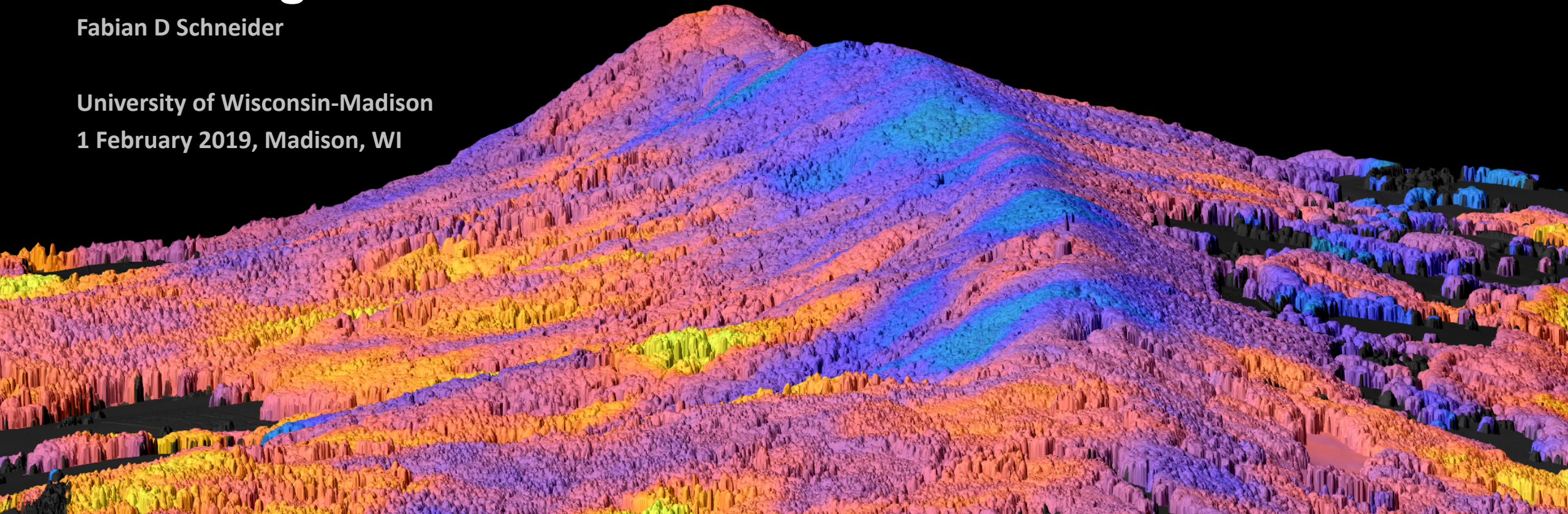
Jet Propulsion Laboratory
California Institute of Technology

Mapping forest functional diversity and ecosystem functioning using remote sensing and ecological modeling

Fabian D Schneider

University of Wisconsin-Madison

1 February 2019, Madison, WI



Biodiversity-Productivity Relationship

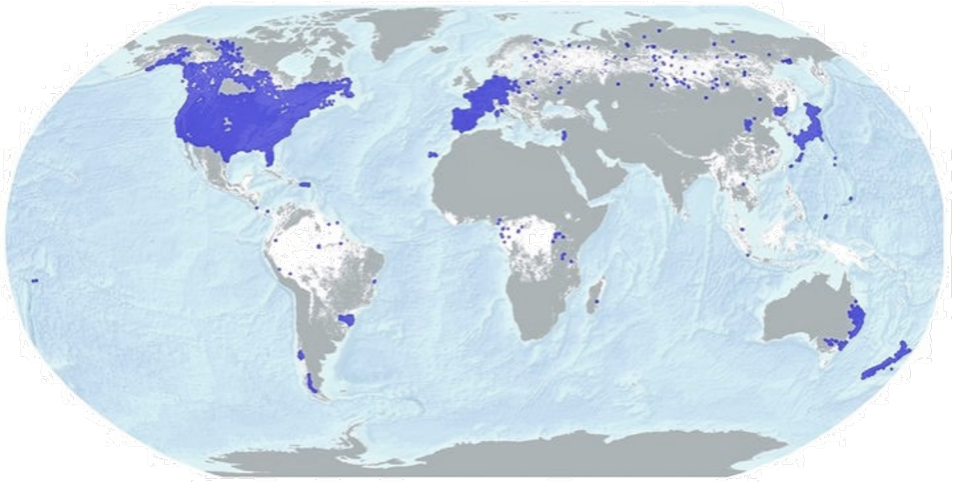
Plant diversity as indicator for ecosystem health, stability and functioning

RESEARCH ARTICLE

FOREST ECOLOGY

Positive biodiversity-productivity relationship predominant in global forests

Jingjing Liang,[1*] Thomas W. Crowther,[2,3]† Nicolas Picard,[4] Susan Wiser,[5] Mo Zhou,[1] Giorgio Alberti,[6] Ernst-Detlef Schulze,[7] A. David McGuire,[8] Fabio Bozzato,[9]

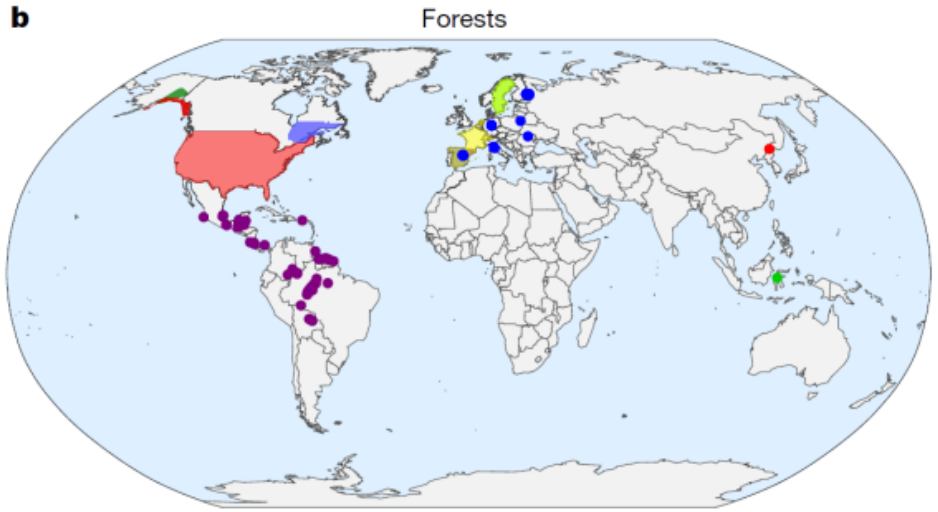


LETTER

doi:10.1038/nature23886

Biodiversity effects in the wild are common and as strong as key drivers of productivity

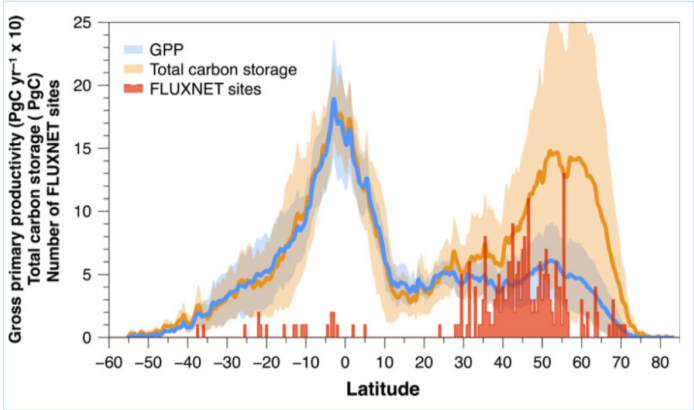
J. Emmett Duffy[1], Casey M. Godwin[2] & Bradley J. Cardinale[2]



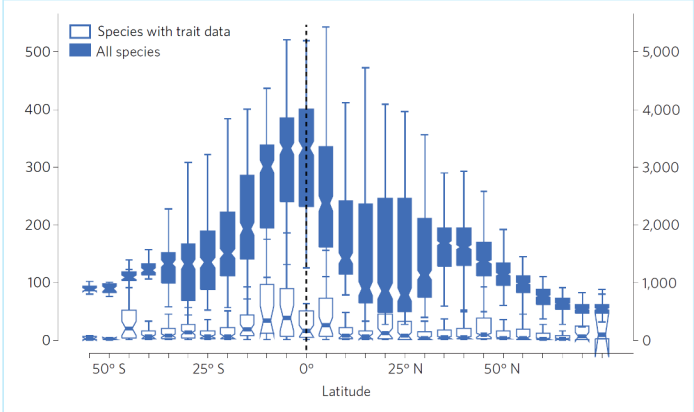
Liang, et al. (2016) Science; Duffy, et al. (2017) Nature

Data Gaps at Global Scale

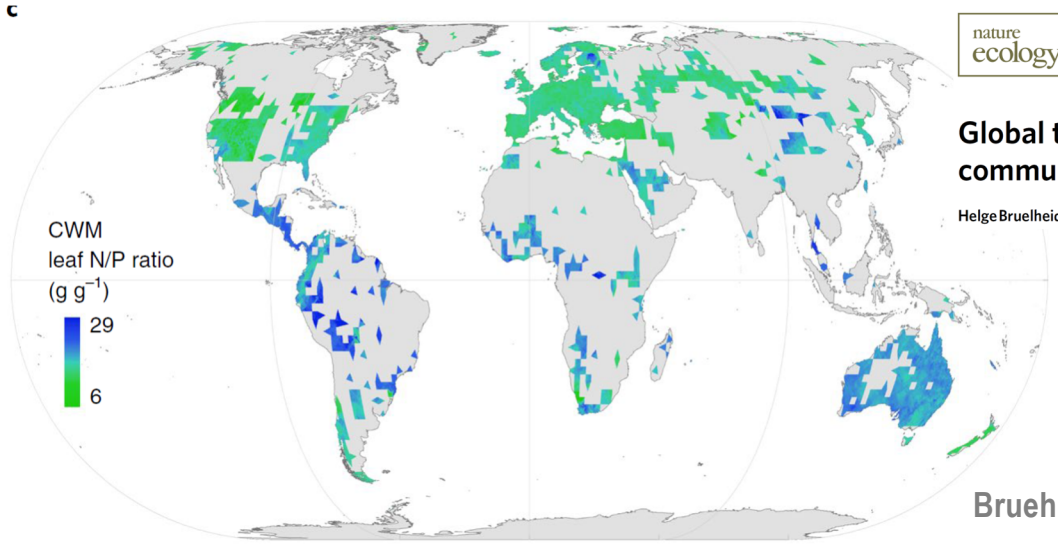
Large parts of the most diverse ecosystems on Earth are under-represented



Schimel et al. 2015



Jetz et al. 2016

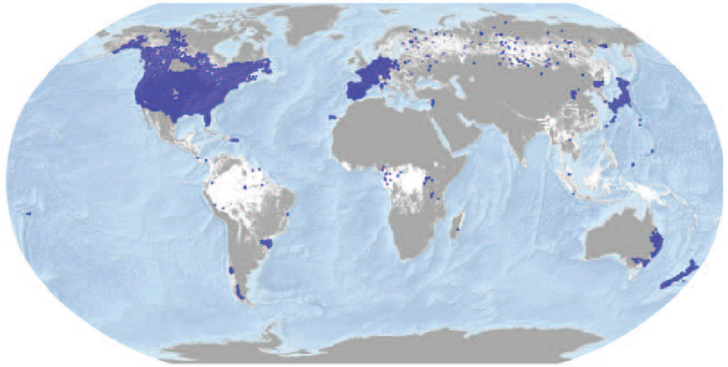


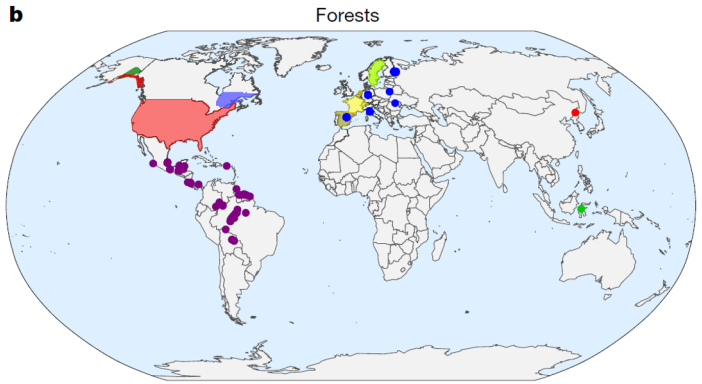
nature ecology & evolution
ARTICLES
https://doi.org/10.1038/s41559-018-0699-8

Global trait–environment relationships of plant communities

Helge Bruelheide[1,2*], Jürgen Dengler[2,3,4], Oliver Purschke[1,2], Jonathan Lenoir[5],

Bruehlheide, et al. (2018) NEE





Data Gaps at Local Scale

Little knowledge about diversity patterns at local scales / within biomes or ecosystems

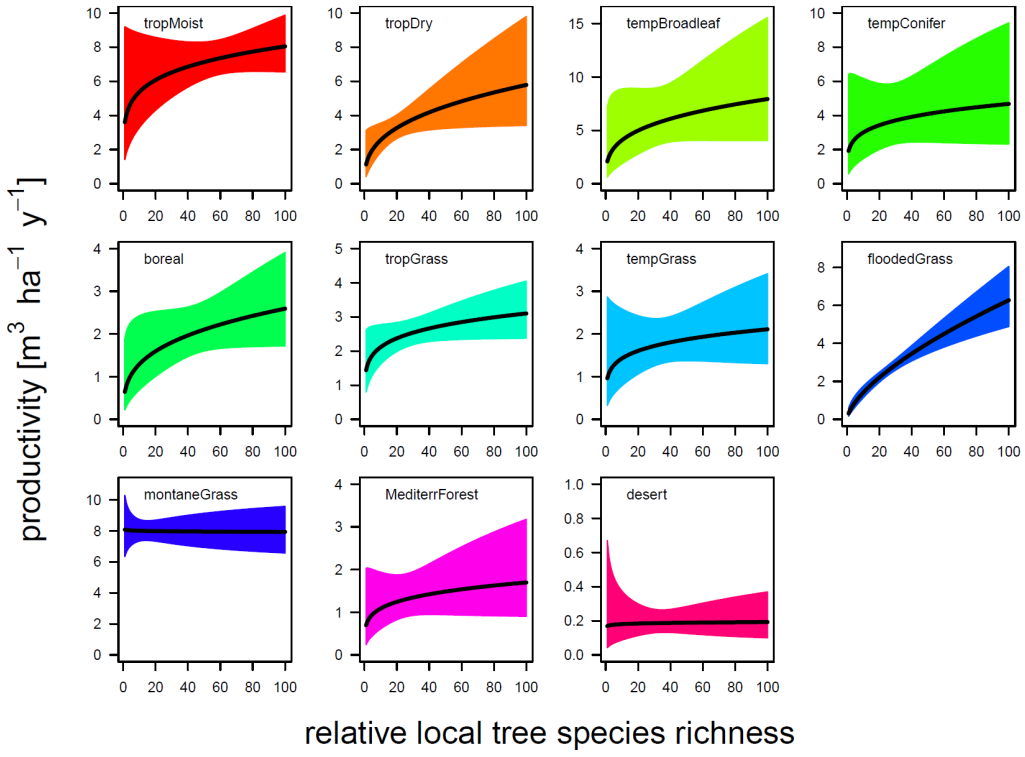
Neither global nor consistent: a technical comment on the tree diversity-productivity analysis of Liang et al. (2016)

Carsten F. Dormann[1], Helge Schneider[1], and Jonas Gorges[1]

[1]Biometry & Environmental System Analysis, University of Freiburg, Germany
carsten.dormann@biom.uni-freiburg.de

January 18, 2019

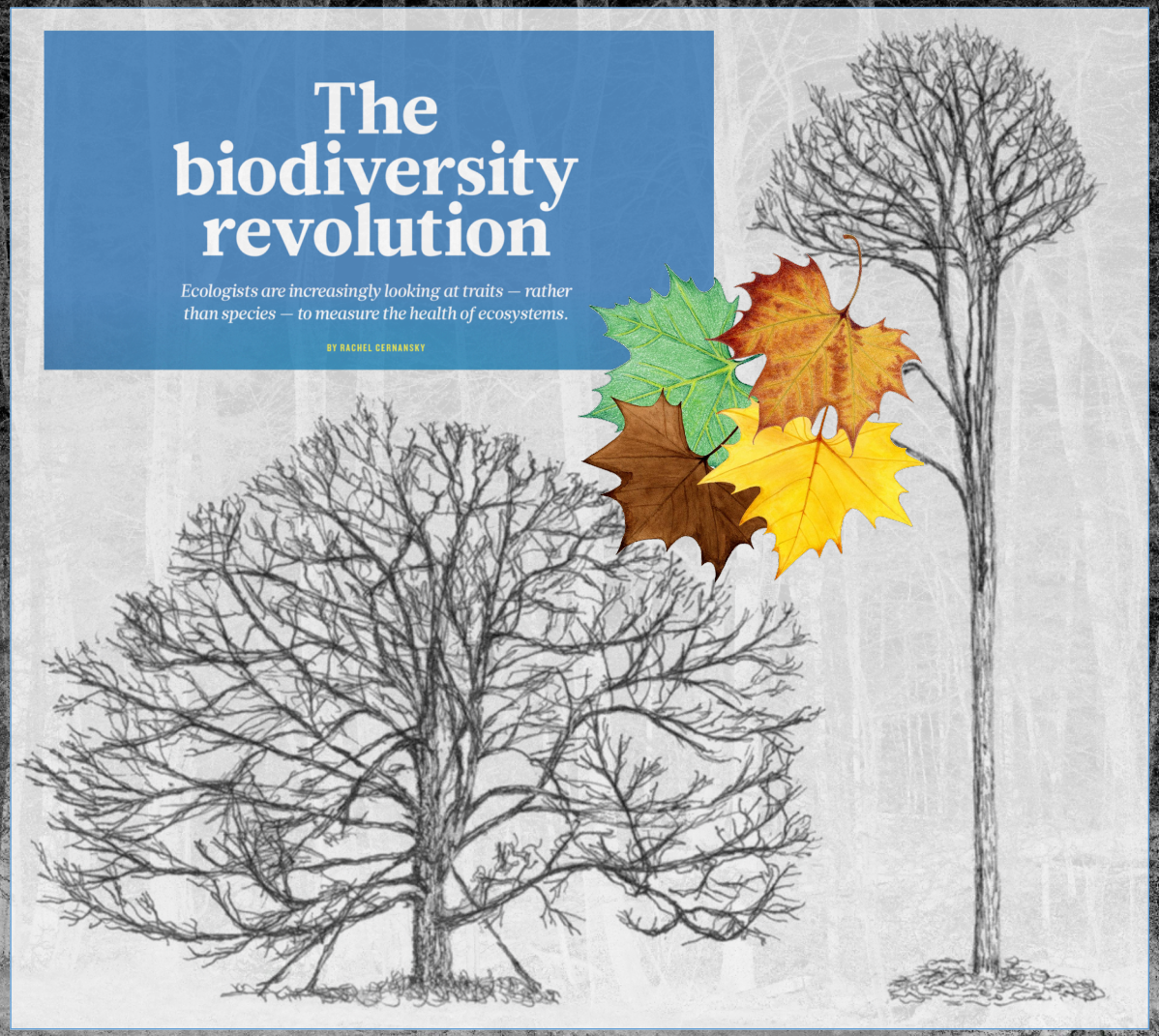
- *bioRxiv preprint posted online Jan 20, 2019*
- "We find that there is virtually **no effect** of relative tree species richness on productivity when computing species richness at the **local scale**."
- "Also, **different ecoregions** have very **different relationships** between tree species richness and productivity."



Biome-specific observed tree-species richness-productivity relationships, with species richness represented as percentage Of regional maximum.

How do we measure Biodiversity?

Remote Sensing of Plant Functional Traits



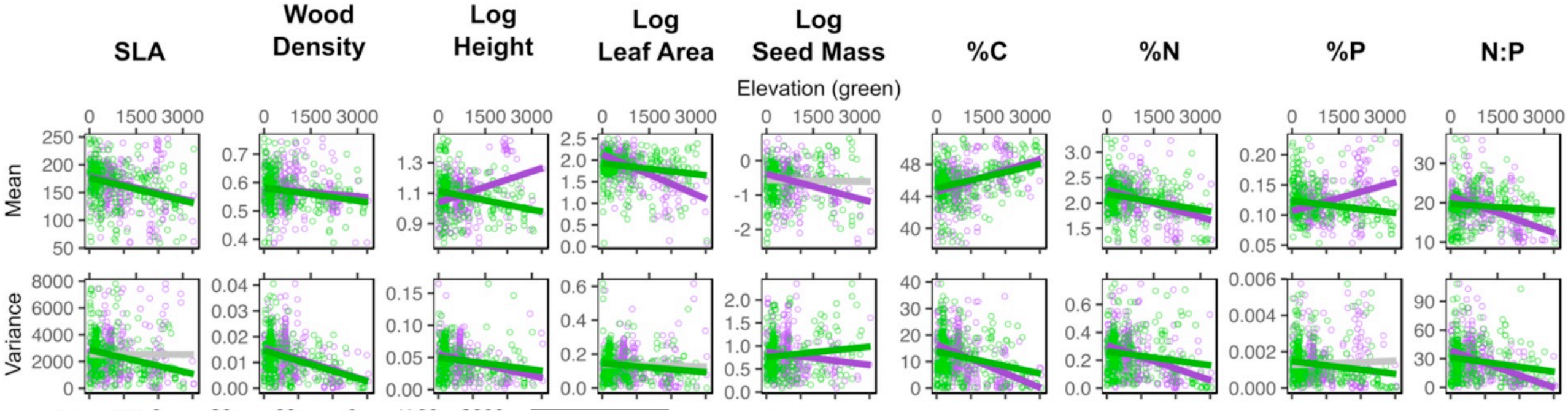
"Just going for species numbers doesn't allow us to harness all this incredibly rich information of how the real world operates."

Functional Diversity

Diversity gradients based on forest functional traits

Climate shapes and shifts functional biodiversity in forests worldwide

Daniel J. Wieczynski[a,1], Brad Boyle[b], Vanessa Buzzard[c], Sandra M. Duran[b], Amanda N. Henderson[b], Catherine M. Hulshof[d], Andrew J. Kerkhoff[e], Megan C. McCarthy[f], Sean T. Michaletz[g], Nathan G. Swenson[h], Gregory P. Asner[i], Lisa Patrick Bentley[j], Brian J. Enquist[b,k], and Van M. Savage[a,k,l]



Wieczynski, et al. (2019) PNAS

Latitude - Elevation

Outline of the Talk

Research questions

Three parts with the aim to develop a method to study spatial patterns of forest functional diversity with remote sensing, and assess its implication on ecosystem functioning.

Model for Trait Validation

How can we map functional diversity from remotely sensed morphological and physiological forest traits, and what spatial patterns can be revealed from those traits?

