Controls of terrestrial photosynthetic seasonality: two aspects of leaf phenology and characterization approaches

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Global warming and land carbon uptake

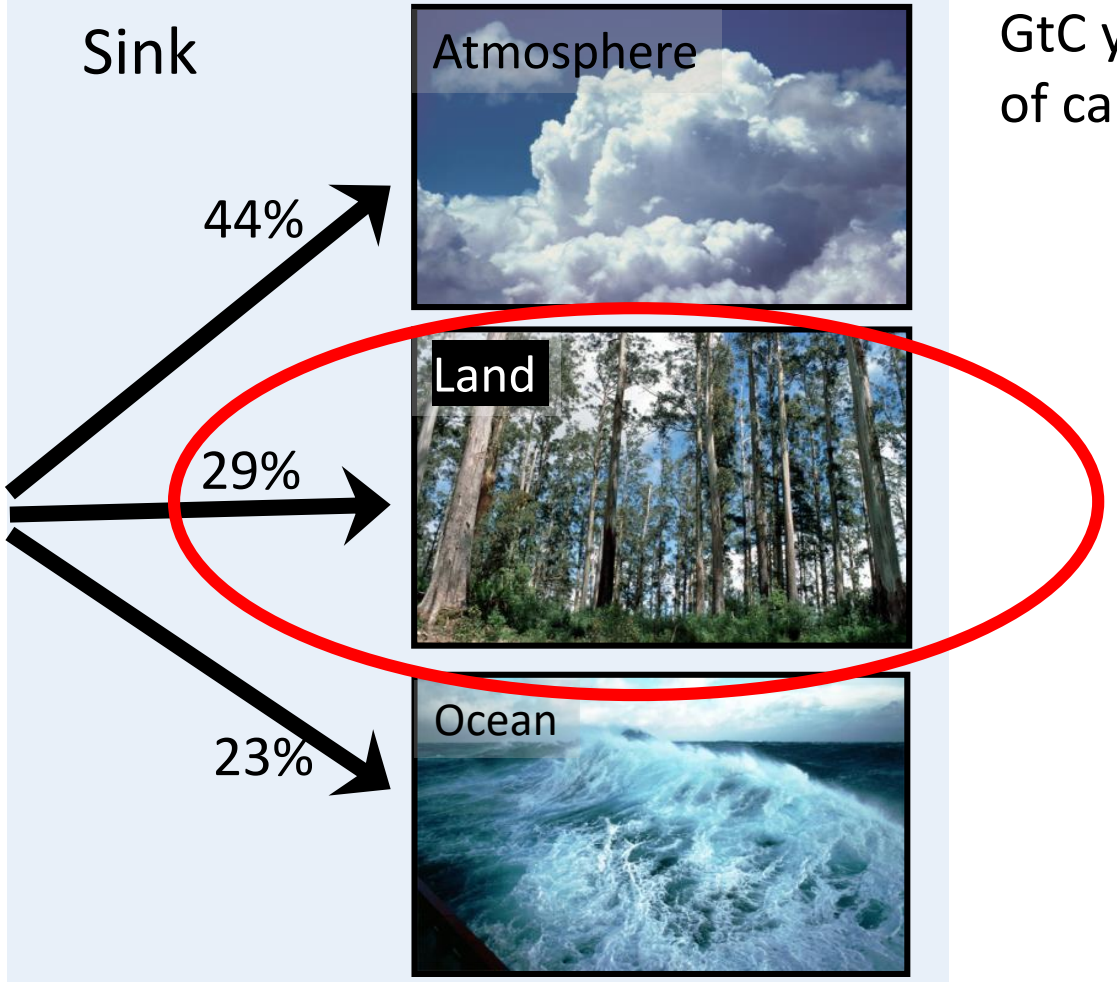
Global carbon budget (2009 – 2018)

Source: 10.96 GtC/yr

86%

14%

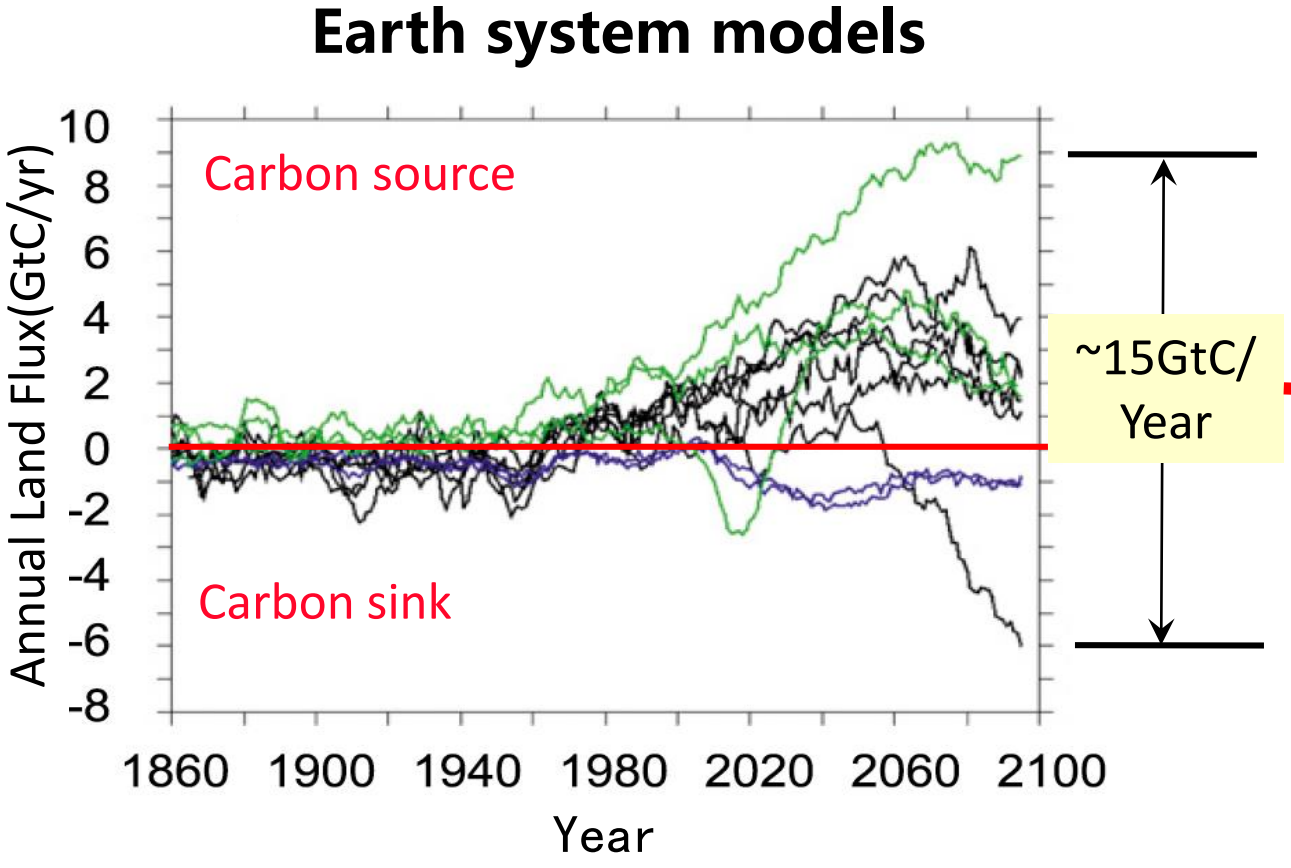
Sink



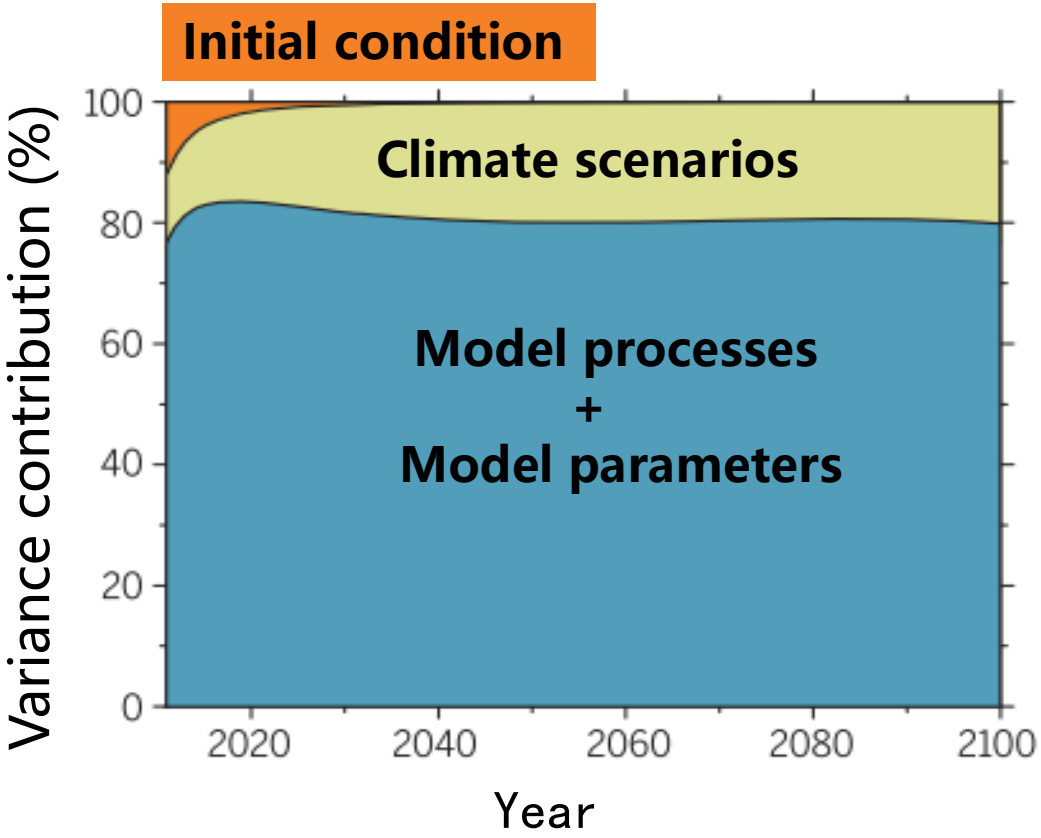
GtC yr^{-1}: Gigatons of carbon per year

