Multiplier".

AtmoFacts

Quantify emissions. Visualize impacts.

Linking Realms from Ground to Orbit

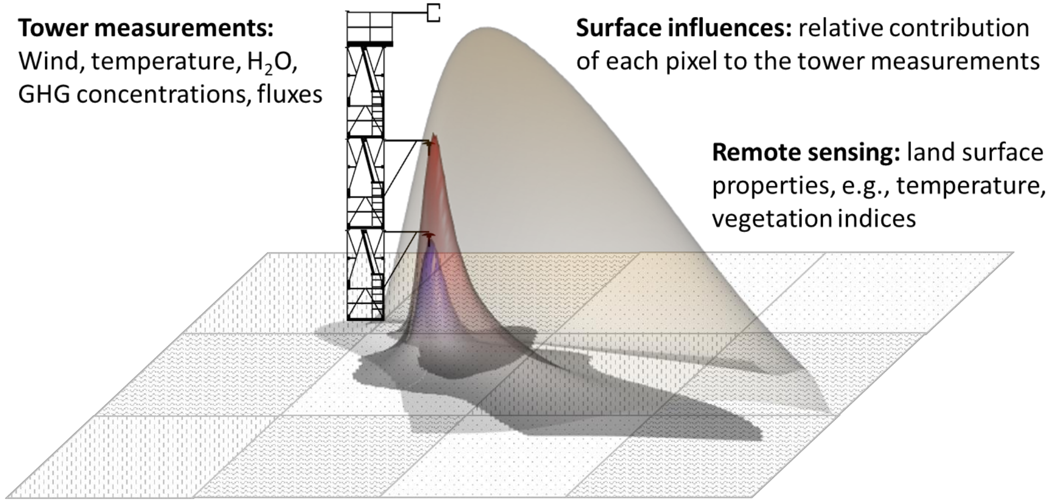
Matching Fluxes *x* States Across Scales

Stefan Metzger, Ph.D.
smetzger@atmofacts.com

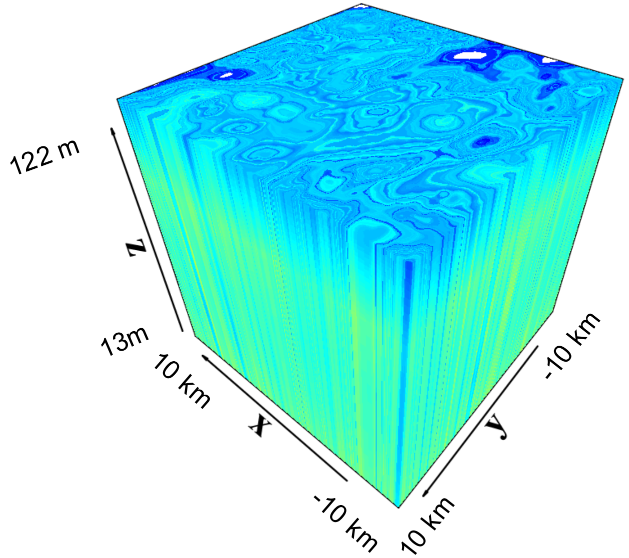
Acknowledgement: NSF Award Number: 2313772 “Closing the energy balance gap at scale”

From observational puzzle to continuity of energy and mass

Classical EC



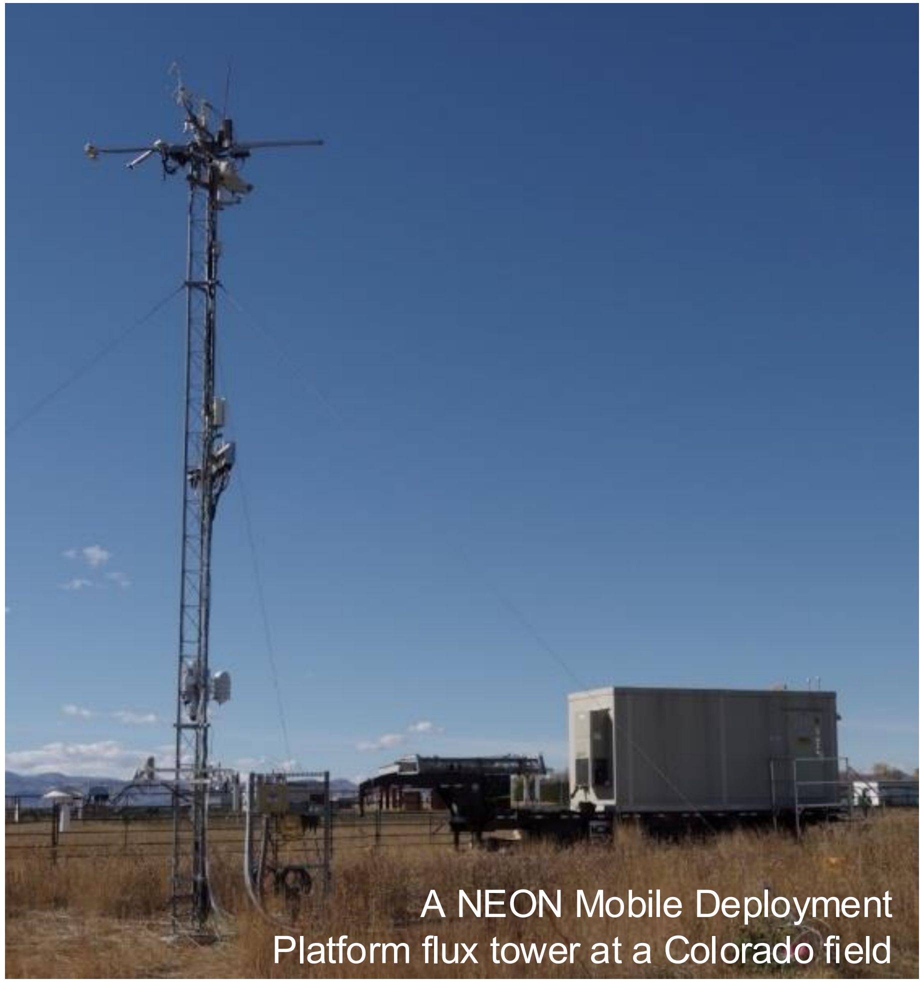
Spatialized EC

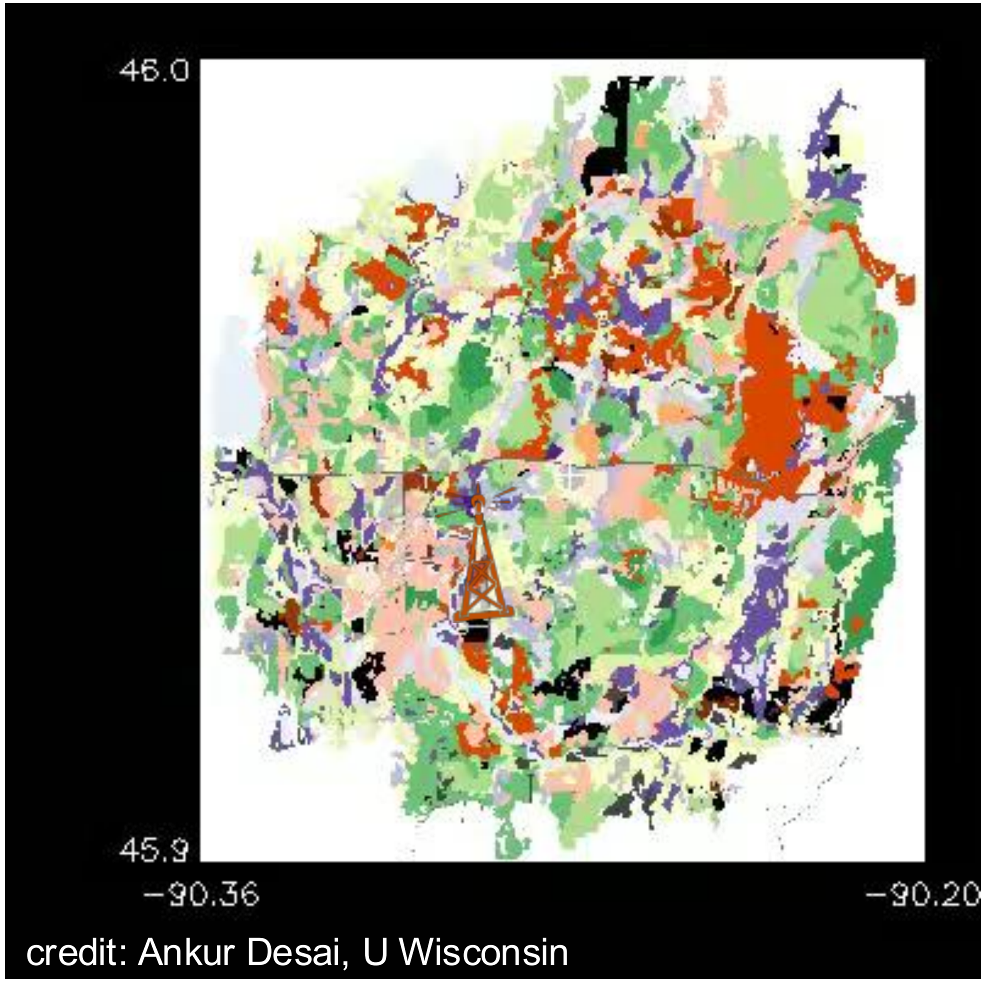


Adopted from: Metzger (2018)

AtmoFacts

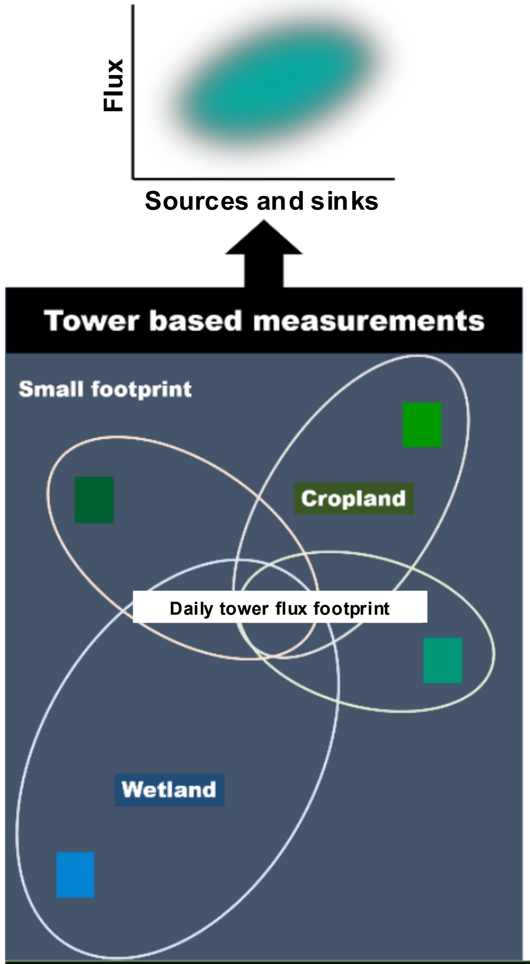
Quantify individual sources and sinks





Spatialized EC runs high-resolution fluxes backwards on the wind

High spatiotemporal resolution quantifies individual sources and sinks through time

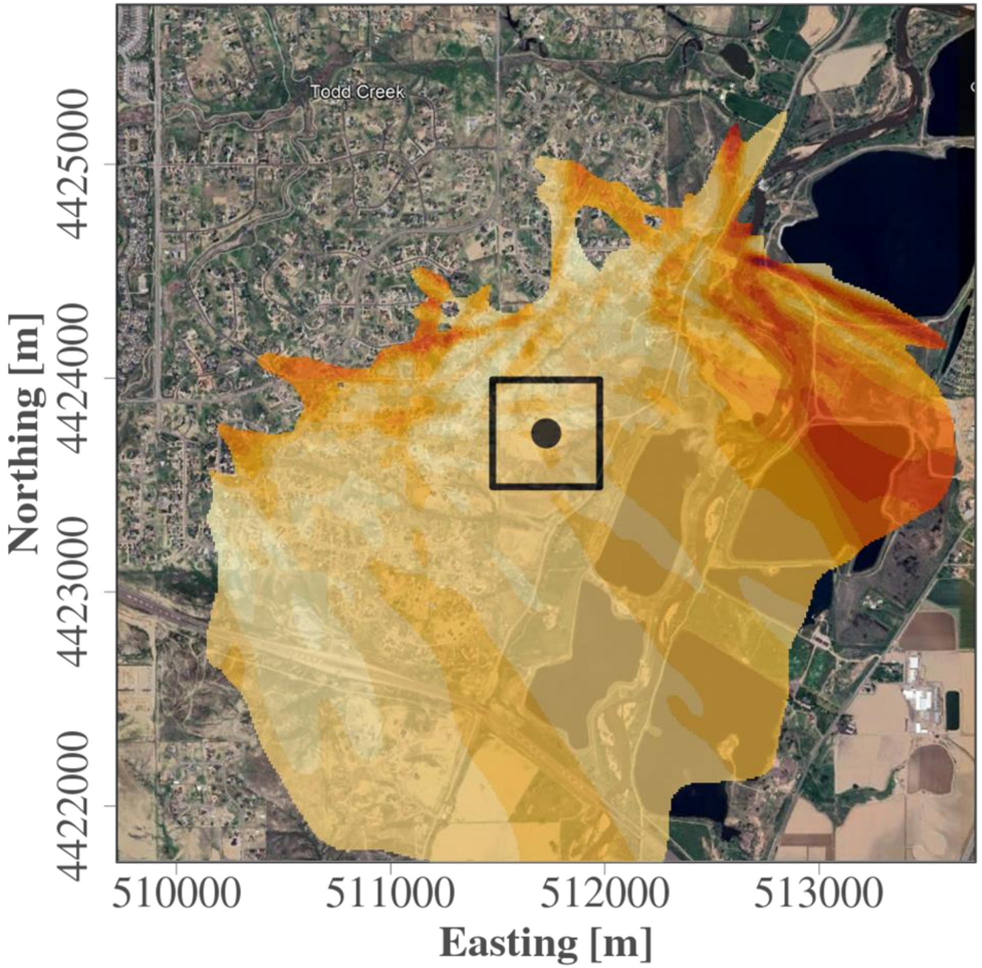


Flux ~ Sources and sinks over heterogeneous landscape

Adopted from: Kong et al. (2022)

Real-world case study – Oil and Gas unmanned methane flux aircraft

In partnership with Black Swift Technologies



AtmoFacts

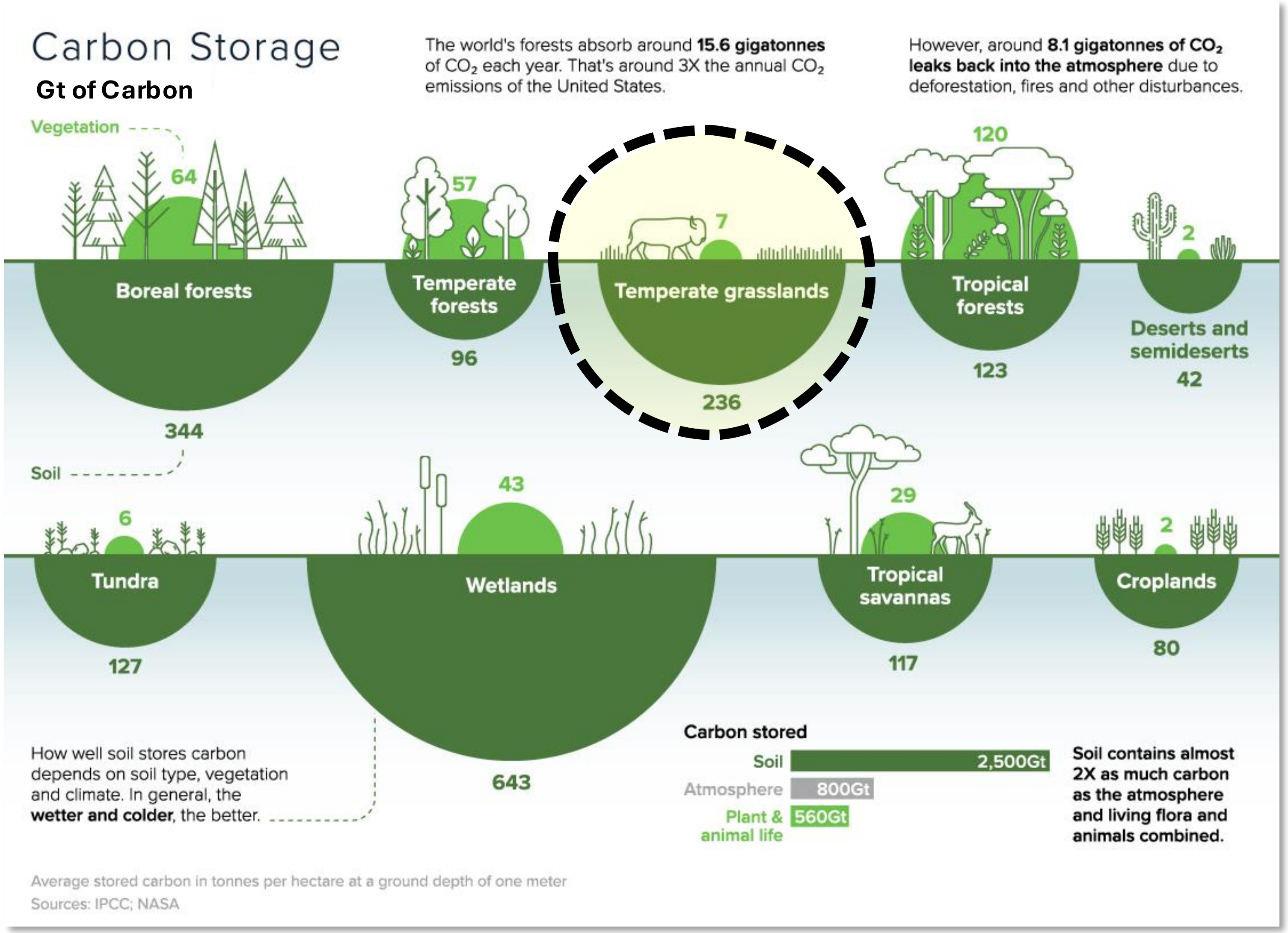
Bridging the gap between science and social benefit: Eddy flux for measurement, reporting and verification of grassland carbon sequestration

Kevin Tu, Kateri Environmental

AmeriFlux Workshop: Remote Sensing and Fluxes Upscaling for Real-world Impact, July 9-10, 2024, LBNL

Why Focus on Grasslands?

