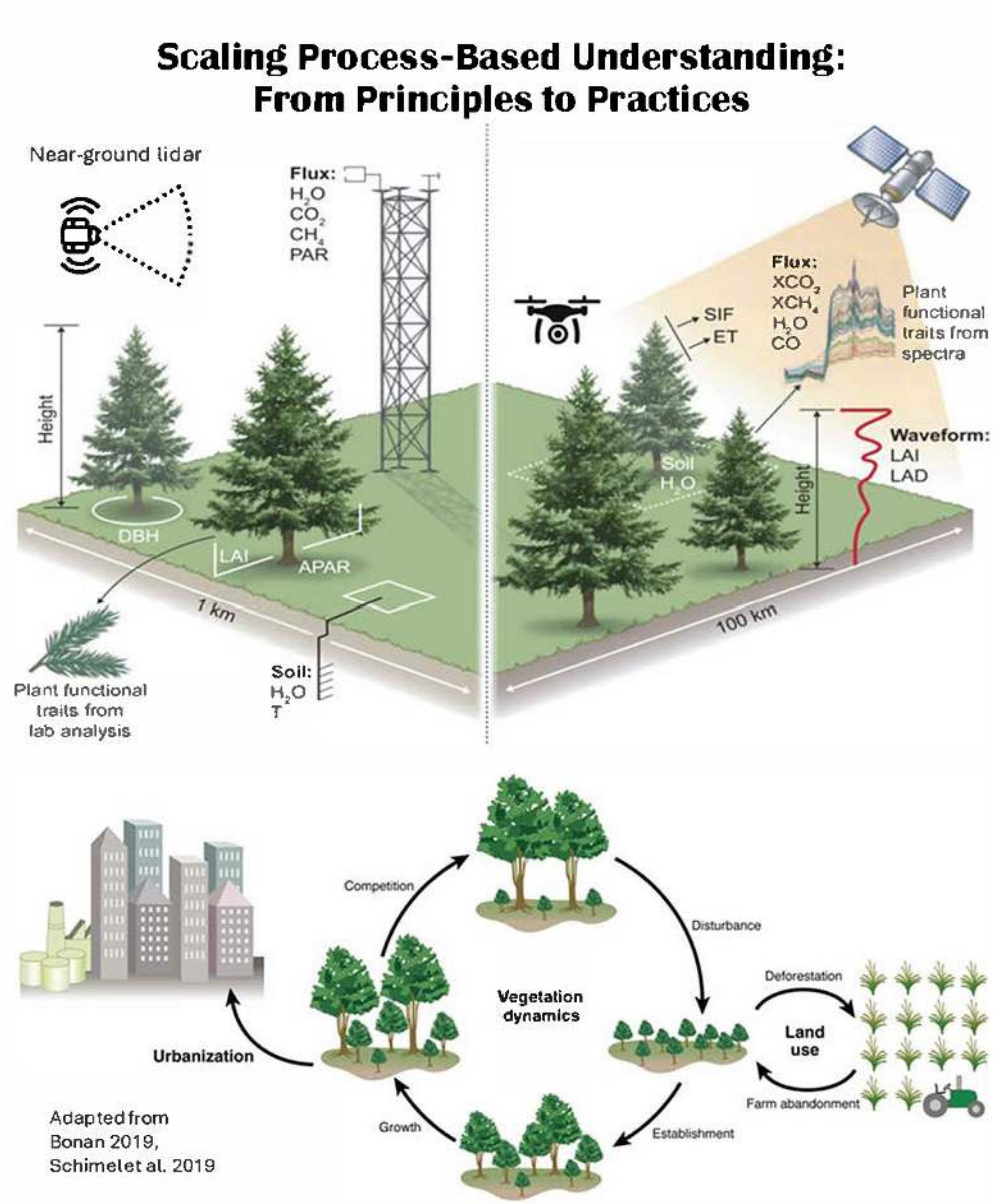
3rd Annual

Dynamic Vegetation Modeling and Observations Conference

Marine Biological Laboratory, Wood Hole, Massachusetts, USA, April 9-11, 2025



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Bottom image: Bonan, G., 2019. Climate change and terrestrial ecosystem modeling. Cambridge University Press.