Model for Predictive Ecology

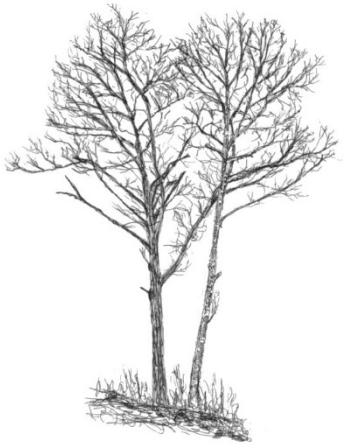
Study Site

Laegern - Switzerland

SRF Einstein 2015

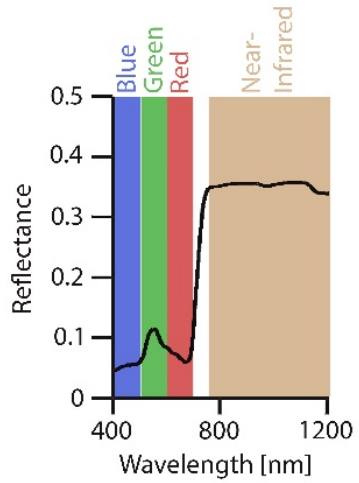
SRF Einstein 2017

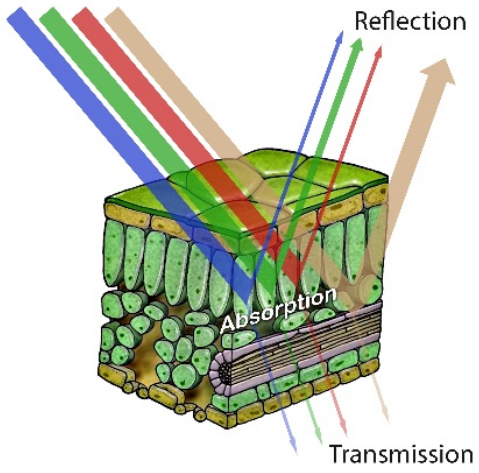
Functional Traits

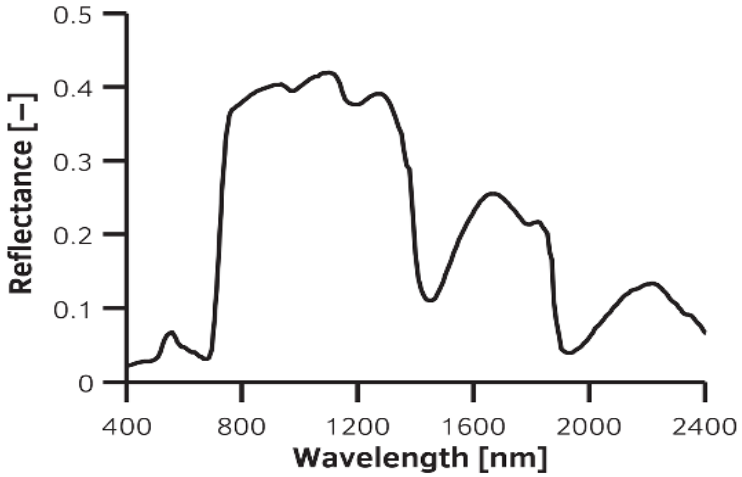


Methods to Measure Traits

Imaging Spectroscopy and Laser Scanning

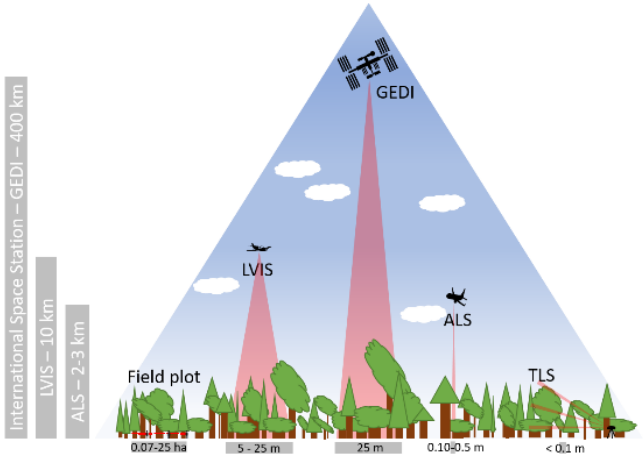


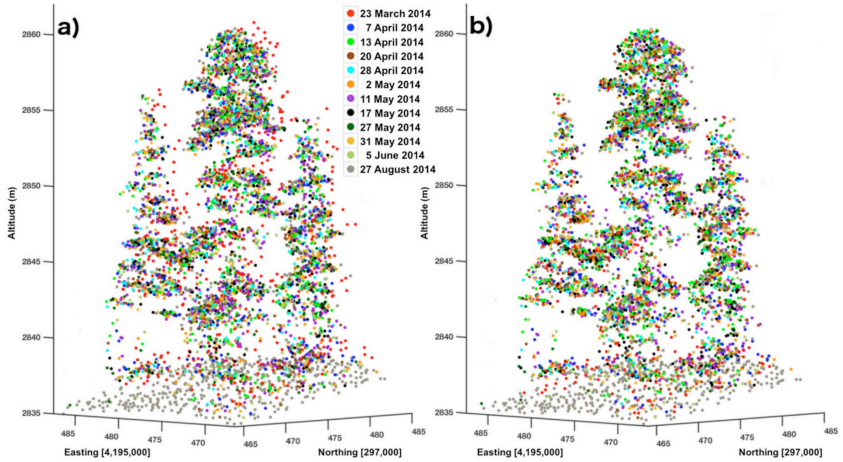


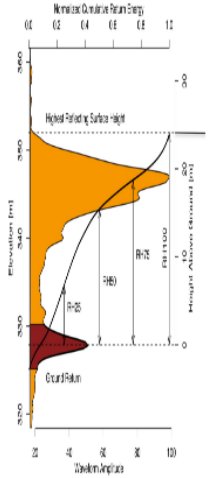


APEX
400 – 2500 nm
@3-14 nm and 2 m

Spaceborne Spectrometer
400 – 2500 nm
@~10 nm and ~30 m







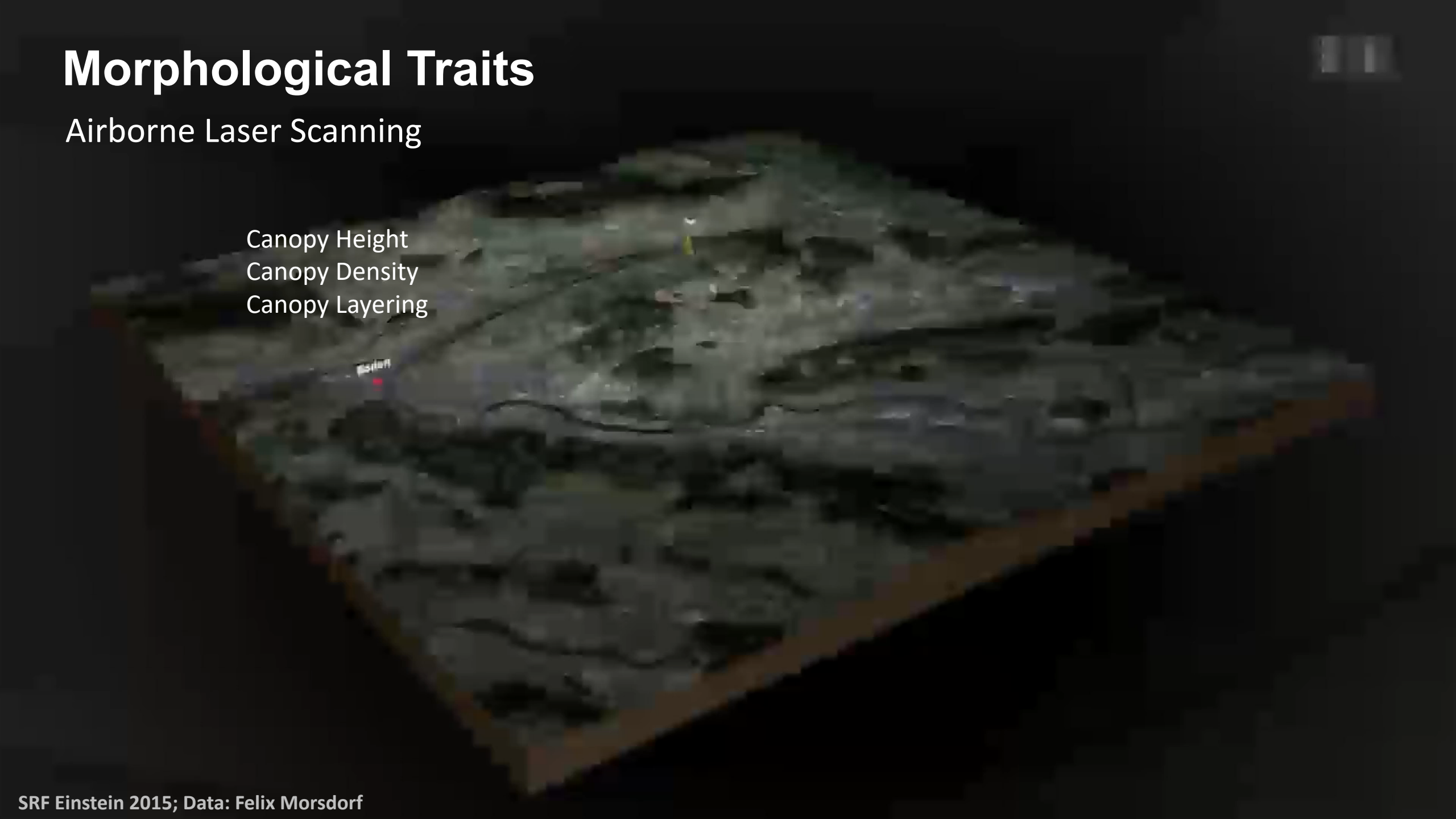
Airborne LiDAR
30 cm Footprint
5-40 pts per m2

Spaceborne LiDAR
~25 m Footprint
~10-30 pts per km2

Schaepman, et al. (2015) RSE; Lee, et al. (2015) RSE; Schneider, et al. (2014) RSE; Ferraz, et al. (2018) RS

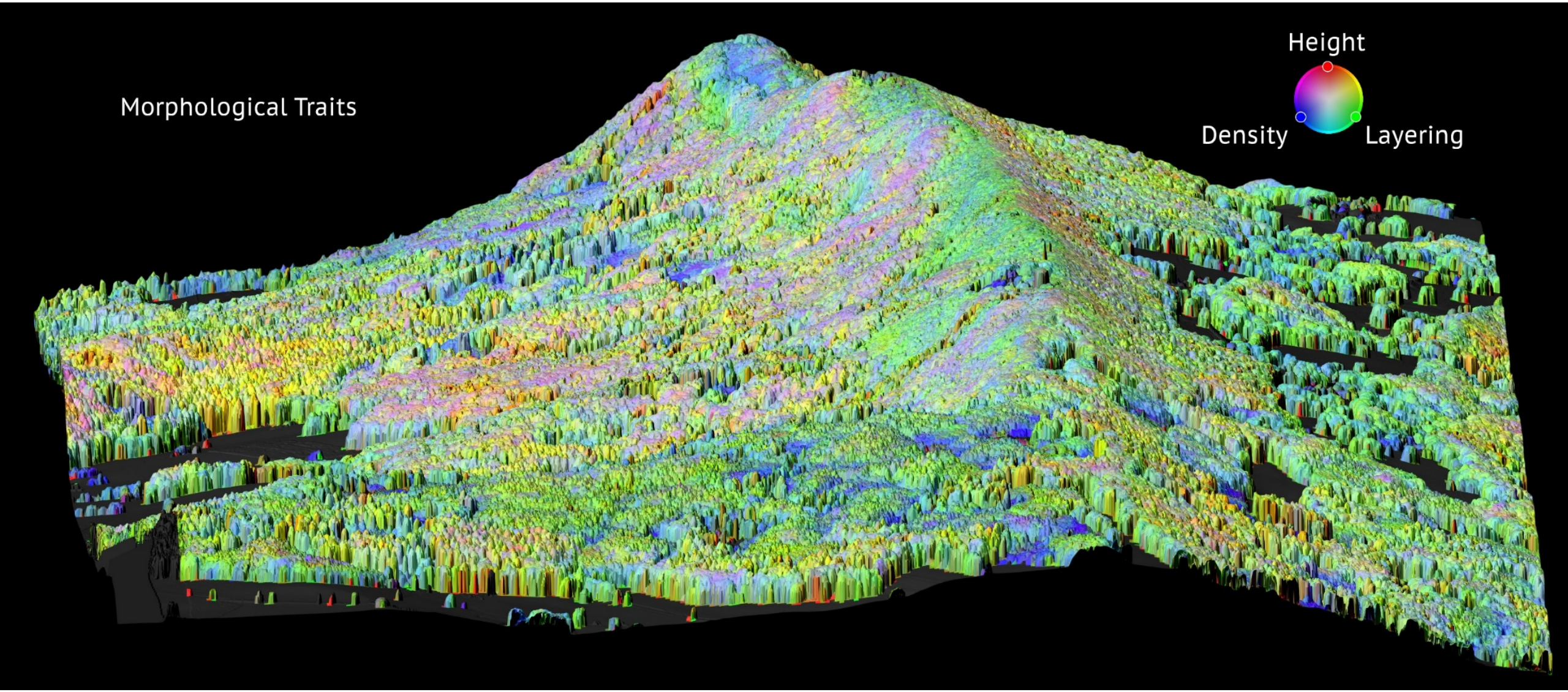
Morphological Traits

Airborne Laser Scanning



SRF Einstein 2015; Data: Felix Morsdorf

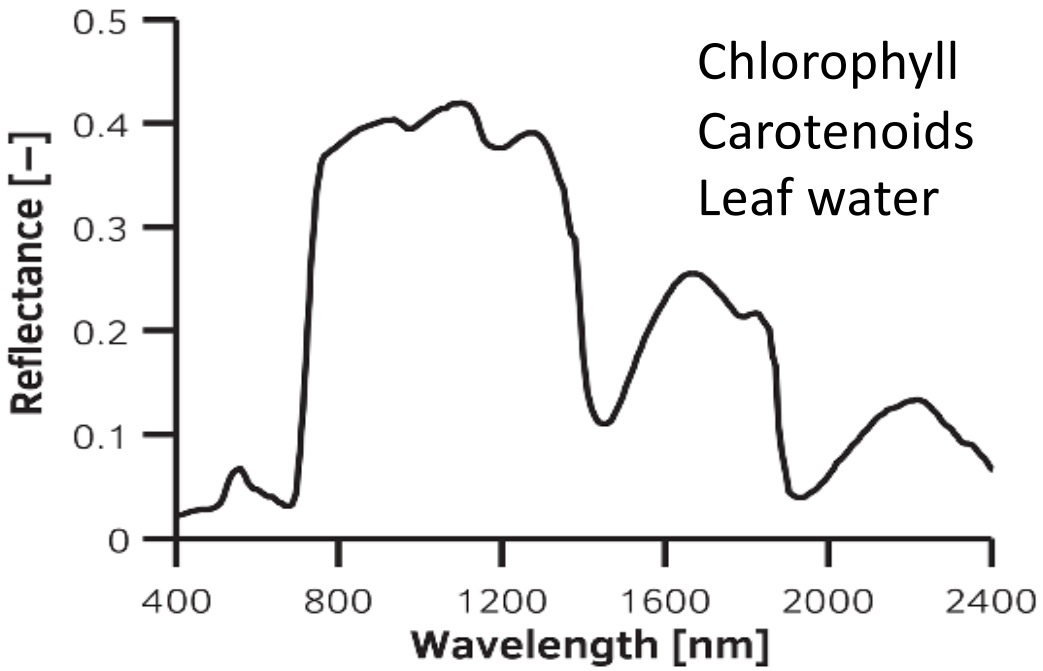
Canopy Morphological Traits

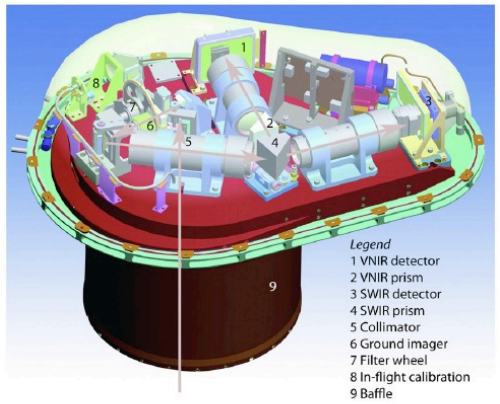


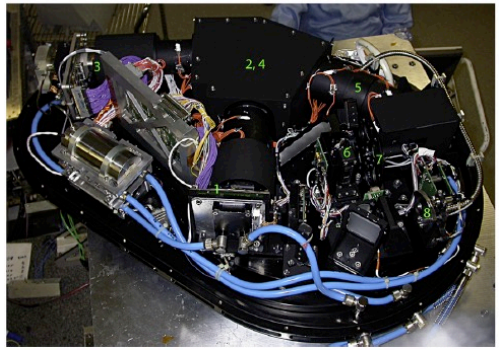
Schneider, et al. (2017) NComms

Method – Imaging Spectroscopy

Airborne imaging spectrometer APEX



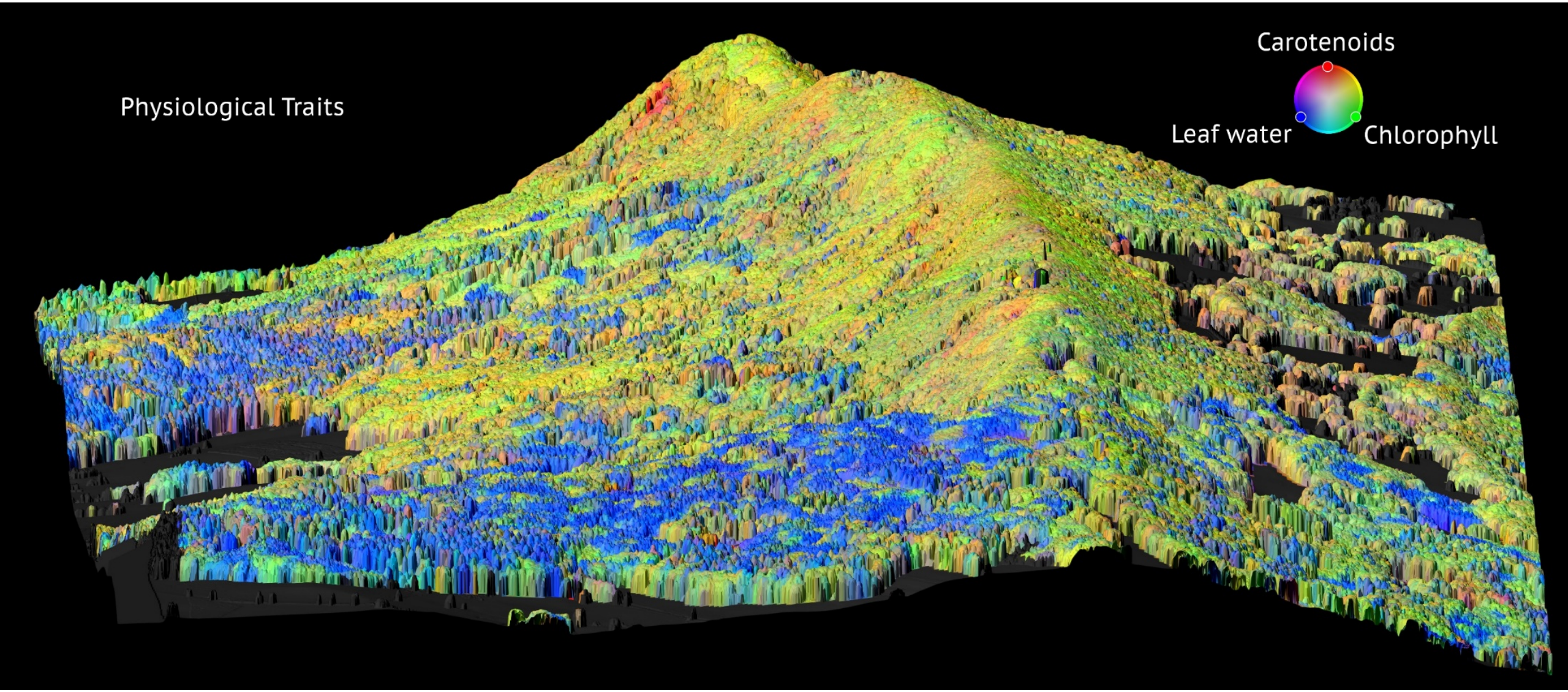




Photos: Andy Hueni

Schaepman, et al. (2015) RSE; Schneider, et al. (2014)