Sustainable land management and conservation of terrestrial ecosystems are crucial for achieving Sustainable Development Goals (SDGs) → including **climate change mitigation** and **reducing biodiversity loss**, **social/community benefits**



https://www.visualcapitalist.com/sp/visualizing-carbon-storage-in-earths-ecosystems/

- Grazing lands (mostly grasslands) occupy about half of the planets land surface[1]
- Within US, grazing lands cover ~28% of the land area (655M acres)[2]
- About 20% of the worlds soil organic carbon (1500 Gt) resides in grazing lands[2]
- The large soil carbon 'debt' due to human activity has potential to be restored[3]

1-World Wildlife Fund (www.worldwildlife.org);
2-Noble Research Institute (www.noble.org/3m);
3-Sanderman et al. (2017: Soil carbon debt of 12,000 years of human land use, PNAS, 114(36): 9575-9580)

1 There is a massive increase in offset and inset credit purchasing – especially in nature based markets

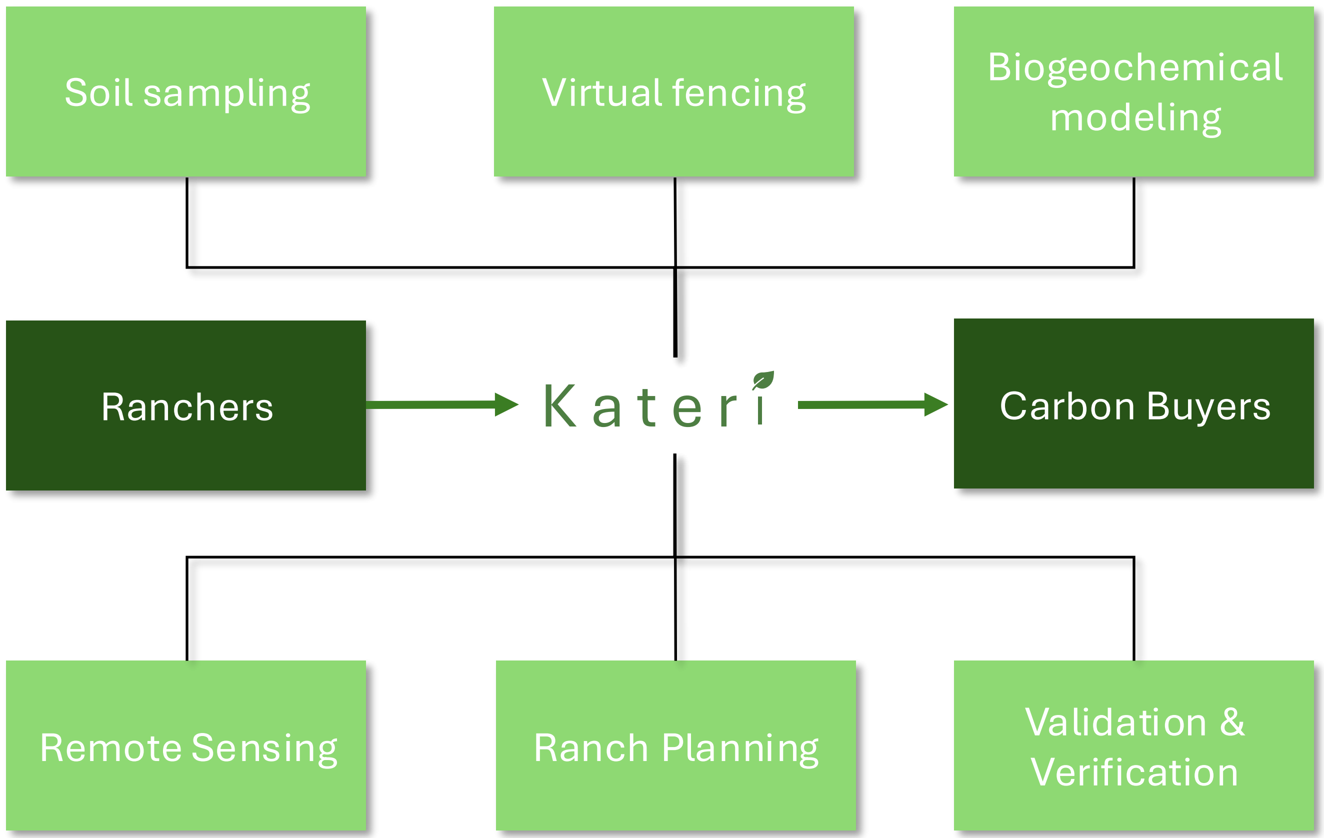
2 Grasslands are an underutilized carbon sink and ranching has historically lacked the technology to scale regenerative methods

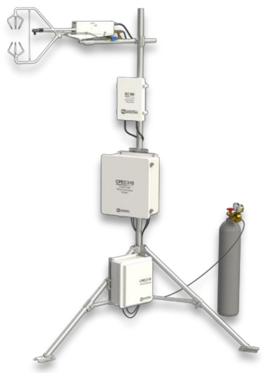
3 Governments around the world are dedicating huge funds to spur more climate friendly agriculture

Significant opportunity for nature-based solutions in one of the world's largest ecosystems

Kateri is a tech-enabled carbon developer combining biogeochemical modeling, virtual fencing, and advancements in soil measurements to unlock the carbon sequestration potential of grasslands through rotational grazing

***Kateri** provides end-to-end services for ranchers to capture the potential of their natural capital*

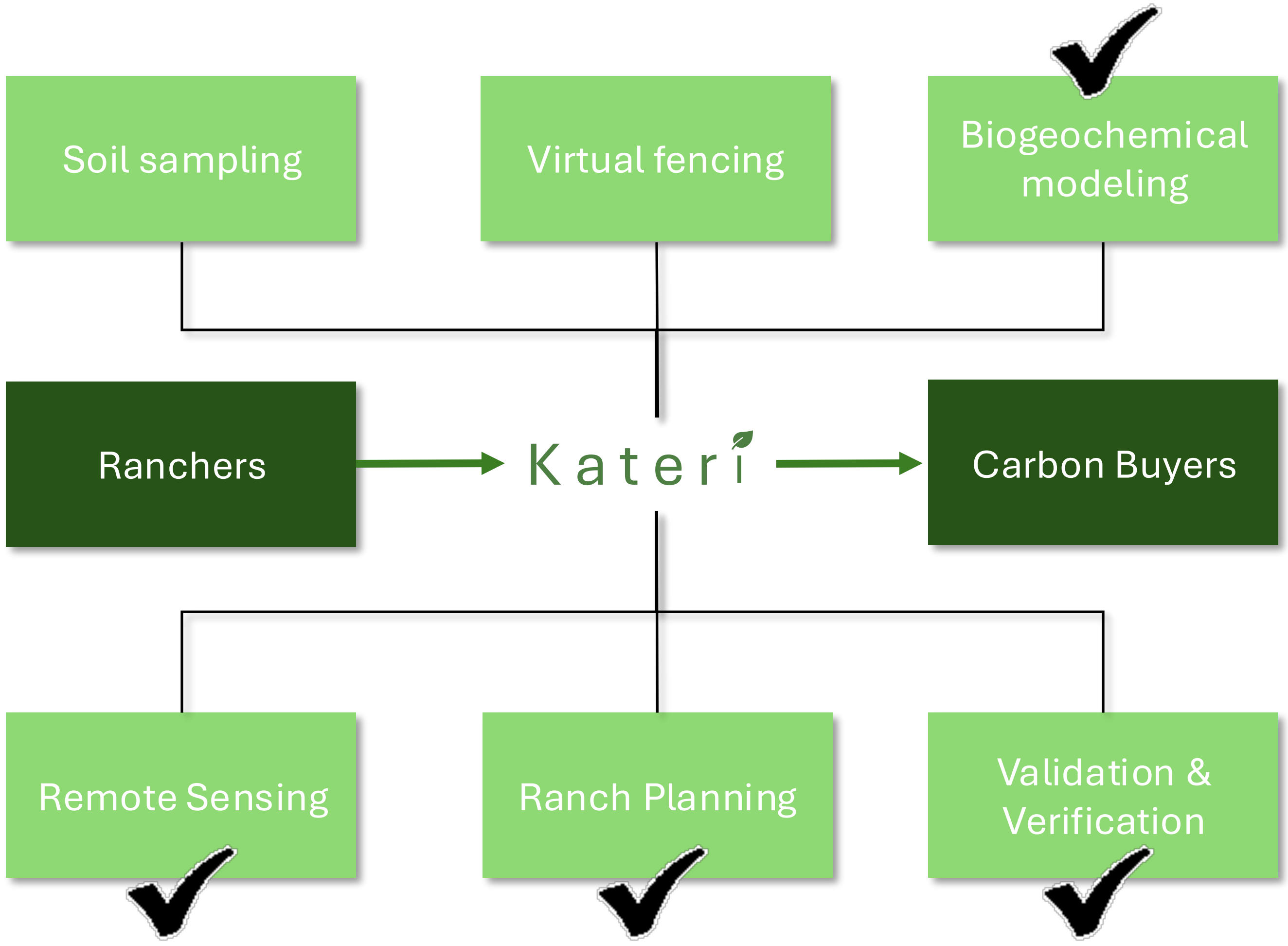




Flux data enables

- biogeochemical model cal/val
- upscaling with remote sensing to project level
- real-time monitoring of management decisions impacts
- verification and validation

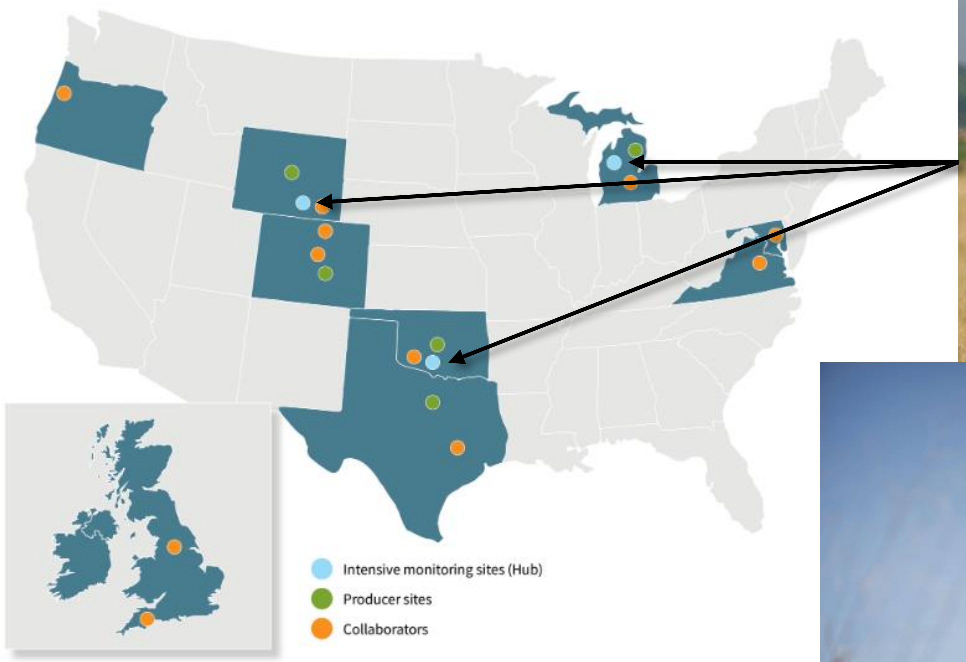
Where do flux towers fit in?



Eddy Flux as the de facto Method for Rangeland Research

1. Rangeland Carbon Tracking and Management (RCTM) system – data from 61 AmeriFlux and NEON sites
2. Metrics, Management, and Monitoring (3M) project – 30 new low-cost flux towers deployed

Researchers from 11 nonprofit organizations, private research organizations and public universities in the United States and the United Kingdom.



- 30 LC flux towers deployed in first year
- 58 LC total towers planned
- SOC stock measurements
- Remote sensing
- Ecosystem biogeochemical modeling

Noble Research Institute (www.noble.org/3m)

Pilot Implementation of Low-cost Eddy Flux for Project Development

Quanterra (https://www.quanterrasystems.com/)

Deploying low-cost Quanterra systems in four rangeland carbon projects

- Prior studies establish low-cost systems as potential alternatives to conventional eddy covariance (Cunliffe et al. 2022, van Ramshorst et al. 2024, Callejas-Rodelas et al. 2024)
- Site locations span a range of climate, soil, vegetation conditions
- Data to be used for **calibration and validation of rangeland carbon flux models** (e.g. MEMS, SNAPGRAZE, RCTM) in combination with SOC stocks

Additional low-cost flux systems to consider

- Licor low-cost eddy flux (still in development)
- Variance Bowen Ratio
- Surface Renewal

Challenges for Eddy Flux with Grassland NbS Projects

https://www.bovinevetonline.com/

$ **Cost** – Conventional eddy covariance systems are too expensive (for credit prices & sequestration rates)

Strong **topographic variation** in typical rangeland landscapes limits tower placement

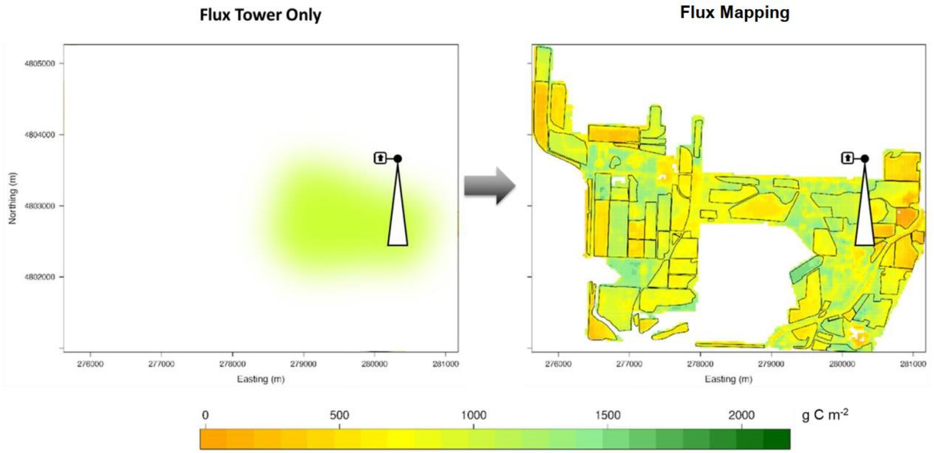
Standards – eddy covariance currently not permitted by registries for grassland CO2 sequestration or model cal/val *– We need guidelines and protocols to facilitate its wider and proper use*

Accuracy – Eddy flux historically used to inform functional relationships but NbS requires a shift in focus to **defensible cumulative NEE** – *How do we minimize uncertainty and ensure accuracy and precision?*

? **Low fluxes** typify low productivity rangeland systems, near uncertainty limits of conventional EC

Next Steps

- **System of systems** – Combining eddy flux with soil SOC stock measurements, animal GPS tracking, remote sensing and modeling
- **Measure-measure** rather than measure-model – Use ‘control towers’ on conventionally and/or ungrazed pastures for baseline or reference scenarios
- **Flux Mapping** – monitor different pastures with a single tower for real-time grazing management:



Remote Sensing Data and the AmeriFlux Website

Margaret Torn
Project Lead,
AmeriFlux Management Project

Rachel Hollowgrass
UX Designer,
AmeriFlux Management Project

Goals of this discussion

1. Introduce the R.S. resources at ameriflux.lbl.gov
2. Hear your feedback and suggestions for current and future resources

Data and AmeriFlux

AmeriFlux Today

- Network consists of 665 tower sites.
- Data discovery is organized around sites.

Data

- Flux and ancillary data from sites
- Data from other networks
  - MODIS and PhenoCam
  - Planned: NASA GeoNEX

Discovery of Data

- Users start with sites

Remote sensing products

https://ameriflux.lbl.gov/remote-sensing-products-overview/

Remote sensing products: an overview

This page is a resource about remote sensing sensors and datasets relevant to terrestrial ecosystem research, to help the flux community get started with research using remote sensing. The table describes common remote sensing platforms, sensors, and missions. Information is categorized by scientific and application areas and spatial and temporal resolution and coverage. The two right-hand columns have links to external websites that provide more detail. (Reference: NASA Earthdata, www.earthdata.nasa.gov)

How to use:

- The buttons above the table have dropdown menus to filter information.
- The search bar filters for rows containing specified word(s)
- "Export to CSV file" and "Print" to PDF options are available below the table
- Check out the blog post for useful tips on using the table.