Source: CDIAC; NOAA-ESRL; Global Carbon Budget 2018

Uncertainty in predicting land carbon uptake

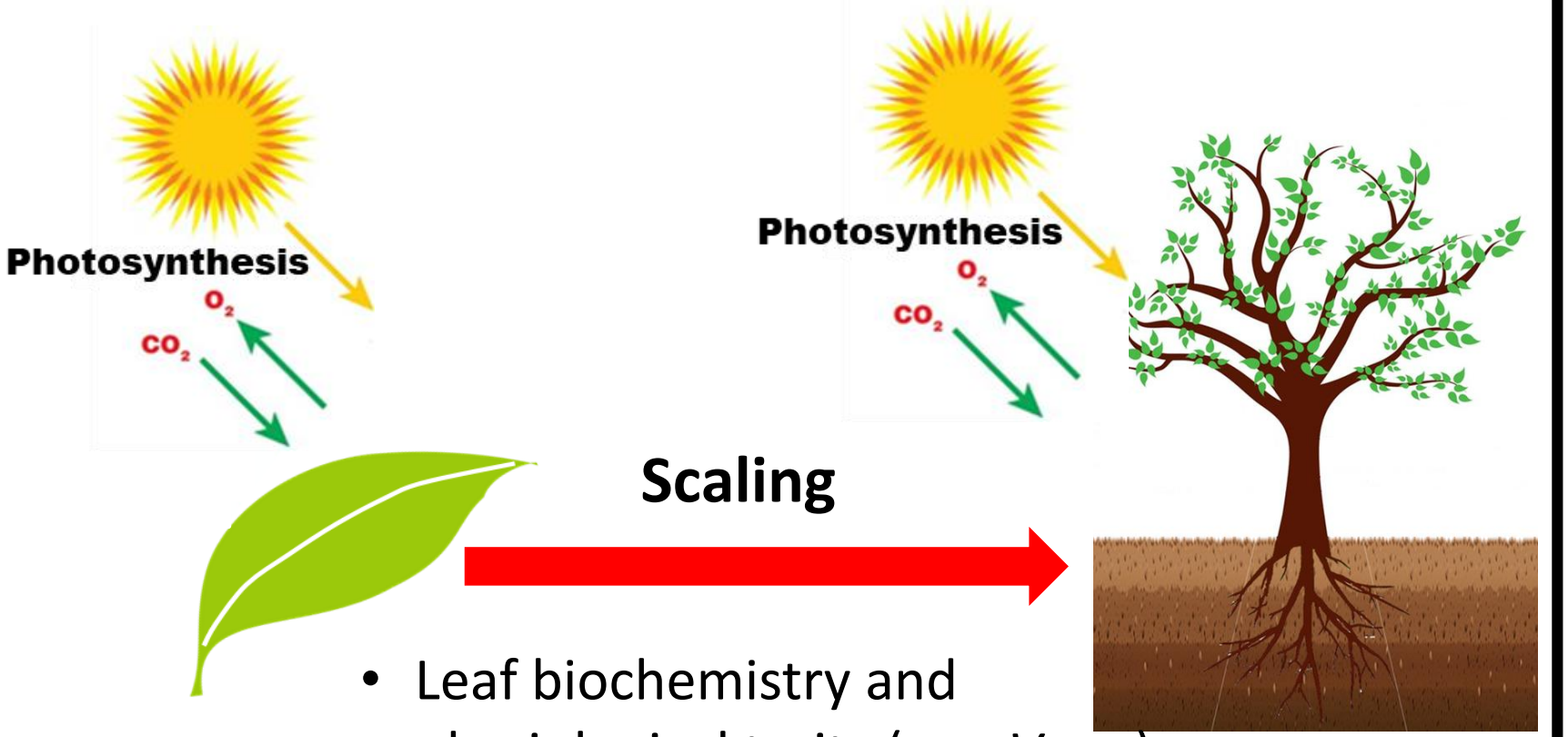


Friedlingstein *et al* (2014) *Journal of Climate*



Bonan & Doney (2018) *Science*

Photosynthesis: scaling processes and challenges



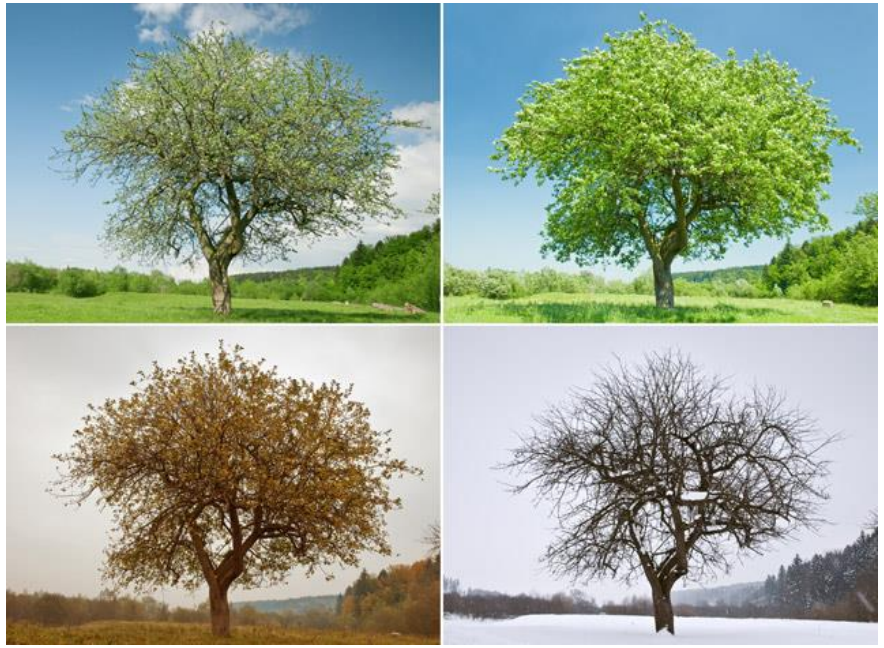
- Leaf biochemistry and physiological traits (e.g. $V_{c,max}$)
- Canopy structure (e.g. leaf area index, LAI)

Scaling

- **Time: Phenology**
- **Space: Plant Functional Type**

Phenology

Phenology is the study of **recurring plant** and animal **life history events** and how these are influenced by **seasonal and interannual variations** in environmental conditions.

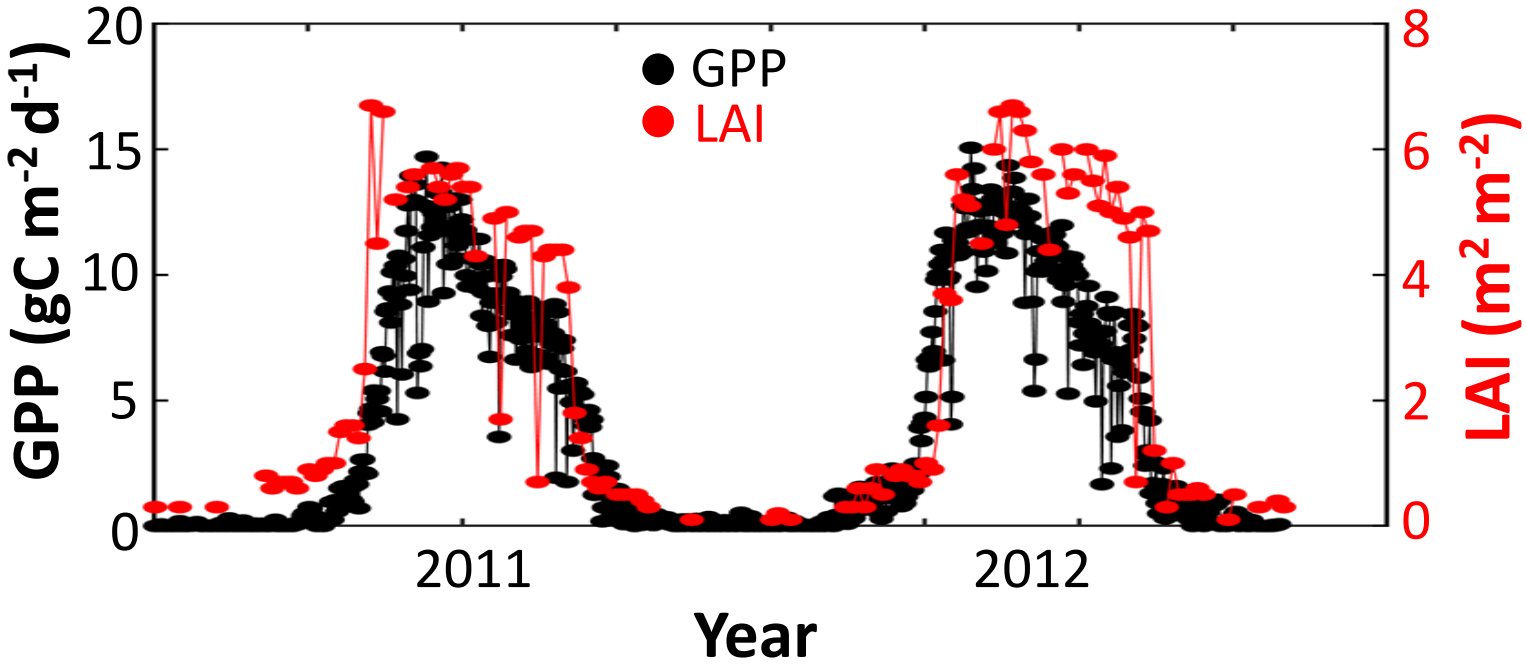


Phenology

Canopy structure
(e.g. Leaf area index, LAI)

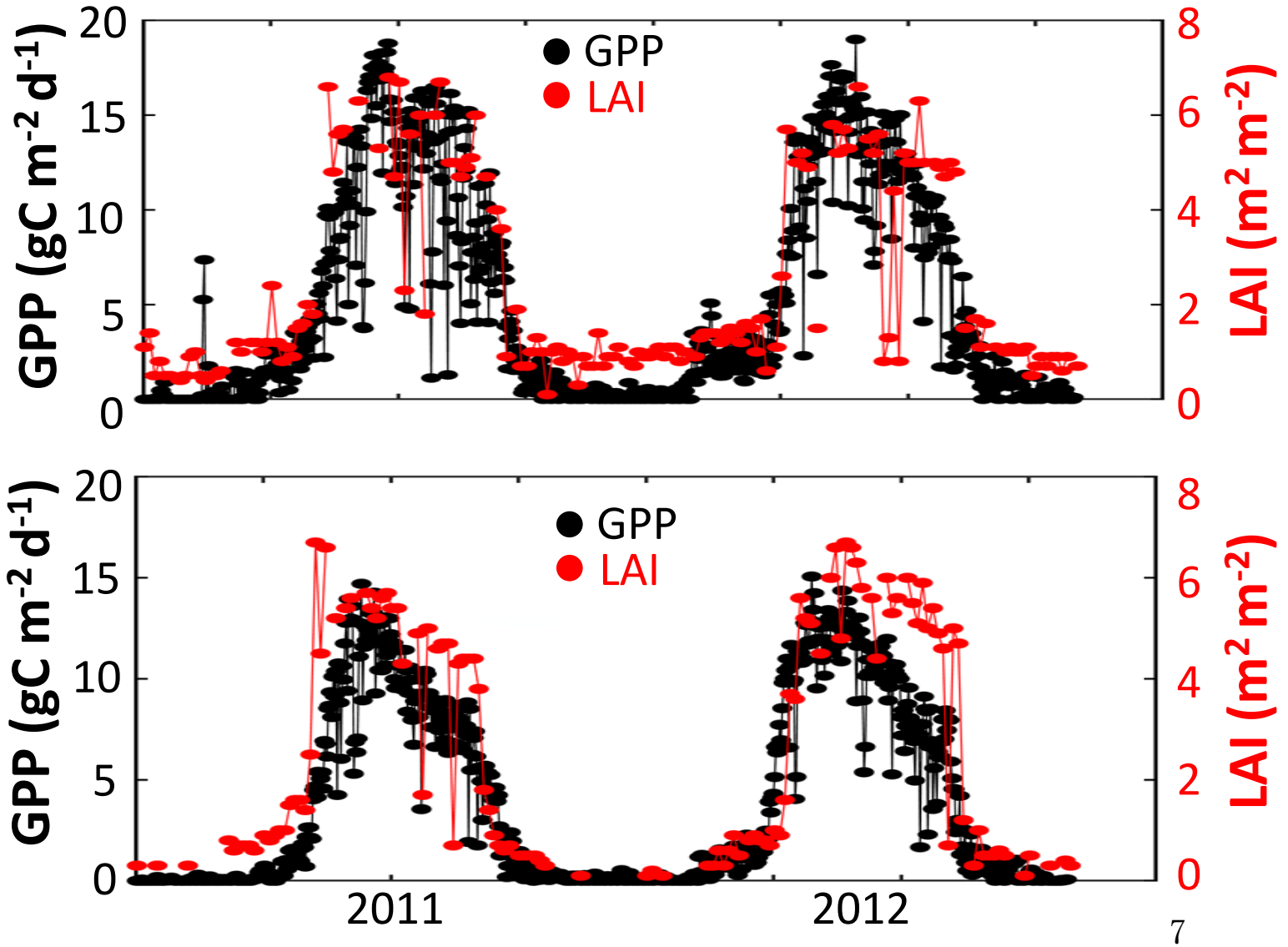
Leaf biochemistry

LAI phenology well tracks GPP seasonality



Source: FLUXNET2015, MOD15A3H

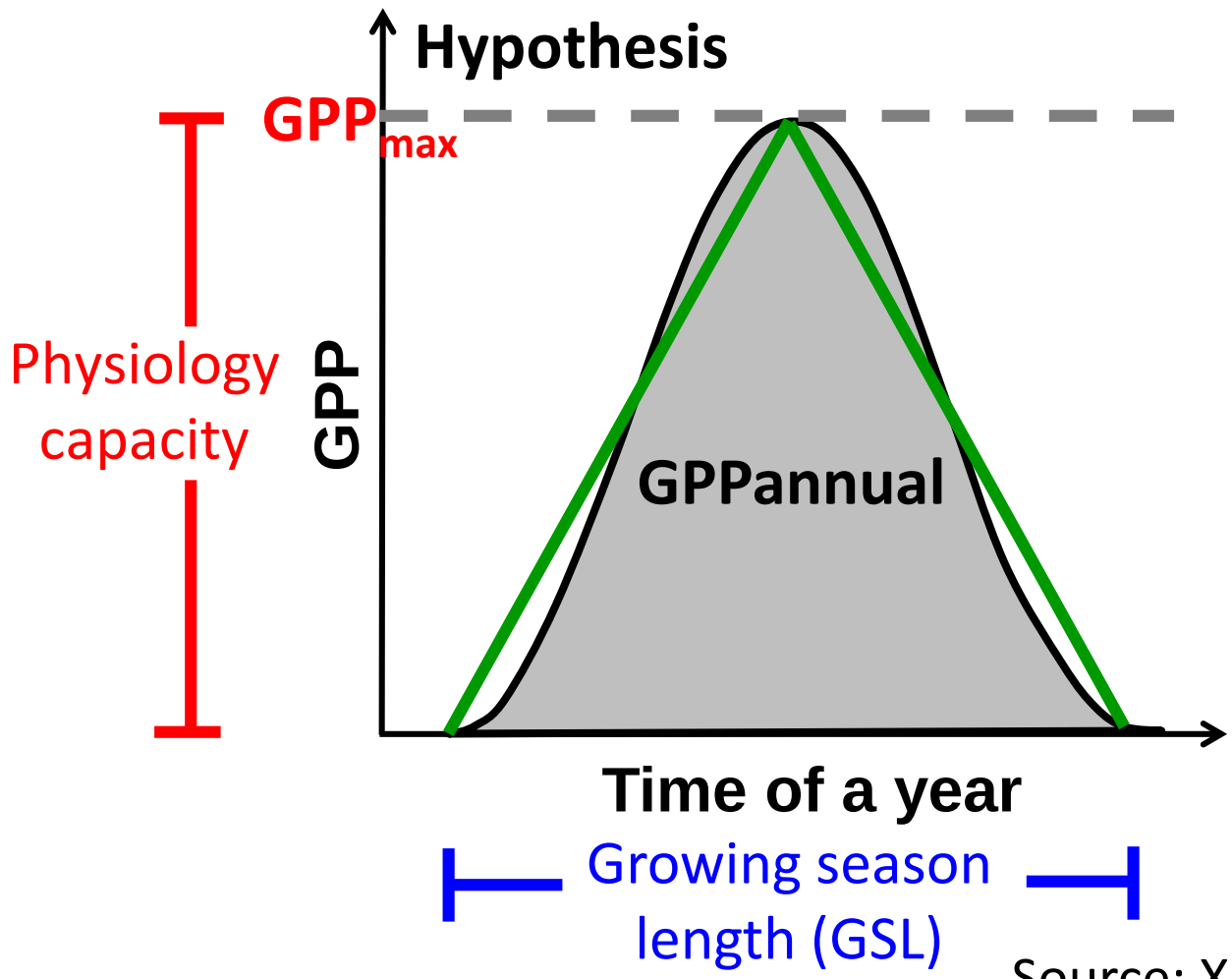
LAI phenology well tracks GPP seasonality