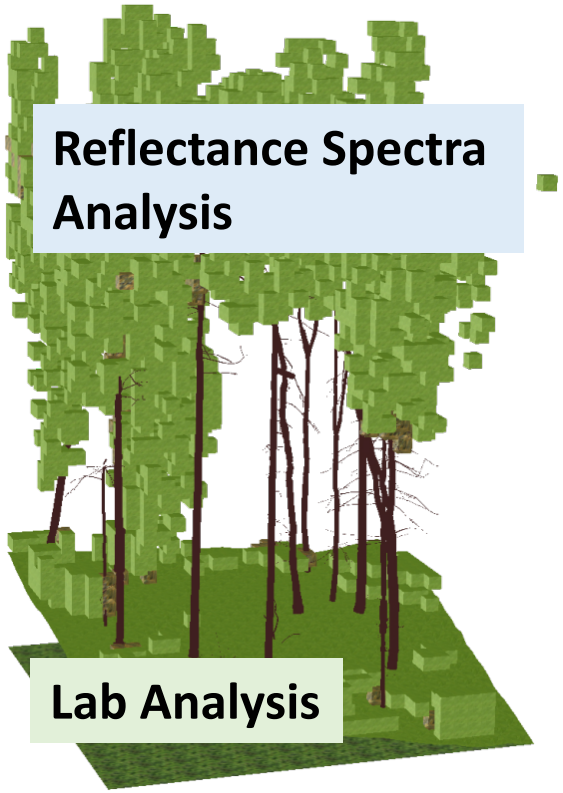
Leaf Physiological Traits

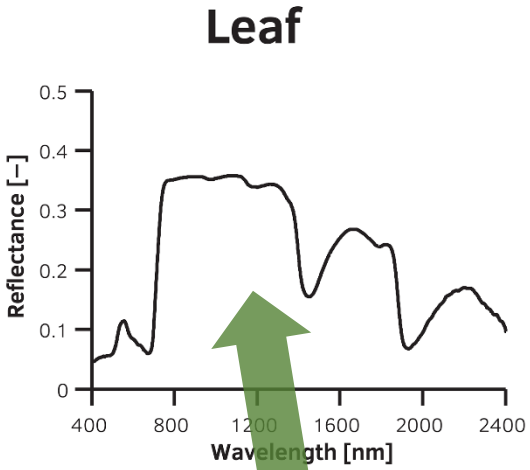


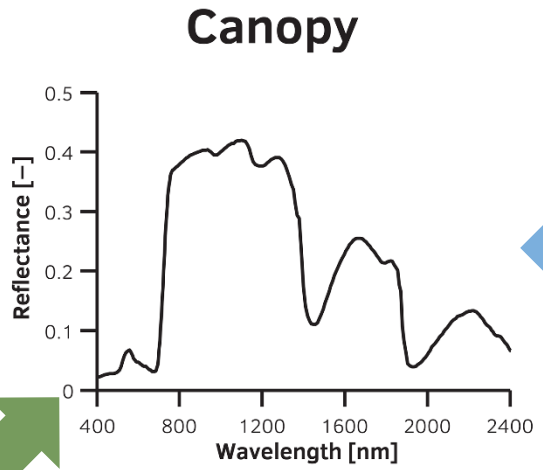
Schneider, et al. (2017) NComms

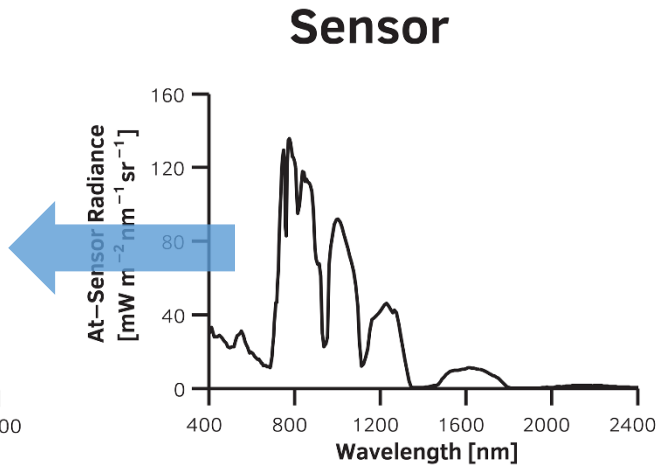
Radiative Transfer Modeling

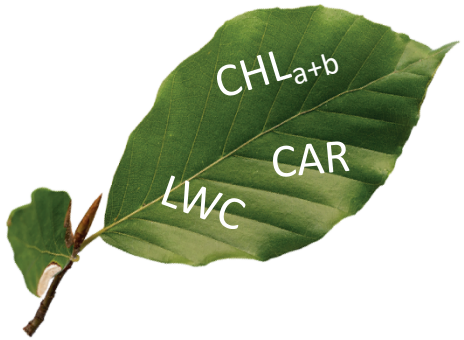
Scaling from Leaf to Canopy to Sensor

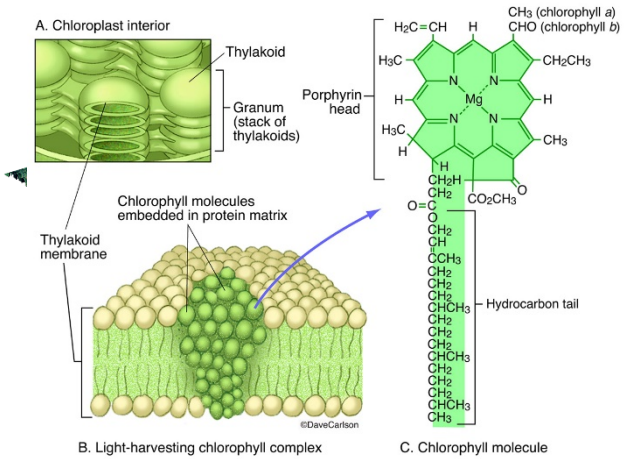


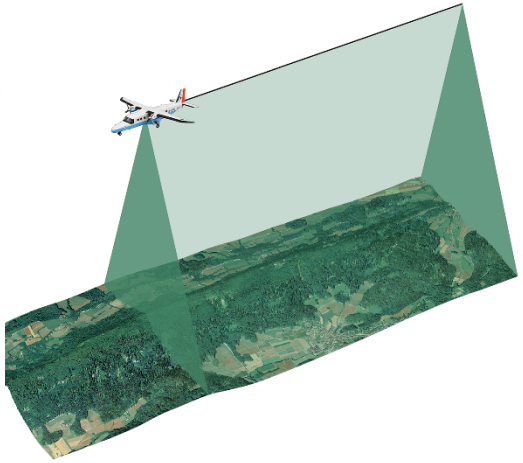






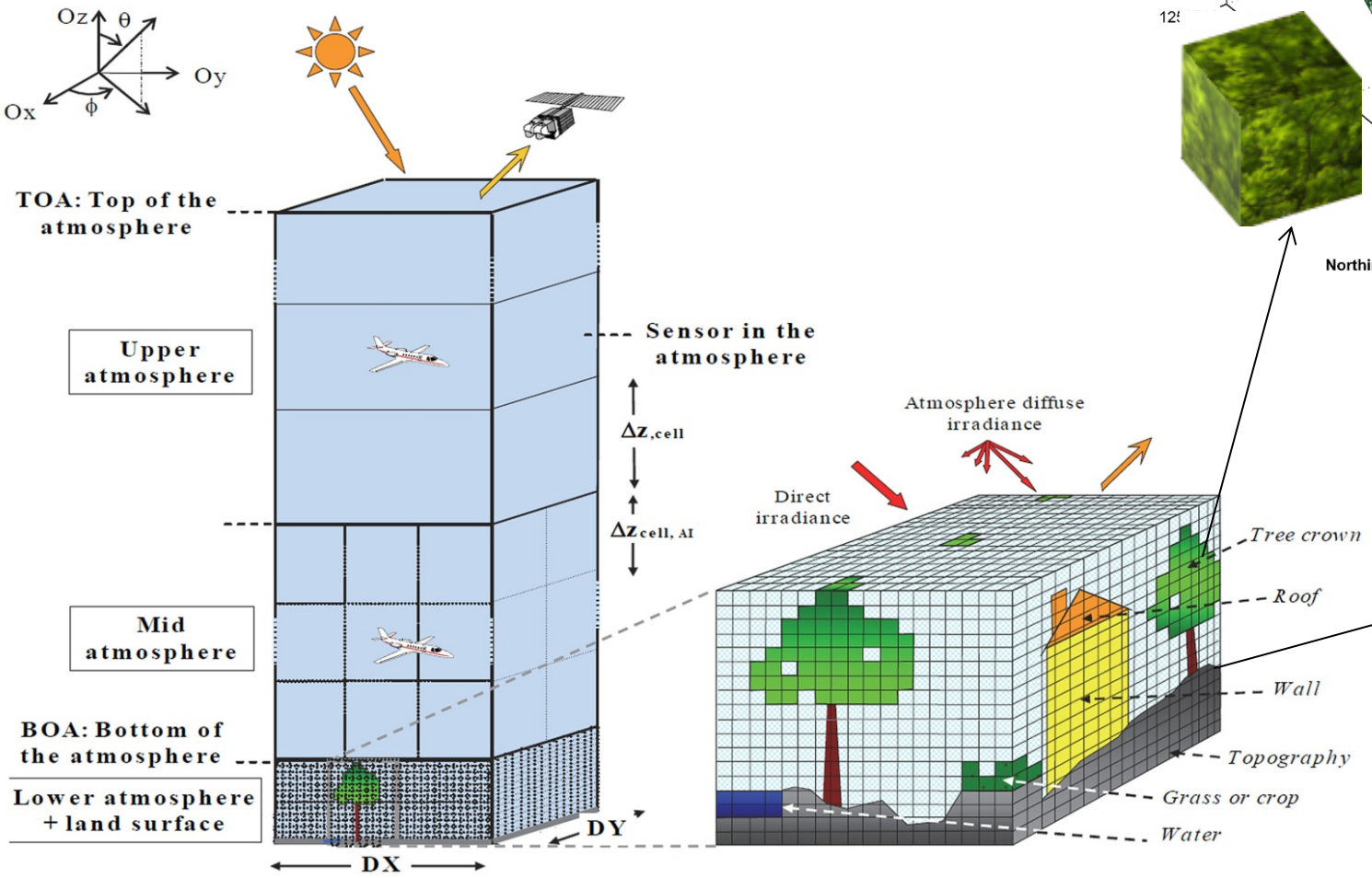


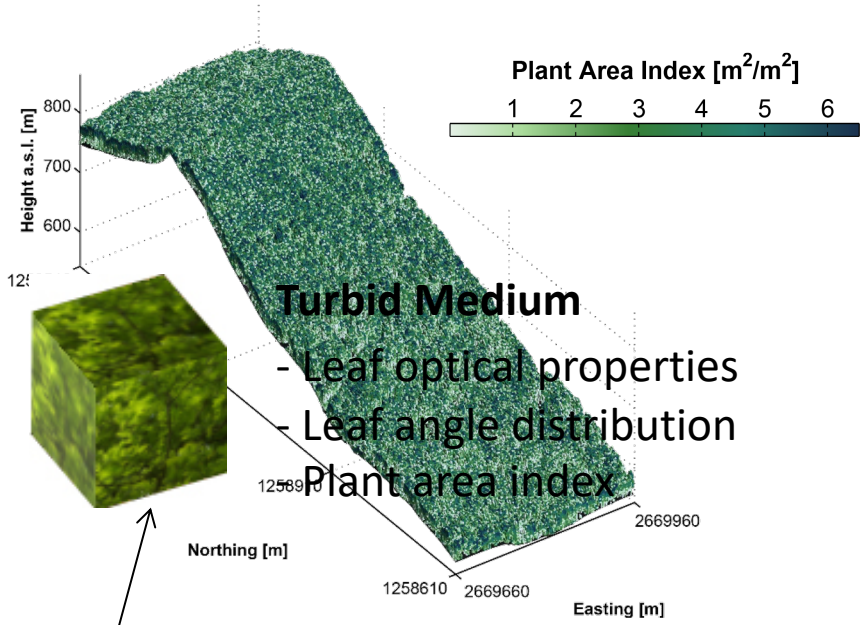




3D Radiative Transfer Model DART

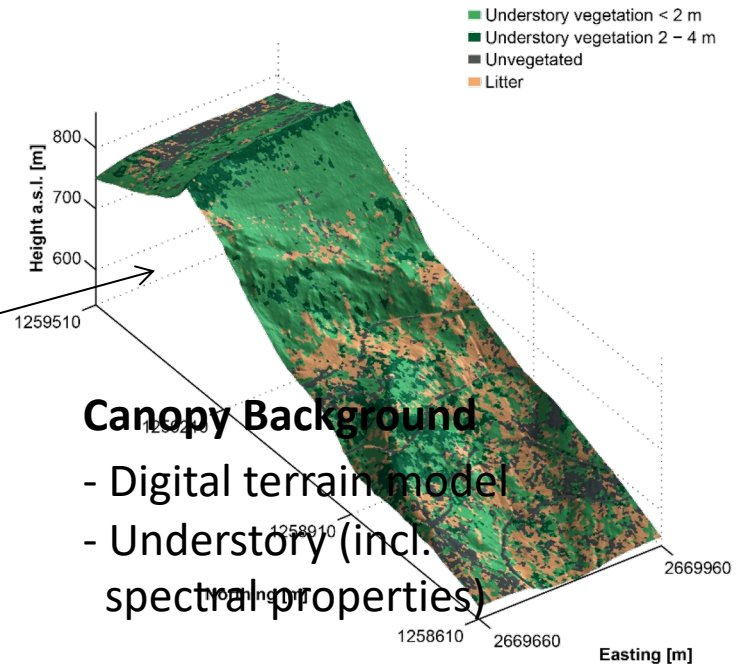
Coupled Canopy-Atmosphere-Sensor Model





Turbid Medium

- Leaf optical properties
- Leaf angle distribution
- Plant area index

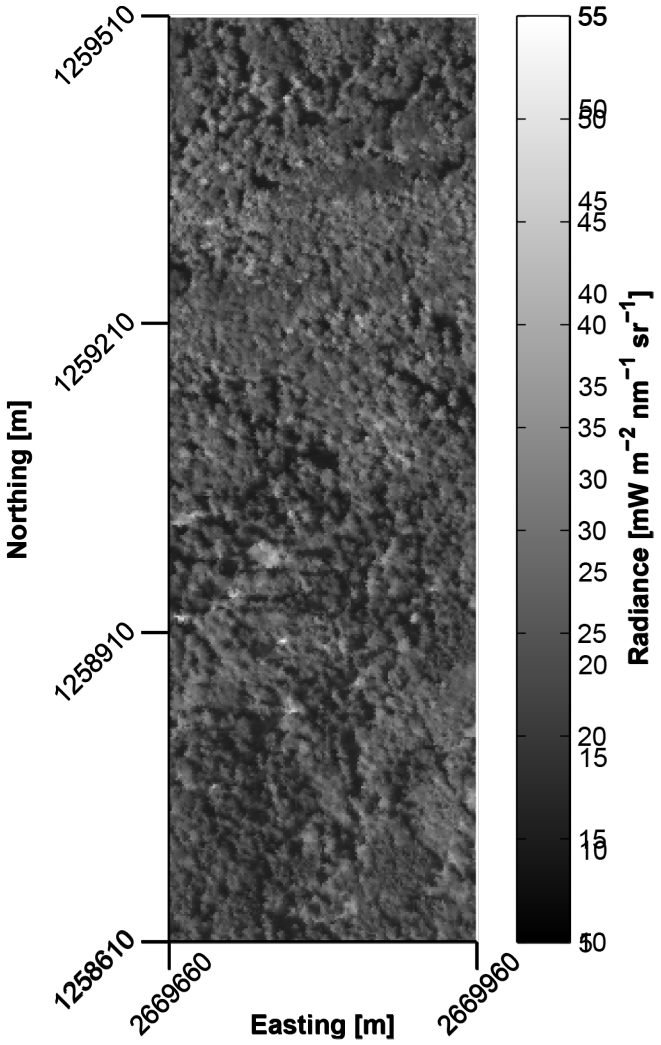


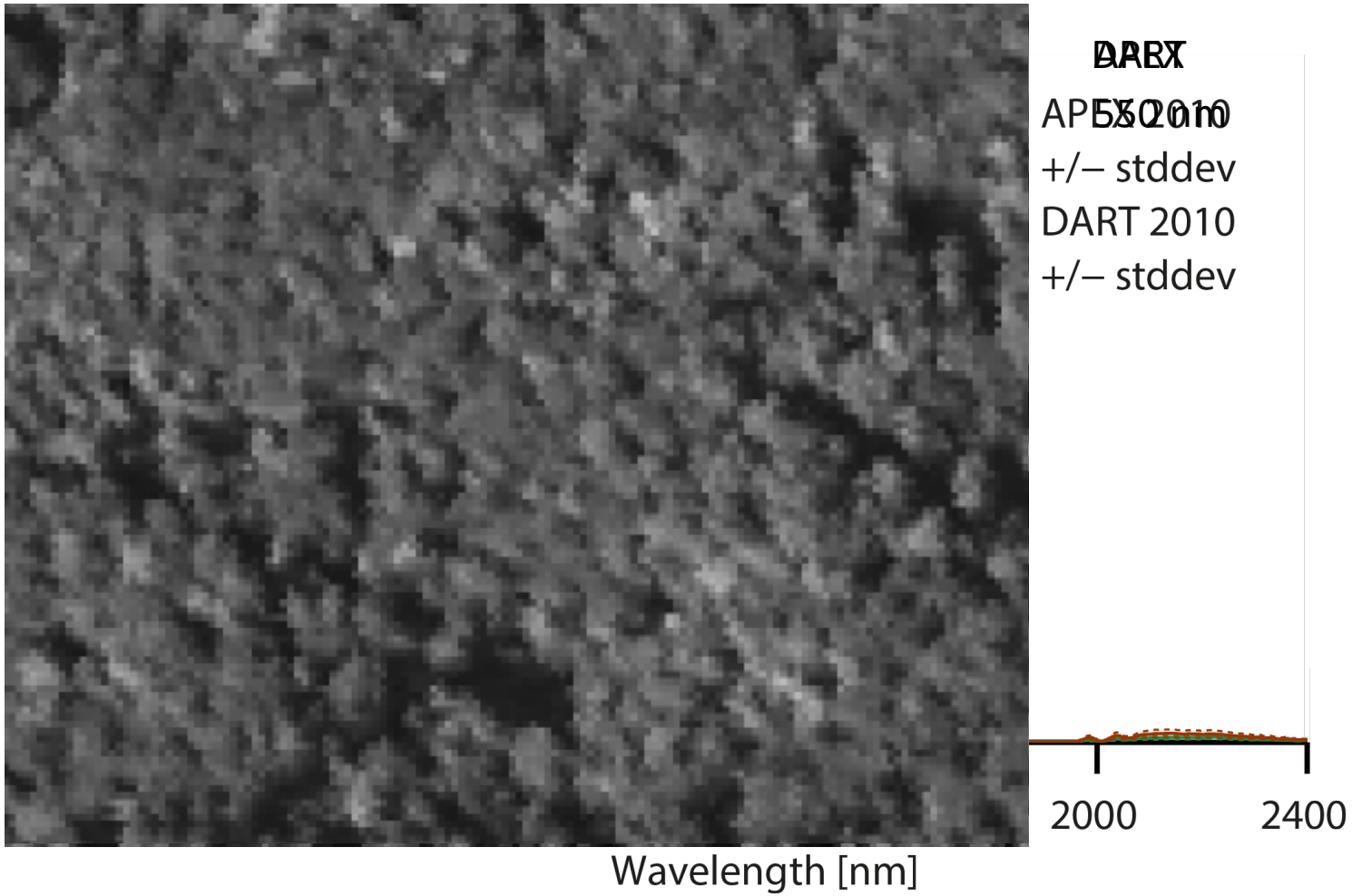
Canopy Background

- Digital terrain model
- Understory (incl. spectral properties)

Schneider, et al. (2014) Remote Sensing of Environment

Comparing Modeled vs Measured

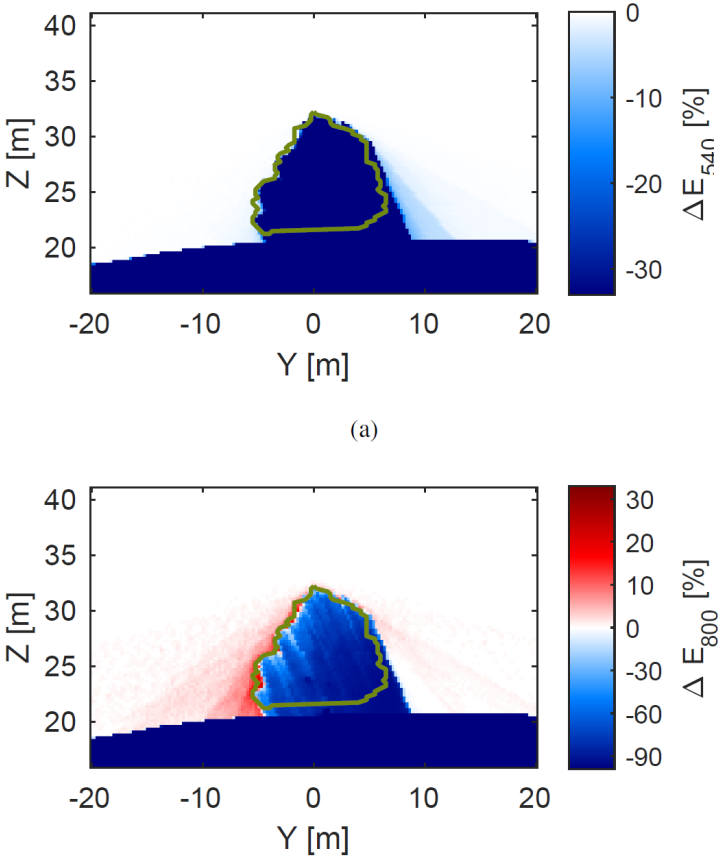




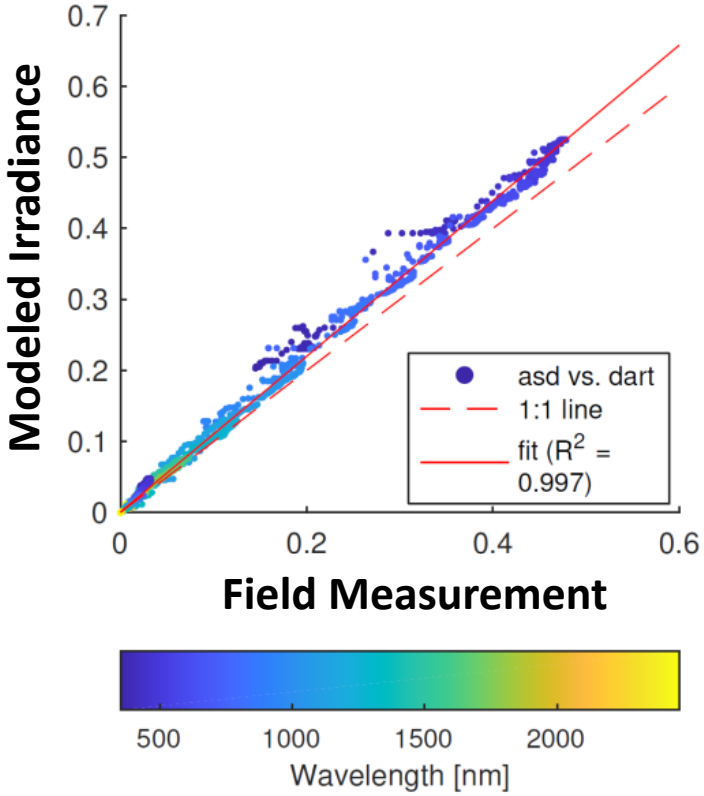
Schneider, et al. (2014, 2015), Schaepman, et al. (2015)

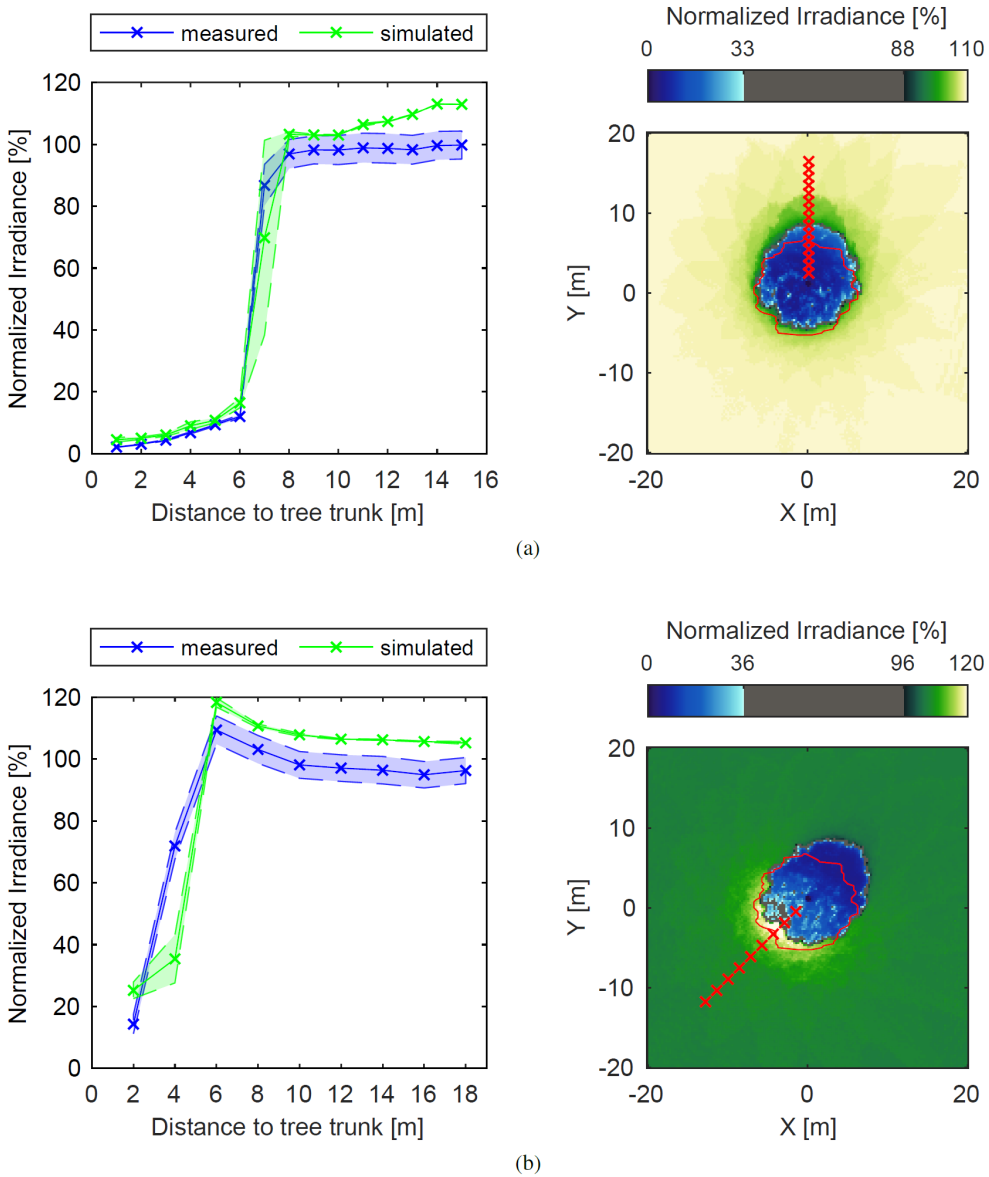
DART High-Res Validation

The Radiation field of a single tree



(a)