The table for RS product page

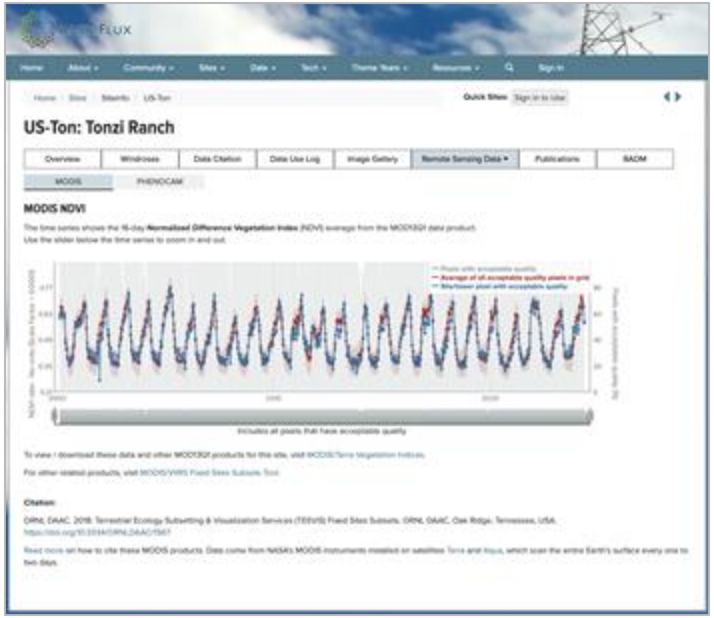
All Classes | Sub-class | Spatial Resolution | Spatial Coverage | Temporal Resolution | Temporal Coverage | Platform/Data type

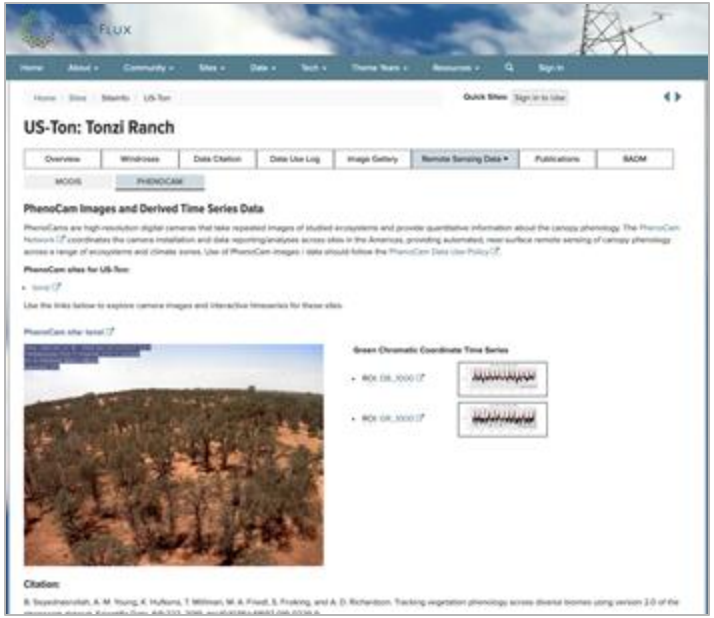
Satellite/Platform | Sensors | Observation/Model | File Format | Clear Filters | Search

Class	Sub-class	Spatial Resolution	Spatial Coverage	Temporal Resolution	Temporal Coverage	Platform Type	Satellite Name	Sensor/ Model/ Mission Name	Observation or Model	File Format	Link to Platforms/ sensors information	Link to data products
Land Surface	Surface reflectance	15m, 30m	Global	Variable	2000-present	Satellite	Terra	ASTER	Observation	HDF-EOS, GeoTIFF	Terra (NASA), ASTER (JPL), ASTER (LP DAAC)	Earthdata Search , Worldview
Land Surface	Surface reflectance	500m, 1km, 0.05°	Global	1-2 days	2000-present	Satellite	Terra, Aqua	*MODIS	Observation	HDF-EOS5	Terra (NASA), Aqua (NASA), MODIS (NASA), MODIS (LP DAAC)	Earthdata Search , Worldview
Land Surface	Surface reflectance	500m, 1km, 5,600m	Global	1-2 days	2017-present	Satellite	Suomi NPP	*VIIRS	Observation	HDF5, HDF-EOS5	Suomi NPP (NASA), VIIRS (NOAA), VIIRS (LP DAAC)	Earthdata Search , Worldview

AmeriFlux website: Remote sensing data

Remote sensing data is presented with an associated AmeriFlux site on the Site Info page.





AmeriFlux website: MODIS data

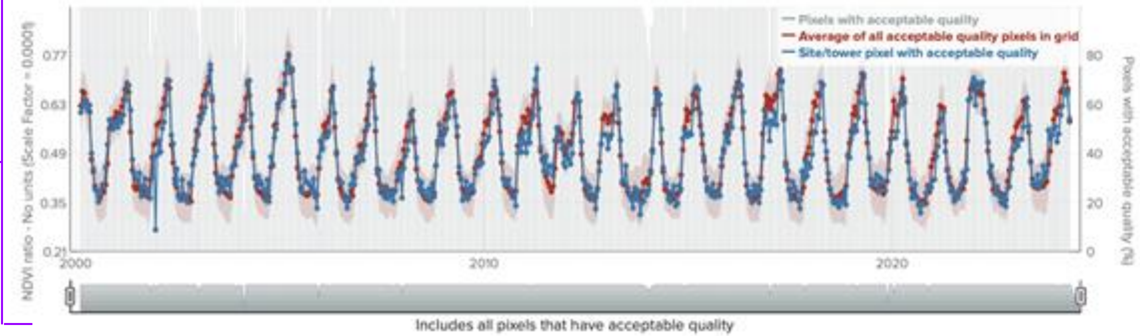
MODIS | PHENOCAM

Description

MODIS NDVI

The time series shows the 16-day **Normalized Difference Vegetation Index** (NDVI) average from the MOD13Q1 data product.
Use the slider below the time series to zoom in and out.

Visualization



Links to source

To view / download these data and other MOD13Q1 products for this site, visit MODIS/Terra Vegetation Indices.

For other related products, visit MODIS/VIIRS Fixed Sites Subsets Tool.

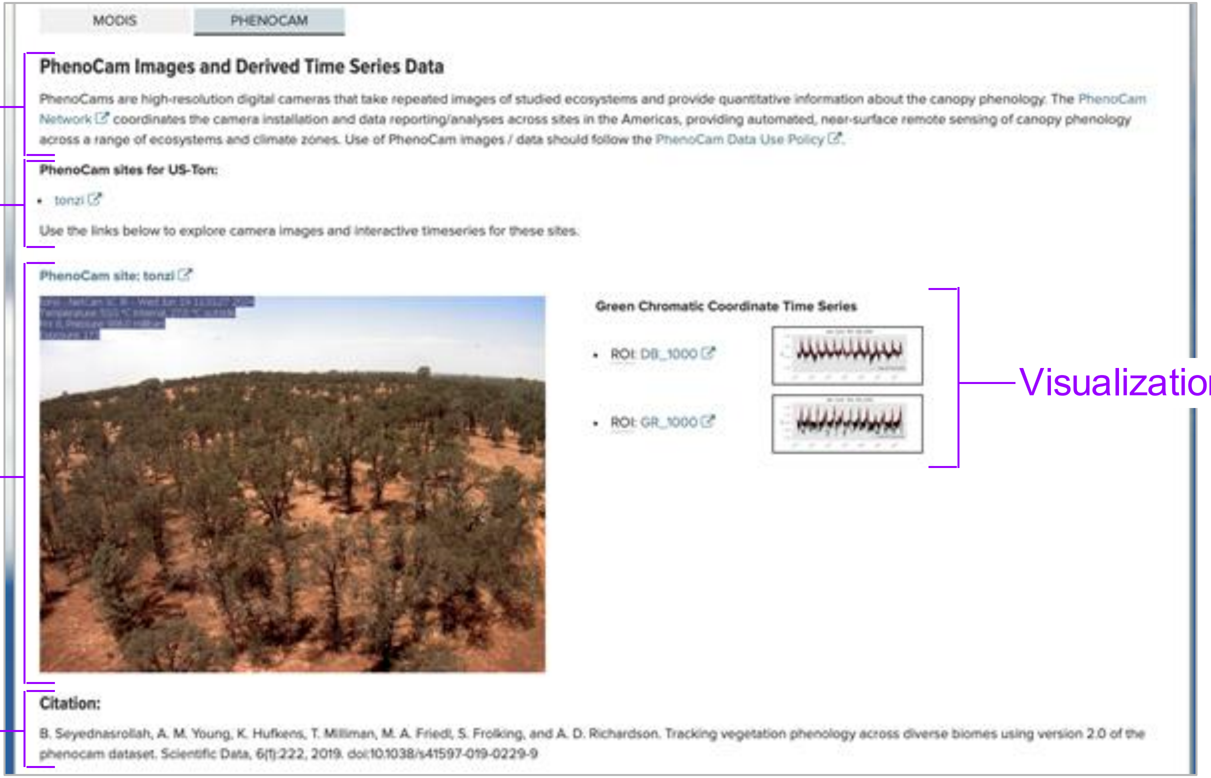
Citation information

Citation:

ORNL DAAC. 2018. Terrestrial Ecology Subsetting & Visualization Services (TESViS) Fixed Sites Subsets. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1567

Read more on how to cite these MODIS products. Data come from NASA's MODIS instruments installed on satellites Terra and Aqua, which scan the entire Earth's surfa
two days.

AmeriFlux website: PhenoCam Network



Description

LInk to source

Image

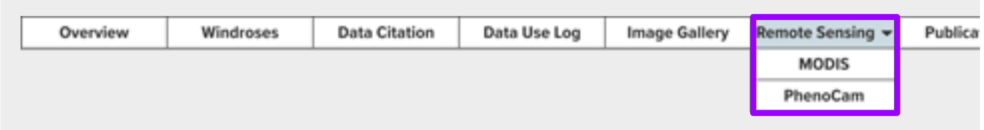
Visualizations

Citation information

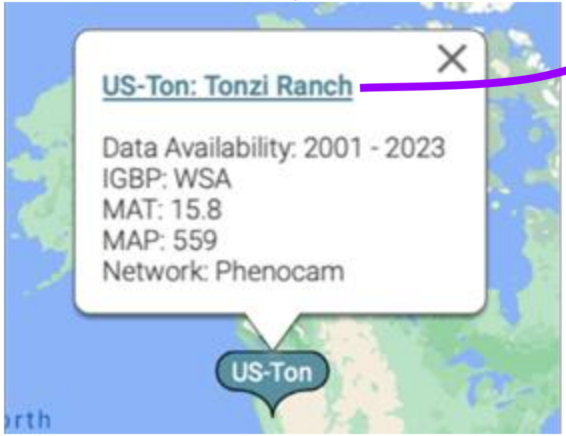
Discovering Data

Starting from the map or from Site Search, a link goes directly to the Site Info page. The drop down menu links to the remote sensing data.