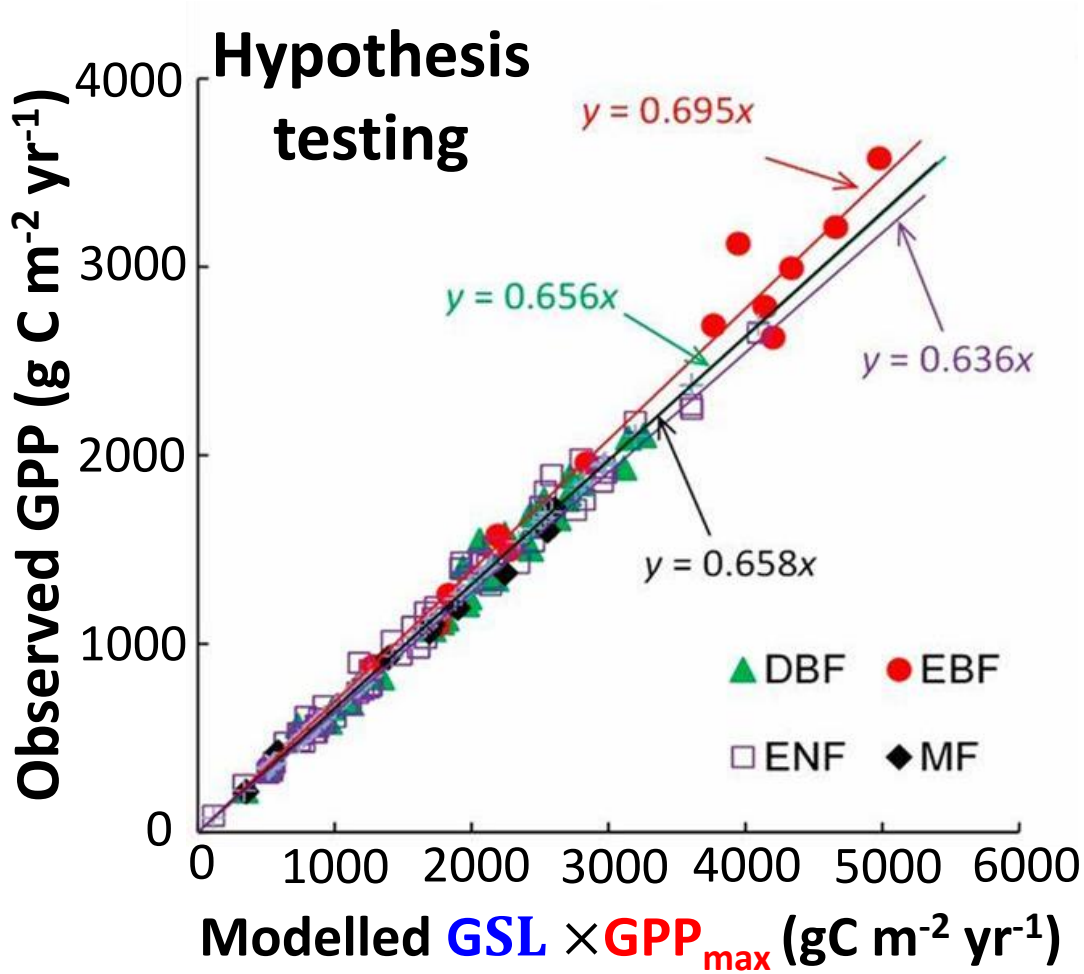


Source: FLUXNET2015, MOD15A3H

Phenology and physiology explains annual GPP

Terrestrial GPP is jointly controlled by plant phenology and physiology

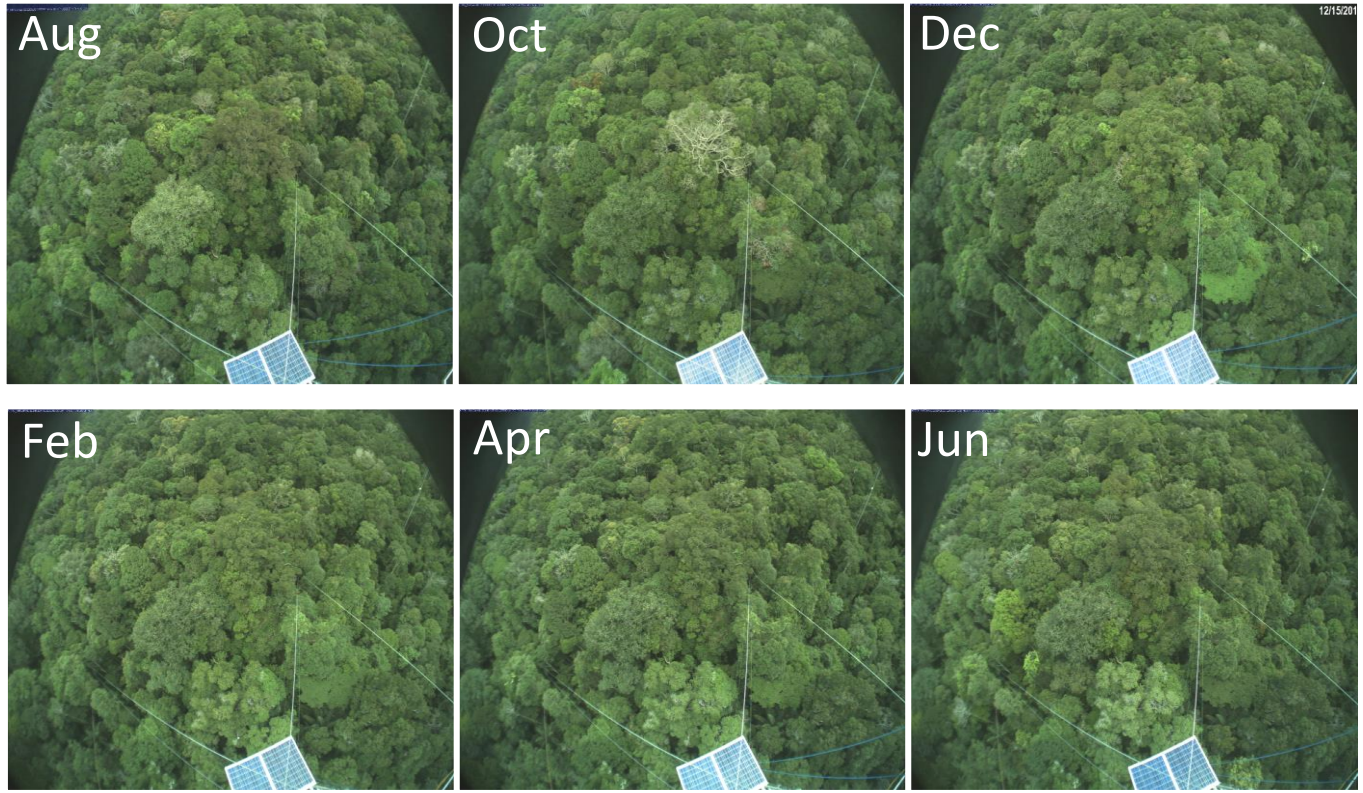




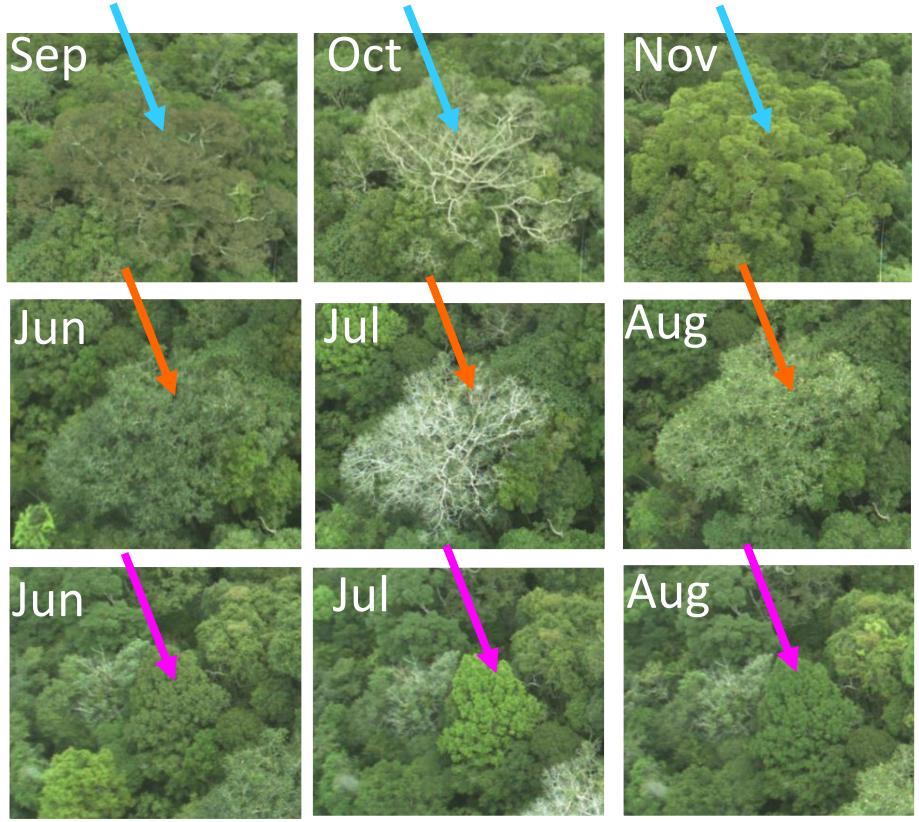
Source: Xia *et al* (2015) PNAS

Cryptic phenology in Amazonian tropical forests

Landscape evergreen



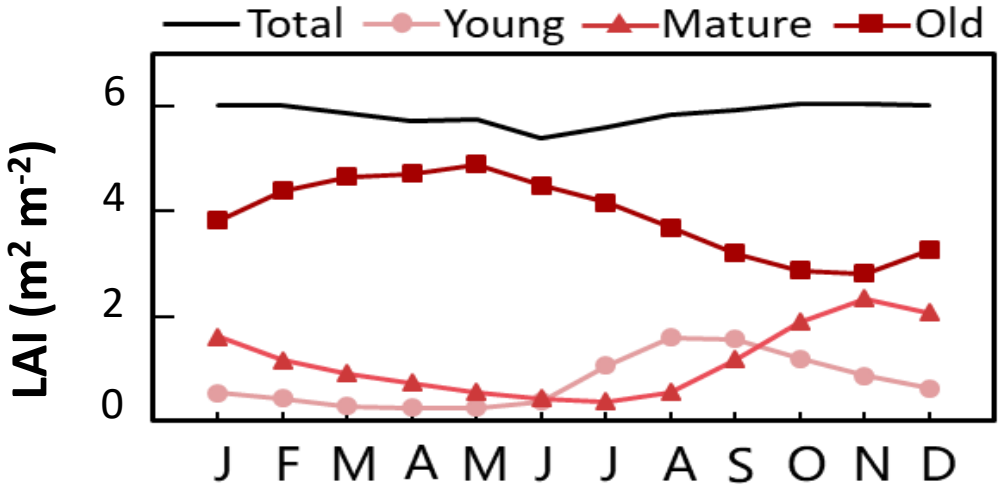
Individual dynamics



Source: Pheno-cam data (2013-2014) at a central Amazonian rainforest, Credit: Bruce Nelson

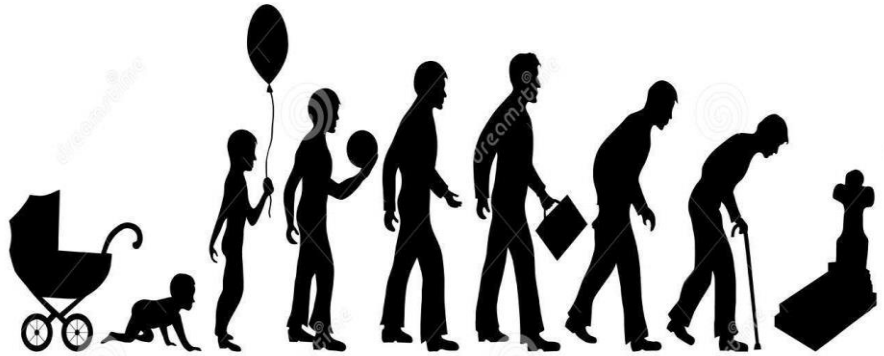
Leaf age phenology explains GPP seasonality

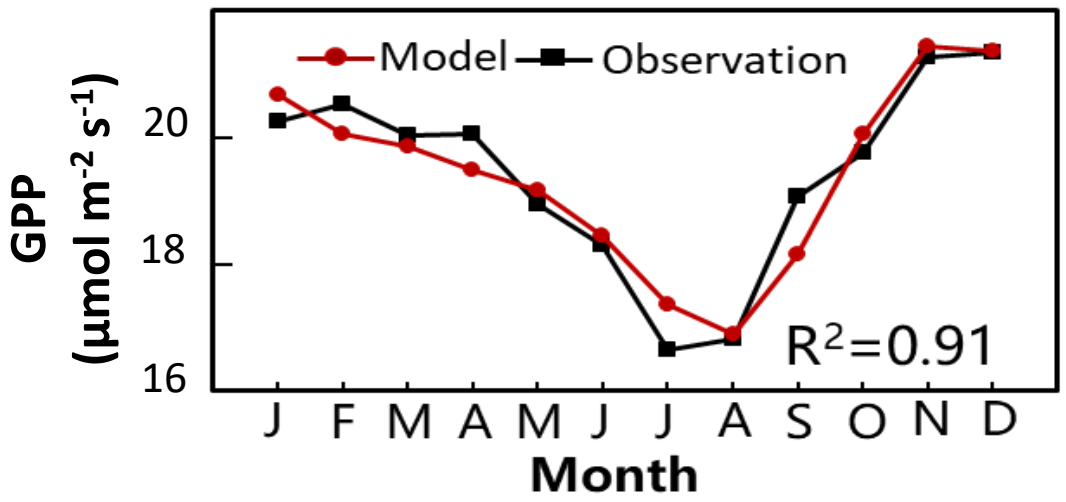
Phenology of leaf age and age-dependent $V_{c,max}$ drives tropical GPP seasonality