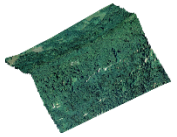
(a)

(b)

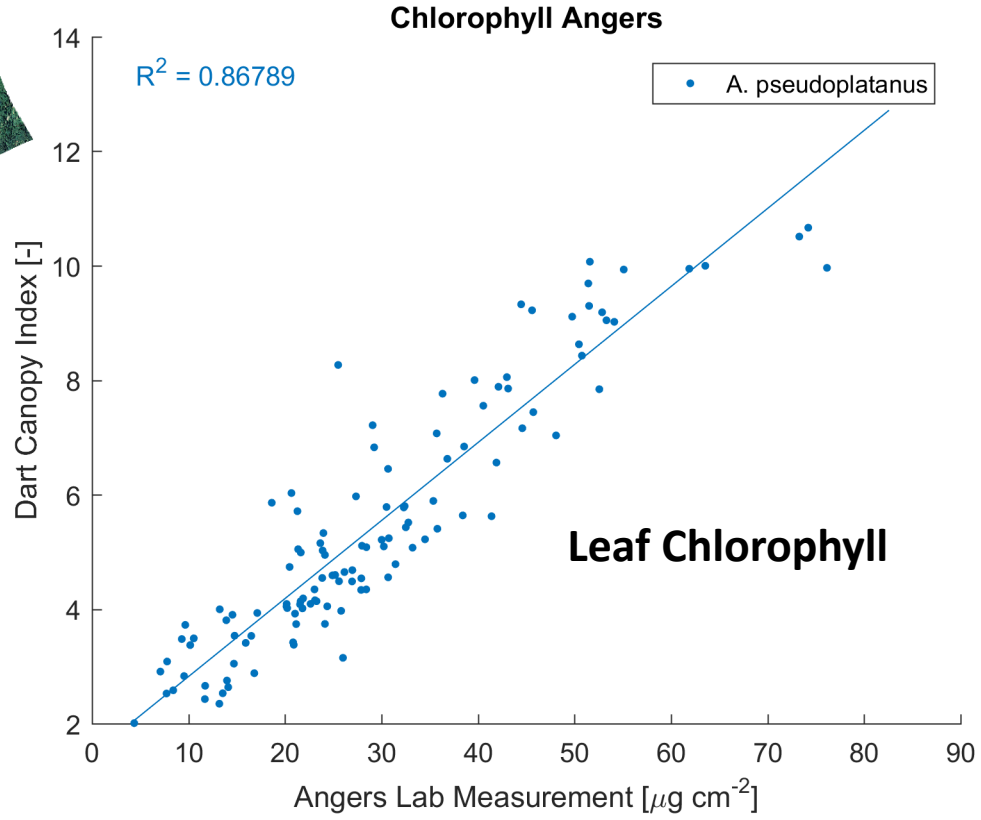
Kükenbrink, et al. (accepted) IEEE TGRS

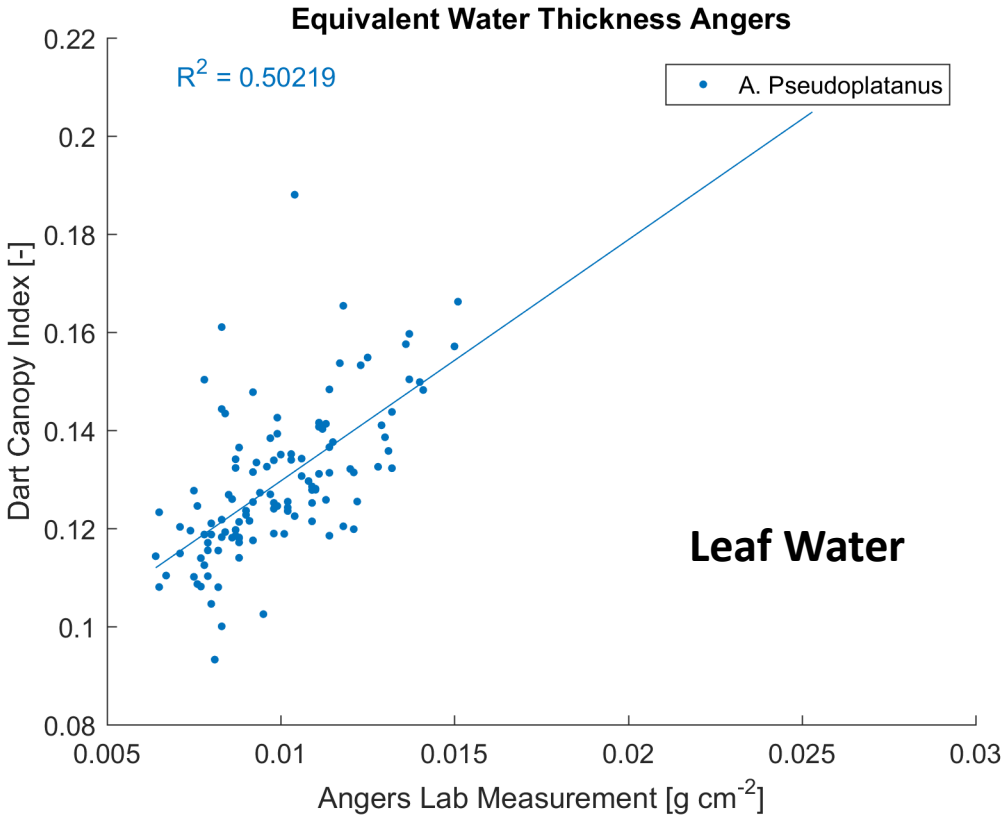
Leaf-Canopy Trait Validation

From leaf to canopy



Ca Leaf Spectra





Laboratory Measurement

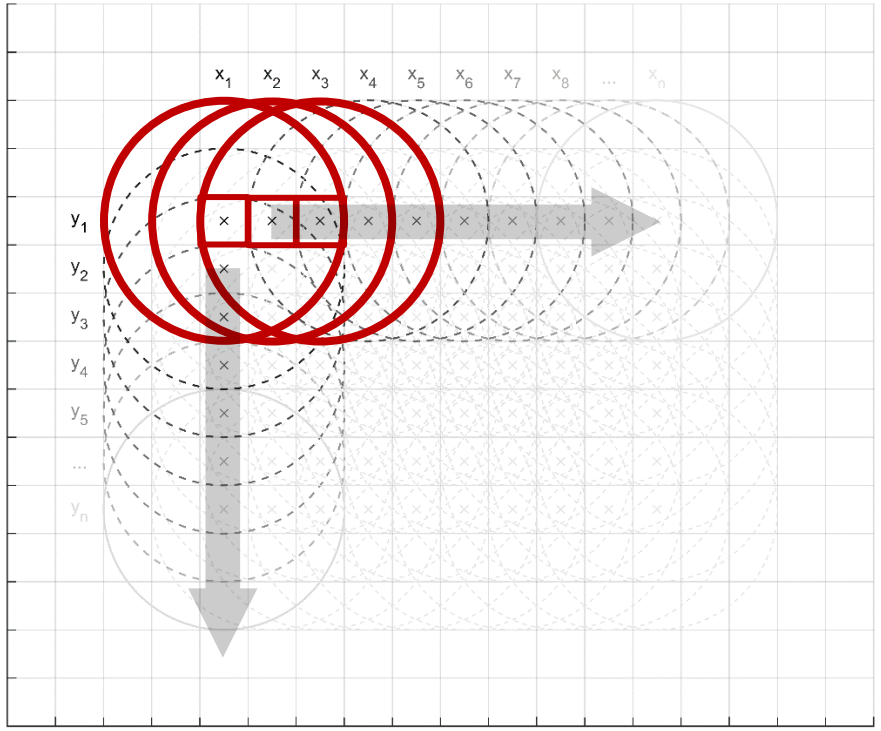
Schneider, et al. (2017) Nature Communications