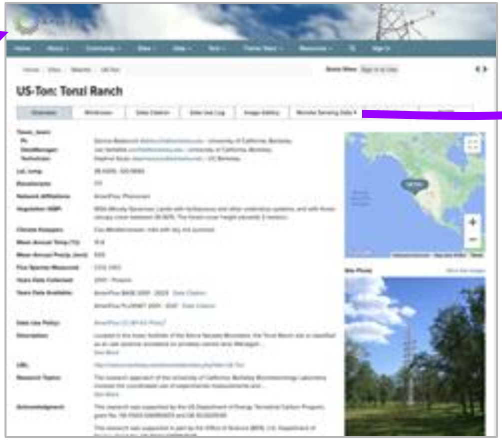
Drop Down Menu



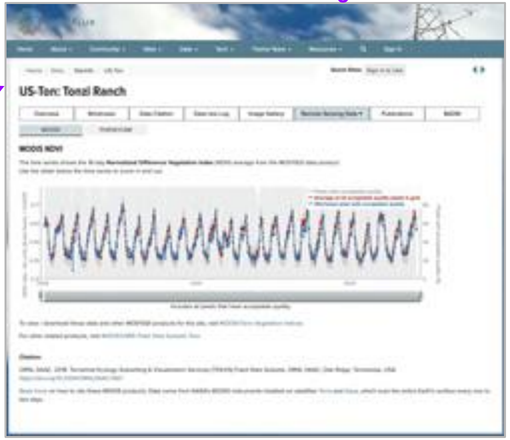
Map



Site Info



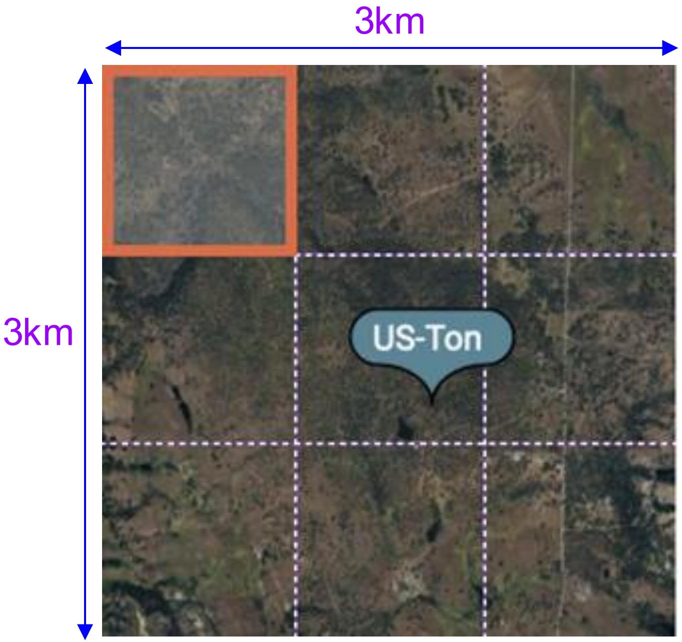
Remote Sensing



Planned Data: NASA GeoNEX

Plan is to normalize the GeoNEX data

- $9km^2$ tile area
- Associate data with each AmeriFlux tower site



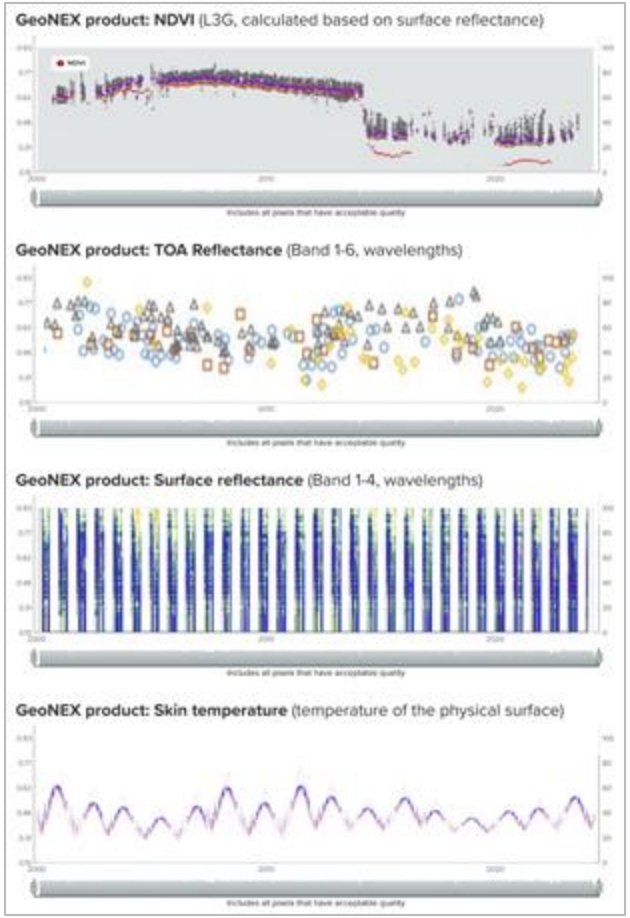
Planned Data: NASA GeoNEX

Plan is to include 4 GeoNEX data products

- NDVI
- TOA Reflectance
- Surface Reflectance
- Skin Temperature

Visualizations

- Will be generated on the AmeriFlux website

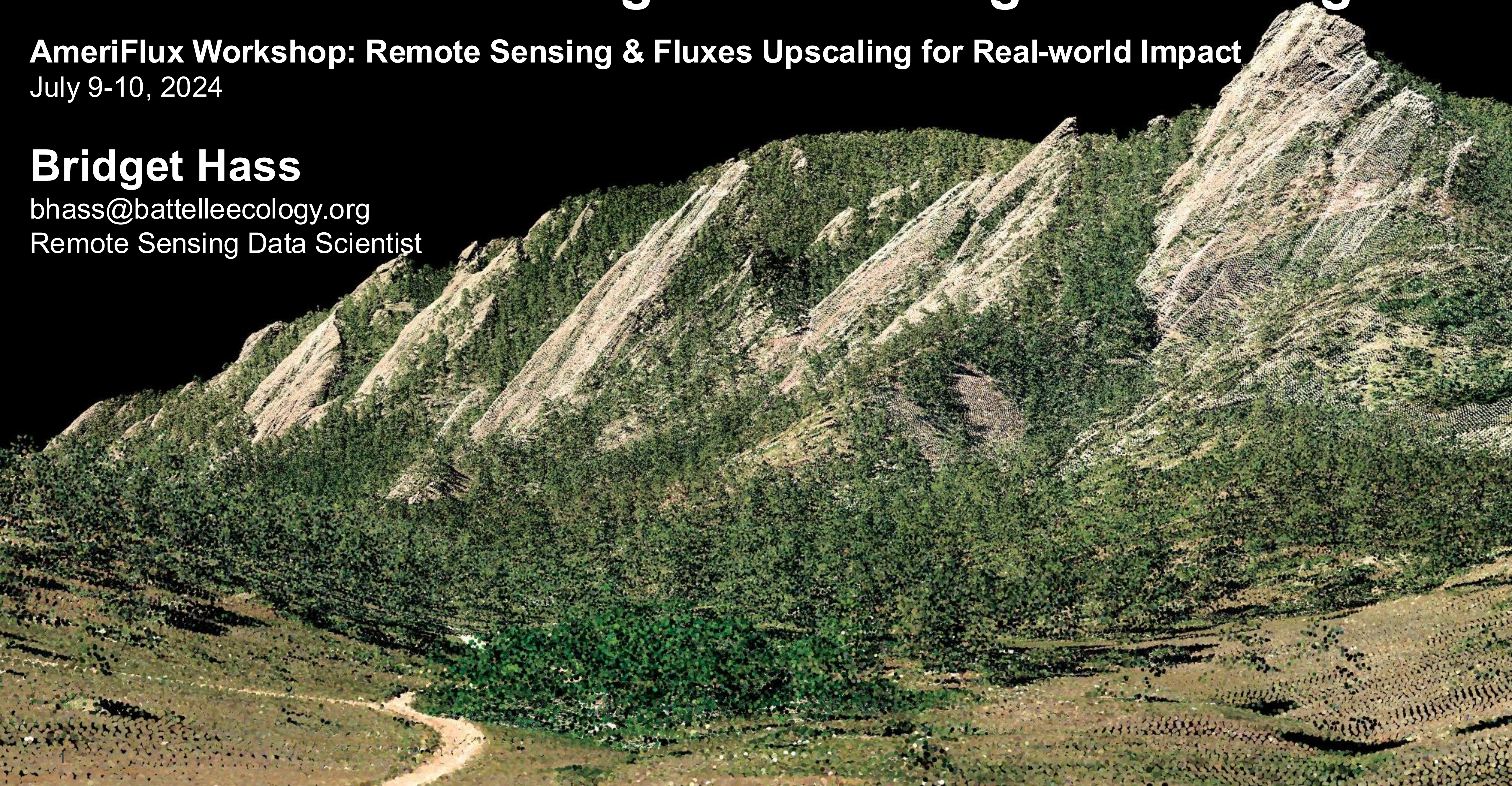


Discussion

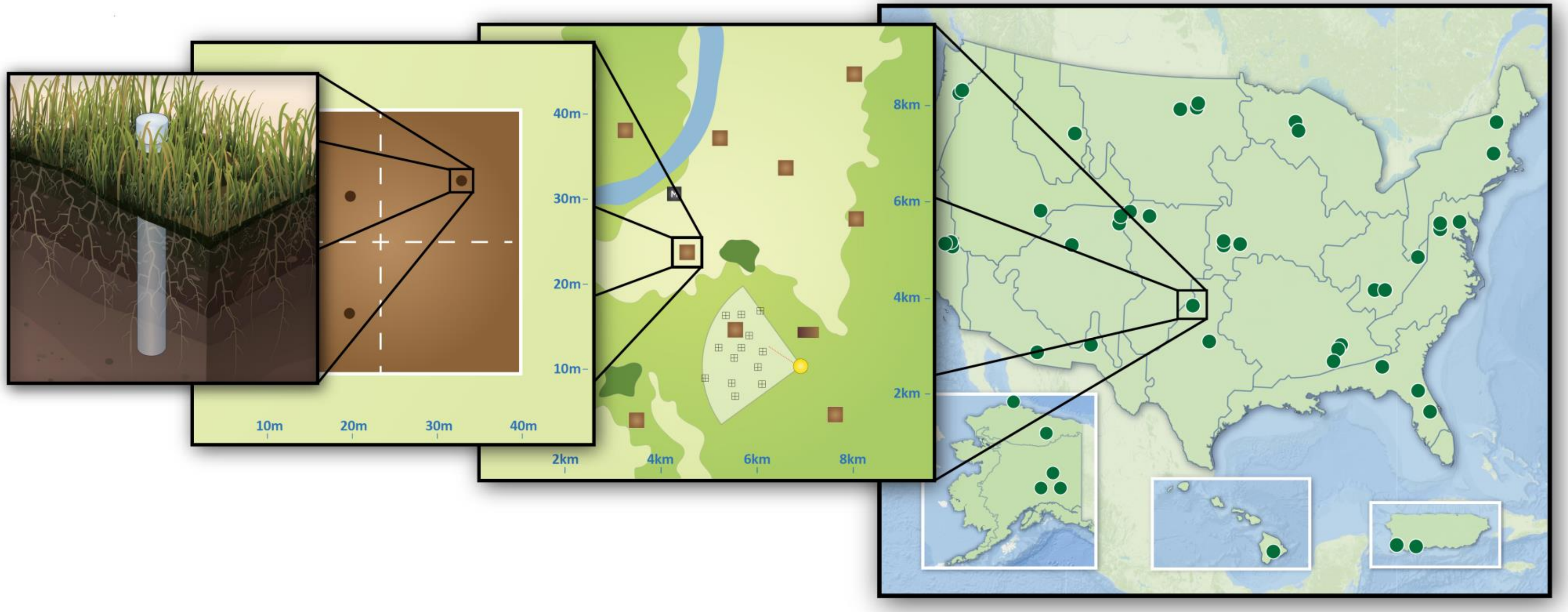
NEON Remote Sensing Data in Google Earth Engine

AmeriFlux Workshop: Remote Sensing & Fluxes Upscaling for Real-world Impact
July 9-10, 2024

Bridget Hass
bhass@battelleecology.org
Remote Sensing Data Scientist



NEON – National Ecological Observatory Network
Continental Scale Ecological Monitoring

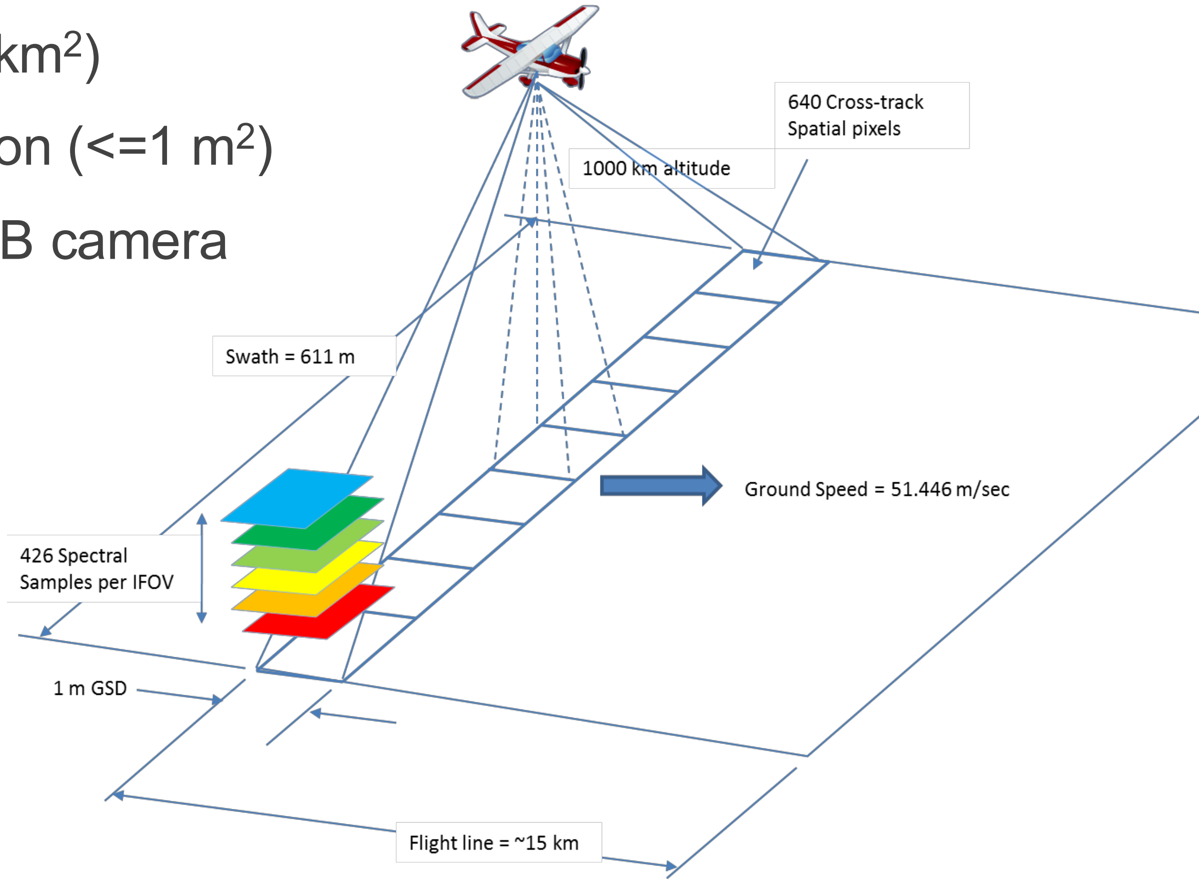


81
FIELD SITES
- 47 terrestrial
- 34 aquatic

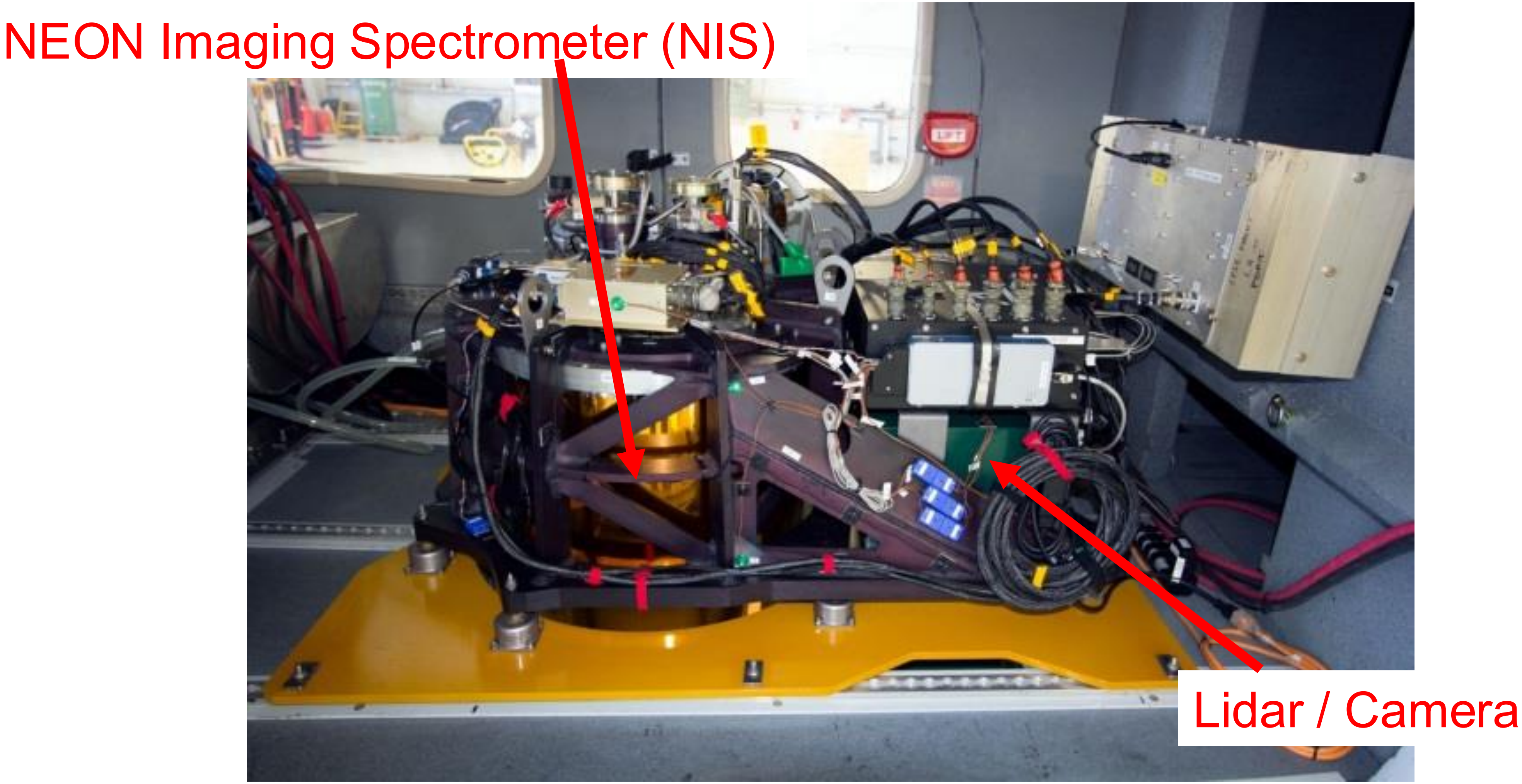
Over
180
DATA PRODUCTS

Airborne Observation Platform (AOP)

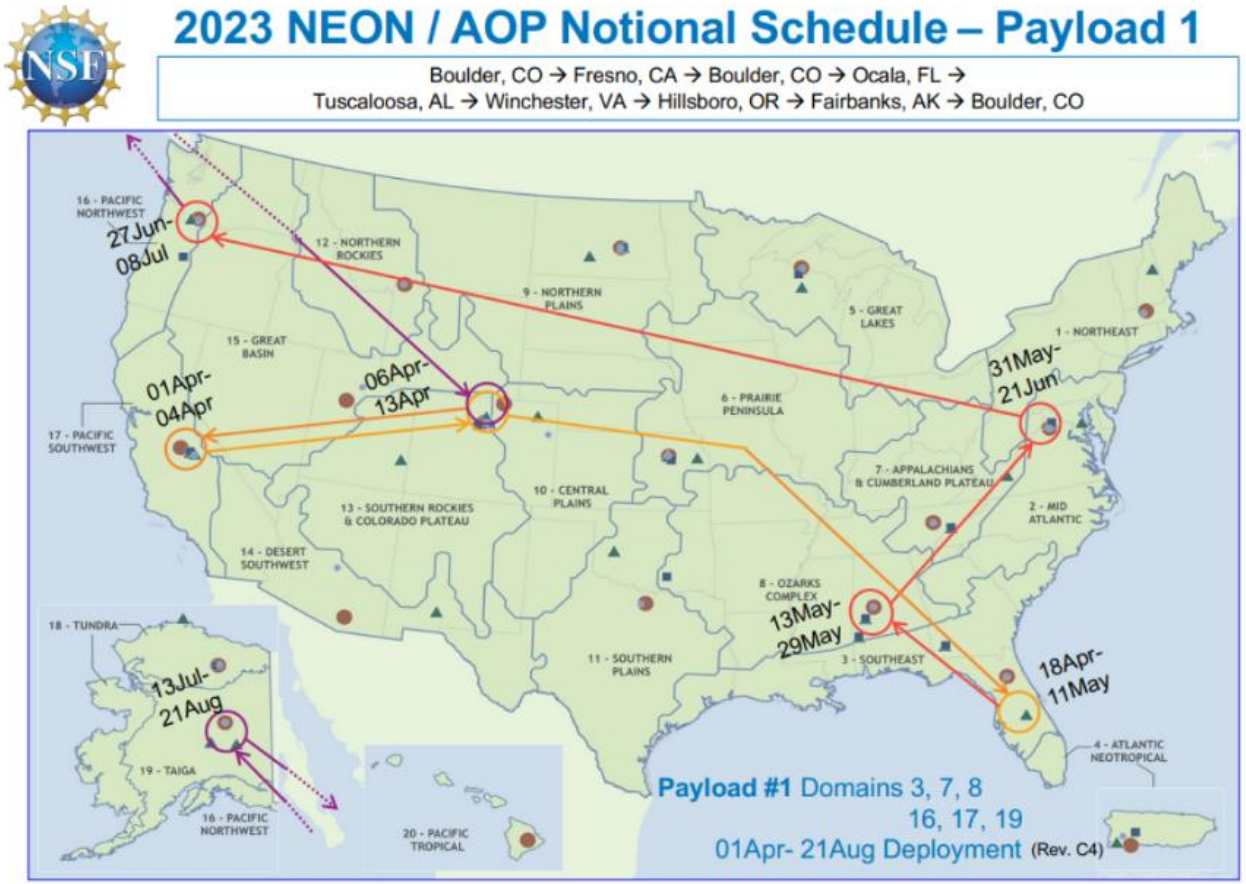
- Collects airborne remote sensing data
- Covers 'regional scale' landscapes (min of 100 km^2)
- Data products generated at high spatial resolution (<=1 m^2)
- Waveform Lidar, Imaging Spectrometer and RGB camera