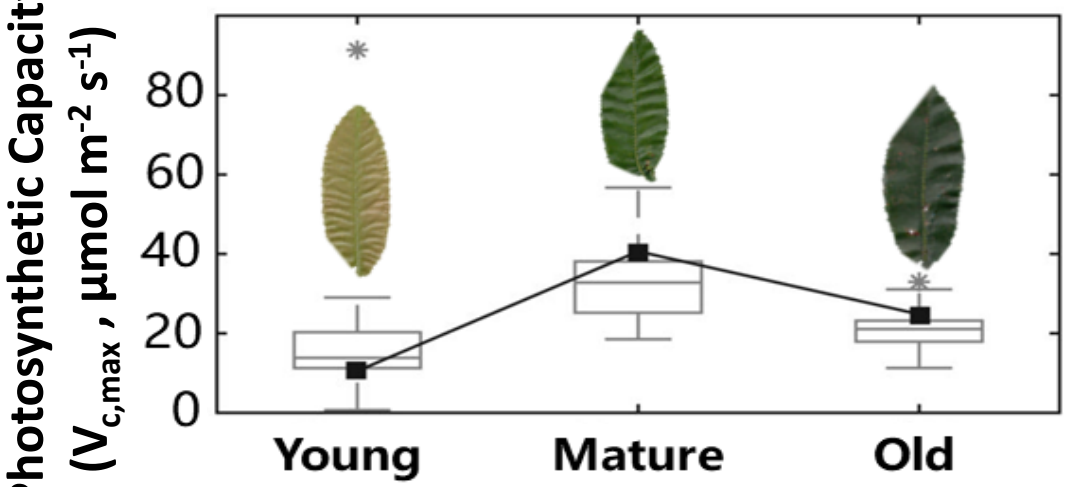


leaf quantity

leaf quality



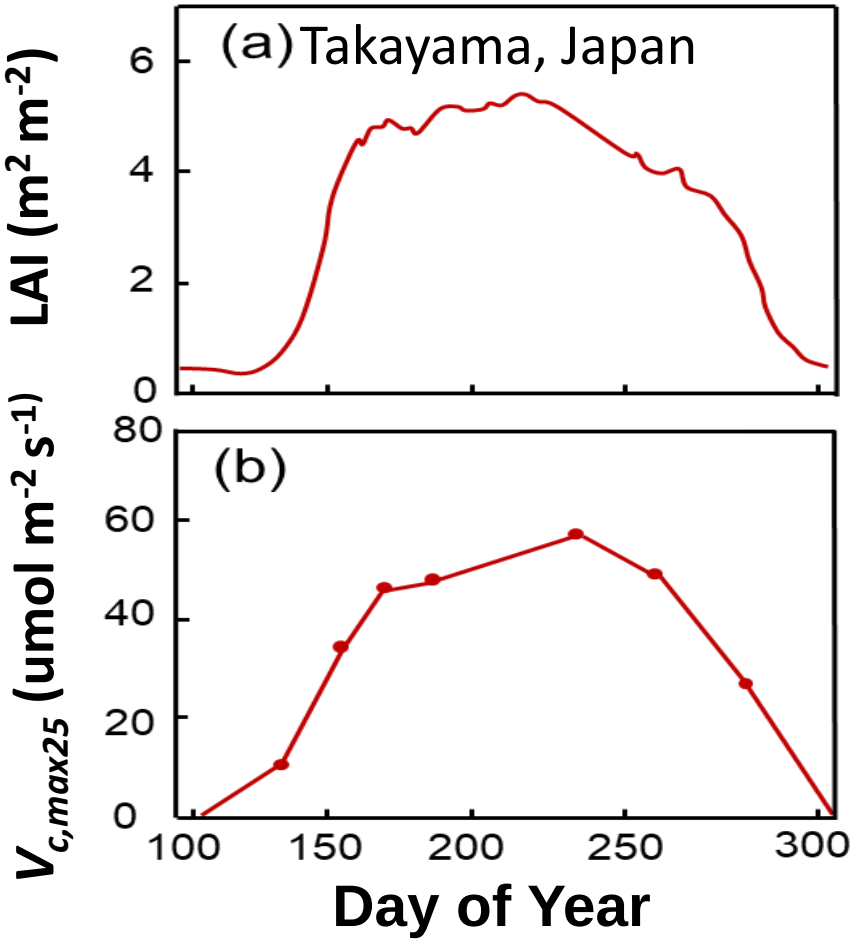




Wu *et al* (2016) *Science*

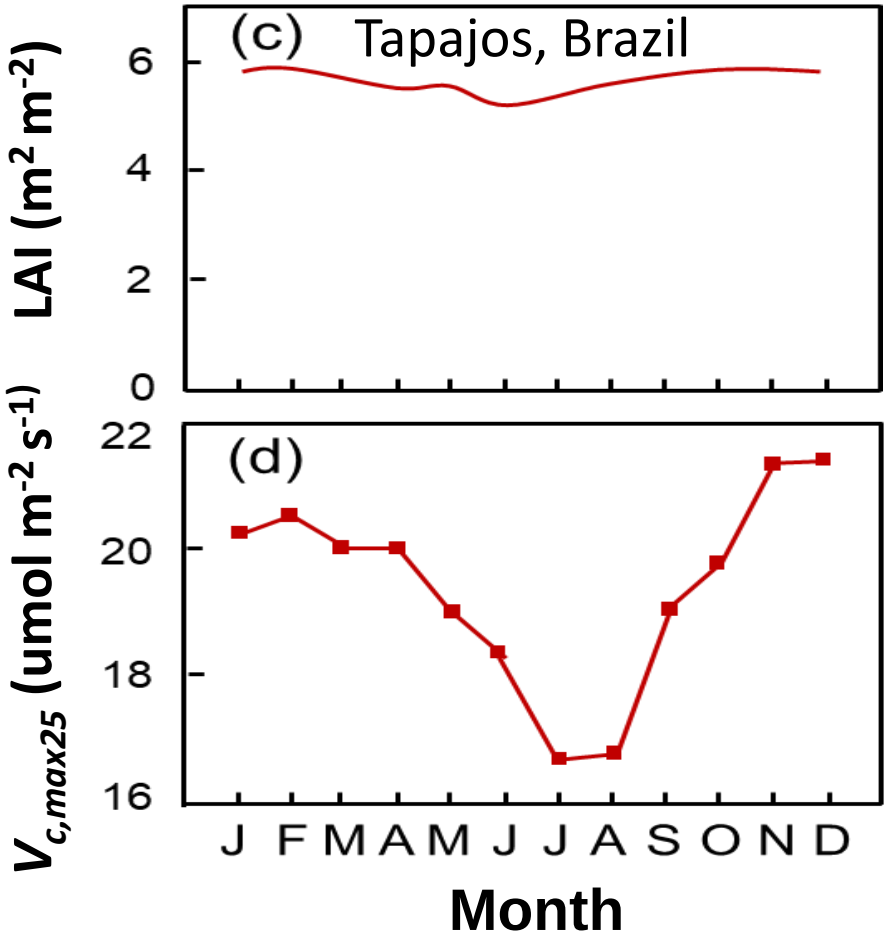
Two aspects of leaf phenology

Temperate Deciduous Forest



Muraoka *et al* (2010) *Journal of Plant Research*

Tropical Evergreen Forest



Wu *et al* (2016) *Science*

If fine-scale variabilities (phenology of leaf quantity and quality) are important for understanding larger-scale ecological processes, can we monitor them from remote sensing?

Potential solutions

- **High resolution satellite images for fine-scale plant phenology monitoring**

- **Vegetation spectroscopy for characterizing temporal and spatial variability in plant traits**

Observational dilemma for plant phenology

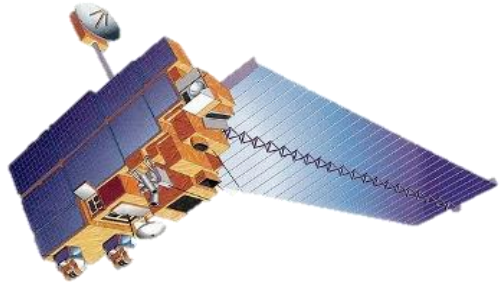
Ground & Proximate measurements

Ground

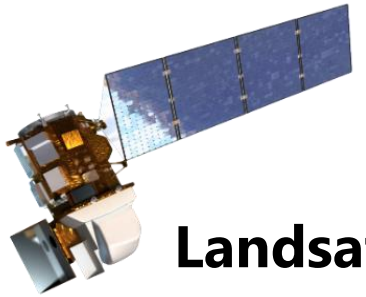
PhenoCam

Drone

Satellite observations



MODIS

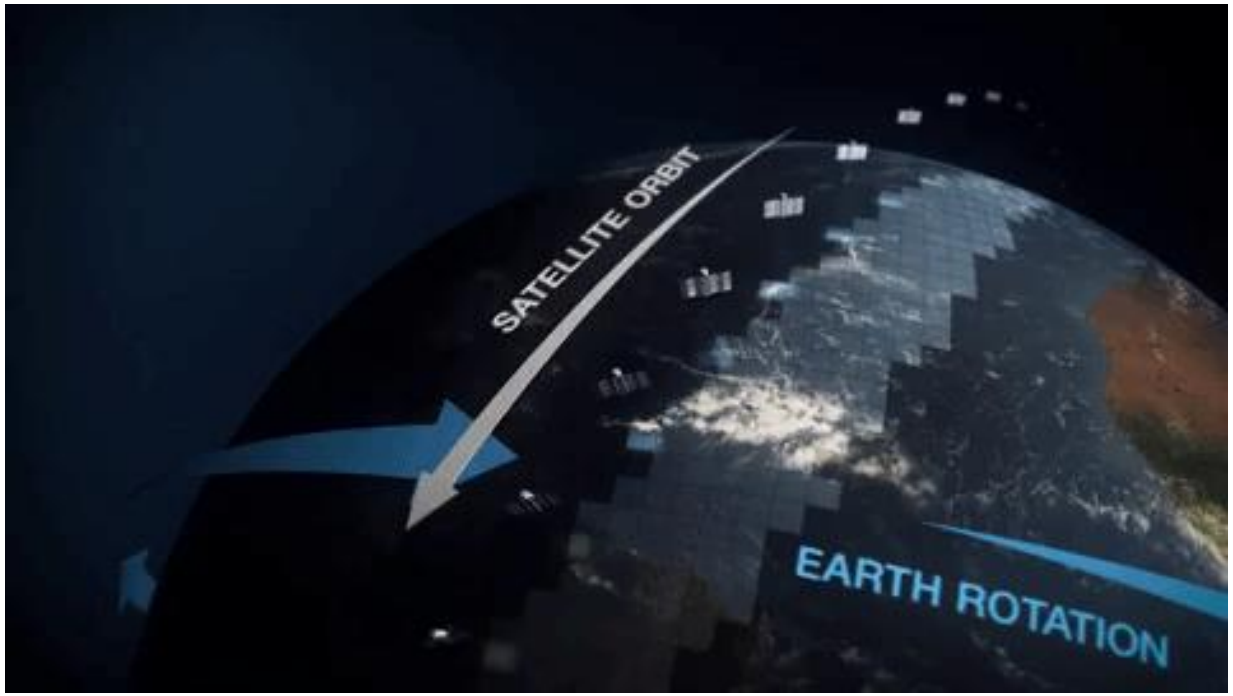


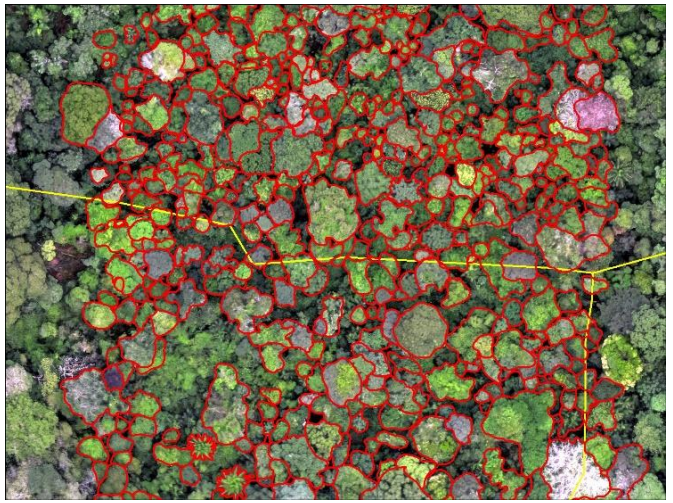
Landsat

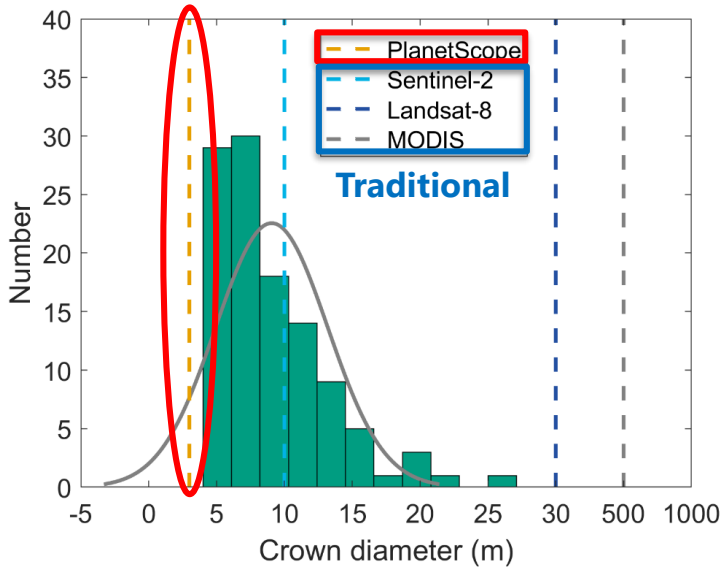
Sentinel-2

- Enable **individual-scale** phenology monitoring but with **limited coverage**.
- Allow for **large coverage** but limited at the **ecosystem-scale**.