Mapping Functional Diversity

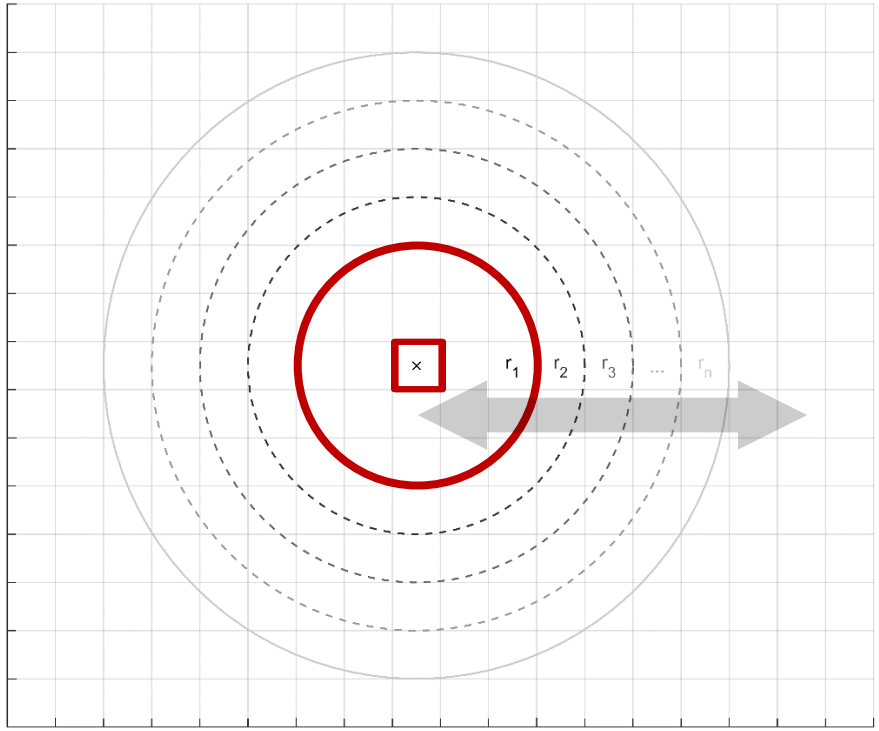
Continuous Diversity Mapping

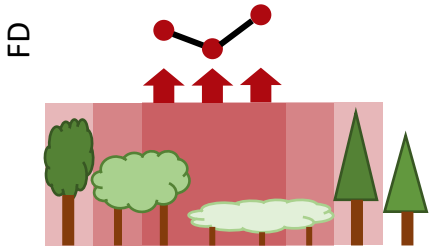
From Traits to Diversity

Moving-Window



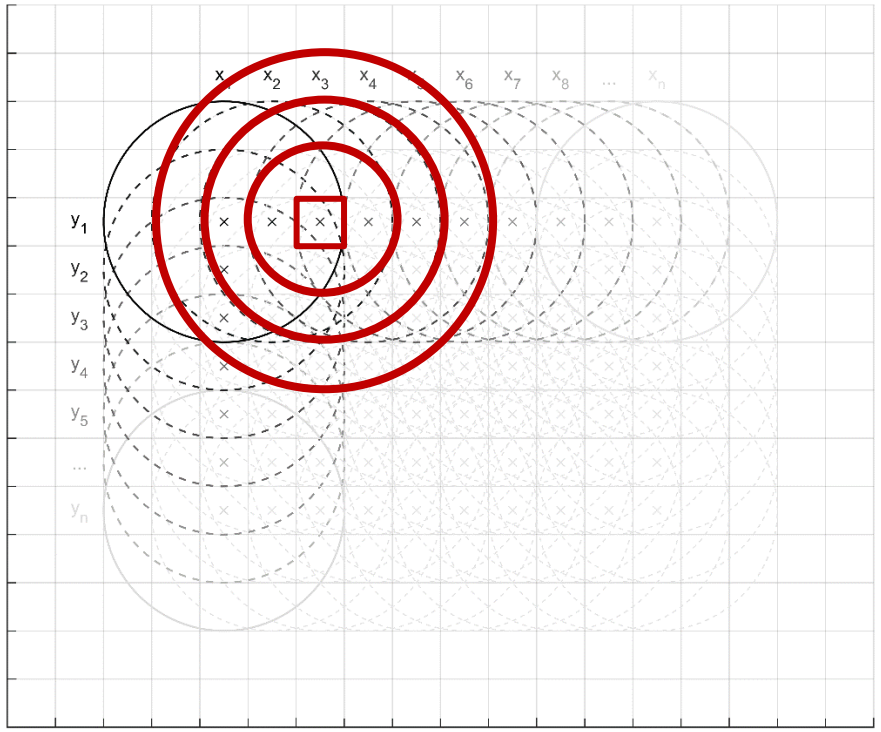
Radius



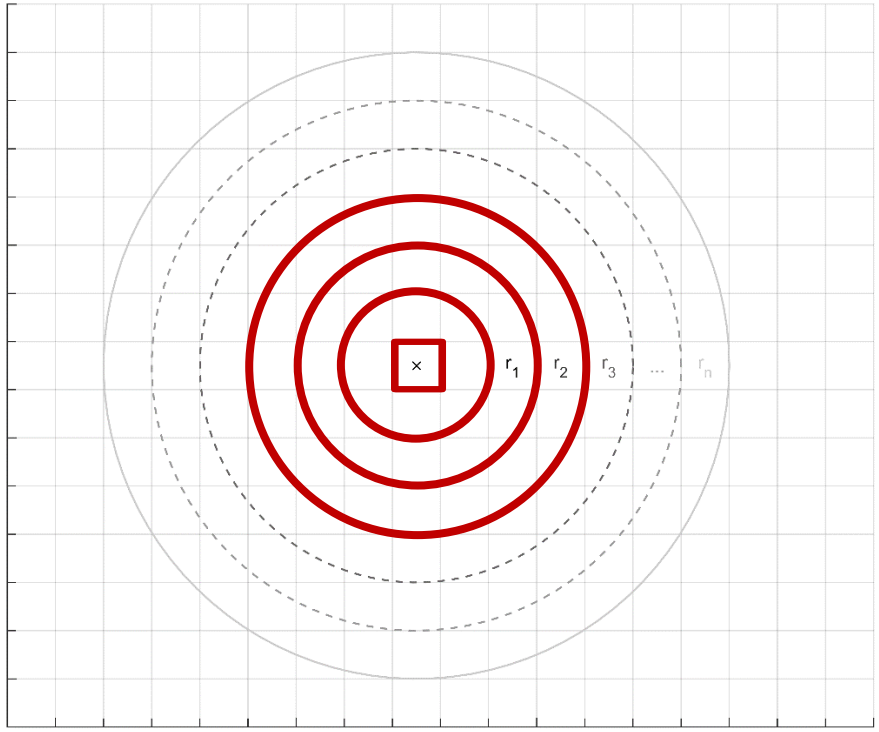


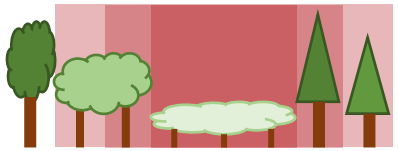
Continuous Diversity Mapping

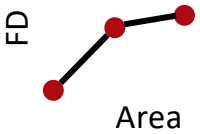
From Traits to Diversity



Radius

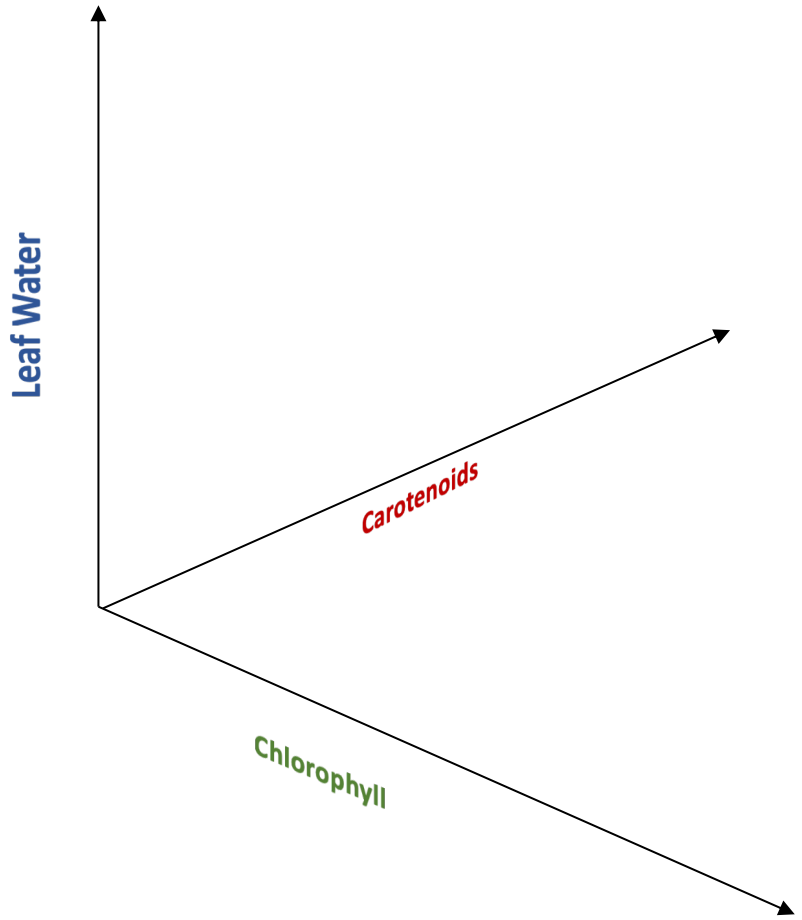


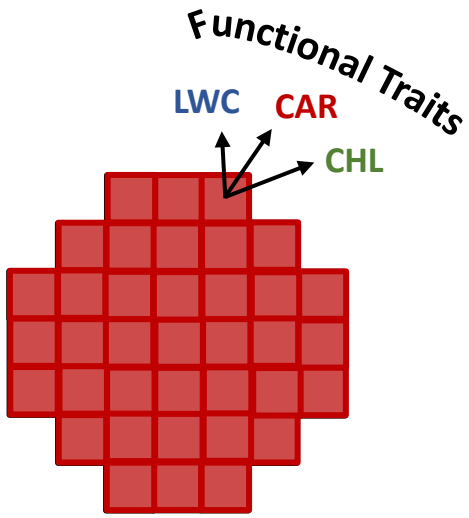




Functional Diversity Measures

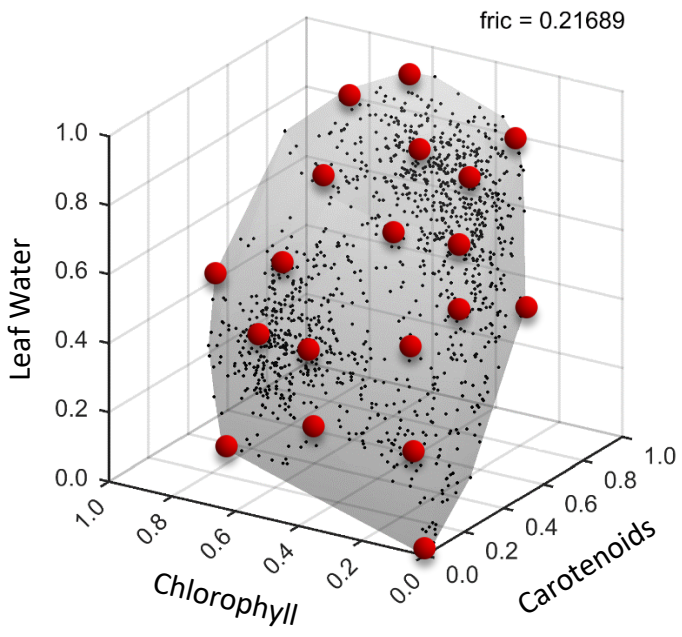
Analyzing the Trait Space



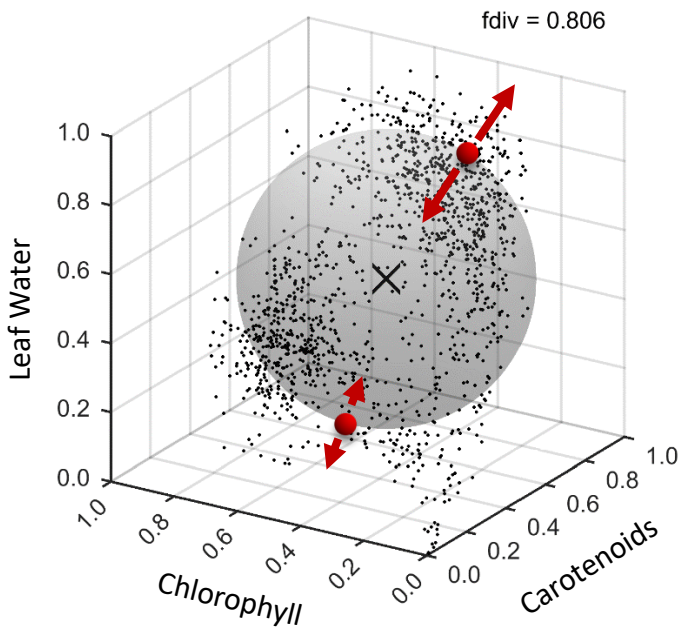


Functional Diversity Measures

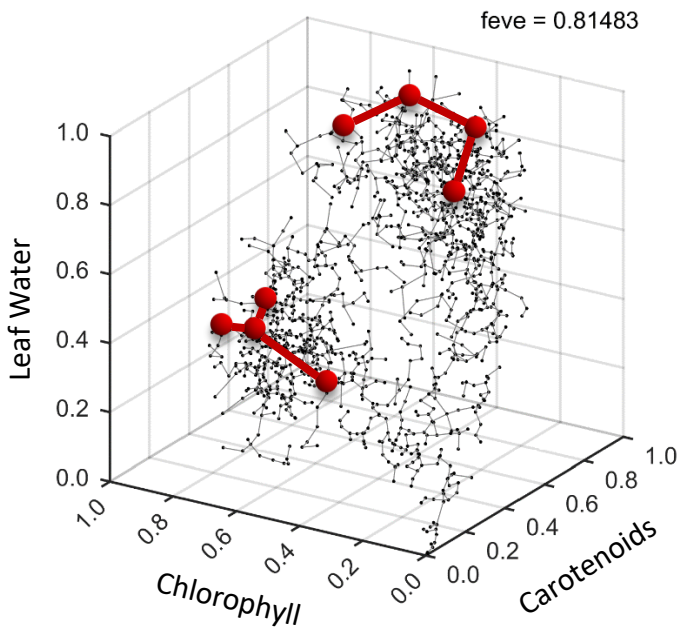
Analyzing the Trait Space



Functional Richness

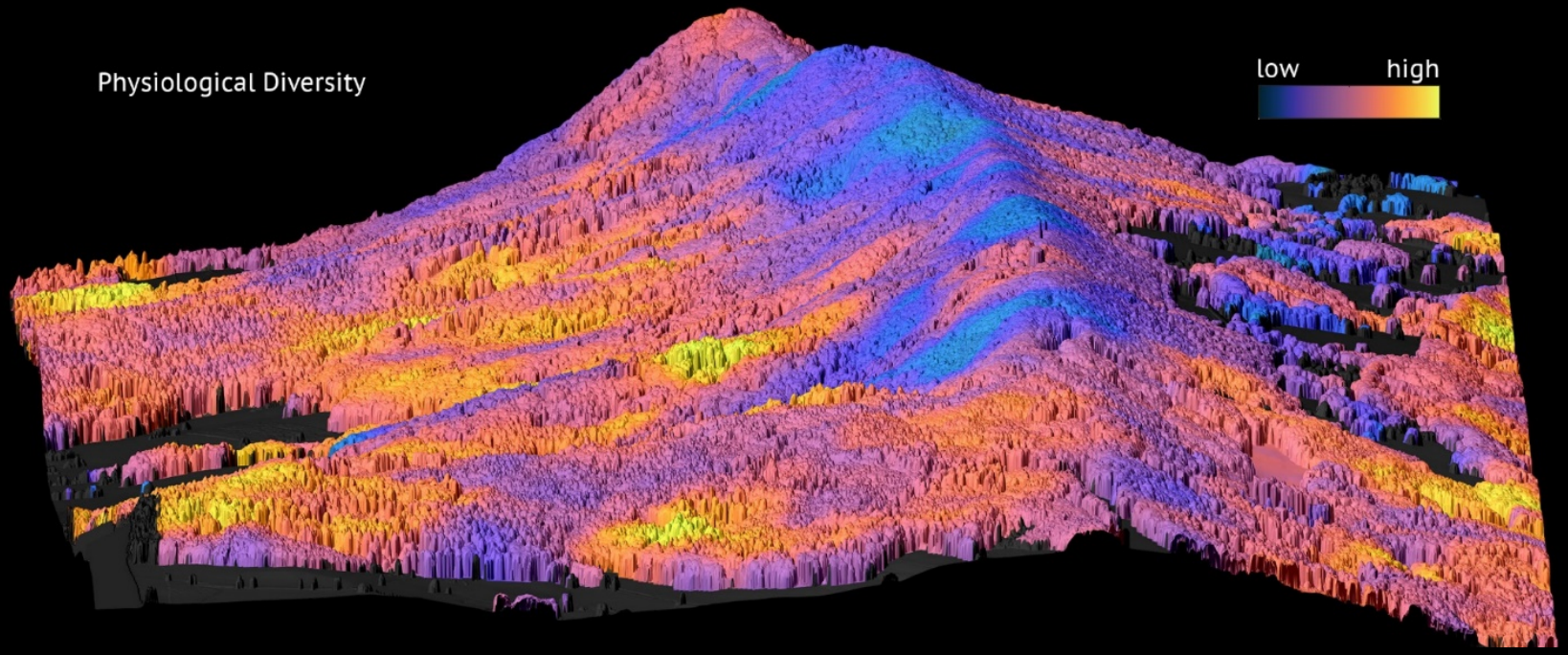


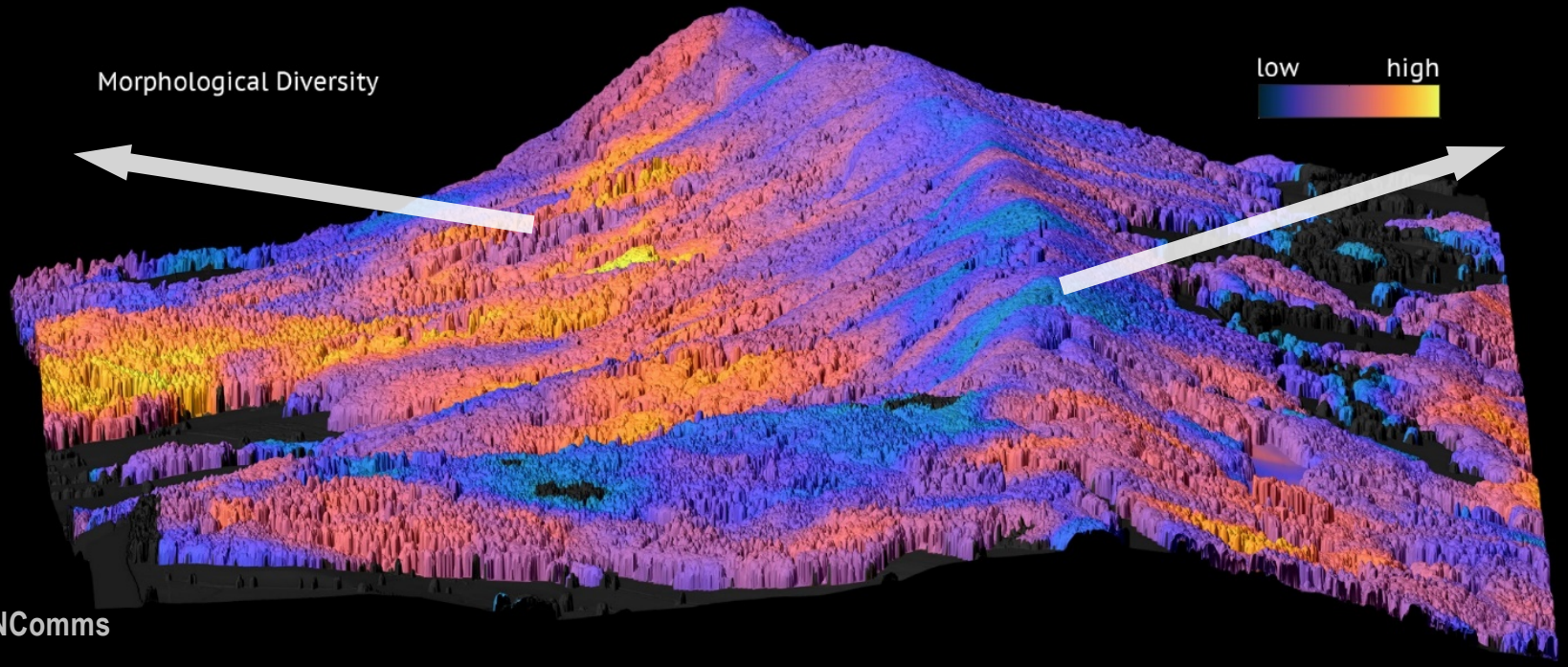
Functional Divergence



Functional Evenness

Schneider, et al. (2017) NComms; Villéger, et al. (2008) Ecology





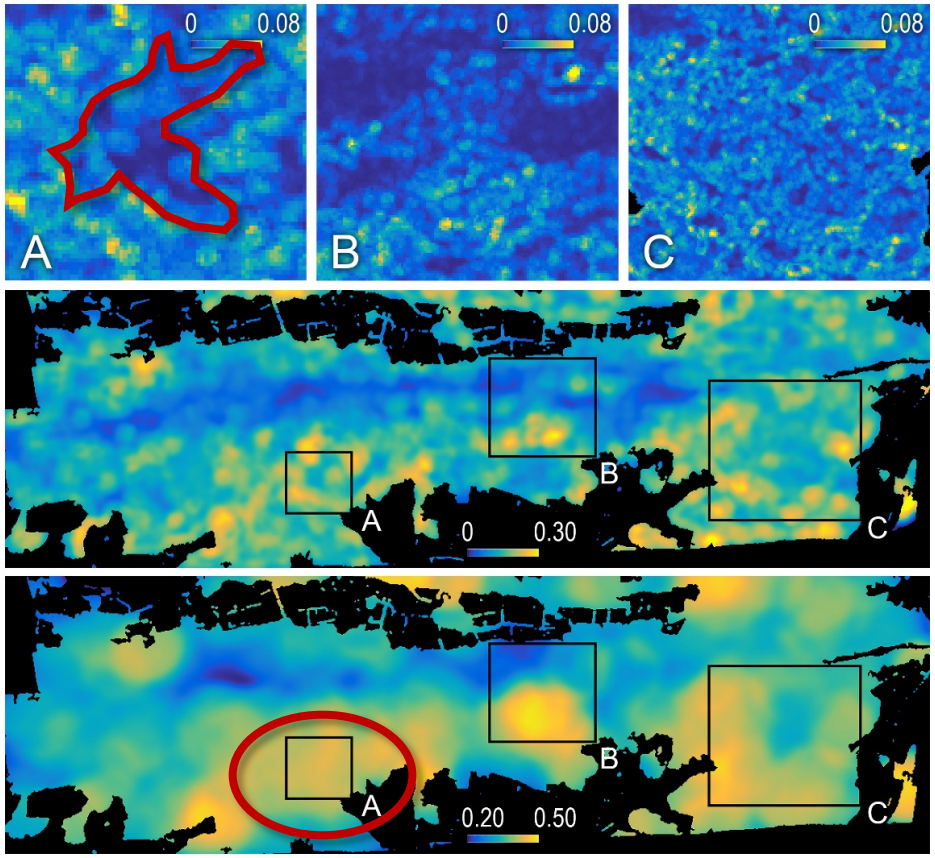
Photos: edaskliokys.ch, rainolo.ch

Schneider, et al. (2017) NComms

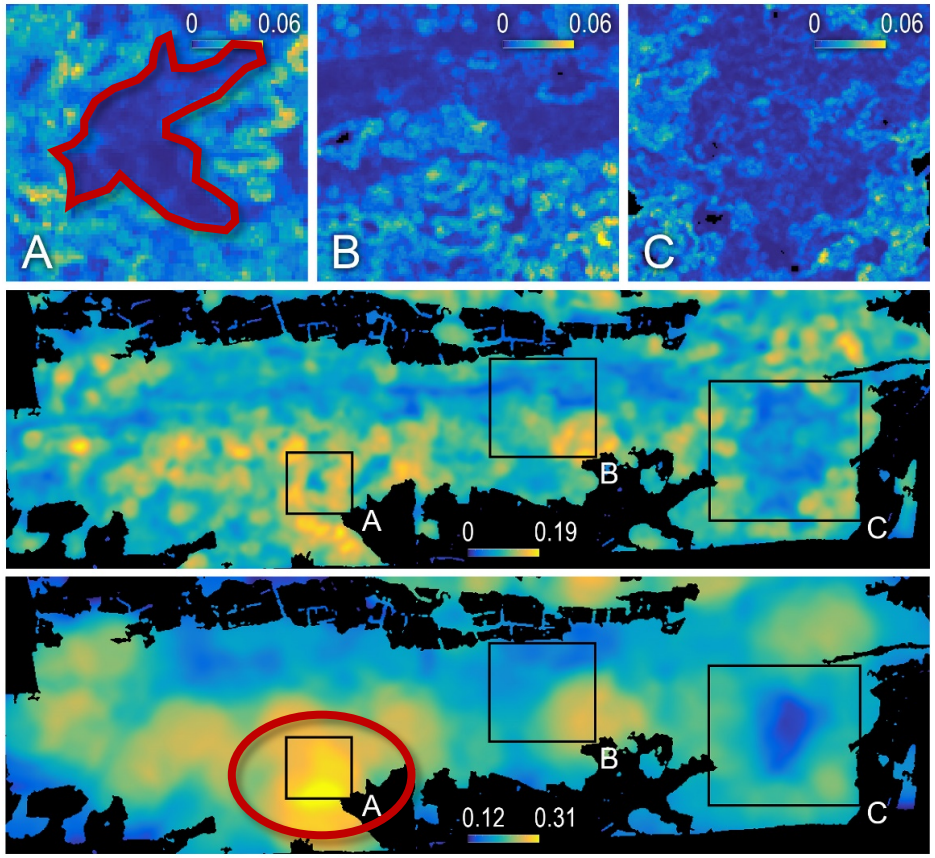
Scale Dependence of Diversity

Diversity-Area Relationship

Physiological Richness



Morphological Richness



12 m Radius

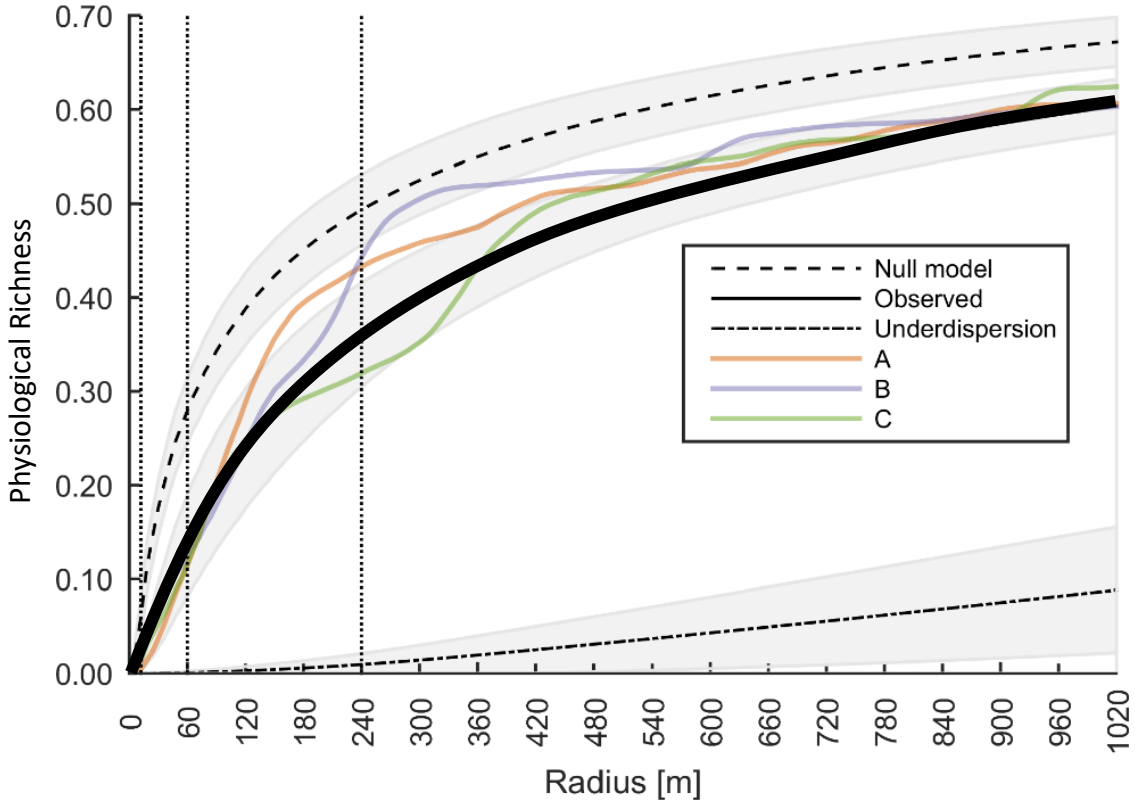
60 m Radius

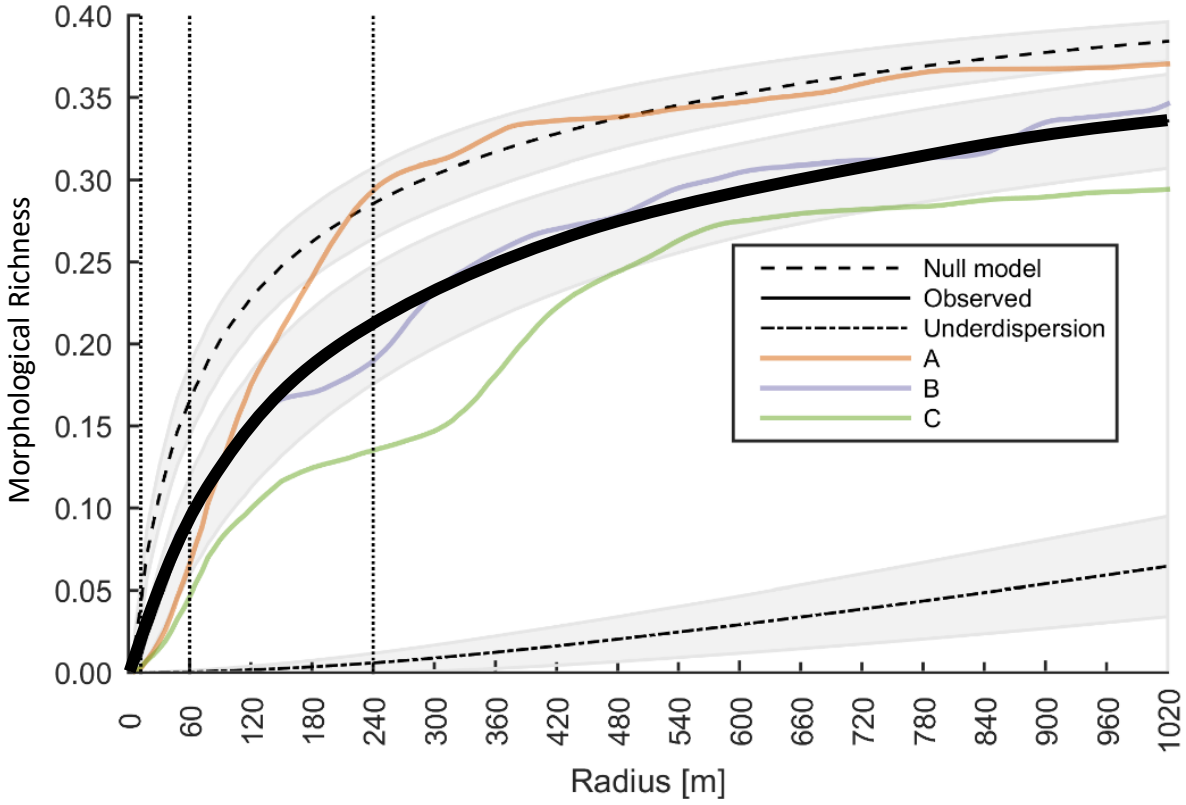