DVMOC. Marine Biological Laboratory, Woods Hole, Massachusetts, USA
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3rd Annual
Dynamic Vegetation Modeling and Observations Conference
April 9-11, 2025

Welcome

Dear Conference Attendee:

Welcome to the 3rd Annual Dynamic Vegetation Modeling and Observations Conference (DVMOC). Building upon the predecessor meeting Eastern regional Dynamic Global Vegetation Conference (ER-DGVM-C), the overarching goals of this DVMOC meeting are to forge closer ties among members of the vegetation modelling science community and to improve connections between the vegetation modeling community and researchers acquiring field and remote-sensing observations that are critical for parameterizing and evaluating the predictive capabilities of dynamic vegetation models.

A critical challenge of bridging modeling and observations in predicting vegetation dynamics is to connect different ecological scales The theme of this year's meeting is thus: "Scaling Process-Based Understanding: From Principles to Practices". Strengthening the connections between models and measurements from plant tissues such as leaves, xylem, and roots, individual trees, to the canopy, ecosystem, and biosphere is increasingly important given the burgeoning complexity of modern dynamic vegetation model formulations and rapid accumulation of plant ecophysiology and ecosystem remote sensing data. Understanding the principles that govern vegetation processes at different scales such as stomatal conductance, photosynthesis, allocation, demographics, diversity, land-use dynamics, disturbance, and carbon-energy-water coupling is necessary to facilitate data assimilation, reduce model uncertainty, and enhance predictive performance. We hope that the presentations and discussions at this year's DVMOC meeting will help advance the discussion of modeling and observations across scales.

We would like to thank our sponsor, Kudan Inc., for their generous support. Their instruments and solutions on 3D mapping provide novel and cost-effective opportunities to understand forest structure and dynamics in unprecedented detail. We also have other vendors (SpectraVista, Spectral Evolution, and METERS) joining our meeting, whose instruments have served our community extensively in characterizing the physiology and behavior of vegetation, and their properties that might be discerned by satellite remote sensing.

We would also like to thank the Analysis, Integration, and Modeling of the Earth System (AIMES) global research network of Future Earth. AIMES brings together Earth system scientists and scholars that work across disciplines to advance innovative, interdisciplinary ways to understand the complexity of the natural world and its interactions with human activities. We thank AIMES for their support of the research community through integrative working groups, outreach activities, and workshops like this one.

Finally, thank you to all attendees and sponsors for participating in this year's conference. We hope you will come away from it with new insights, collaborations, friendships and purpose.

Best regards,

Xiangtao Xu
Conference Co-Chair
Cornell University

Paul Moorcroft
Conference Co-Chair
Harvard University

Hannah Liddy
AIMES Executive Officer
Columbia University

3rd Annual
Dynamic Vegetation Modeling and Observations Conference (DVMOC)

CONFERENCE PROGRAM

WEDNESDAY, APRIL 9, 2025

4:00-6:00 pm Check-in, set up posters

6:00-7:00 pm Dinner in dining hall

7:00-7:10 pm Welcome and Opening Remarks

7:10-8:20 pm ORAL SESSION 1: **SCALING PROCESS-BASED UNDERSTANDING: FROM PRINCIPLES TO PRACTICES**

8:20-8:30 pm Poster Pop-Up Talks

8:30-10:00 pm EVENING POSTER SESSION & MIXER

THURSDAY, APRIL 10, 2025

7:30-8:50 am Breakfast in dining hall

9:00-10:35 am MORNING ORAL SESSION 1: **SCALING PROCESS-BASED UNDERSTANDING: FROM PRINCIPLES TO PRACTICES CONTINUED**

10:35-10:55 am Coffee break

10:55-12:30 MORNING ORAL SESSION 2: **FOREST STRUCTURE, DEMOGRAPHY, AND BIODIVERSITY**

12:30 pm Group photo

12:45-1:30 pm Lunch in dining hall

1:30-4:30 pm FREE TIME for impromptu meetings, walks, soccer, etc.

4:30-5:30 pm Pre-dinner snacks by POSTERS

5:30-6:30 pm Dinner in dining hall

6:40-7:30 pm EVENING ORAL SESSION 1: **AI FOR ECOLOGY**

7:30-8:15 pm EVENING ORAL SESSION 2: **LINKING DATA WITH MODELS**

8:15-8:30 pm Poster Pop-Up Talks

8:30-10:00 pm POSTERS MIXER SESSION

FRIDAY, APRIL 11, 2025

7:30-8:50 am Breakfast in dining hall

9:30-10:15 am MORNING ORAL SESSION 1: **FOREST CARBON, WATER, AND ENERGY CYCLING**

10:15-10:45 am COFFEE BREAK

10:45-11:35 am MORNING ORAL SESSION 2: **FOREST CARBON, WATER, AND ENERGY CYCLING CONTINUED**

11:35-11:50 am Student and postdoc presentation awards, announcement of next co-chairs and date

11:50-12:00 pm Conference feedback and general discussion

12:00-1:00 pm Lunch in dining hall

Conference End

3rd Annual
Dynamic Vegetation Modeling and Observations Conference

ORAL & POSTER SCHEDULE

Updated: April 3, 2025

All talks will be held in the Meigs Room, next to the Dining Hall of the Swope Center, MBL.