Observational opportunity: PlanetScope







PlanetScope

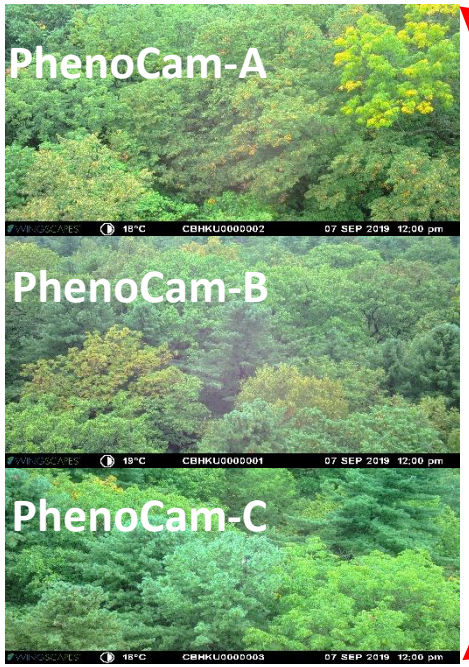
Composited by 190+ micro-satellites

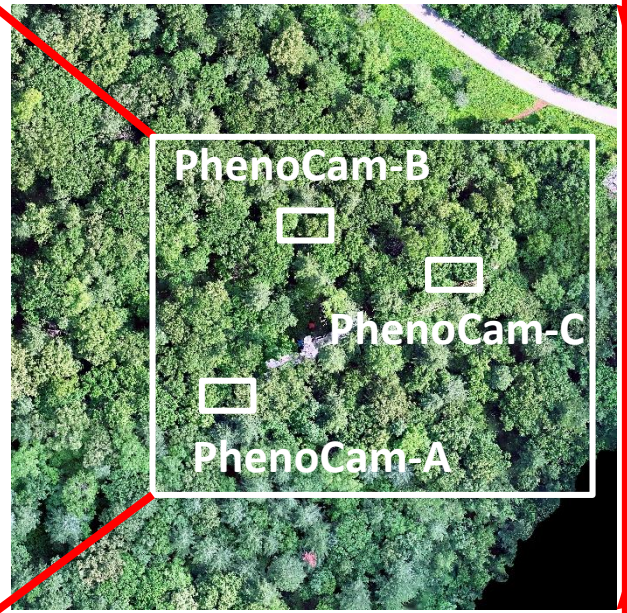
- 3m
- Near daily
- 2018-present

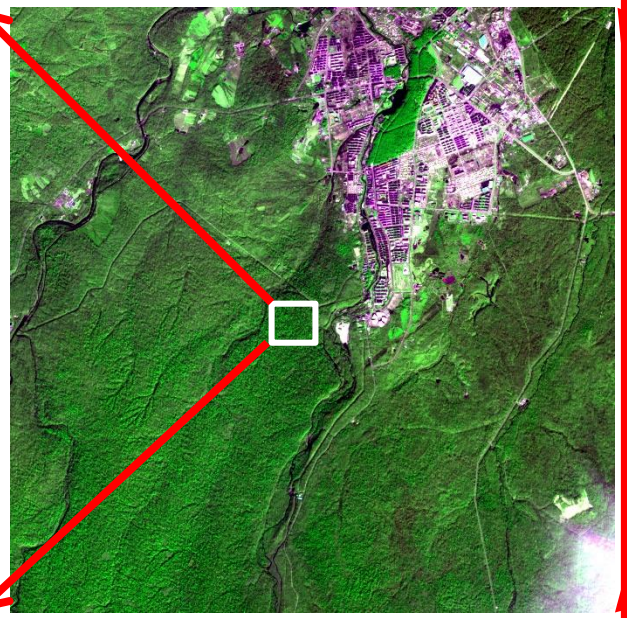
A New Opportunity

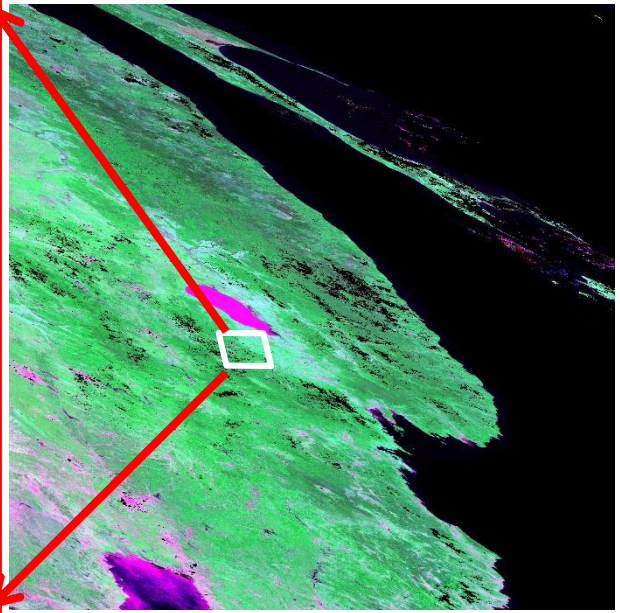
Multi-scale approaches for leaf phenology

Example site: Mt. Changbai canopy crane site in Northern China









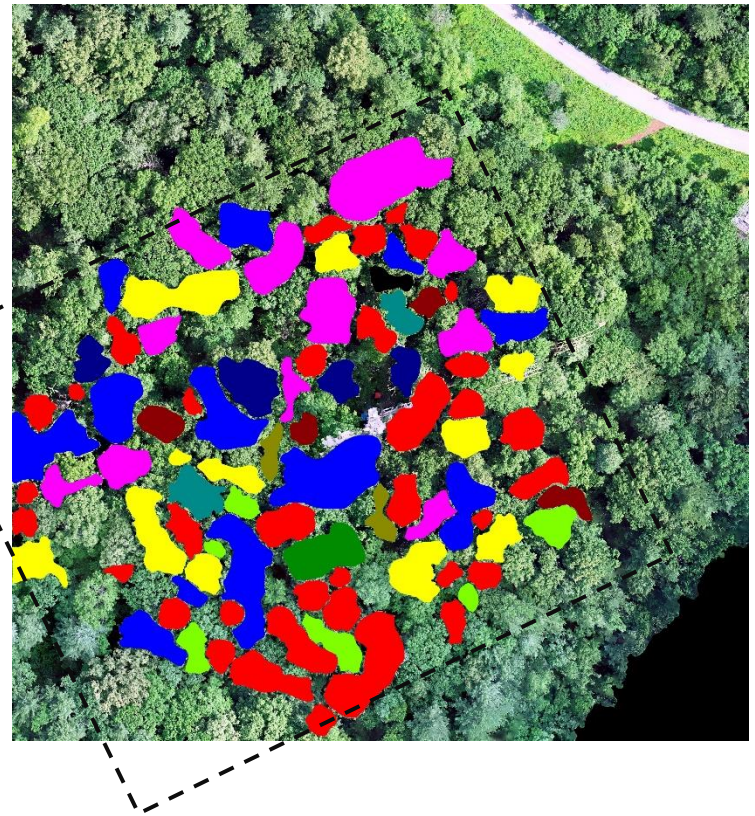
PhenoCam
(<0.01m)
limited in spatial coverage

Drone
(0.01m)
limited in site/ time

PlanetScope
(3m, daily)
2018 - present

MODIS
(500m, daily)
2000 - present

Individual tree delineation



PK FM TA AM
JM UL QM TM
PA UD BP Study area

Pinus Koraiensis (红松)

Fraxinus Mandshurica (水曲柳)

Tilia Amurensis (紫椴)

Acer Mono (色木槭)

Juglans Mandshurica (核桃楸)

Quercus Mongolica (蒙古栎)

Tilia Mandshurica (糠椴)

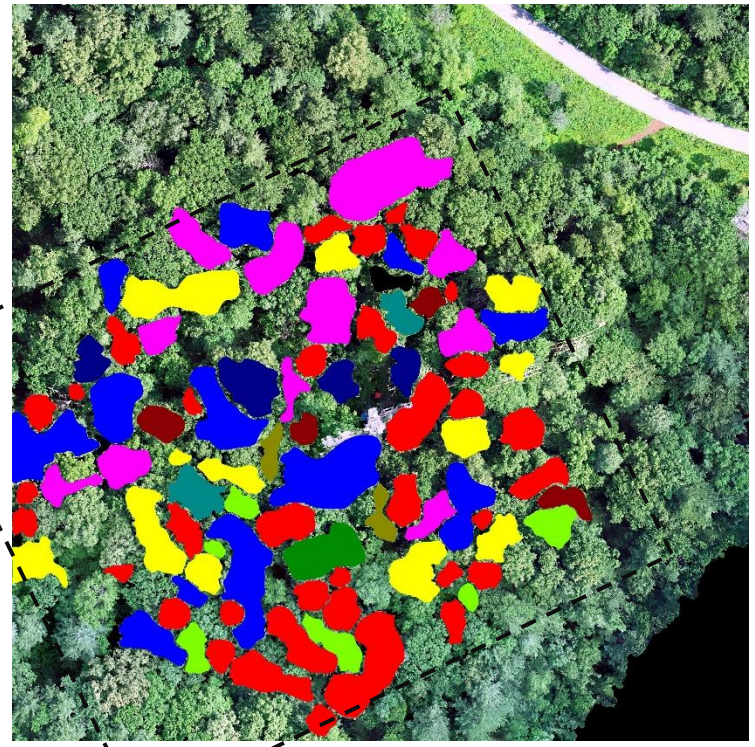
Phellodendron Amurense (黄檗)

Ulmus Davidiana (春榆)

Betula Platyphylla (白桦)

Ulmus Laciniata (裂叶榆)

Crown-scale autumn leaf phenology



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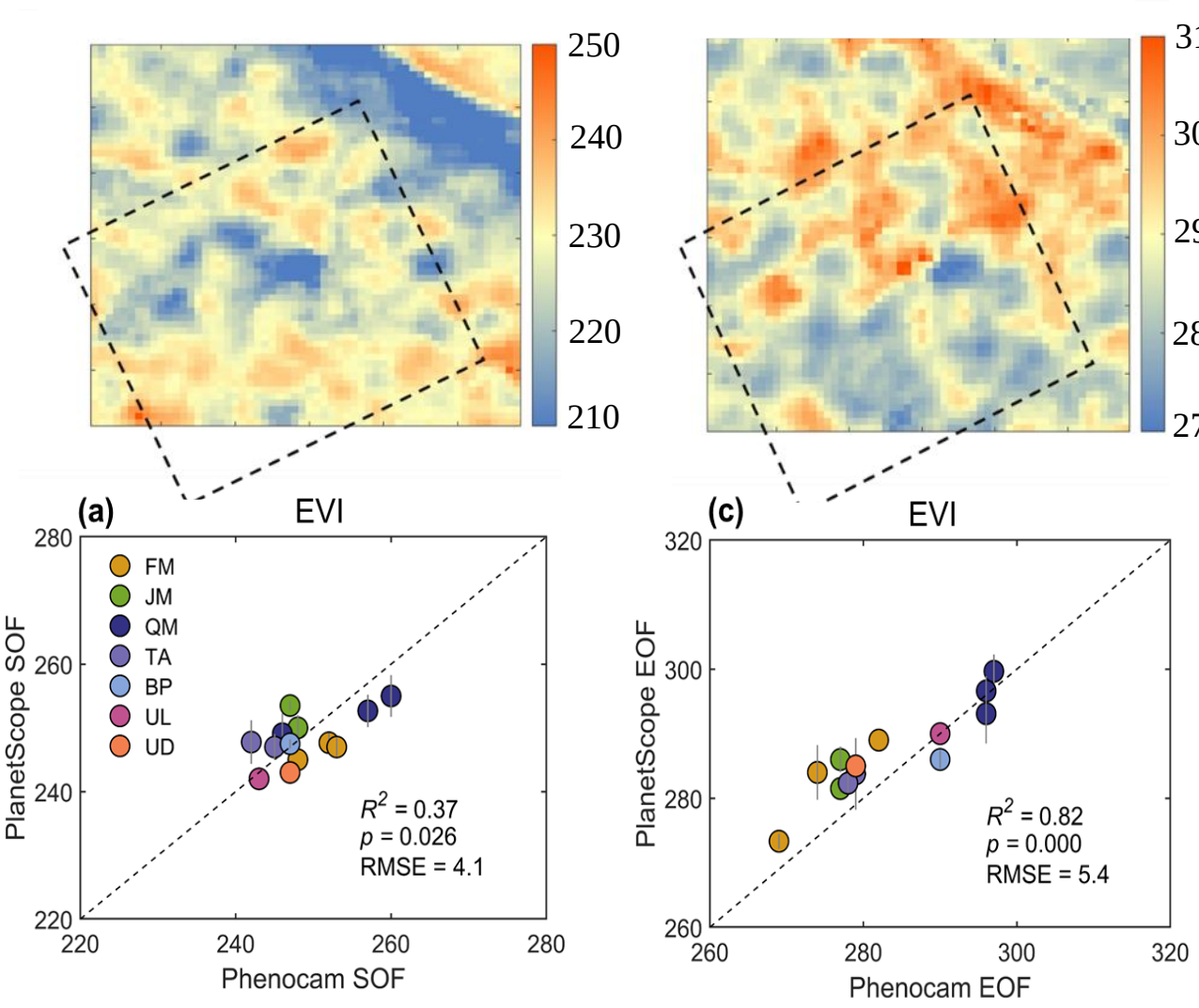