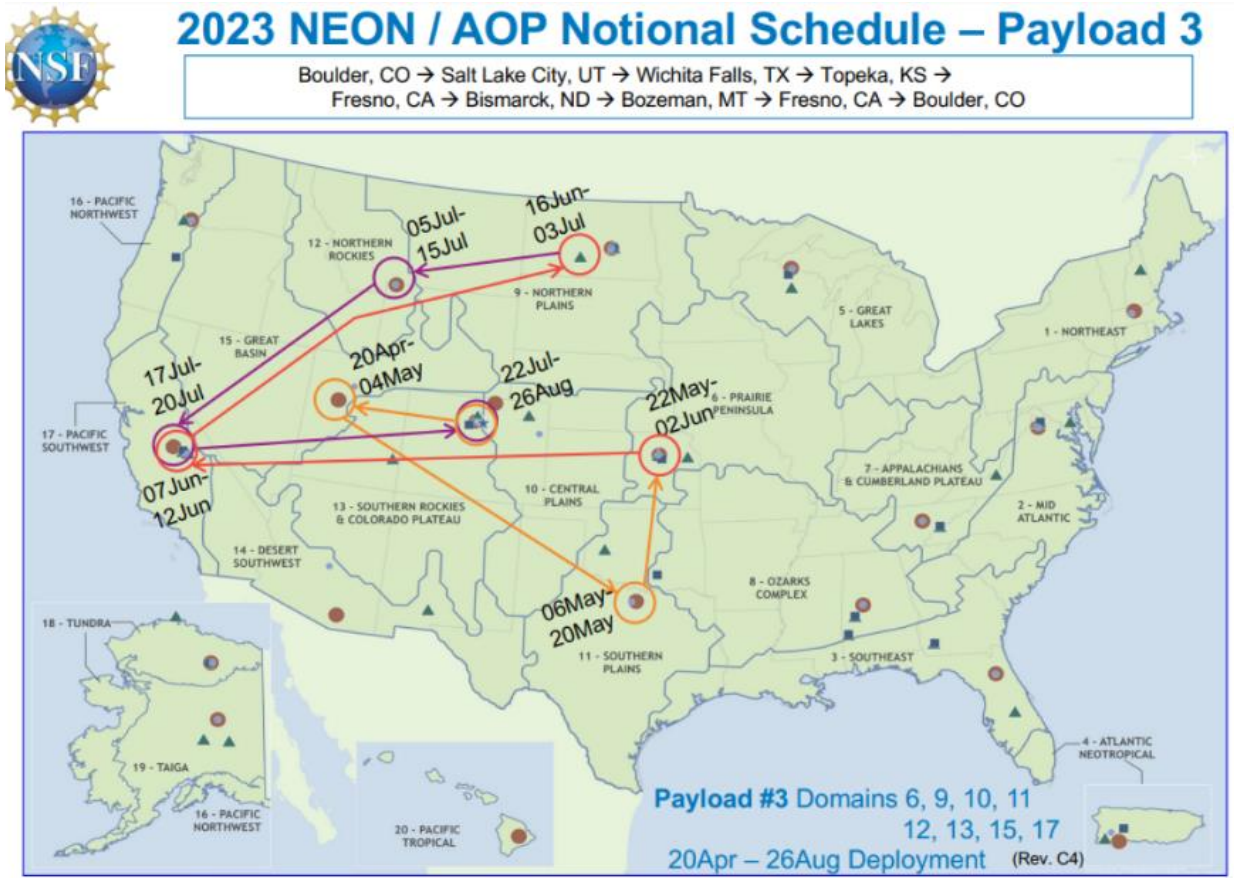


AOP Payloads



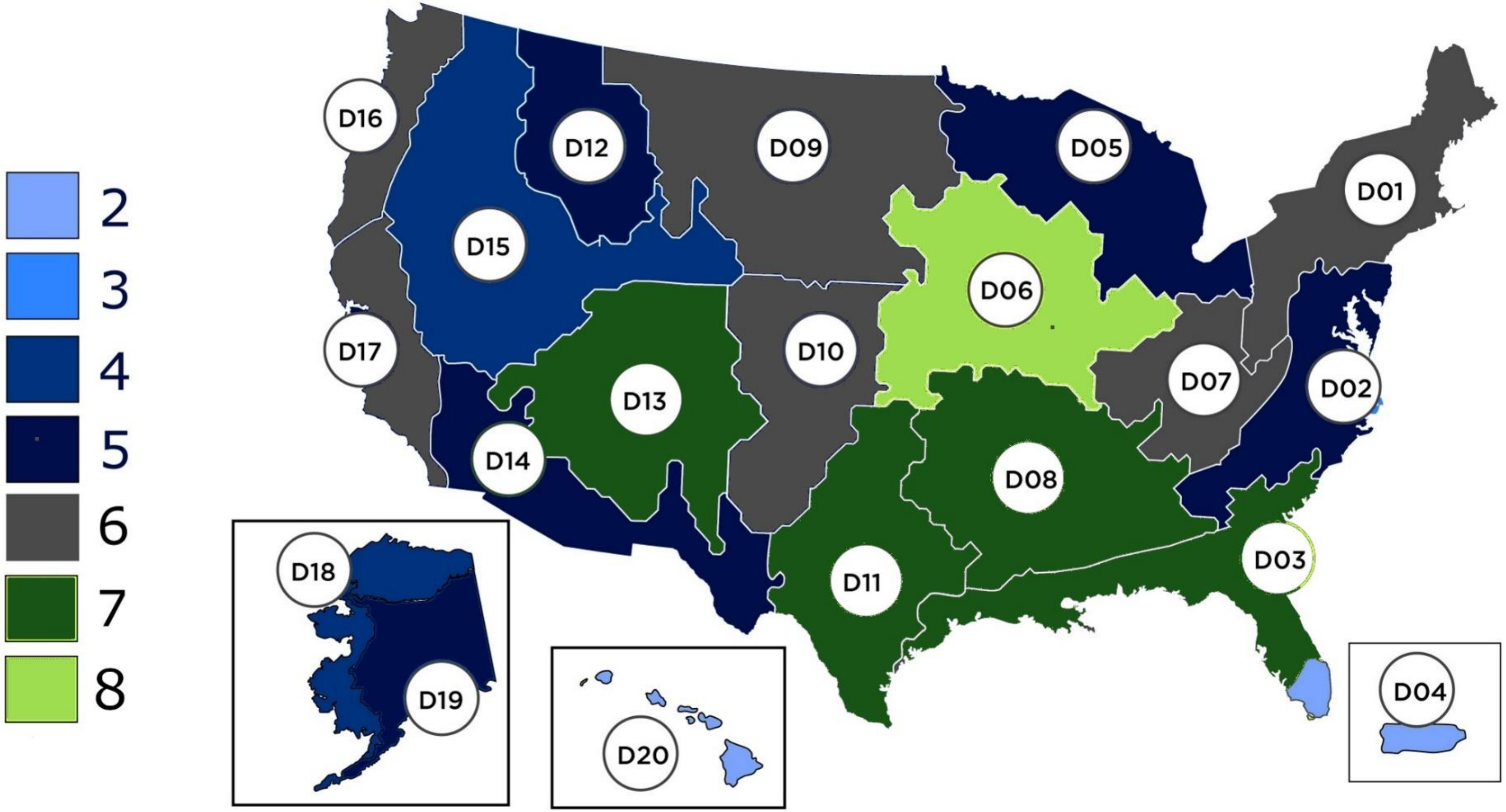
AOP Flight Schedule





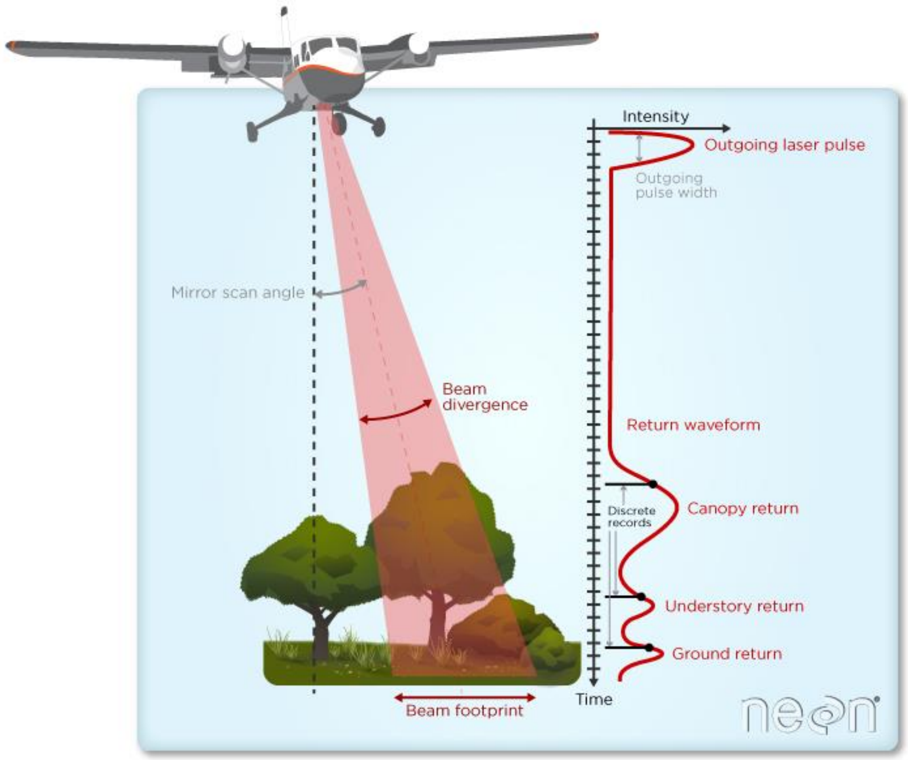
Current & Past AOP Schedule: https://www.neonscience.org/data-collection/flight-schedules-coverage

2013 - 2023 AOP collections

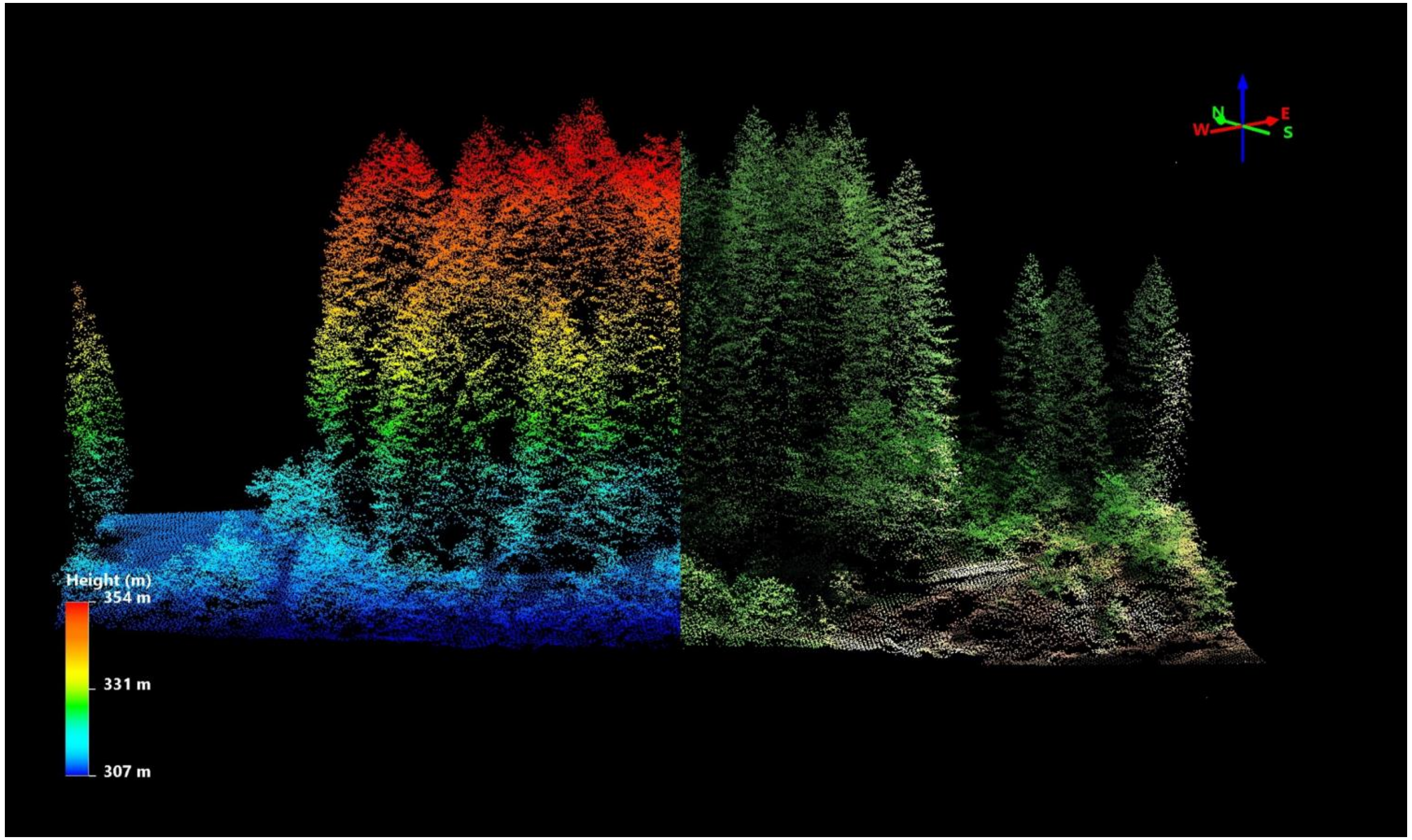


180+ peer reviewed publications using AOP data (https://neon.dimensions.ai/discover/publication)

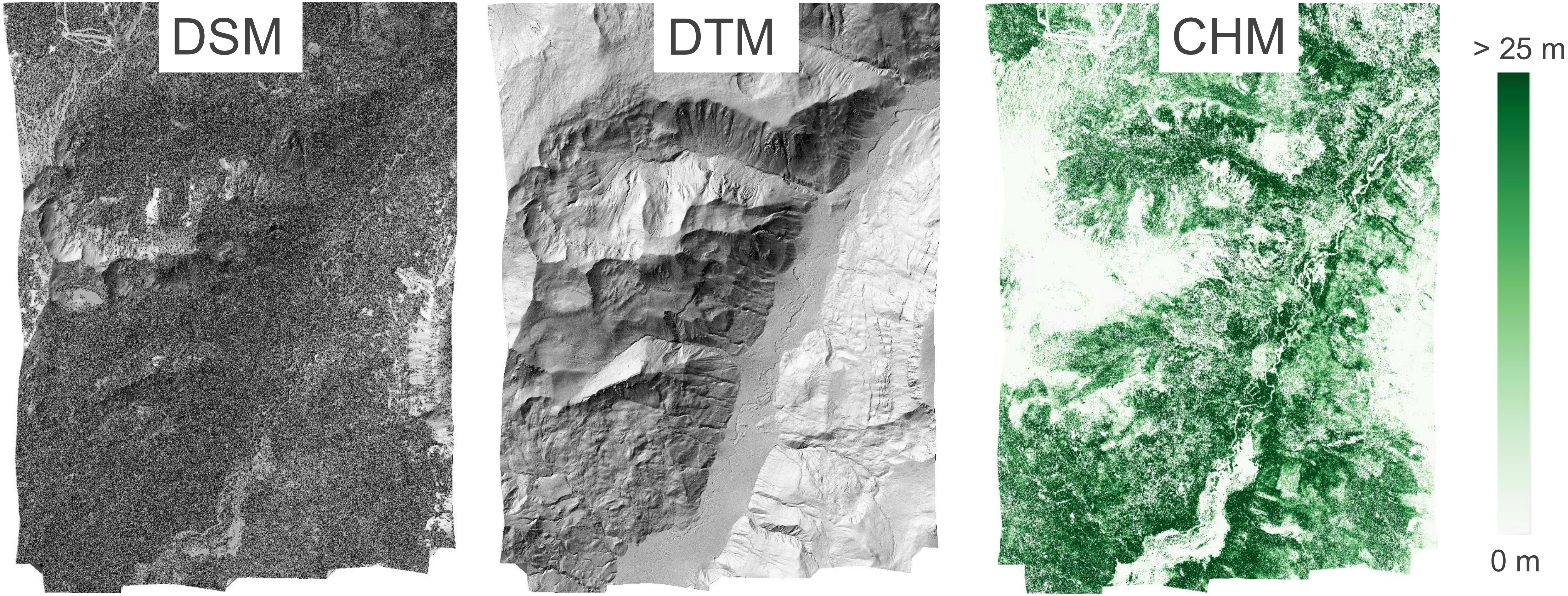
AOP LiDAR



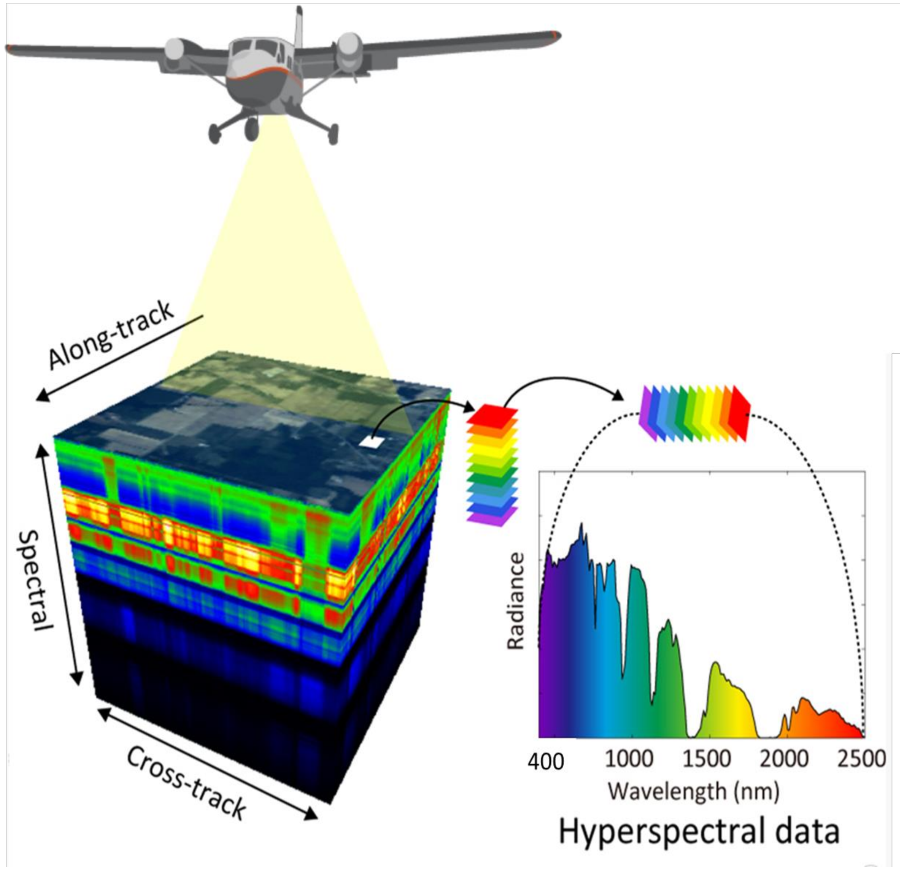
Discrete Point Clouds Classified & Colorized