WEDNESDAY, APRIL 9, 2025			
	WEDNESDAY EVENING ORAL SESSION 1: SCALING PROCESS-BASED UNDERSTANDING: FROM PRINCIPLES TO PRACTICES		
7:00	Xiangtao Xu, Paul Moorcroft	Welcome and opening remarks	
7:10	Kyla Dahlin (KEYNOTE)	Lollipops, Voxel Trees, and Slaps of Green Goo: Incorporating Forest Structure into Productivity Models	Michigan State University
	VENDOR TALKS		
8:00	Juan Wee	Seeing the Forest through Lidar SLAM, and beyond	Kudan
8:10	Nicolas Venjean	Advancement in Field UV-VIS-NIR Spectroscopy of Soil and Clay Minerals	Spectral Evolution
8:20	Poster Pop-Up Talks	1-minute 1-slide talks for poster presenters ● Sara Cerasoli ● Yanlei Feng ● Paco Frantzen ● Ruofei Jia ● Nancy Y. Kiang	
8:30	**EVENING POSTER SESSION & MIXER**		

THURSDAY, APRIL 10, 2025			
	THURSDAY MORNING ORAL SESSION 1: SCALING PROCESS-BASED UNDERSTANDING: FROM PRINCIPLES TO PRACTICES CONTINUED		
9:00	Evan M. Gora (KEYNOTE)	Quantifying and scaling agents of tree death: drones, big trees, and the role of storms	Cary Institute of Ecosystem Studies
9:50	Yanlan Liu	Impacts of multilayer canopy and cohort-based representations on modeled ecosystem-scale evapotranspiration	The Ohio State University

10:05	Xiangtao Xu	Toward a global generic tree biomass allometry: convergence in aboveground biomass scaling to tree size and wood density across biomes	Cornell University
10:20	Wenge Ni-Meister	Evaluation of a GEDI waveform-based biomass density model in tropical forests	Hunter College of The City University of New York
10:35	**COFFEE BREAK**		
	THURSDAY MORNING ORAL SESSION 2: FOREST STRUCTURE, DEMOGRAPHY AND BIODIVERSITY		
10:55	Jessica Needham (KEYNOTE)	Demographic Controls on Forest Dynamics: From Leaf Physiology to Large Tree Mortality	Lawrence Berkeley National Laboratory
11:45	Cameron Scholl	Characterizing Spatiotemporal Drivers of European Spongy Moth Defoliation Using A Novel Satellite-Based Algorithm	Cornell University
12:00	Xiulin Gao	Understand prescribed fire and thinning effects on fuel and wildfire dynamics in the Sierra Nevada mixed-conifer forest using a vegetation demography model	UC Berkeley and Lawrence Berkeley National Lab
12:15	Katja Irob	Dryland Forests on the Edge: The Fight for Long-Term Survival in a Changing Climate	Hebrew University of Jerusalem
12:30	**GROUP PHOTO**		
12:45	**LUNCH**		
1:30	**SUNSHINE, FREE TIME, IMPROMPTU MEETINGS**		
4:30	**PRE-DINNER SNACK BREAK BY POSTERS**		
5:30	**DINNER**		
	THURSDAY EVENING ORAL SESSION 1: AI FOR ECOLOGY		
6:40	Yiqi Luo (KEYNOTE)	AI-facilitated scientific discovery from big data and process-based modeling	Cornell University
	THURSDAY EVENING ORAL SESSION 2: LINKING DATA WITH MODELS		
7:30	Michael Dietze	The PEcAn+SIPNET Terrestrial Carbon Cycle Reanalysis of North America: Development and Initial Validation	Boston University
7:45	Liling Chang	Predicting Wildfire Impacts on Californian Ecosystems using a Terrestrial Biosphere Model Constrained by Remote-Sensing and Ground Measurements	Florida State University