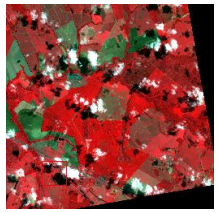
Wu *et al* (2021) *ISPRS Journal of Photogrammetry and Remote Sensing*

Technical issues of PlanetScope and solutions

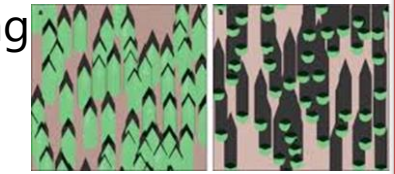
Satellite Measurements

Artifacts

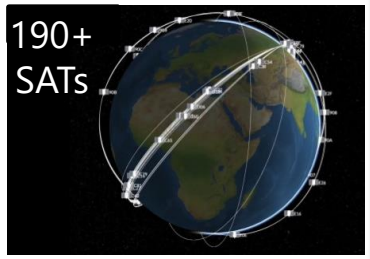
Cloud and shadow effects



Sensor viewing geometry effects



Cross-sensor DN-scaling inconsistency



Biophysics

Canopy structure

Leaf biochemistry

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Postdoctoral Researcher,
University of Hong Kong

Remote Sensing of Environment
Volume 246, 1 September 2020, 111865

Cross-sensor calibration

Multi-scale integration of satellite remote sensing improves characterization of dry-season green-up in an Amazon tropical evergreen forest

Jing Wang [a], Dedi Yang [b], Matteo Detto [c], Bruce W. Nelson [d], Min Chen [e], Kaiyu Guan [f], Shengbiao Wu [a], Zhengbing Yan [a], Jin Wu [a]

Remote Sensing of Environment
Volume 264, October 2021, 112604

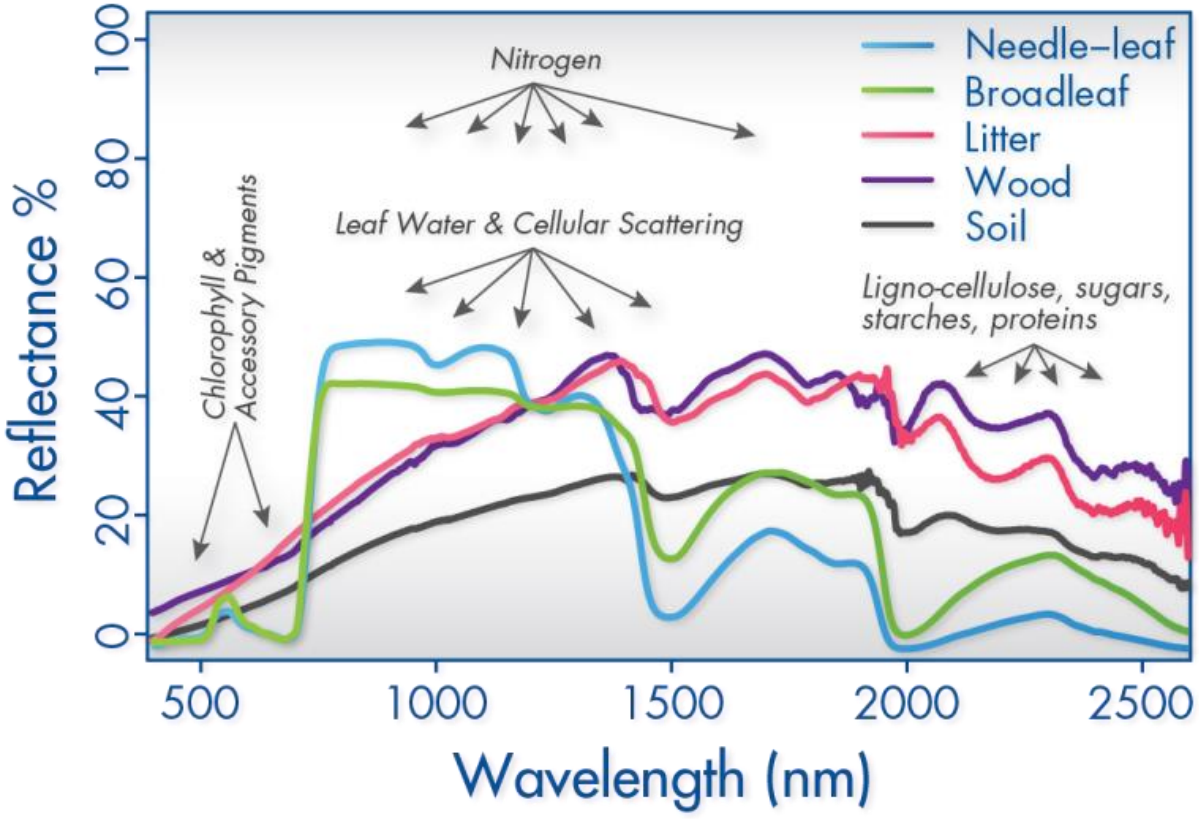
Automatic cloud/shadow screening

Automatic cloud and cloud shadow detection in tropical areas for PlanetScope satellite images

Jing Wang [a], Dedi Yang [b], Shuli Chen [c], Xiaolin Zhu [d], Shengbiao Wu [a], Marc Bogonovich [a], Zhengfei Guo [a], Zhe Zhu [e], Jin Wu [a]

Vegetation spectroscopy

- Spectroscopic (“hyperspectral”) remote sensing
  - All materials interact with light energy in different and characteristic ways
  - Utilizes spectrometers to characterize light in narrow wavebands reflected from or transmitted through plants and other materials
  - Infers key plant functional traits from hyperspectral data acquired

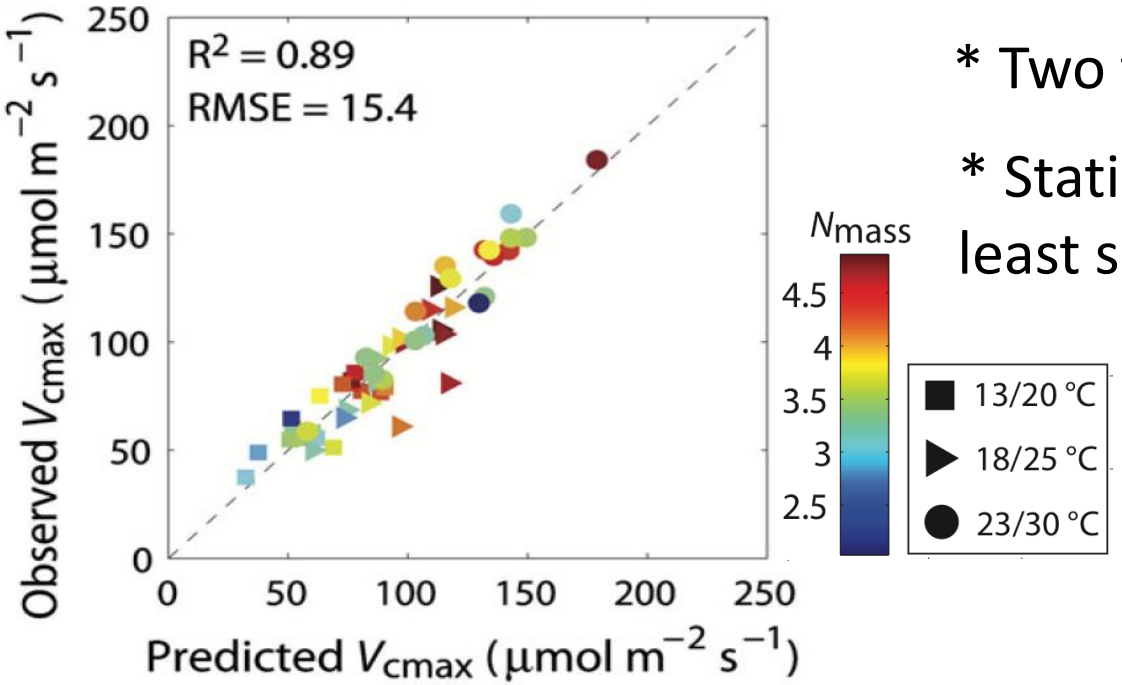


Cavender-Bares *et al* (2020) *Remote Sensing of Plant Biodiversity*; Credit to Shawn Serbin

Spectroscopy approach for photosynthetic capacity

Pioneering work from Dr. Shawn Serbin

Shawn Serbin, Staff Scientist,
Brookhaven National Laboratory



* Two temperate species

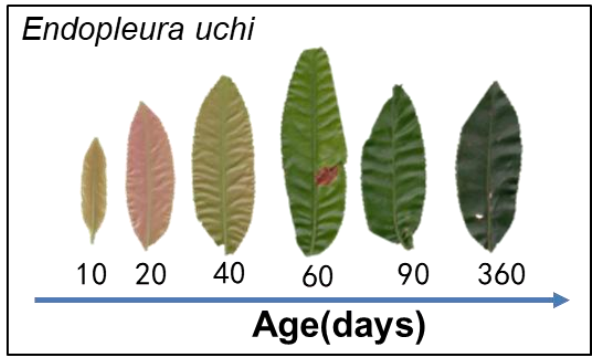
* Statistical modelling: partial least square regression (PLSR)

Whether the apporach can be generalizable across more species, forest sites, and leaf age is still unknown.

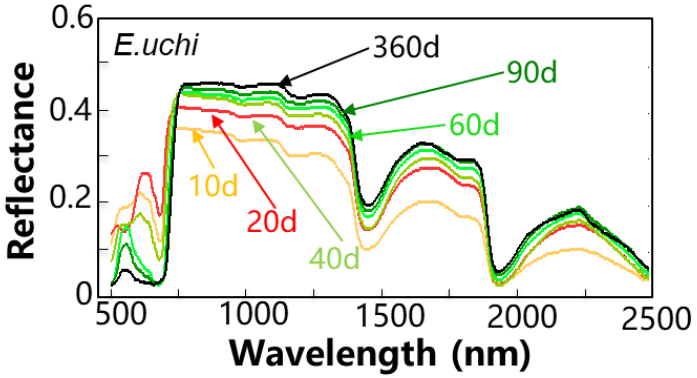
Serbin *et al* (2012) *Journal of Experimental Botany*