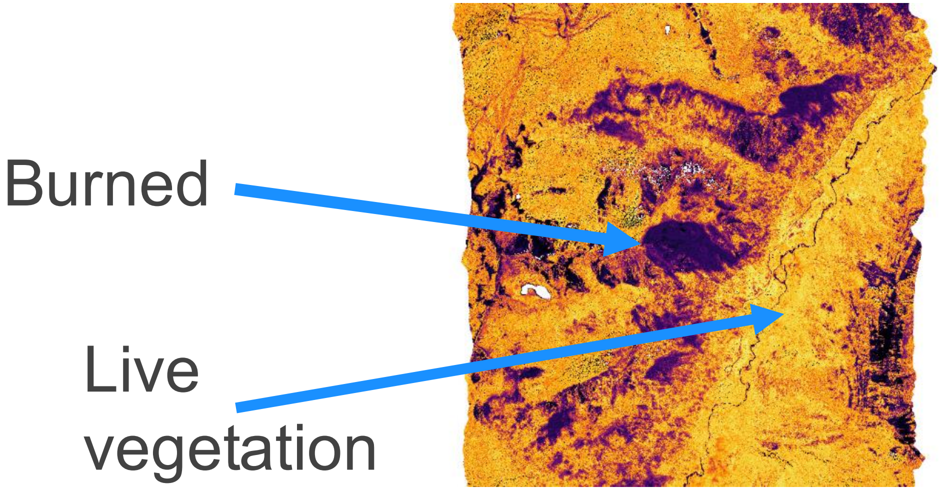


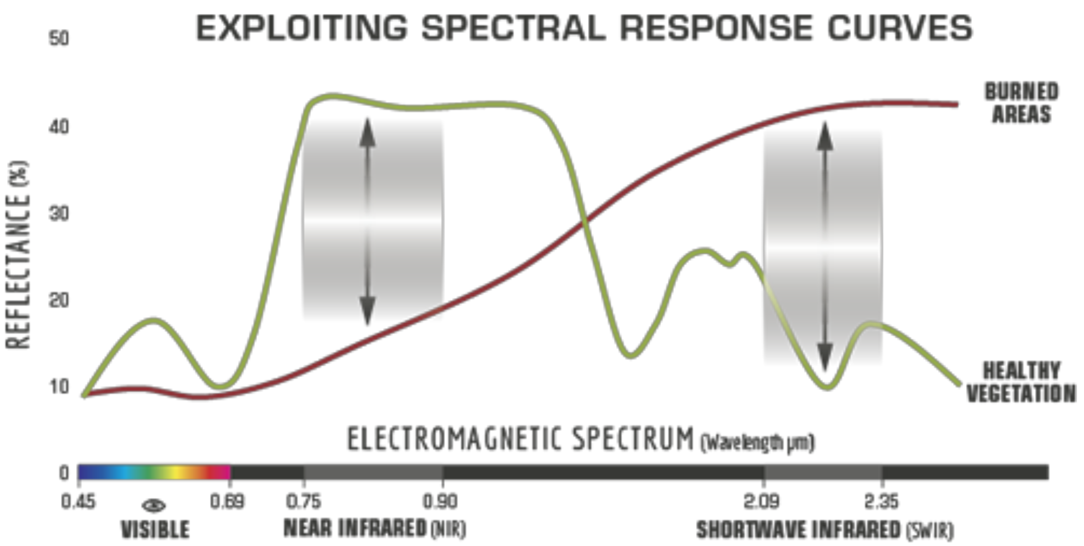
Lidar Raster Data
Elevation Models, Canopy Height, Slope/Aspect



AOP Hyperspectral







https://www.earthdatascience.org/courses/earth-analytics/multispectral-remote-sensing-modis/normalized-burn-index-dNBR/

Hyperspectral Data Products

https://www.neonscience.org/data-collection/imaging-spectrometer

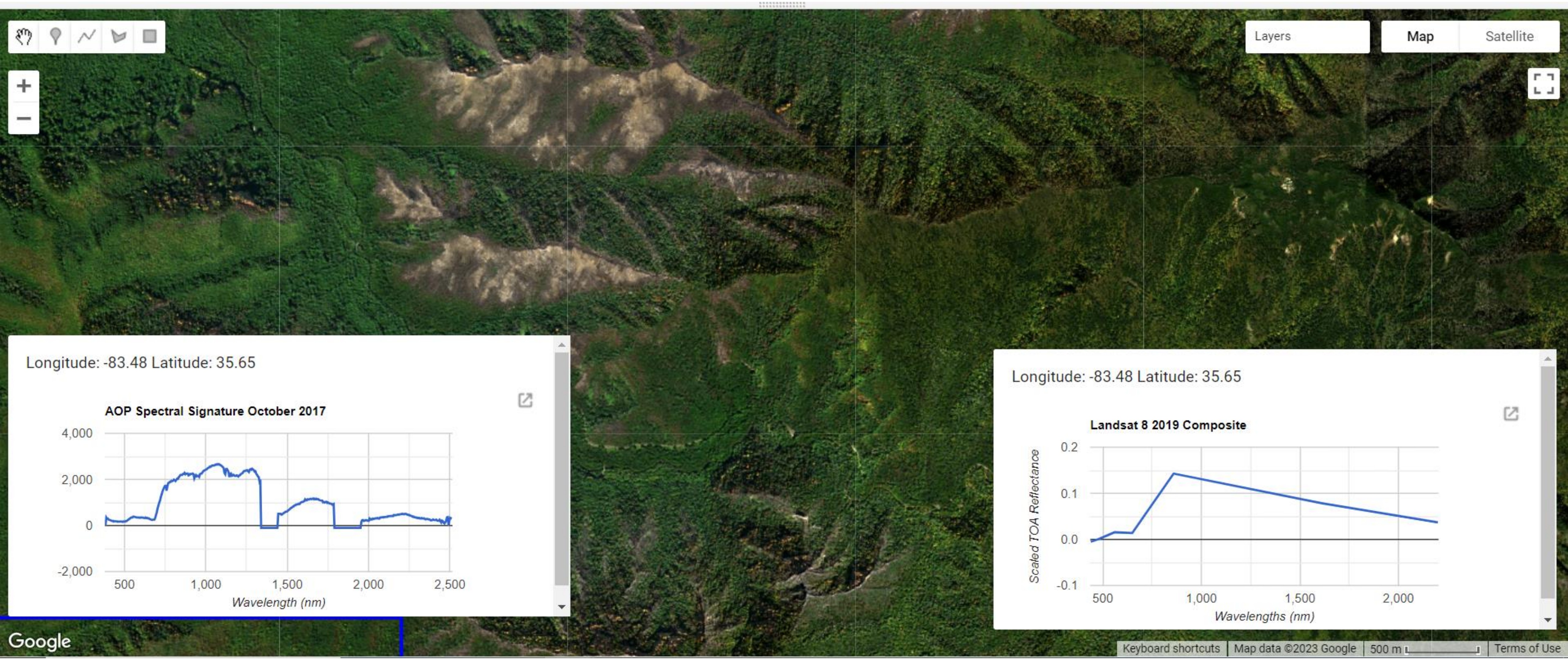
Level 1

- Spectrometer Orthorectified at-Sensor Radiance (DP1.30008.001)
- Spectrometer Orthorectified Surface Directional Reflectance (DP1.30006.001)

Level 2 / 3

- ~~Canopy Nitrogen (DP2.30018.001)~~
- Canopy Water Content (DP2.30019.001) →
  - Moisture Stress Index (MSI)
  - Normalized Difference Infrared Index (NDII)
  - Normalized Difference Water Index (NDWI)
  - Normalized Multi-band Drought Index (NMDI)
  - Water Band Index (WBI)
- ~~Canopy Xanthophyll Cycle (DP2.30020.001)~~
- ~~Canopy Lignin (DP2.30022.001)~~
- Vegetation Indices - Spectrometer (DP2.30026.001) →
  - Normalized Difference Vegetation Index (NDVI)
  - Enhanced Vegetation Index (EVI)
  - Atmospherically Resistant Vegetation Index (ARVI)
  - Photochemical Reflectance Index (PRI)
  - Soil Adjusted Vegetation Index (SAVI)
- Albedo - Spectrometer (DP2.30011.001)
- LAI - Spectrometer (DP2.30012.001)
- fPAR - Spectrometer (DP2.30014.001)

Hyperspectral Resolution



AOP Sampling Collection Requirements

- Clear skies (<10% cloud cover)

high quality, unobscured reflectance data

- Nominal AOP flying altitude = 1000 m AGL

collect data at the scale of individual plants

- Minimum 10 km x 10 km box for terrestrial sites

collect regional scale area around NEON sites

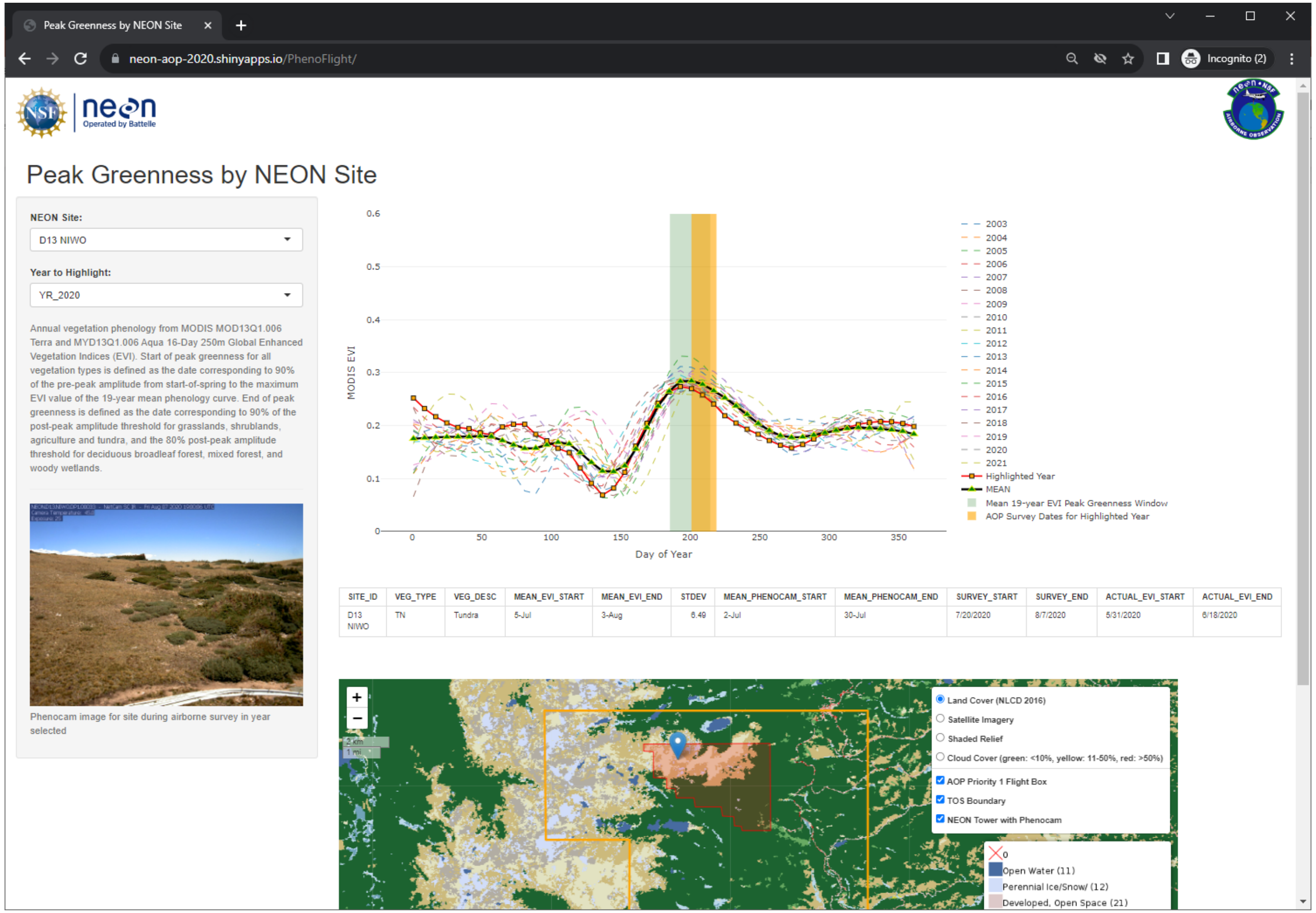
- Fly at peak 'greenness' (phenology)