240 m Radius

Schneider, et al. (2017) NComms

Scale Dependence of Diversity

Diversity-Area Relationship

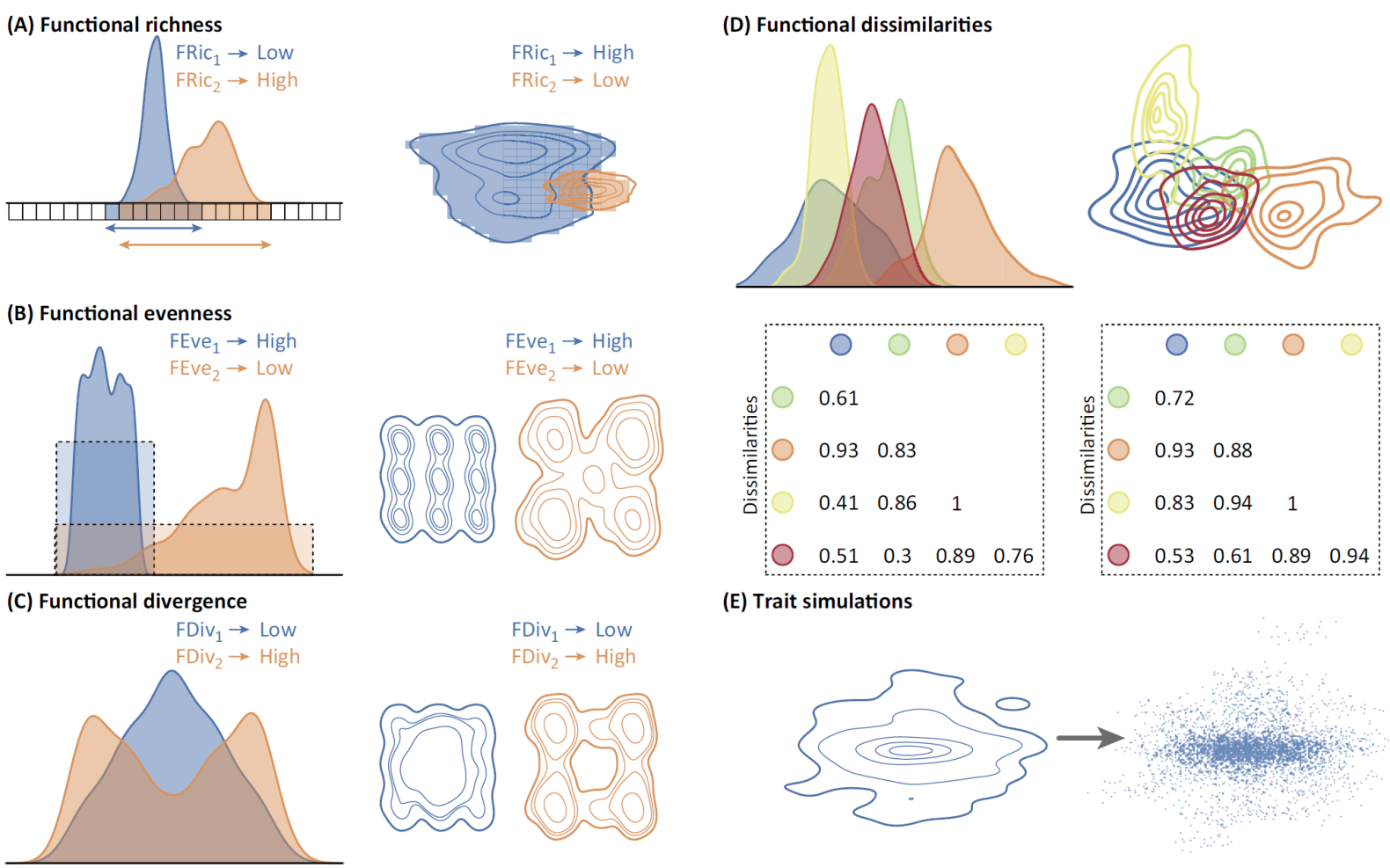


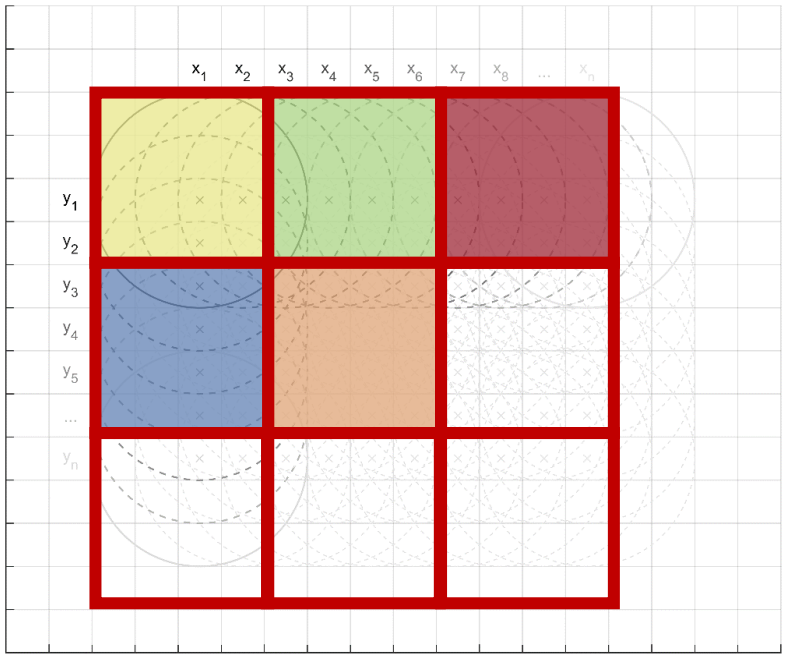


Schneider, et al. (2017) NComms

Trait Probability Density

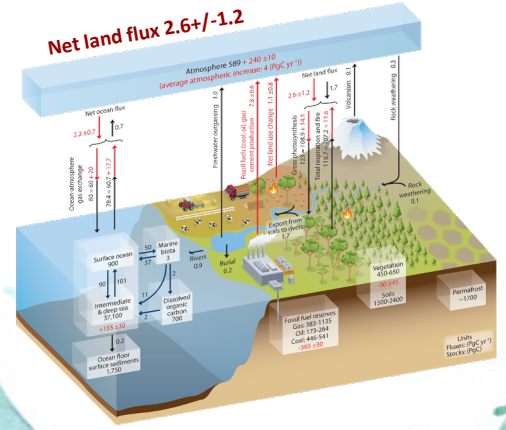
Niche as probabilistic hypervolume





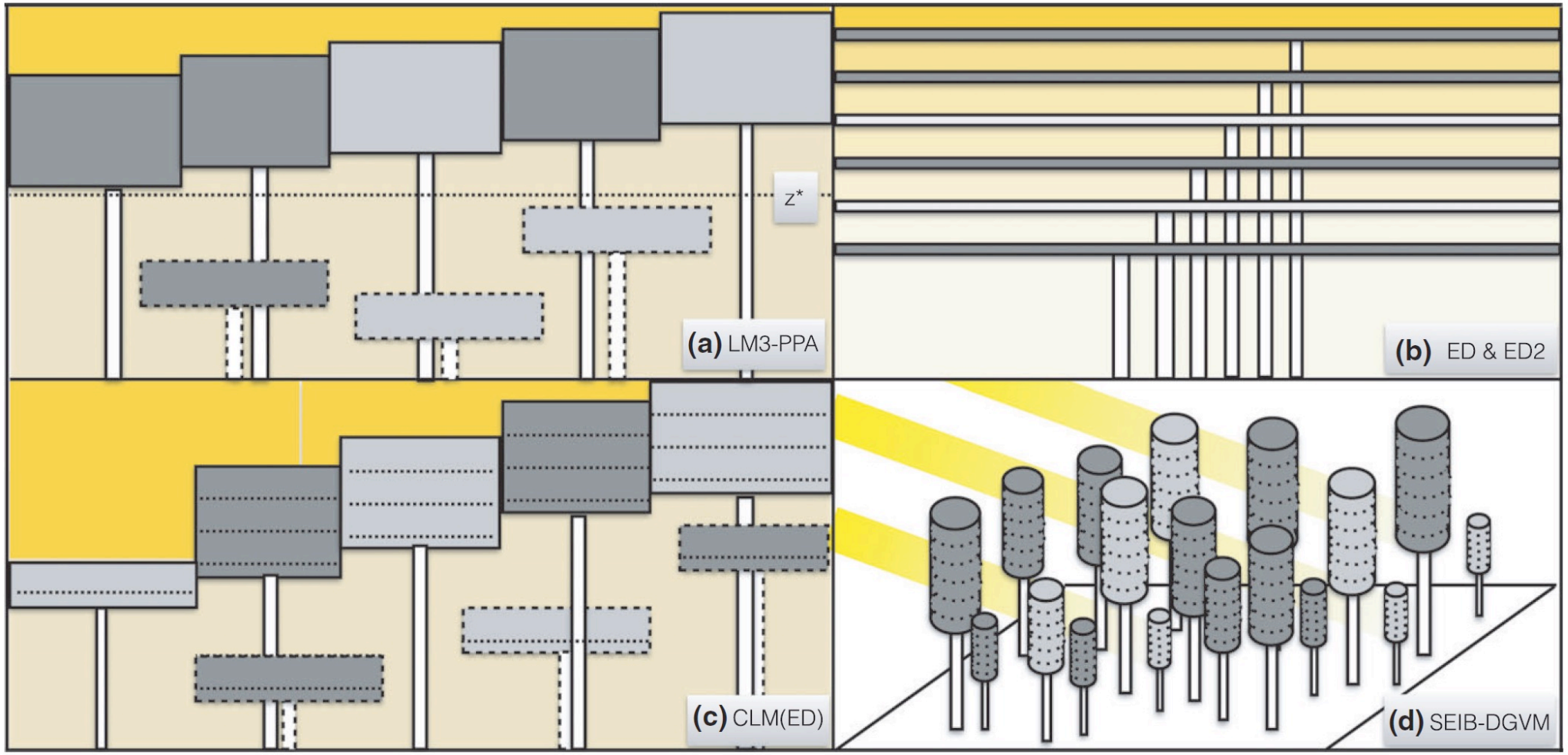
Carmona, et al. (2016) TREE

From Diversity to Functioning



Ecosystem Demography ED2

A cohort-based dynamic vegetation model

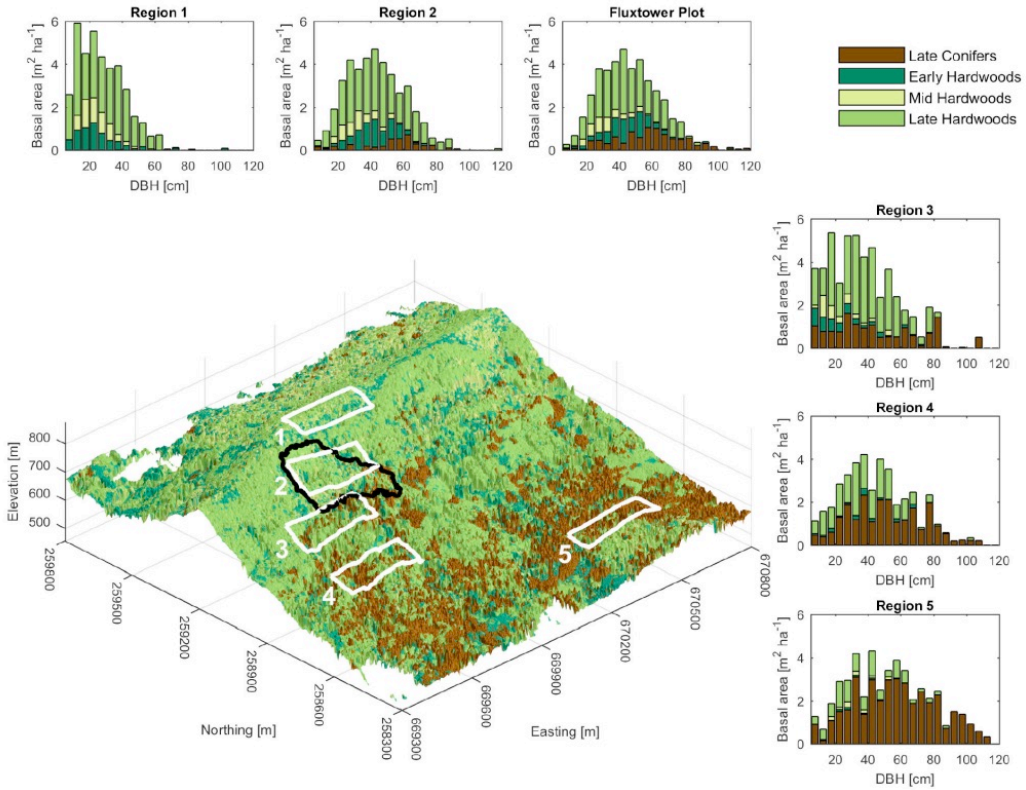


Fisher, et al. (2017) GCB

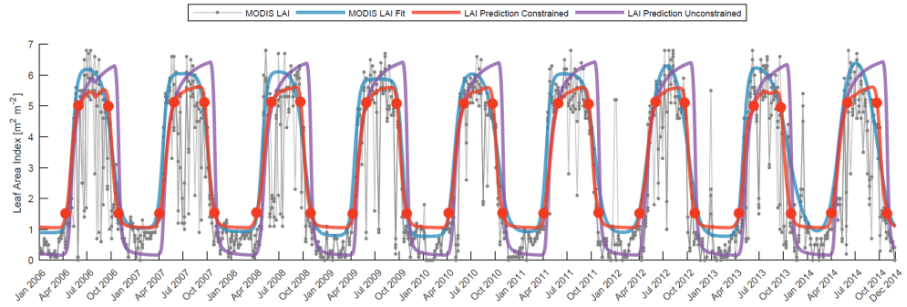
From Diversity to Functioning

Informing an Ecosystem Model with Remote Sensing Data

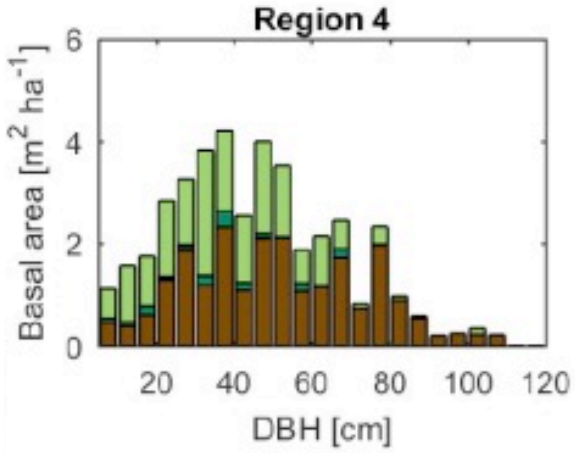
- Composition, Structure, Phenology



Phenology



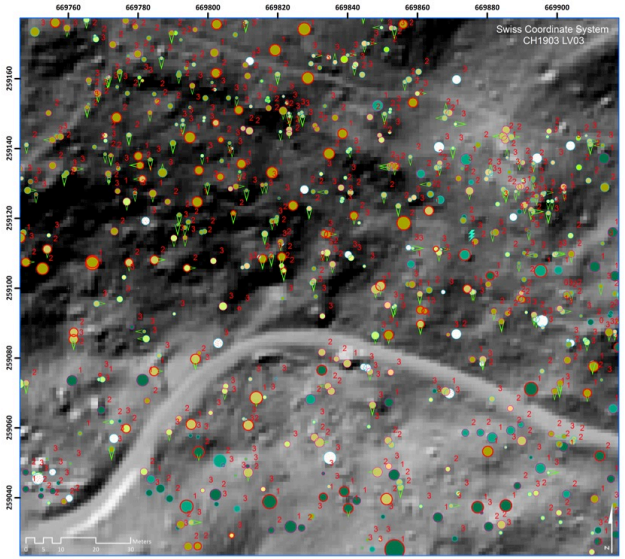
Structure
Composition



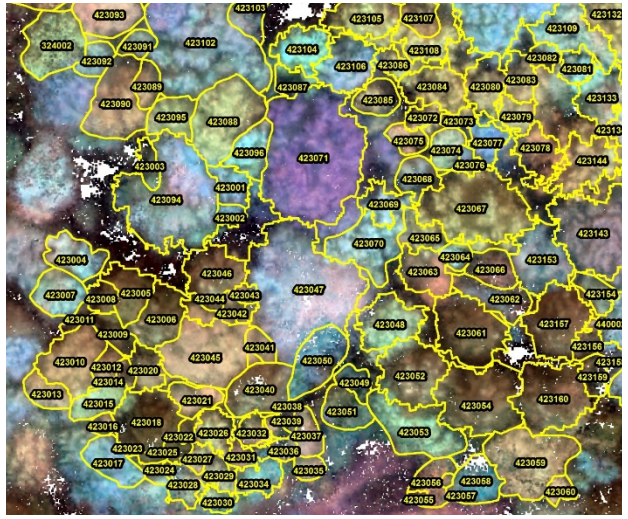
Schneider, et al. in preparation; Moorcroft, et al. (2001) EM

Composition

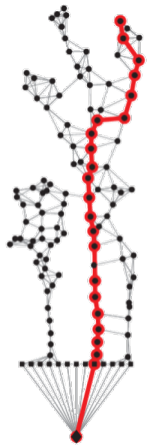
PFT classification using ground data and random forest classifier



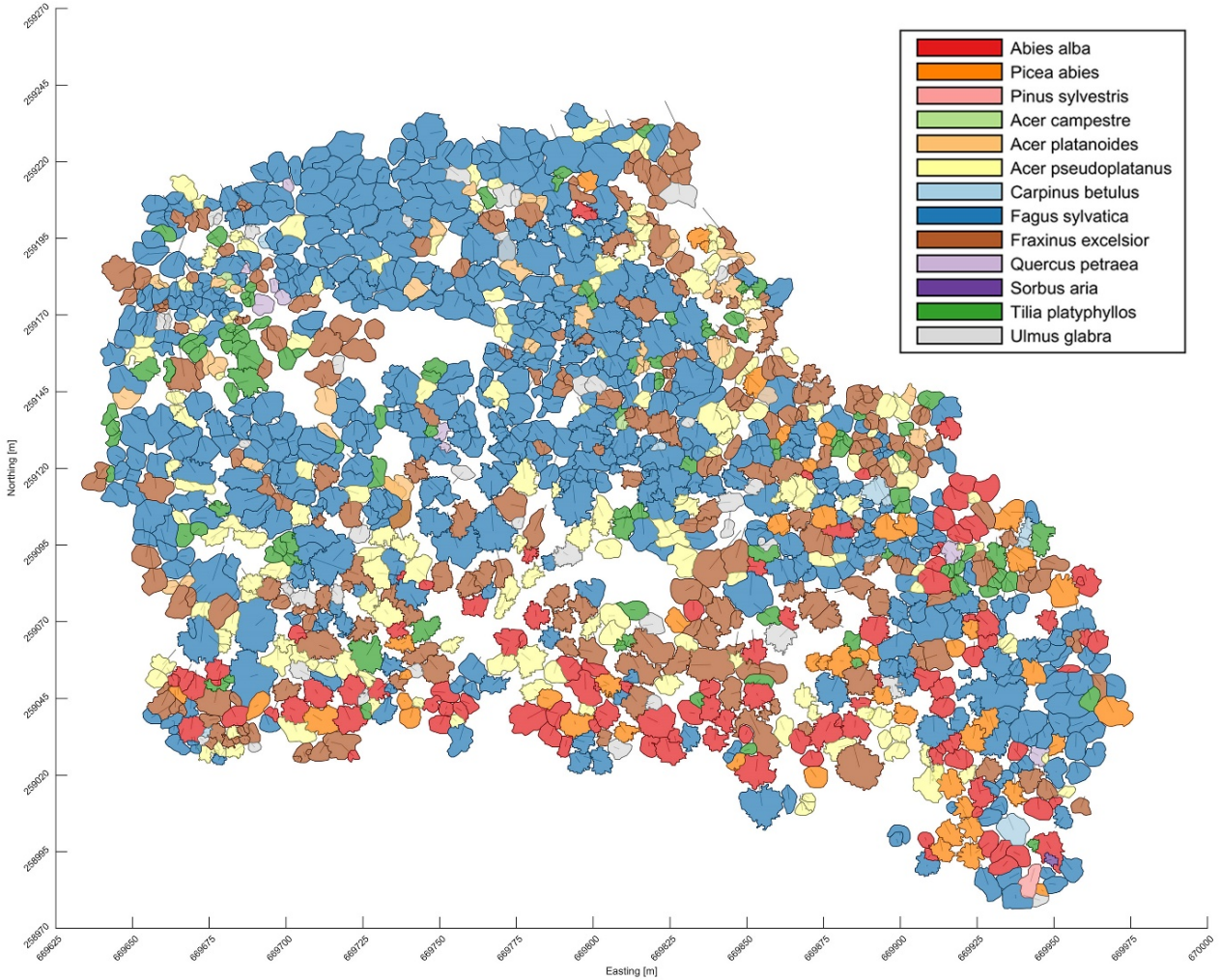
Ground Measurements



Crown Map

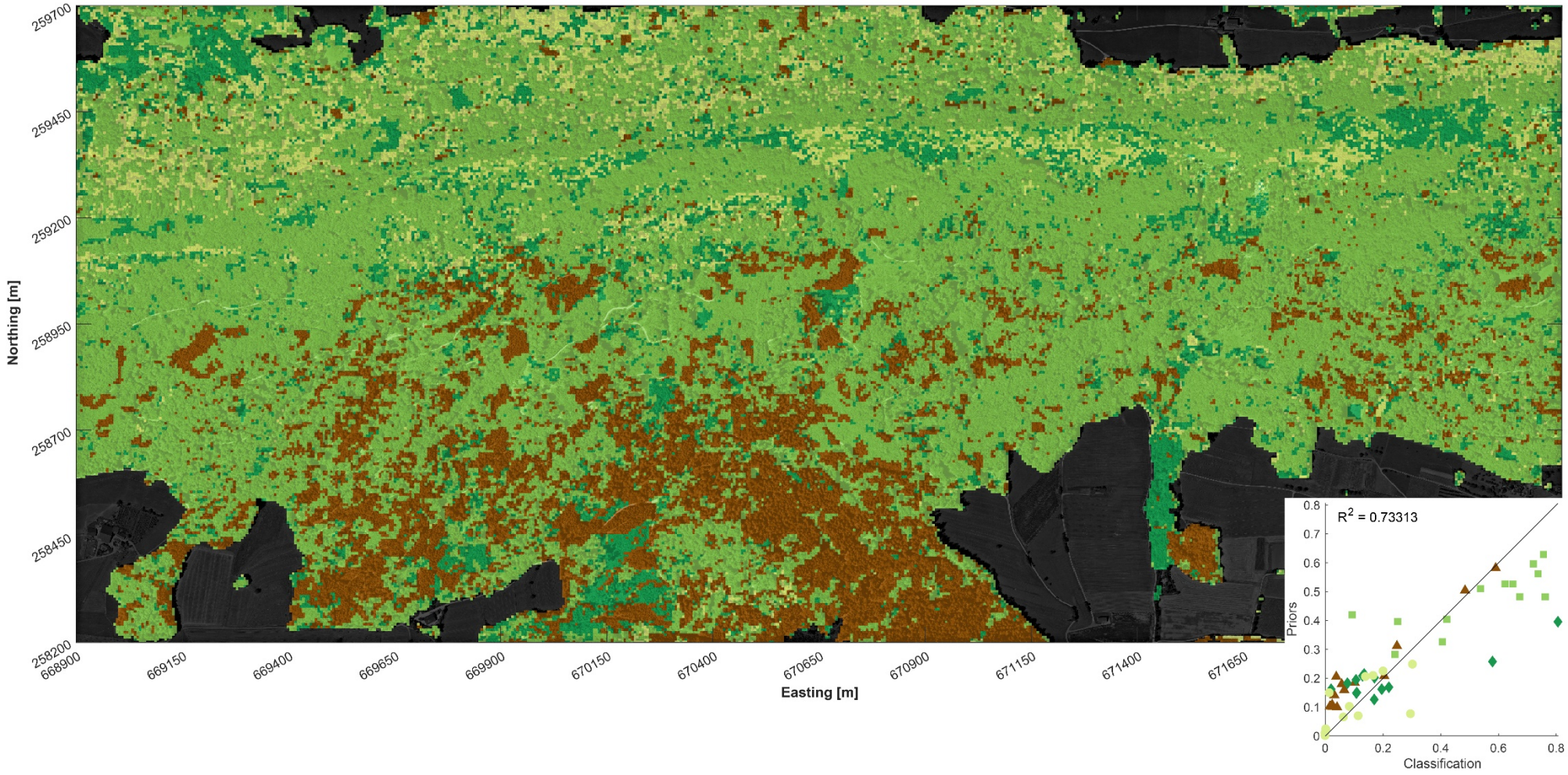


Parkan & Tuia (2015)



Composition

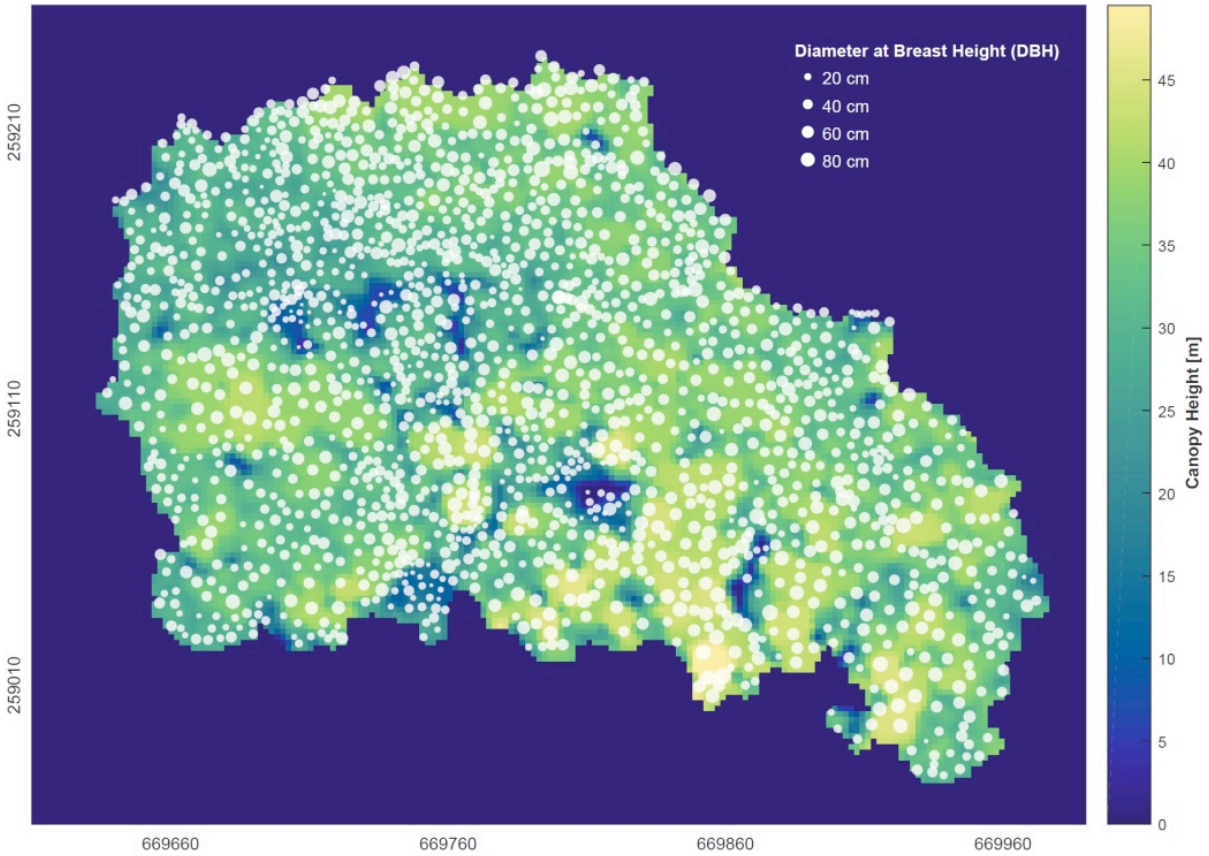
PFT classification using ground data and random forest classifier