Temporal generalizability issues

(a) Example species in Amazon

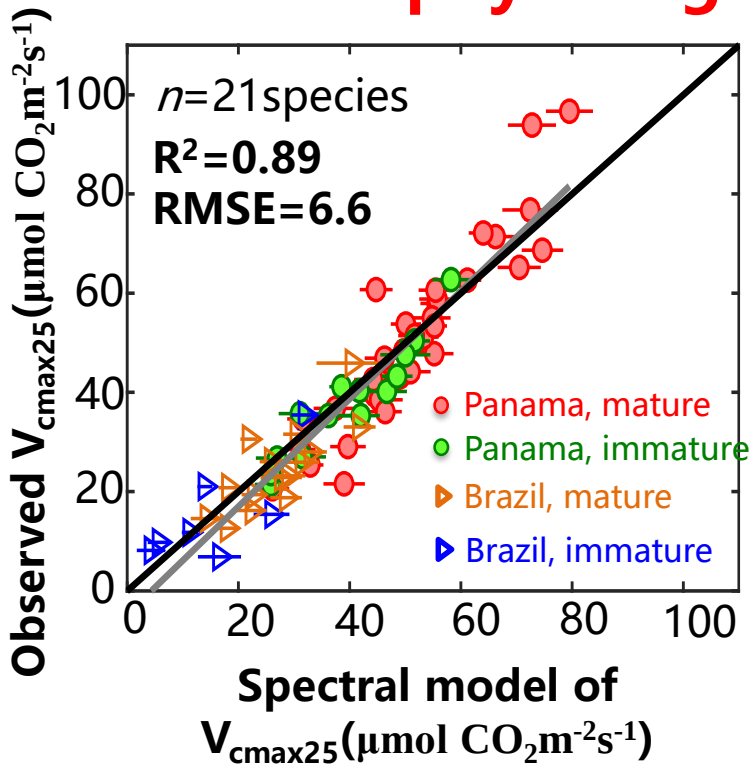


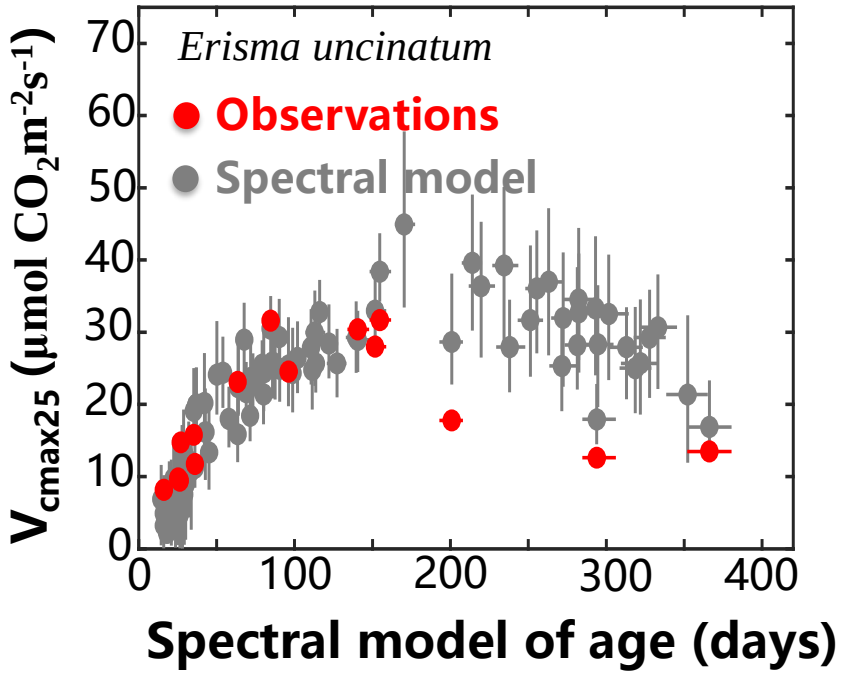
(b) Leaf spectra change with leaf age



Wu *et al* (2017) *New Phytologist*

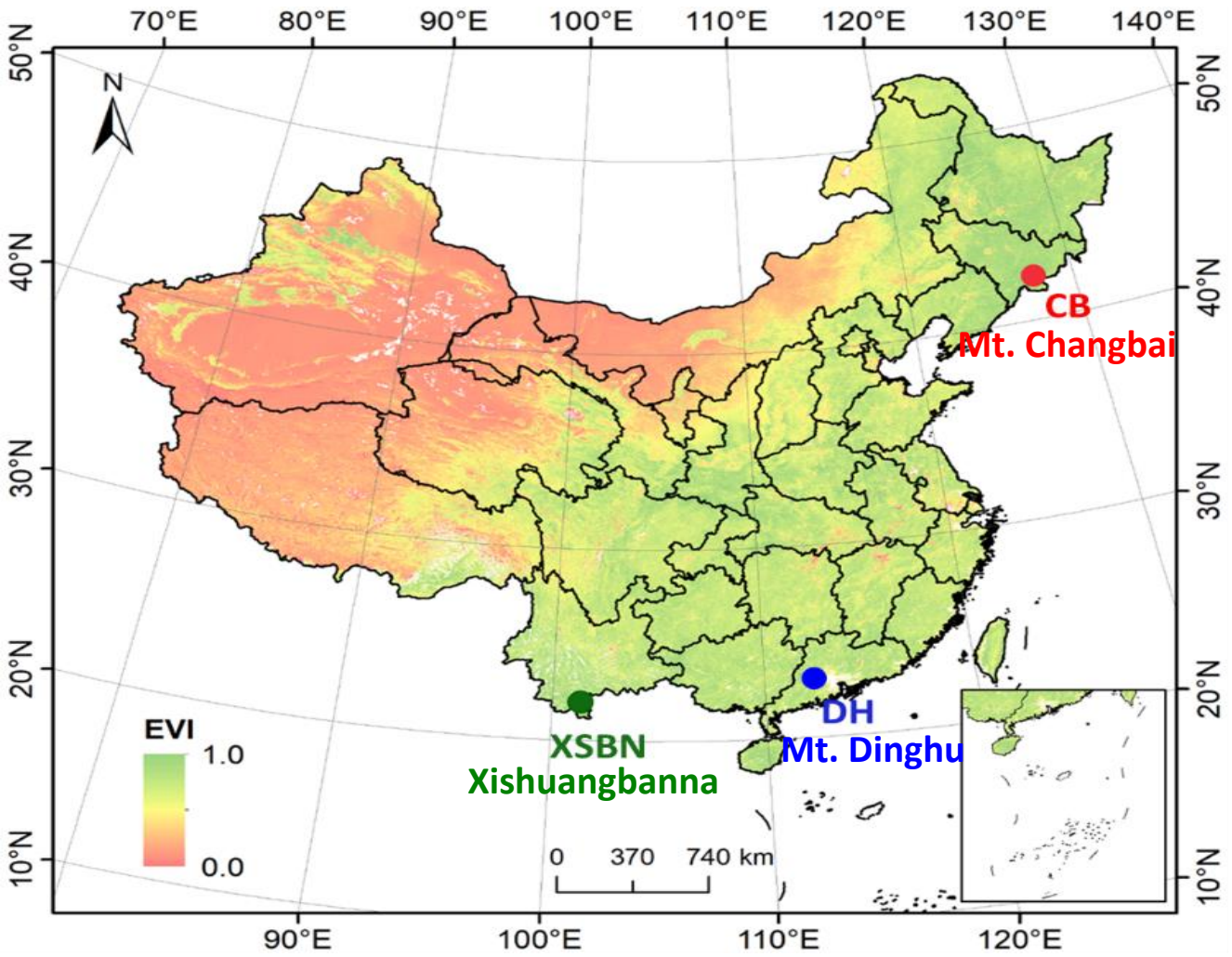
Seasonal convergence in spectra-physiological trait relationship





Wu *et al* (2019) *New Phytologist*

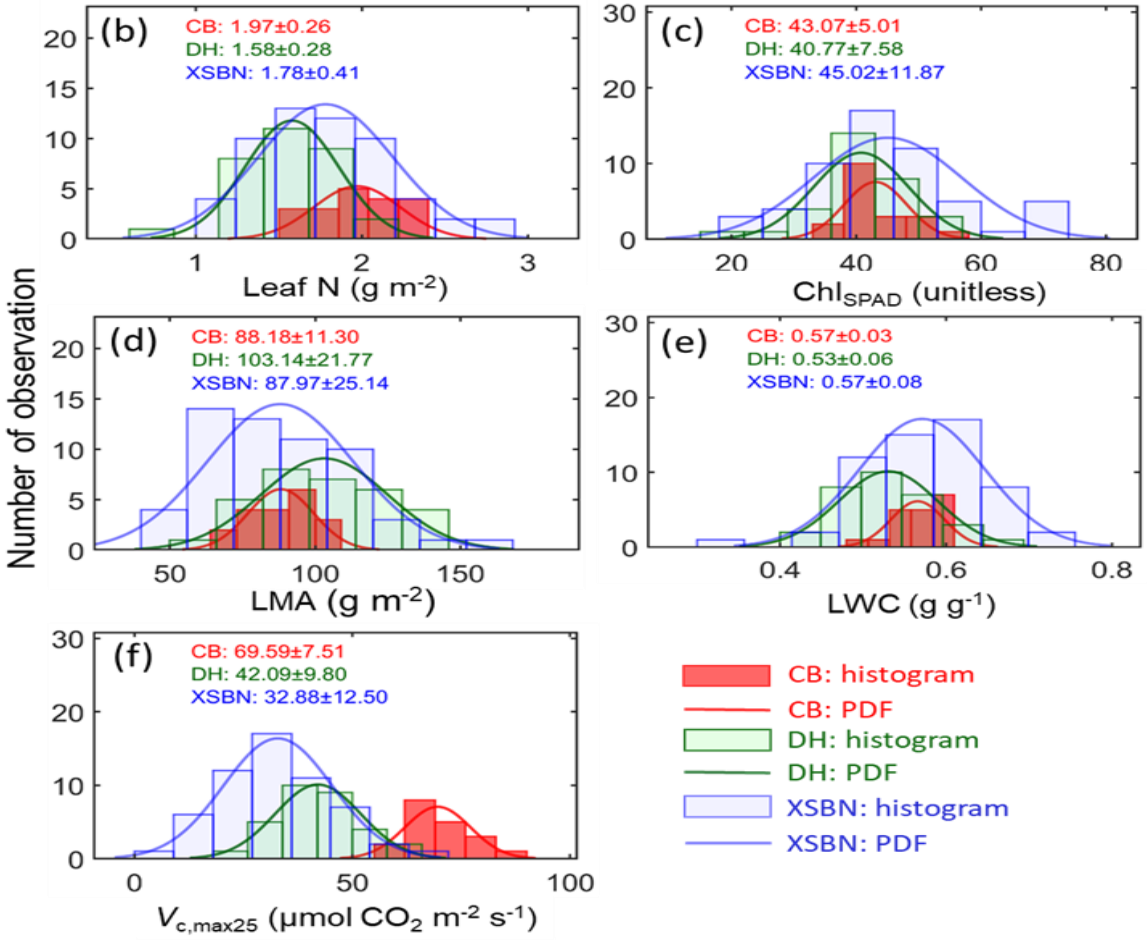
Cross-biome generalizability issue



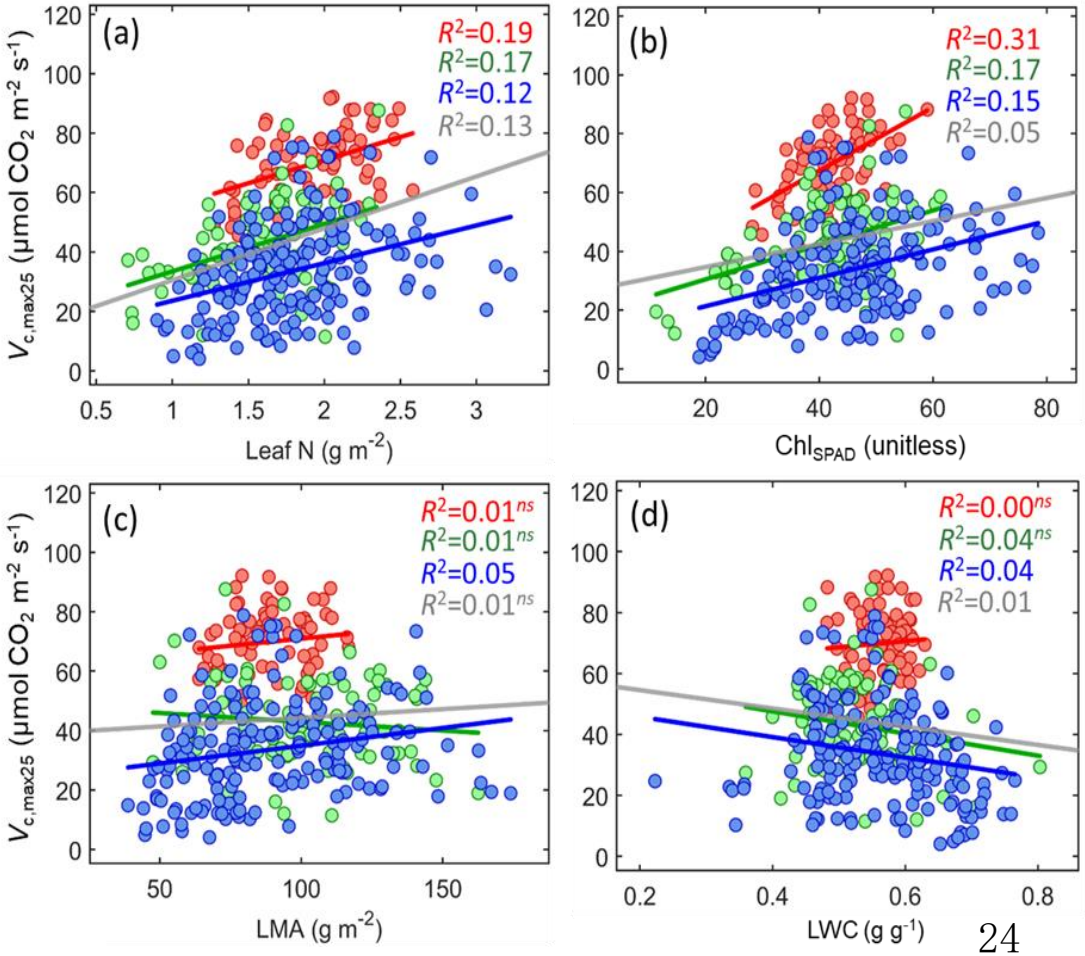
Zhengbing Yan,
Postdoctoral Researcher,
University of Hong Kong

Weak, biome-specific trait-V_{cmax25} relationships

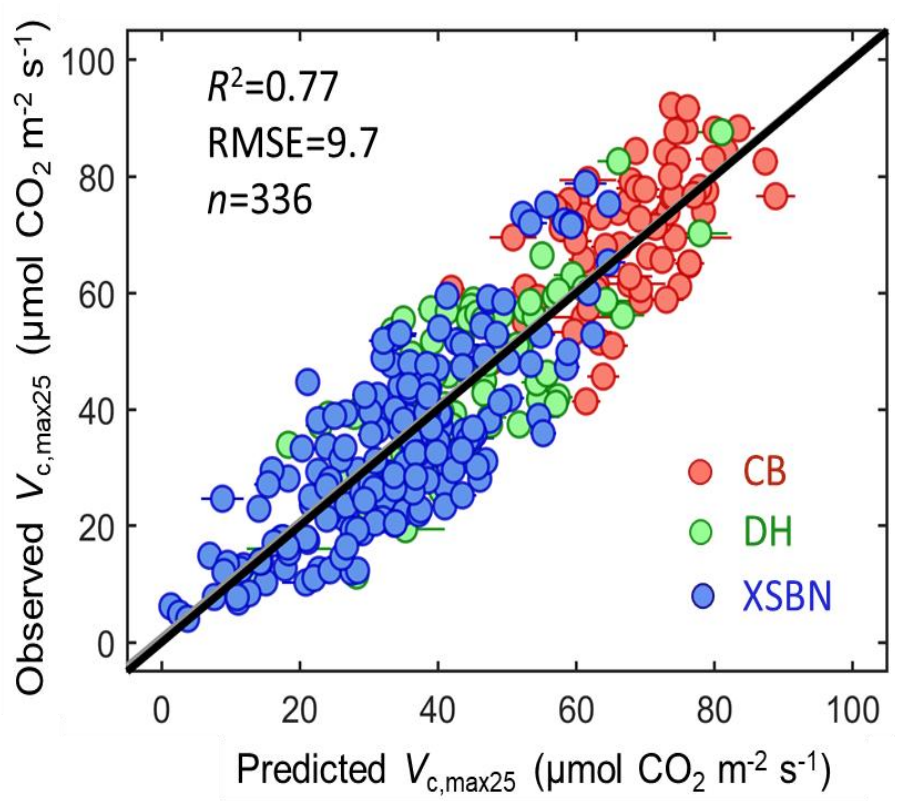
Cross-biome decoupling between regular traits and V_{cmax25}