consistency between annual collections

- Fly N-S lines, solar angles above 40°

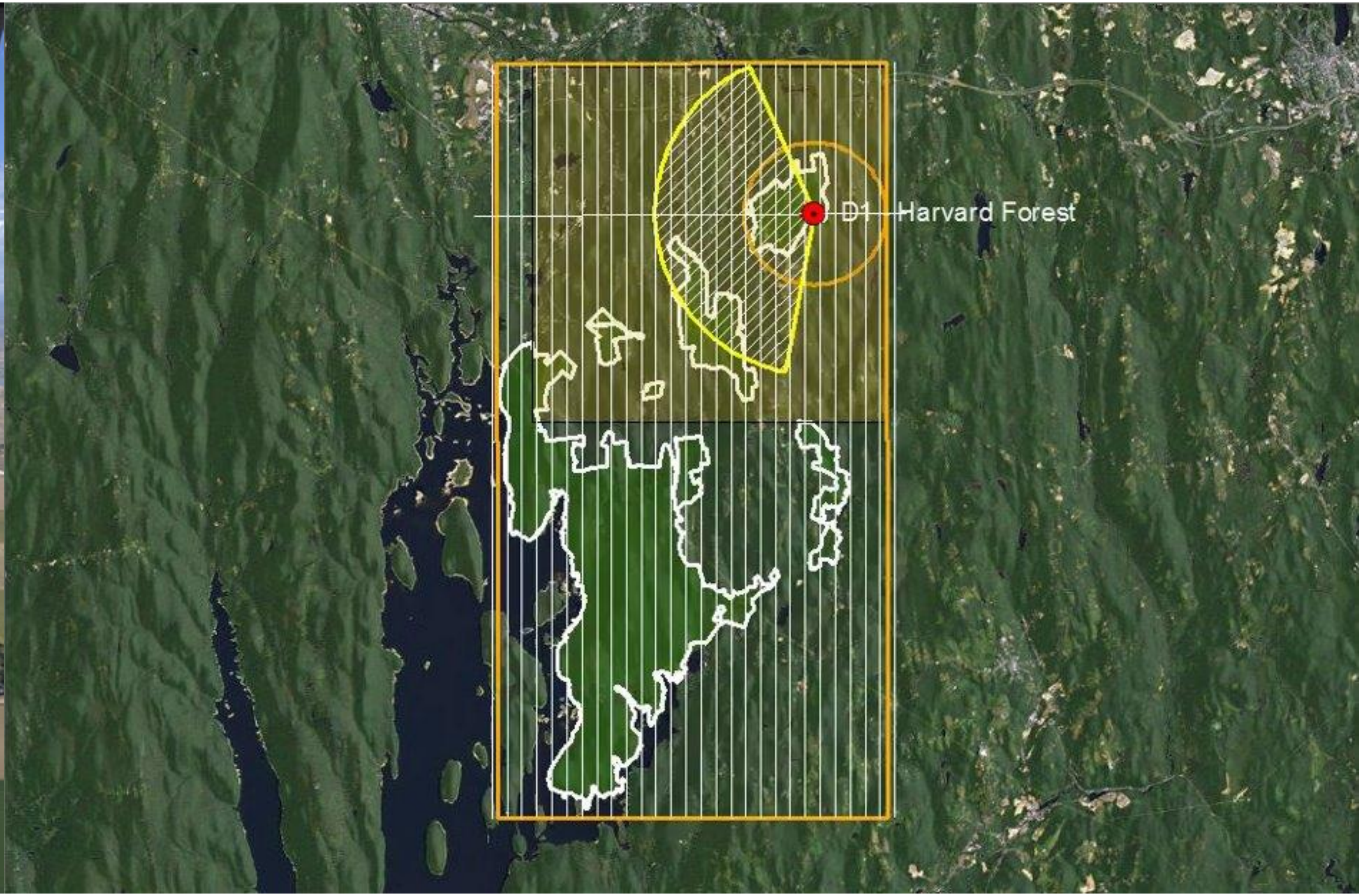
*consistency between flight lines**

https://neon-aop-2020.shinyapps.io/PhenoFlight/



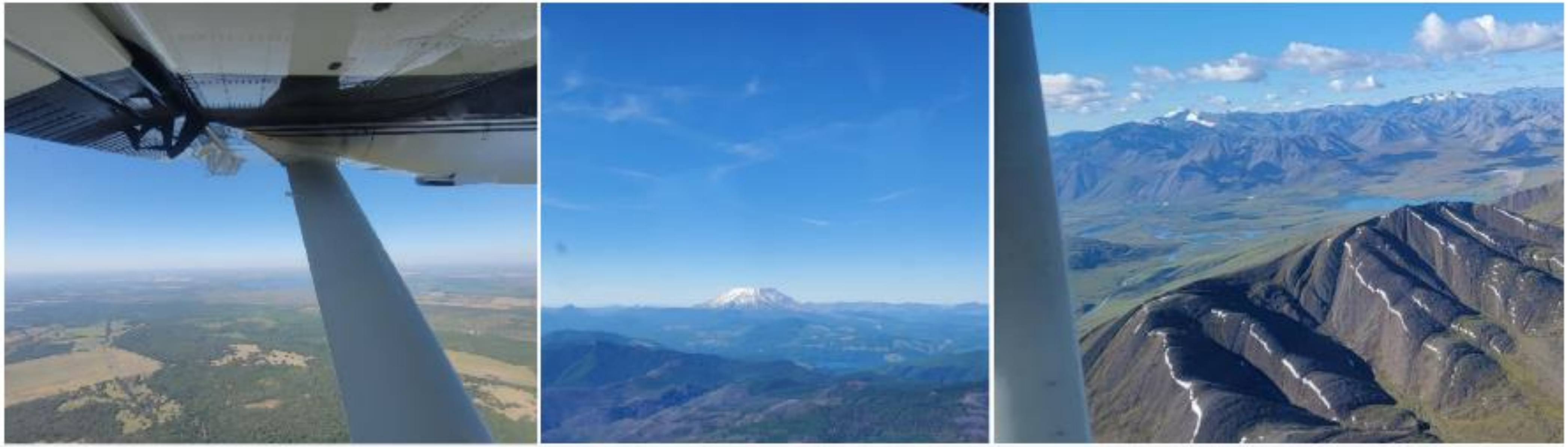
neon
Operated by Battelle

AOP Flight Plan Design



QA & Uncertainty Considerations

Weather Quality / Cloud Conditions

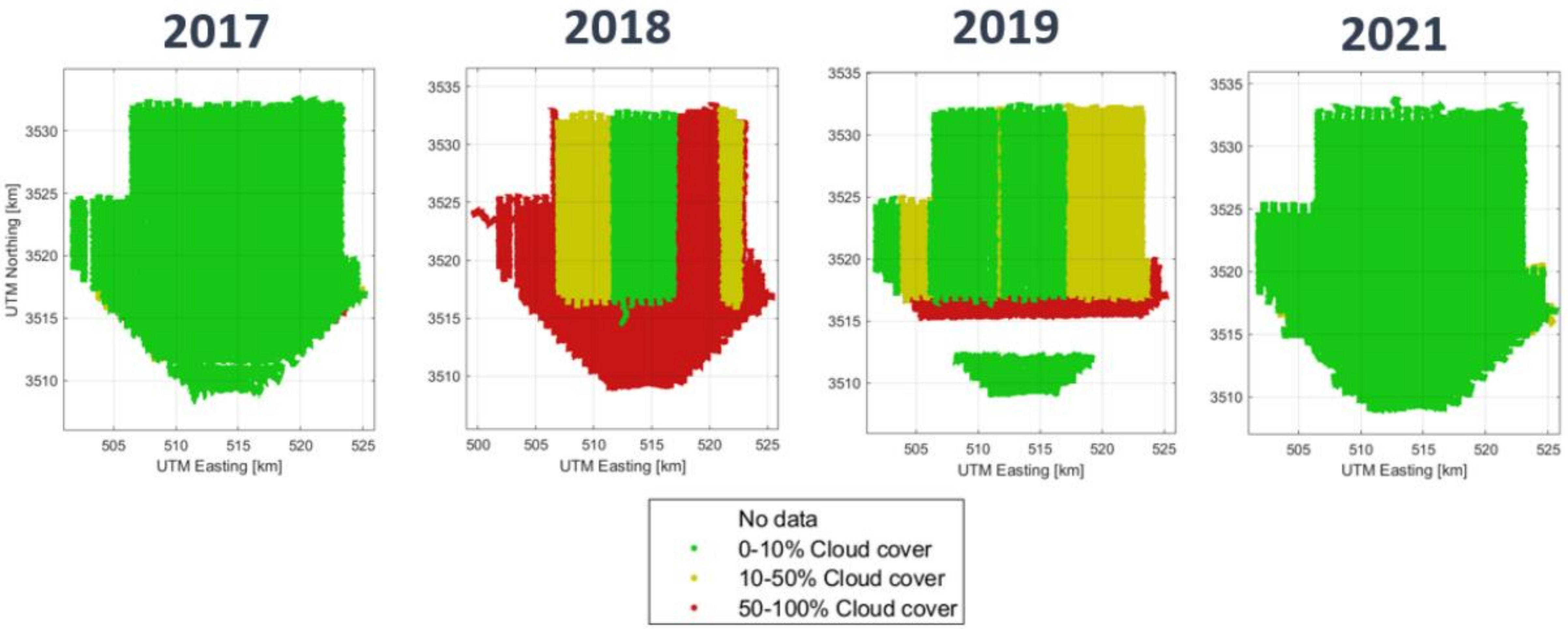


Cloud cover percentage during AOP flights. Left: green (<10%), Middle: yellow (10-50%), Right: red (>50%).

Daily flight reports: https://www.neonscience.org/data-collection/daily-flight-reports

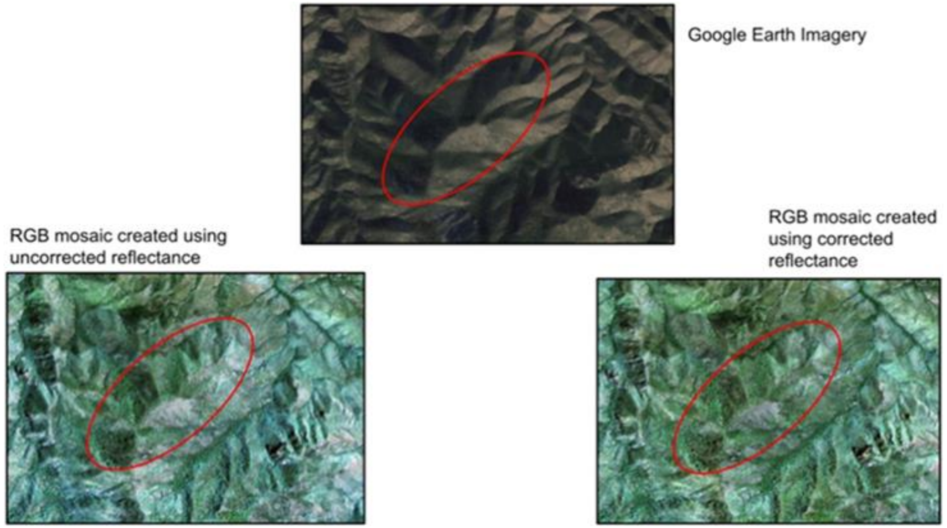
Weather Quality / Cloud Conditions

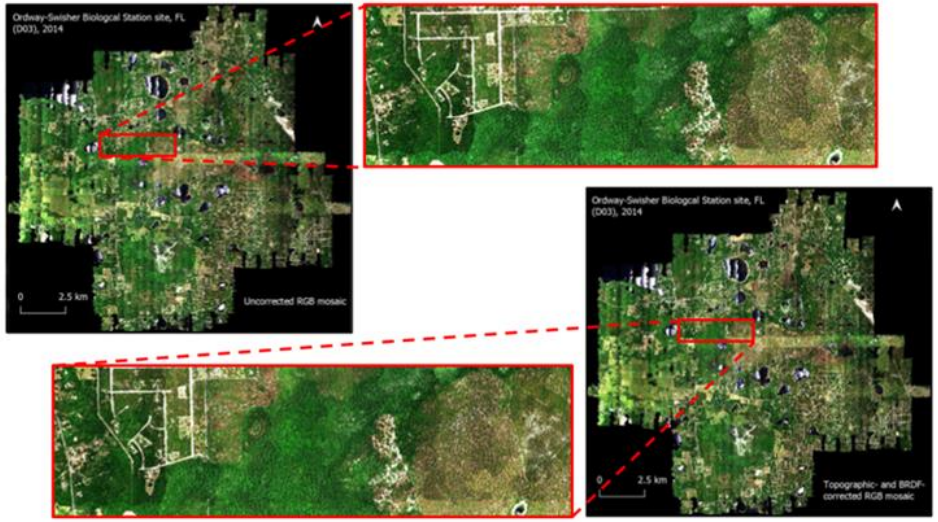
Example weather conditions & coverage @ SRER



Updates to spectrometer-derived data products

- 2022-2024 spectrometer data processing is underway, 2022 spectrometer data available provisionally
- Now generating L1 reflectance data corrected for topographic and BRDF effects using the HyTools Python package[1]. Directional reflectance data (L1) will continue to be generated, but not L3.
- Starting with 2022-2024 data, using the BRDF- and topographic-corrected reflectance data to generate higher level (L2, L3) products (e.g. veg/water indices, 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.

AOP Data Access

- **Data Portal** – manual data download through website
  - data.neonscience.org
  - includes important docs and info about NEON data products

- **API** – programmatic download
  - R (neonUtilities)
  - Python scripts/tutorials (Python version of neonUtilities in progress, expected Fall 2024)

- **Google Earth Engine (GEE)**
  - Subset of data available now, adding more
  - Publicly searchable/findable in the GEE Publisher Data Catalog soon!

AOP Image Collections on GEE

```
// Bidirectional (BRDF & topographic corrected) reflectance, DP3.30006.002
var refl002 = ee.ImageCollection('projects/neon-prod-earthengine/assets/HSI_REFL/002')

// Directional reflectance, DP3.30006.001
var refl001 = ee.ImageCollection('projects/neon-prod-earthengine/assets/DP3-30006-001')

// NOTE: directional reflectance will be moved to the path below, by end of July 2024
// var sdrCol = ee.ImageCollection('projects/neon-prod-earthengine/assets/HSI_REFL/001')

// RGB Camera, DP3.30010.001
var rgb = ee.ImageCollection('projects/neon-prod-earthengine/assets/RGB/001')

// CHM (Ecosystem Structure), DP3.30015.001
var chm = ee.ImageCollection('projects/neon-prod-earthengine/assets/CHM/001')

// DEM (DSM & DTM), DP3.30024.001
var dem = ee.ImageCollection('projects/neon-prod-earthengine/assets/DEM/001')
```

GEE Data Demo Links:

Interactive Spectral Visualization App

https://tinyurl.com/d05-spectra-app

GitHub Repo – UNDE Demo Scripts

https://tinyurl.com/unde-aop-gee-demo

https://www.neonscience.org/resources/learning-hub

Workshops & Courses

NEON offers workshops to train students and researchers on key skills to work with NEON and NEON-like data.

READ MORE

```
S <- mgp_perhorizon

# Join chemical and physical data from biogeo
tables
B <- full_join(mgp_perbiogeosample,
               mgc_perbiogeosample,
               by=c('horizonID','biogeoID',
                    'siteID','domainID',
                    'setDate','collectDate',
                    'horizonName','pitID',
                    'biogeoSampleType'))

# Select only 'Regular' samples (not audit)
B <- B[B$biogeoSampleType=="Regular" &
         !is.na(B$biogeoSampleType),]
```

Code Hub

We provide software code to help you work with NEON data as well as links to code contributed by the community.

CODE HUB

Learning Hub

From self-paced tutorials to teaching modules you can use in your classroom, see what we and members of our community provide.

LEARNING HUB

Operated by Battelle

720.746.4844 | neonscience@battelleecology.org | neonscience.org

Status of AOP Data in Google Earth Engine

- **Why GEE?**
  - Free and openly available for research applications
  - Can easily conduct analysis on full sites over multiple years
  - Pre-loaded satellite imagery for scaling applications
  - Built-in cloud-based algorithms for raster & hyperspectral analysis
- **New in 2023**
  - Added QA bands and metadata information (image properties)
  - Tutorial series for working with AOP GEE Public Datasets
- **Plan for 2024**
  - Add BRDF-corrected reflectance data to GEE (starting with 2022-2024 AOP data)
  - Reflectance, DEM, CHM, RGB Camera datasets available upon request
  - Make AOP datasets publicly searchable on GEE (expected by Aug 2024)

AOP Data Products (Green on GEE)

LIDAR PRODUCT NAME	PRODUCT #
LiDAR Slant Range Waveform	DP1.30001.001
Discrete Return LiDAR Point Cloud	DP1.30003.001
Ecosystem Structure (CHM)	**DP3.30015.001**
Elevation – LiDAR (DTM, DSM)	**DP3.30024.001**
Slope and Aspect – LiDAR	DP3.30025.001

CAMERA PRODUCT NAME	PRODUCT #
High-resolution orthorectified camera imagery	DP1.30010.001
High-resolution orthorectified camera imagery mosaic	**DP3.30010.001**

SPECTROMETER PRODUCT NAME	L1	L2	L3
Spectrometer Orthorectified at-Sensor Radiance	DP1.30008.001		
Spectrometer Orthorectified Surface Directional Reflectance	DP1.30006.001		DP3.30006.001*
Spectrometer Orthorectified Bi-Directional Reflectance*	DP1.30006.002		DP3.30006.002
Vegetation Indices - Spectrometer		DP2.30026.001	DP3.30026.001
Canopy Water Content		DP2.30019.001	DP3.30019.001
…and more!			

Full list of NIS data products can be found here: https://www.neonscience.org/data-collection/imaging-spectrometer

Additional Info on BRDF correction + Suspended AOP Products in Development

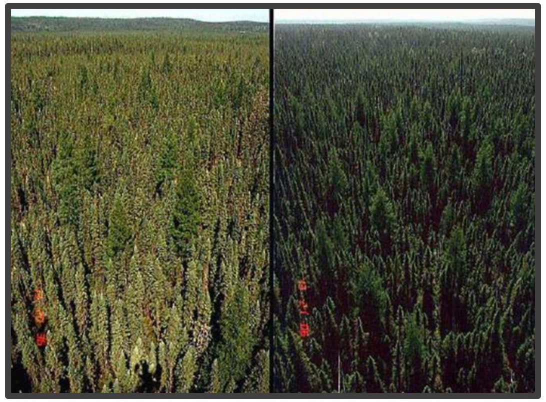
Why BRDF correction?

Surface reflectance anisotropy

Objects look differently when viewed from different angles, and when illuminated from different directions.

Black Spruce Forest

Sun behind observer — Sun opposite observer



All shadows are hidden leading to a bright image

Shadowed centers of trees

Soybeans field

Sun behind observer — Sun opposite observer

Specular (mirror-like) reflection of leaves

Barren field with rough surface

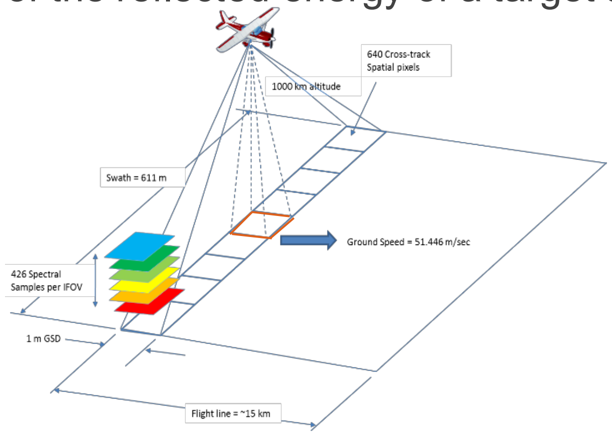
Sun behind observer — Sun opposite observer

Shadows hidden

Photographs by Donald W. Deering, NASA/GSFC
Source: https://www.umb.edu/spectralmass/terra_aqua_modis/modis

Bidirectional Reflectance Distribution Function (BRDF)

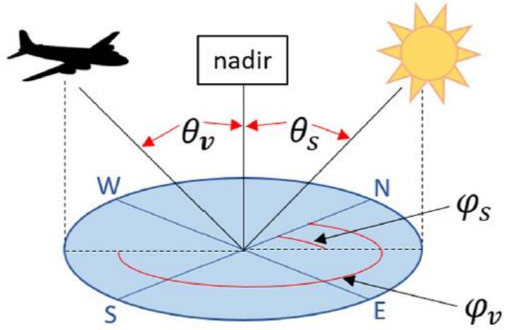
BRDF (units sr^{-1}) describes the directional dependence of the reflected energy of a target as a function of **illumination** and **viewing** geometry



BRDF also depends on

- Wavelength
- Structural and optical properties of the surface

Defining viewing and illumination geometry



θ_s Solar Zenith angle

φ_s Solar Azimuth angle

θ_v View Zenith angle

φ_v View Azimuth angle

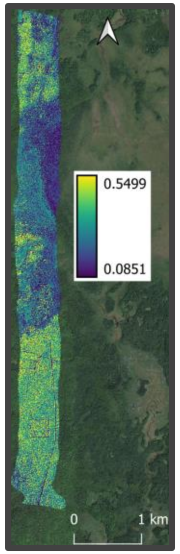
Queally, Natalie, et al. "FlexBRDF: A flexible BRDF correction for grouped processing of airborne imaging spectroscopy flightlines." *Journal of Geophysical Research: Biogeosciences* 127.1 (2022): e2021JG006622

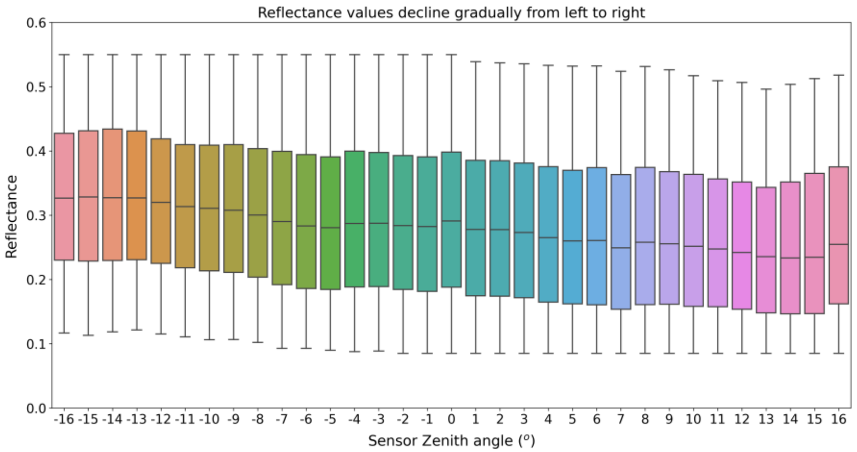
Lucht, Wolfgang, Crystal Barker Schaaf, and Alan H. Strahler. "An algorithm for the retrieval of albedo from space using semiempirical BRDF models." *IEEE Transactions on Geoscience and Remote sensing* 38.2 (2000): 977-998.