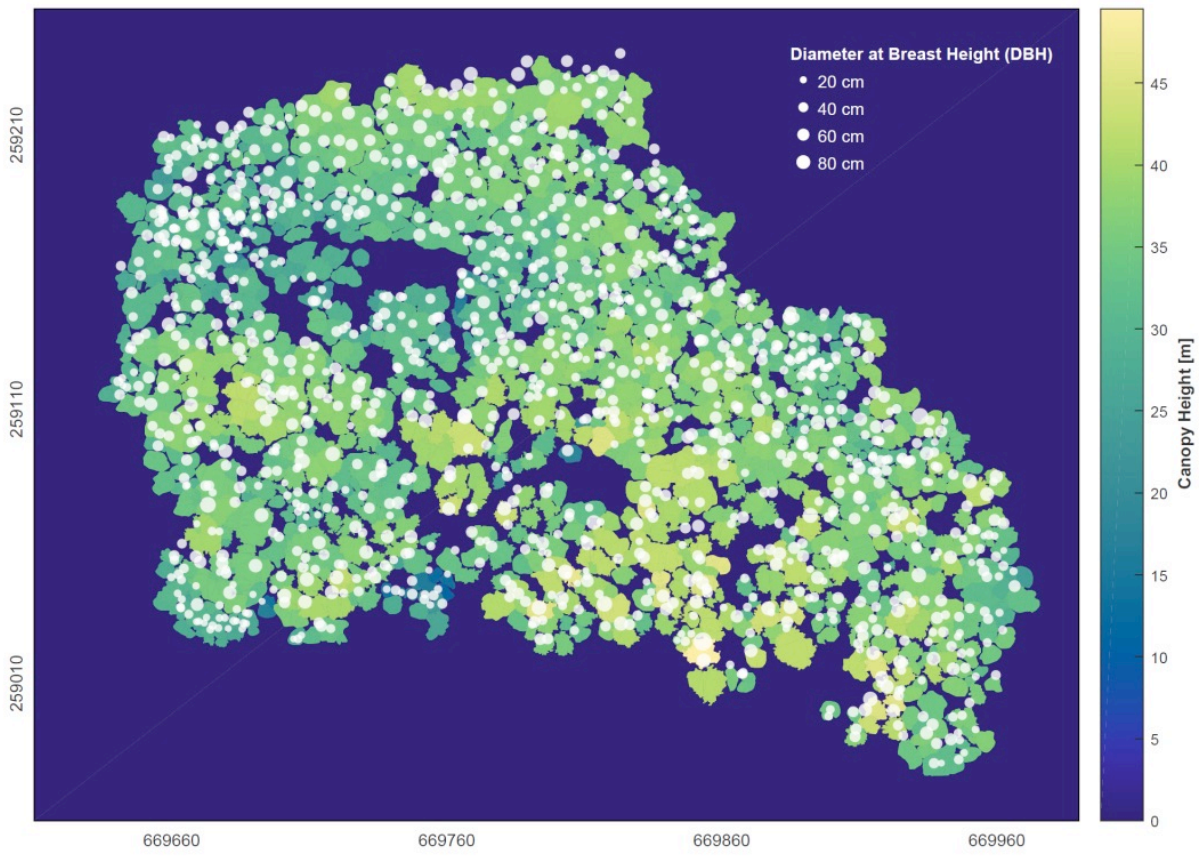


Late Conifers
Early Hardwoods
Mid Hardwoods
Late Hardwoods

Size Distributions

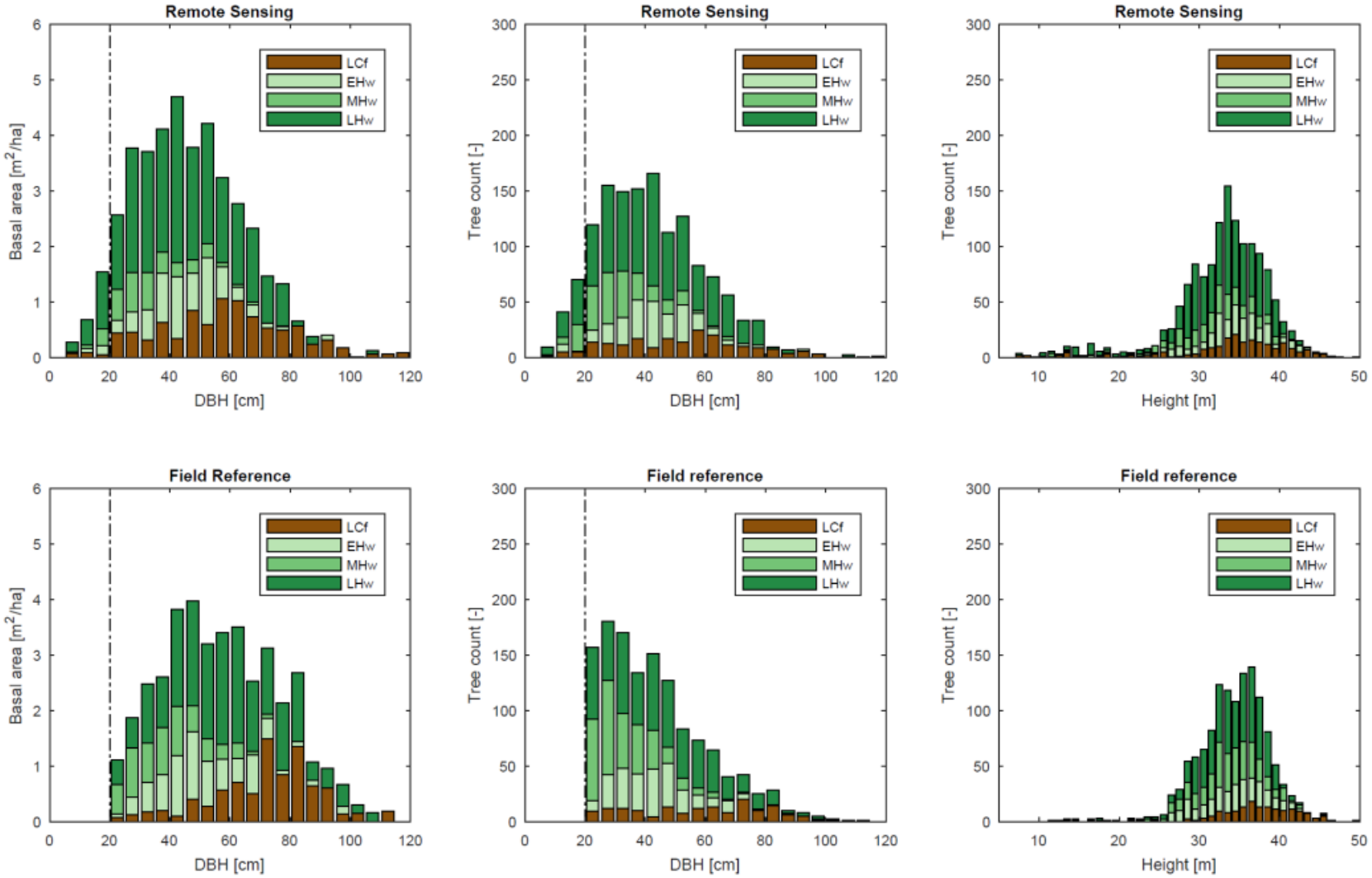
Diameter at Breast Height (DBH), Basal Area, Height





Size Distributions

Diameter at Breast Height (DBH), Basal Area, Height



Remote Sensing

Field Measurements

Predicting Carbon Uptake

RS Data to Improve Model Predictions in ED2

Fluxtower

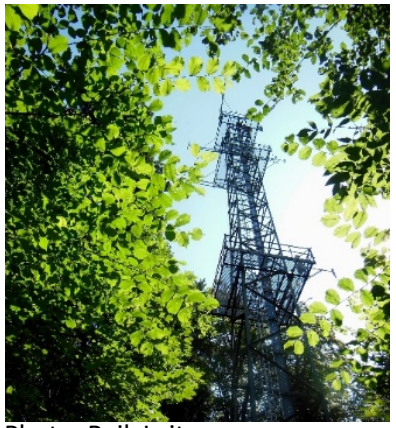
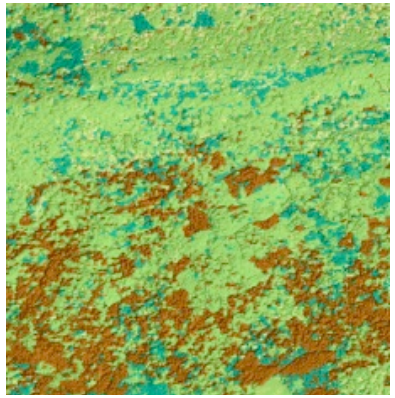
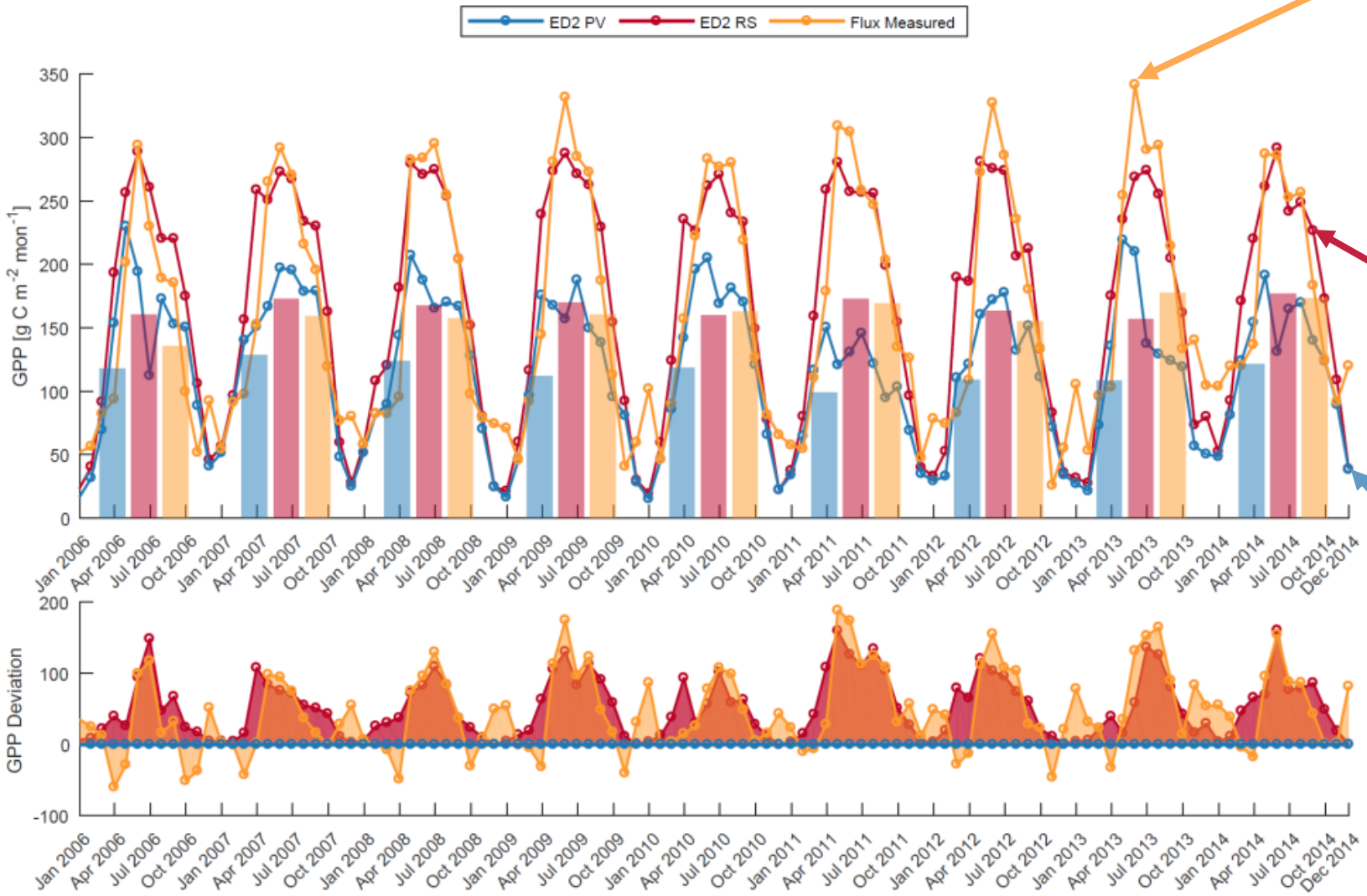


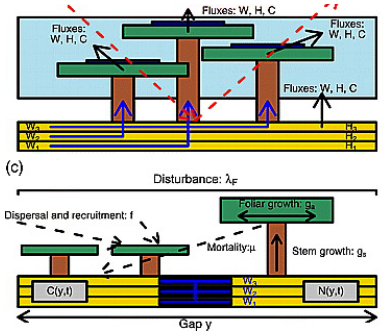
Photo: Reik Leiterer

RS informed





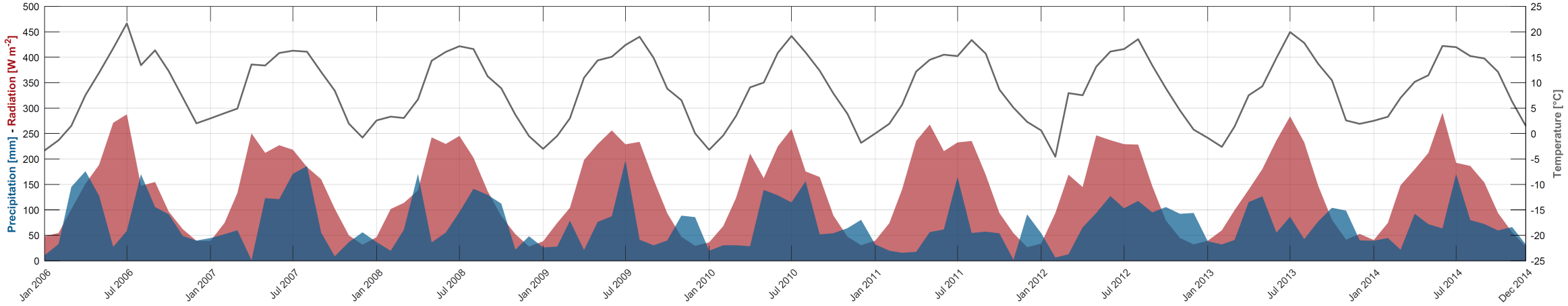
Uninformed model

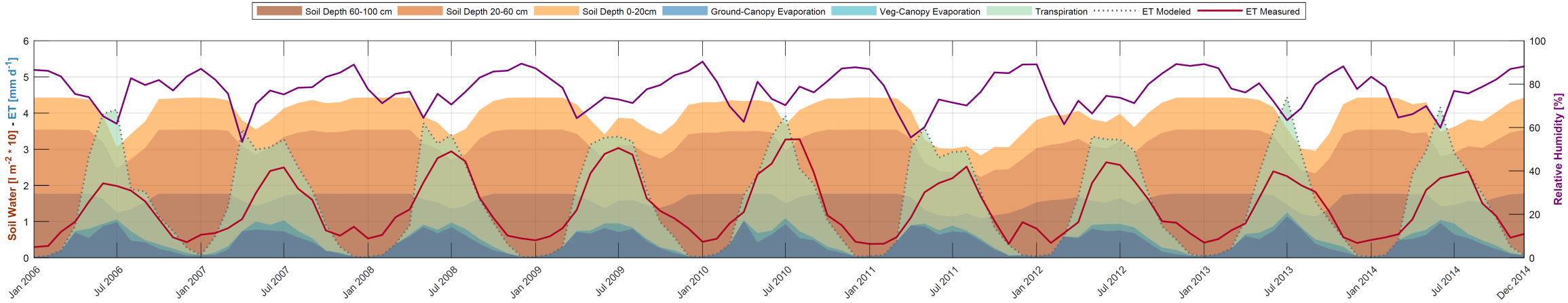


Schneider, et al. in preparation; Moorcroft, et al. (2001) EM

ED2 Outputs

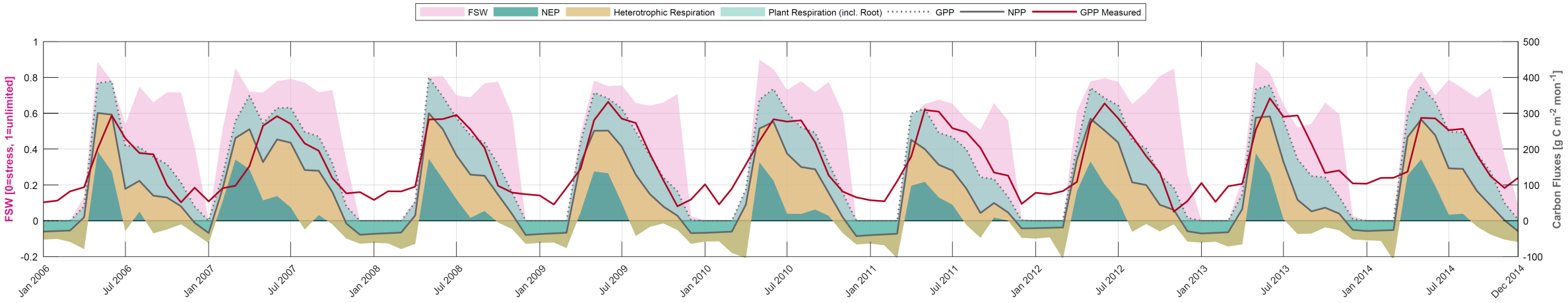
Meteo drivers, soil water and evapotranspiration (ET)

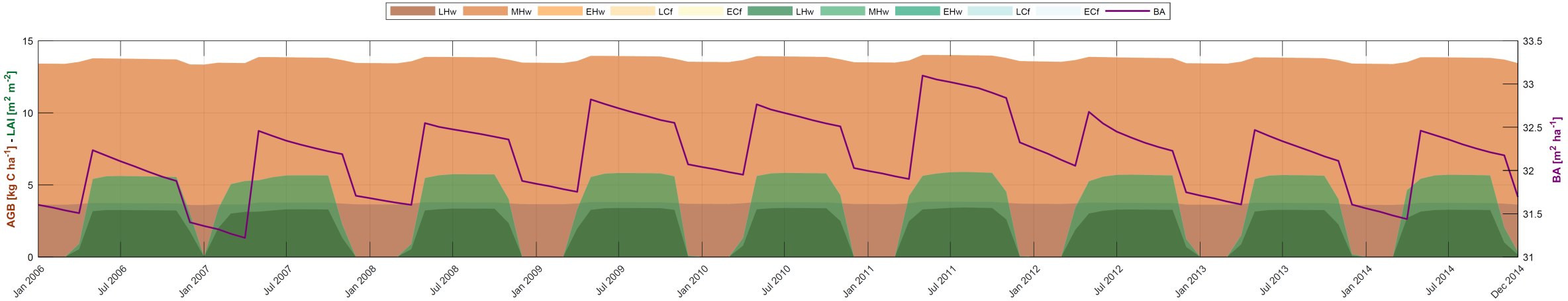




ED2 Outputs

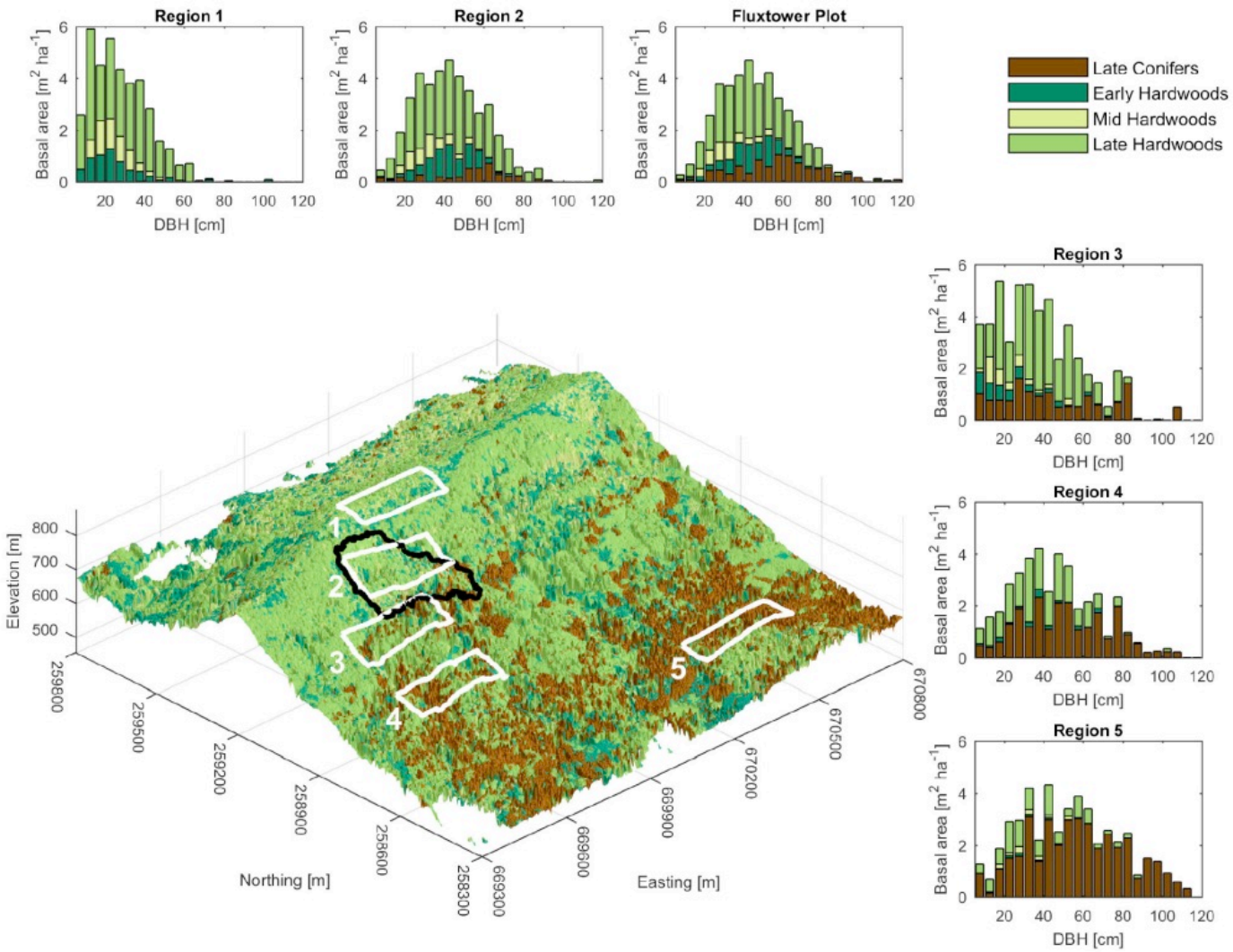
Carbon fluxes (GPP, NEP, R), leaf area index (LAI), above ground biomass (AGB), basal area (BA)

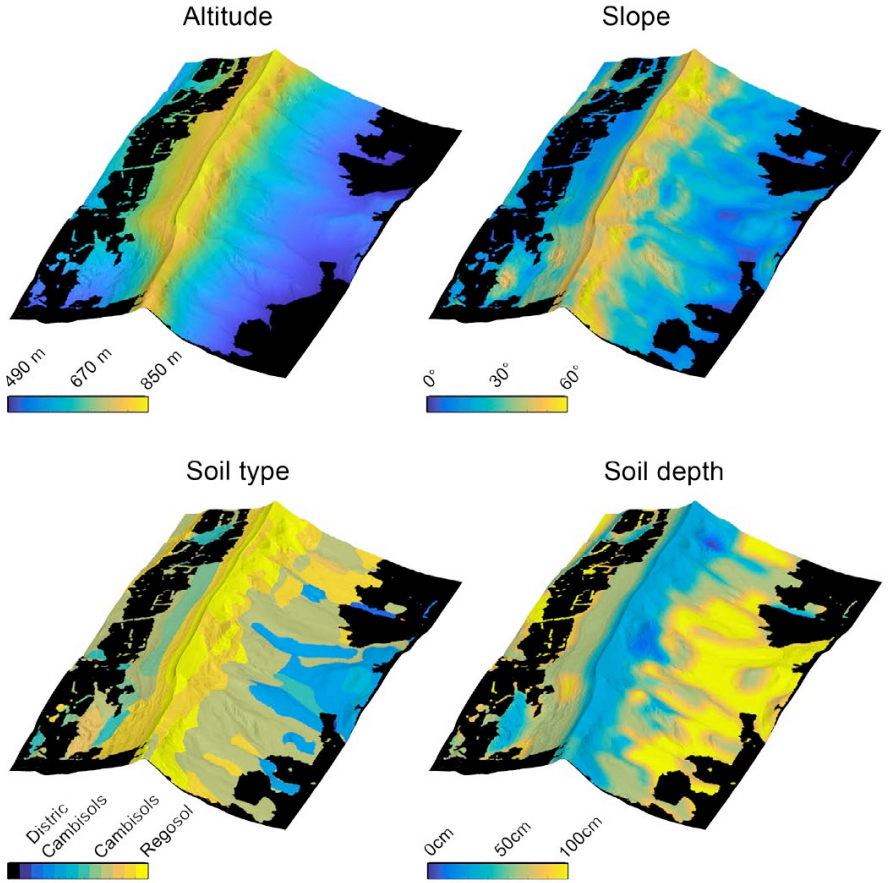




Diversity-Productivity Relationship

Along an environmental gradient – with changing soil and topography





Conclusion

Part I

- How can we derive morphological and physiological traits consistently in space and how can we compare and validate them?
    - Airborne **laser scanning** allows to derive morphological traits at canopy scale
    - Airborne **imaging spectroscopy** allows to derive physiological traits at leaf scale
    - **Radiative transfer** modeling can make the datasets comparable and allows to test the scaling from leaf to canopy level

Conclusion

Part II

- How can we map functional diversity from remotely sensed morphological and physiological forest traits, and what spatial patterns can be revealed from those traits?
    - **Moving window** approach for continuous diversity mapping, comparable across scales
    - **Functional richness** as a simple and effective way to map functional diversity
    - Strong **elevation gradient** from more diverse forest in lower elevations to lower diversity forest at the top under harsh environmental conditions

Conclusion

Part III

- How can we integrate remote sensing data into an ecological model to predict diversity-productivity relationships?