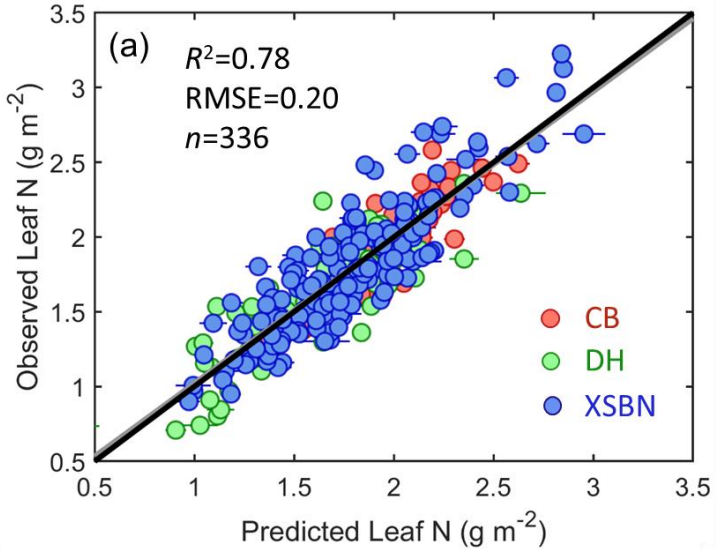


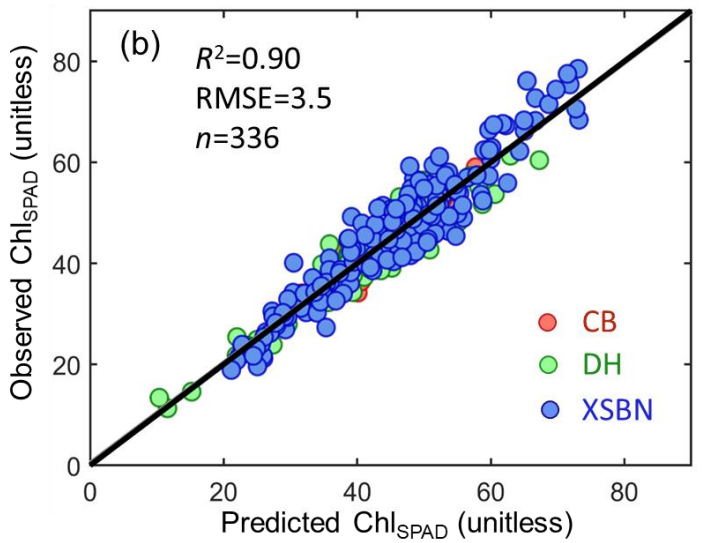
Weak relationships between regular traits and V_{cmax25}

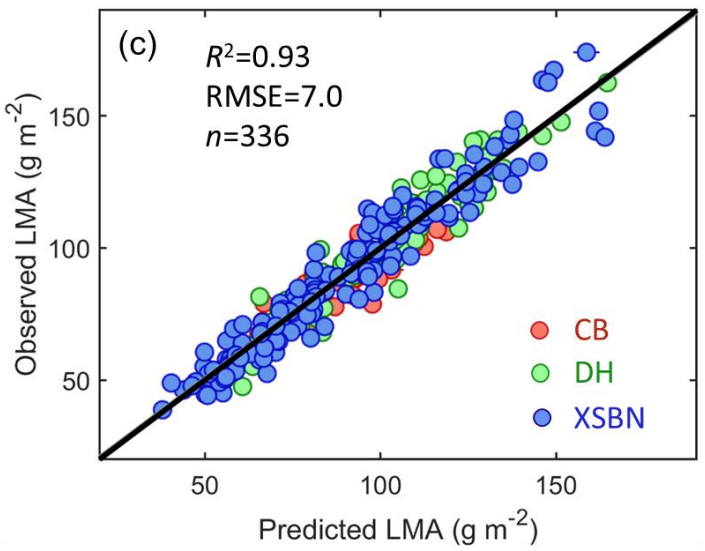


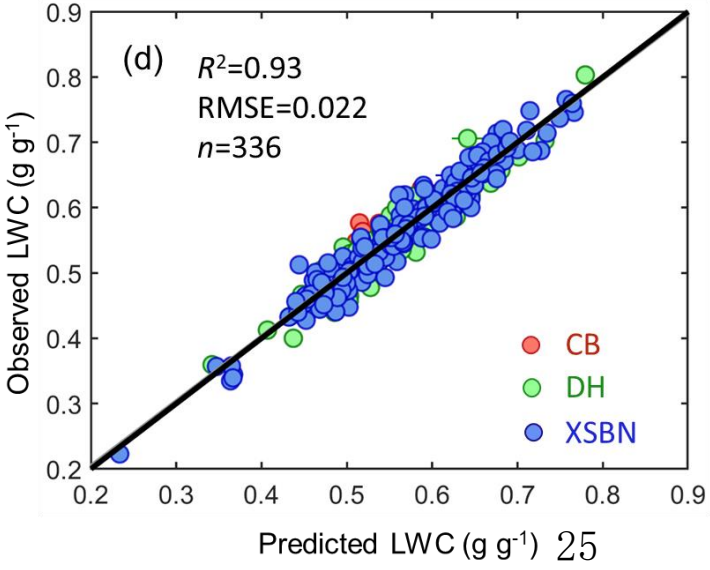
Spatial generalizability in spectra-trait relationships











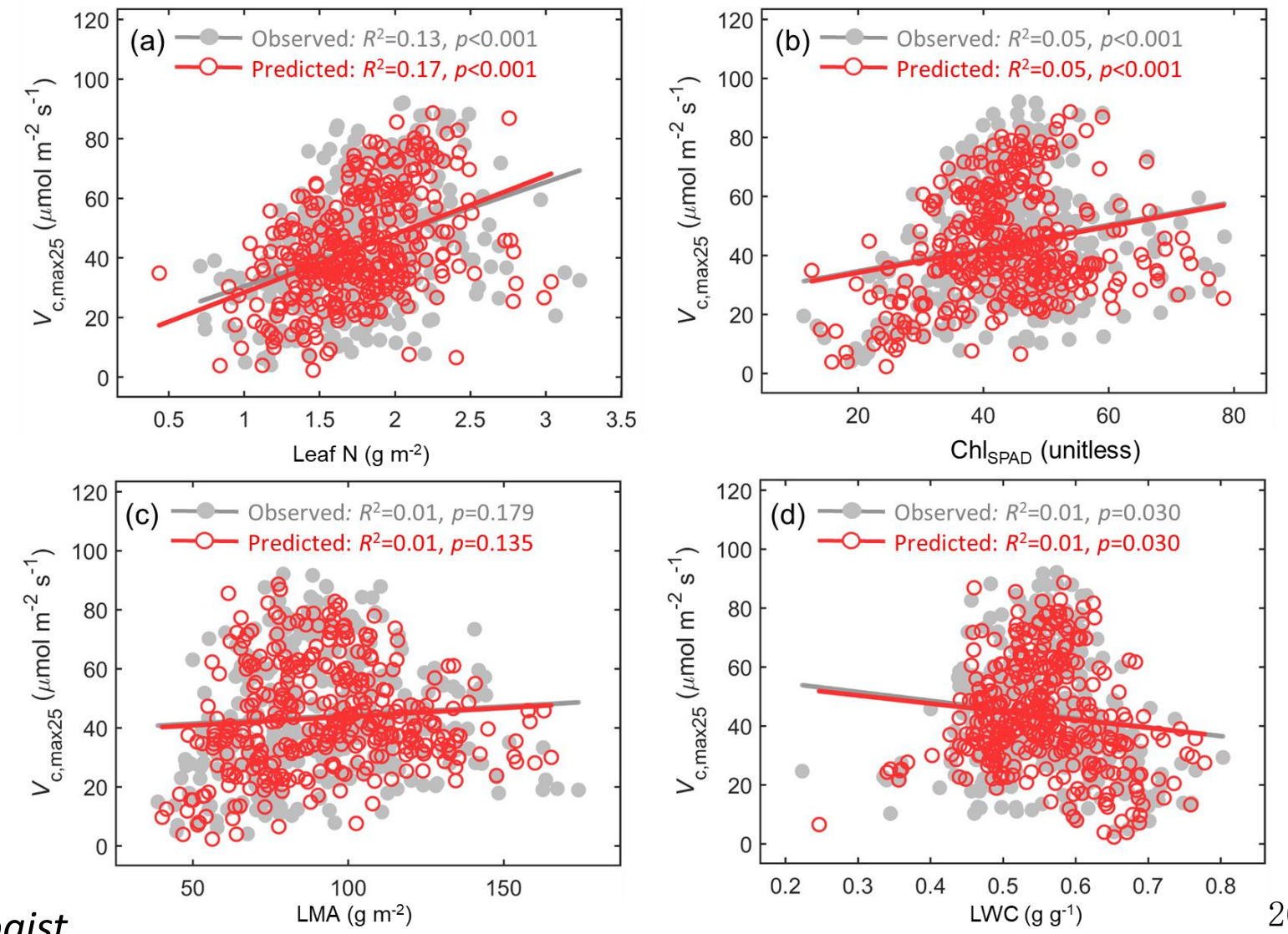
Yan *et al* (2021) *New Phytologist*

A novel way to represent trait-trait relationships

Provide novel ways to

1) study trait-trait relationships;

2) to parametrize next generation trait-based ecosystem models



Yan *et al* (2021) *New Phytologist*

Summary

- Leaf phenology is tightly linked to plant photosynthesis seasonality, and there are two aspects of leaf phenology: quantity (i.e. leaf area index) and quality (i.e. leaf biochemical and physiological traits)
- High (spatial and temporal) resolution PlanetScope satellites offer a promising way to monitor crown-scale leaf phenology, with implications for further understanding of individual-to-ecosystem phenological scaling.
- Hyperspectral remote sensing offers an effective and scalable means to monitor spatial and temporal variability in leaf physiological traits.

Acknowledgements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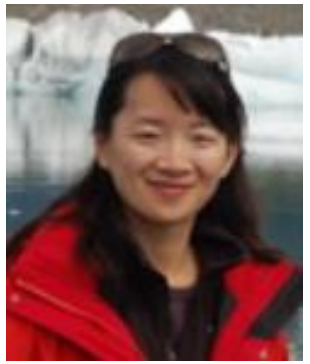
Alistair Rogers


Shawn Serbin


Lingli Liu


Han Wang


Yanjun Su

Students: Zhengfei Guo, Guangqin Song, Yingyi Zhao, and Yang Chen

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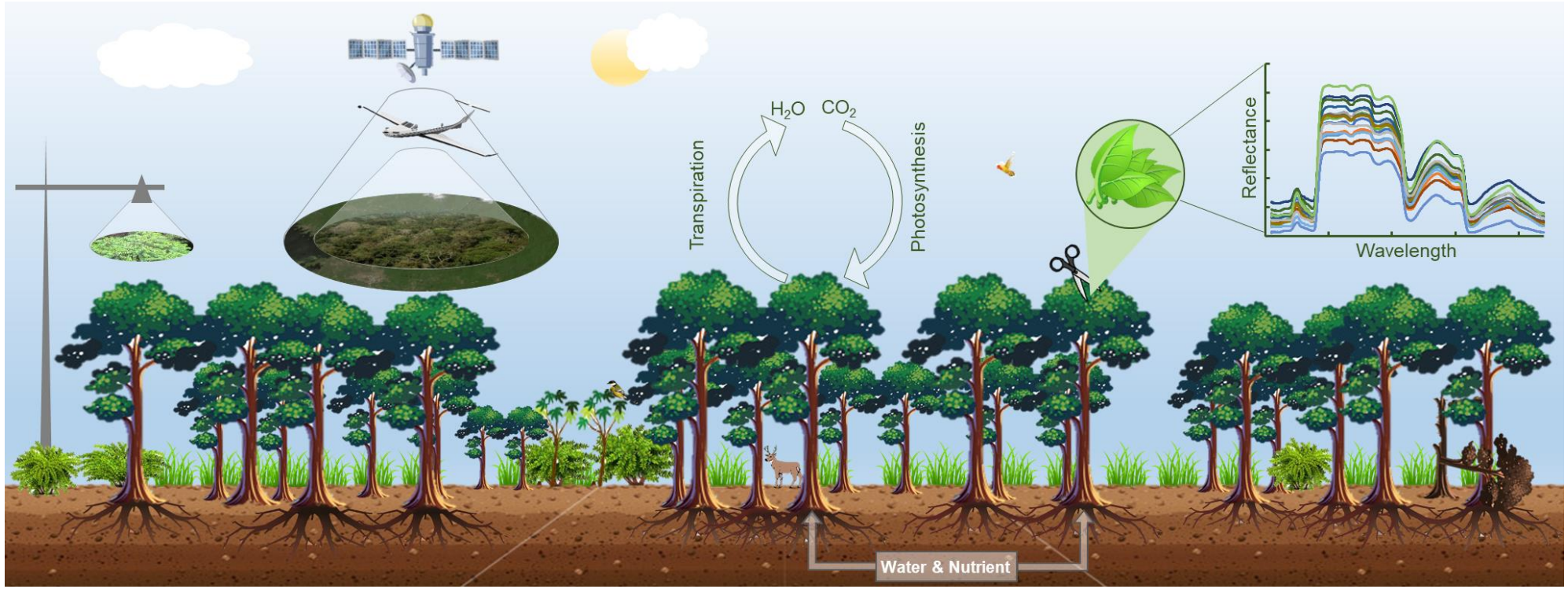

Thanks You!

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