Impact of BRDF effects on reflectance

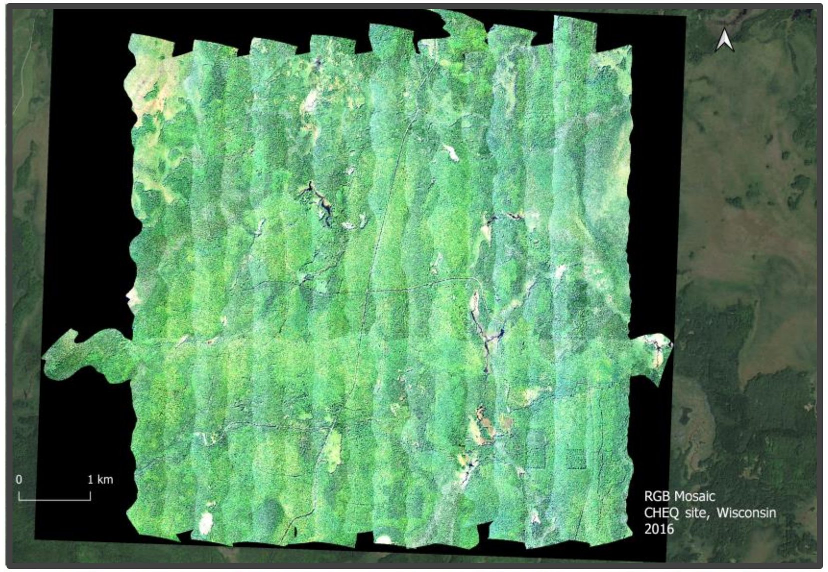
Within a flight line: Reflectance values decline slightly from left to right in the cross-track direction

Reflectance at Wavelength = 900 nm





Across flight lines: Discontinuity in brightness levels at flight line boundaries



Impact of BRDF effects on higher level products

Colgan, Matthew S., et al. "Mapping savanna tree species at ecosystem scales using support vector machine classification and BRDF correction on airborne hyperspectral and LiDAR data." *Remote Sensing* 4.11 (2012): 3462-3480.

Figure 6. Effect of view zenith angle on reflectance. Spectra shown are for an example tree (**a**) before and (**b**) after applying the BRDF model for four viewing geometries (legend indicates view zenith angle; solar zenith angle and relative azimuth angle were approximately constant).

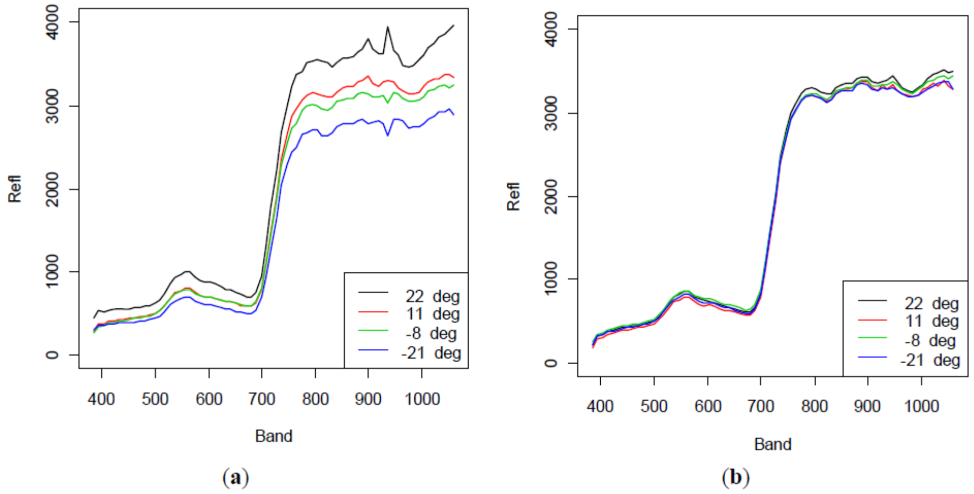
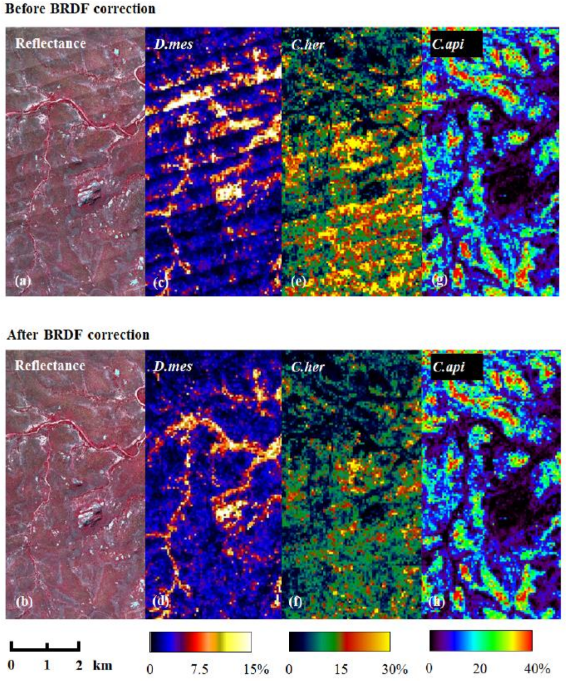


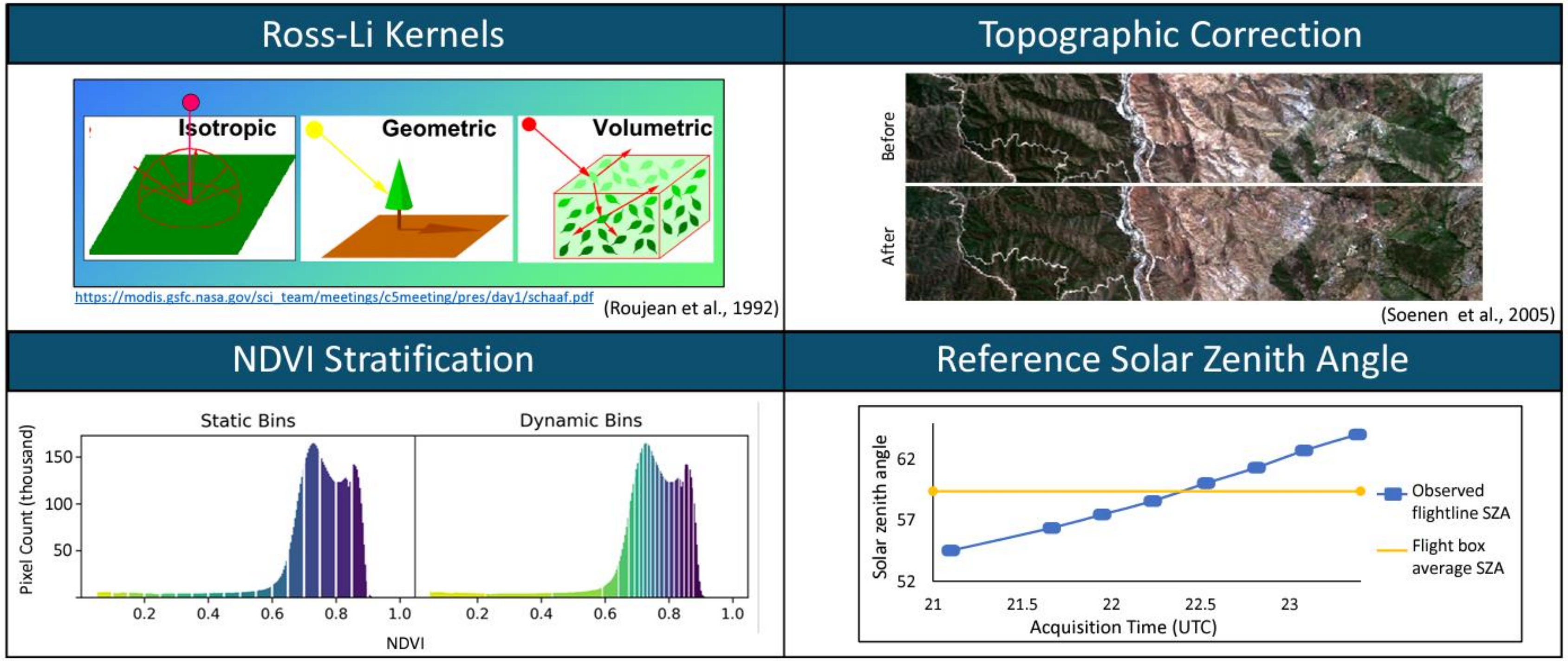
Figure 7. Effect of BRDF correction on species prediction probabilities. The test area spanned 16 flight lines and is the same across all panes. (**a**) False-color infrared of hyperspectral data before BRDF correction and (**b**) after BRDF correction. (**c–h**) Probability maps for several example species. Species with lower mean probabilities (e.g., *D.mes*, *C.her*) exhibited the largest reduction in flight line artifacts post-BRDF correction, whereas species with higher probabilities (e.g., *C.api*) typically had few or no artifacts before or after BRDF correction. These test maps were generated using SVM Model 1 (hyperspectral data only) to avoid confounding interpretation with additional LiDAR input.



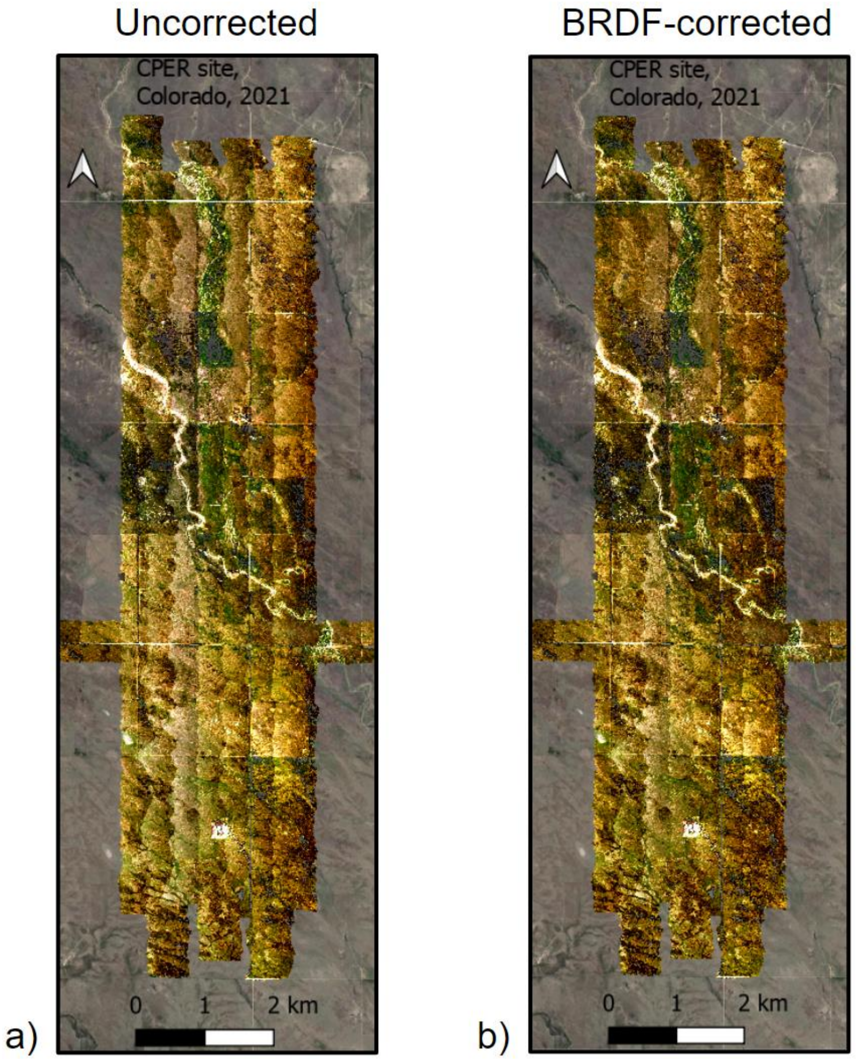
FlexBRDF for performing BRDF and topographic corrections

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.

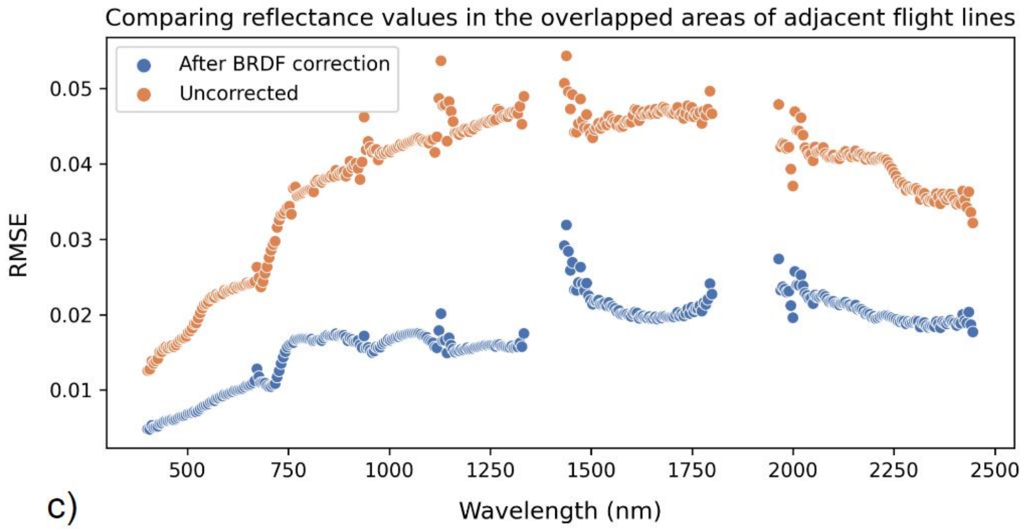
HyTools - open-source python package for implementing FlexBRDF https://github.com/EnSpec/hytools/tree/master/hytools



Evaluating BRDF-corrected reflectance



- Corrections tested at multiple sites
- Same parameter set to be used for all sites



Foliar Trait Products in Development - 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

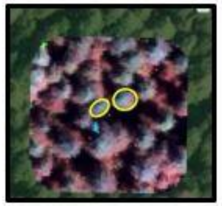
BRDF correction
Topographic correction
Wavelength resampling

Corrected reflectance

Select flight lines which are least cloud-affected

Extract AOP Data for Foliar Sampling Locations

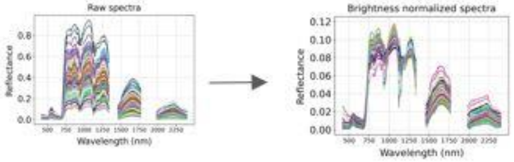
Woody individuals



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)

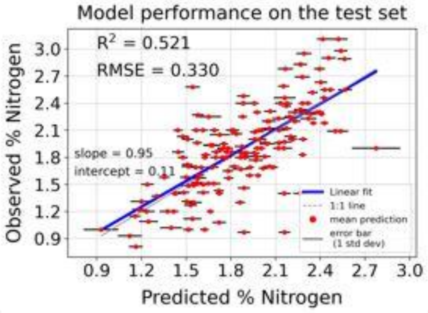
For the remaining 1m pixels within a crown, perform brightness normalization on the spectra to reduce the effect of internal canopy shadows



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

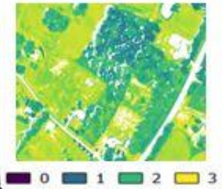
Model inputs: 331 hyperspectral bands

Partial Least Squares Regression (PLSR) modeling

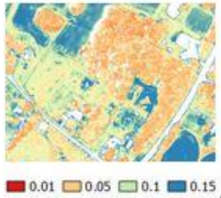


Map Foliar Traits and Characterize Uncertainty

Mean % N



Std dev % N



Preliminary Results

PLSR models trained on percent Nitrogen data collected for three NEON domains (D01, D02, and D07)