  - Size distribution: Tree height, density and DBH to estimate basal area from lidar
  - Vertical profiles of plant area density

  - Composition: Random forest PFT classification using both lidar and spectroscopy

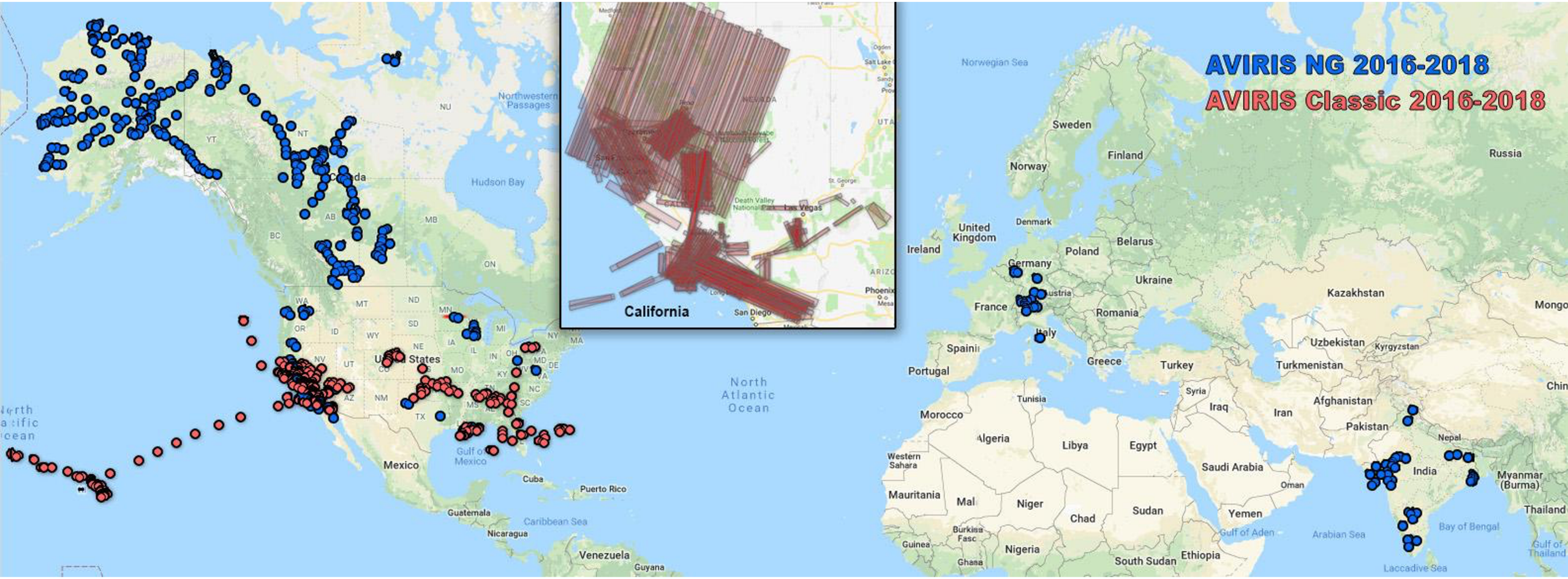
  - Driven by meteorology, ED2 can accurately predict carbon (GPP, NEP, R) and water fluxes (ET)

Outlook

- What is the relationship between functional diversity and productivity at a temperate mixed forest site, and what is driving it (structure, composition, environment)?
- Study functional diversity within and across biomes and ecosystems
- Scale trait and diversity mapping to large-scale spaceborne observations

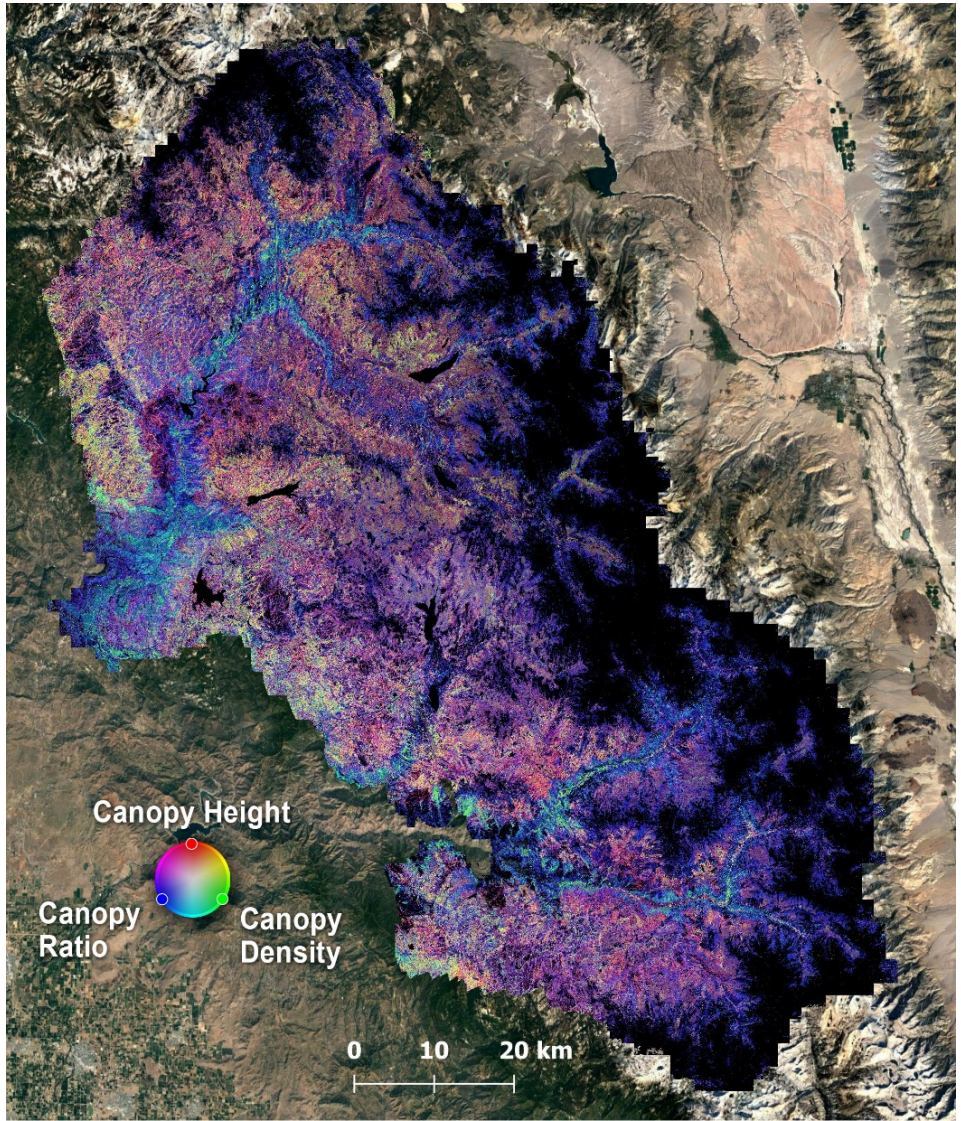
Imaging Spectroscopy Data across Biomes

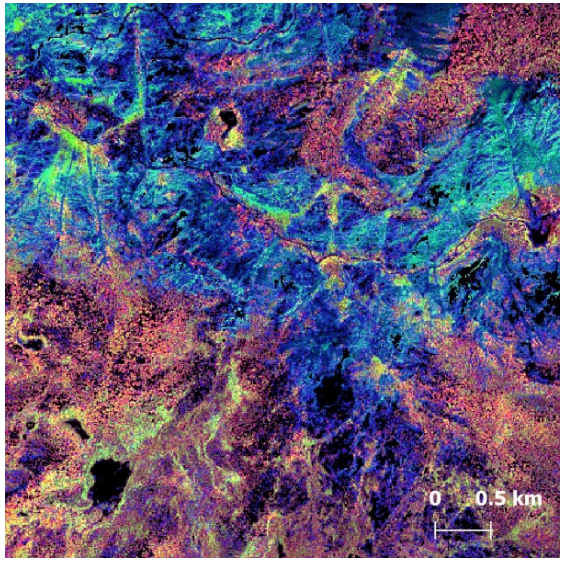
Map of AVIRIS coverage 2016-2018

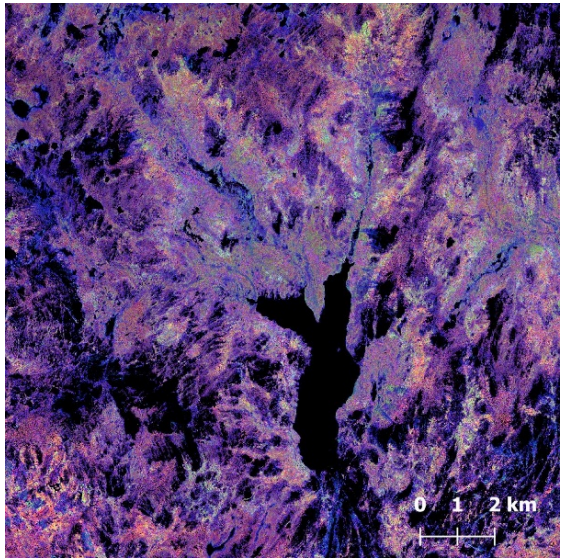


Up-Scaling of Trait and Diversity Mapping

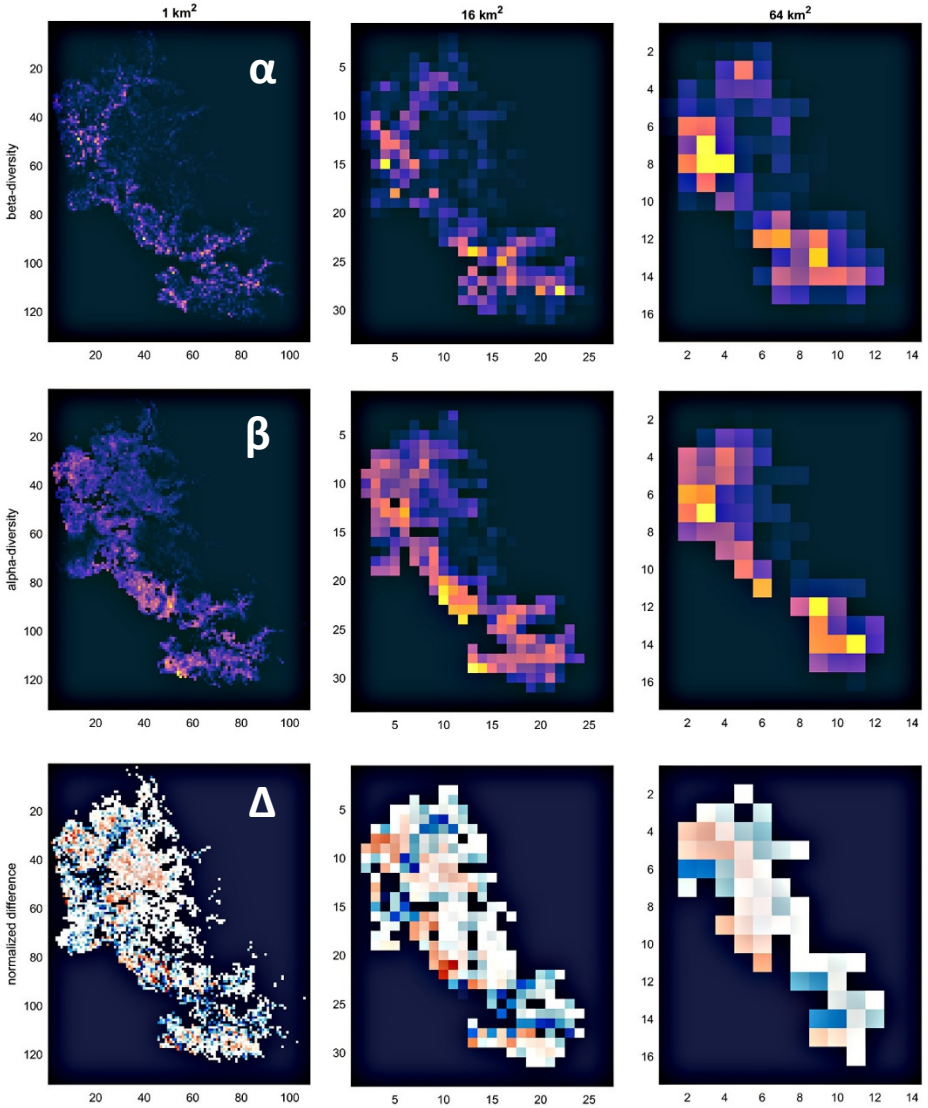
Sierra Nevada - Large-scale lidar and imaging spectroscopy data





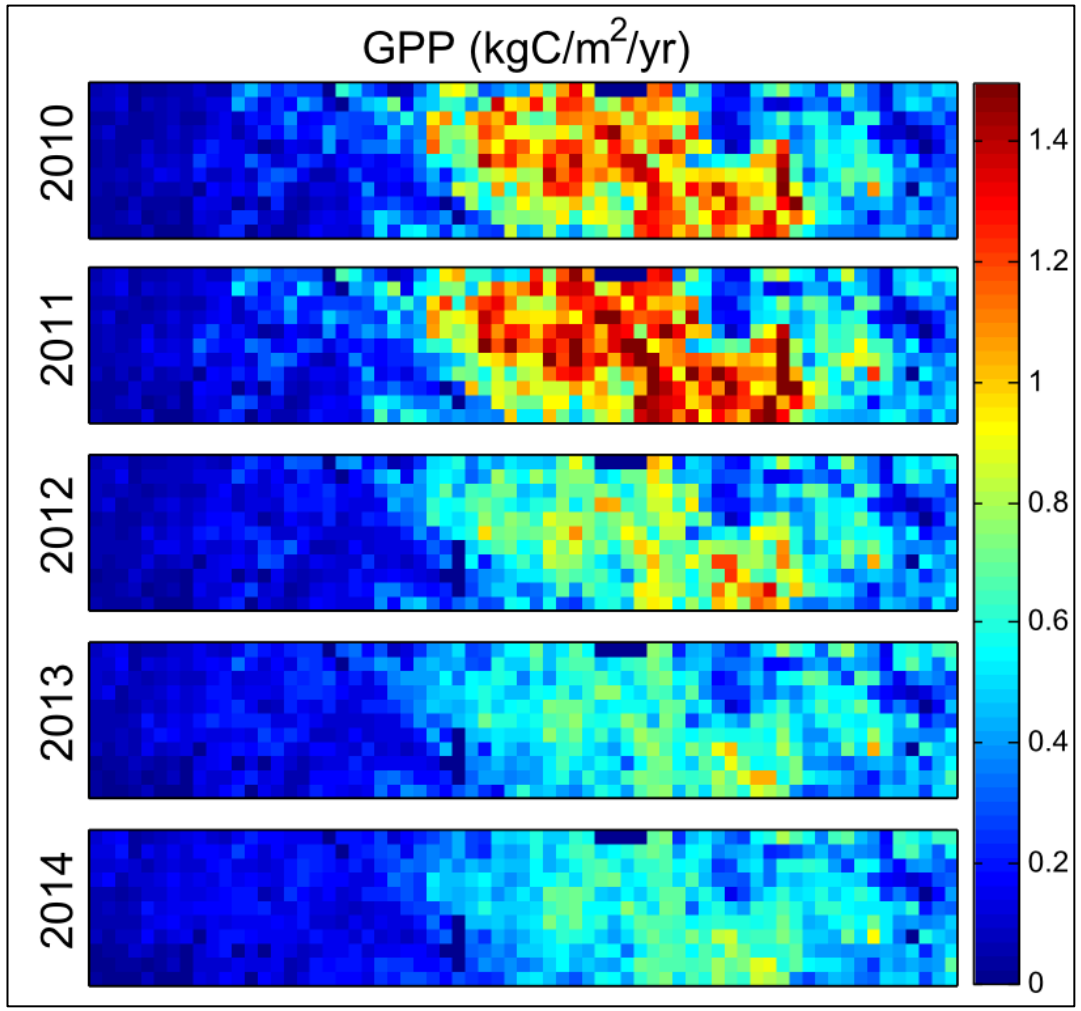


Functional Richness at 1 - 16 - 64 km^2 scale



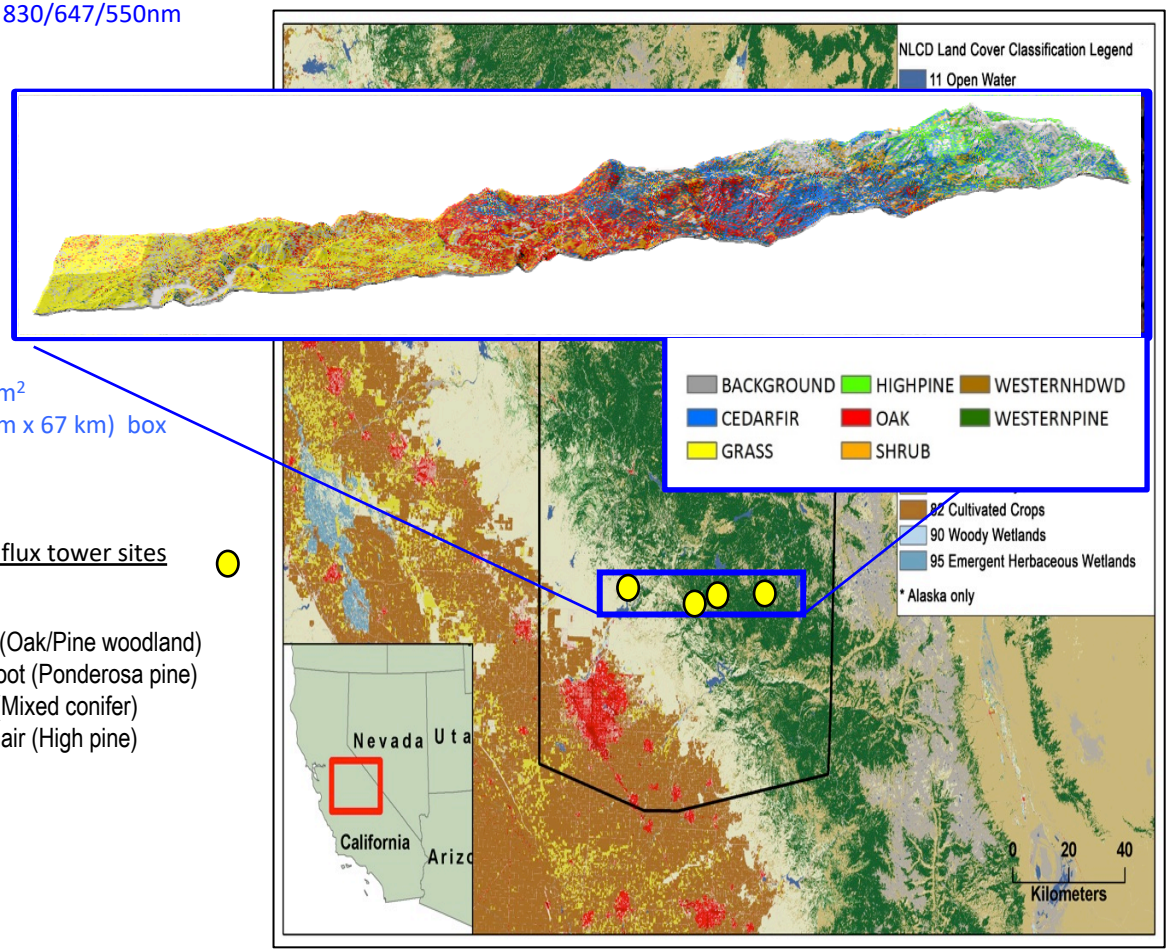
Ecological Modeling at Larger Scales

ED2 modeling over the Sierra Nevada mountains



June 2013 acquisition
RGB 830/647/550nm

(Bogan et al., in revision)



737km^2
(11 km x 67 km) box

CZO flux tower sites

SJER (Oak/Pine woodland)
Soaproot (Ponderosa pine)
P301 (Mixed conifer)
Shorthair (High pine)

Thank you

Michael Schaepman, Felix Morsdorf,
Bernhard Schmid, Paul Moorcroft, David Schimel,
Phil Townsend, Tom Painter, Marcos Longo,
Antonio Ferraz, Ryan Pavlick

URPP Global Change and Biodiversity

Jet Propulsion Laboratory
California Institute of Technology

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