8:00	Benjamin Felzer	Evaluating historical carbon dynamics of the Terrestrial Ecosystem Model with TRENDY forcing using the ILAMB protocol	Lehigh University
8:15	Poster Pop-Up Talks	• Nancy Y. Kiang • Rong Li • Yixin Ma • Leila Mirzagholi • Wenge Ni-Meister • Kassia Symstad	
8:30	**THURSDAY EVENING POSTER SESSION & MIXER**		

FRIDAY, APRIL 11, 2025			
	FRIDAY MORNING ORAL SESSION 1: FOREST CARBON, WATER, AND ENERGY CYCLING		
9:30	Jingyi Bu	Evapotranspiration modeling from Water-Energy-Carbon coupling: Synergistic use of thermal land surface temperature and solar-induced chlorophyll fluorescence from remote sensing	University of New Hampshire
9:45	Yan Chen	Response of Gross Primary Productivity to Water and Heat Stresses in Earth System Models	University of Connecticut
10:00	Dan Short Gianotti	Scaling Roles of Water-Use Efficiency and Leaf Area in Large-Scale Water/Carbon Coupling	MIT
10:15	**COFFEE BREAK**		
10:45	Kaighin McColl (KEYNOTE)	Emergent Simplicity of Continental Evapotranspiration	Harvard University
11:35	Student and postdoc presentation awards, announcement of next co-chairs and date		
11:50	Conference feedback and general discussion		
12:00	**LUNCH**		
1:00	**CONFERENCE END**		

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POSTER LIST

All posters will be located outside of the Meigs Room for the duration of the conference.

Name	Title	Affiliation
Sara Cerasoli	Hydrological Signatures of Agricultural Management	Massachusets Institute of Technology
Yanlei Feng	The Impacts of Wind Disturbances on the Amazon Carbon Sink through Data-Driven Synthesis	Massachusetts Institute of Technology
Paco Frantzen	Global monitoring of vegetation water dynamics using the microwave backscatter-incidence angle relation	Delft University of Technology
Ruofei Jia	The Global Soil Carbon Sink: Evidence and Uncertainties from Repeated Soil Carbon Measurements	Massachusetts Institute of Technology
Nancy Y. Kiang	Phanerozoic Vegetation Boundary Conditions for Climate Feedbacks in Earth System Models	NASA Goddard Institute for Space Studies
Nancy Y. Kiang	The Metabolic Rate of the Biosphere: Photon Energy Use in Terrestrial Vegetation Biomes	NASA Goddard Institute for Space Studies
Rong Li	Canopy Structural Traits and their Heterogeneity: From Data to Models	Cornell University
Yixin Ma	Environmental Drivers of Tropical Tree Growth: Model-Data Comparison at a Wet Tropical Forest	Cornell University
Leila Mirzagholi	Enhance Local Surface Warming Effects of Deforestation Across the Globe	NASA GISS
Wenge Ni-Meister	Extracting Cohort-Level Vegetation Structure from GEDI Lidar Waveform Data Using a Geometric-Optical Radiative Transfer Model	Hunter College of The City University of New York
Kassia Symstad	Laboratory measurements of bryophyte carbonyl sulfide fluxes	Rutgers University

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ORAL AND POSTER ABSTRACTS

(Alphabetical order)

Evapotranspiration modeling from Water-Energy-Carbon coupling: Synergistic use of thermal land surface temperature and solar-induced chlorophyll fluorescence from remote sensing

Jingyi Bu[1], Guojing Gan[2], Yanchun Gao[3]

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[2] *Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, China, gjgan@niglas.ac.cn*
[3] *Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, China, gaoyanc@igsnrr.ac.cn*

Abstract. Evapotranspiration (ET) is a critical link between the water, energy, and carbon cycles. It facilitates the movement and transformation of water and energy and plays a vital role in plant physiological processes that affect carbon dynamics. By integrating remote sensing observations, it is possible to accurately estimate ET, monitor water stress, and manage water resources more effectively. The two most widely utilized types of remote sensing ET models are temperature-based and conductance-based. The temperature-based models use land surface temperature (LST) from thermal sensors to estimate sensible heat flux, deriving ET as a residual of the surface energy balance or from the available energy. However, it's challenging to upscaling the ET snapshots to values for daily or longer timescale particularly under cloudy skies. Conductance-based ET models, such as Penman-Monteith (P-M) model, can effectively utilize vegetation physiological information but require calibration using sparsely distributed flux observations, with upscaling to regional levels often achieved by setting fixed parameters for common Plant Functional Types (PFT).

Building on this, we combined the strengths of both model types to develop a canopy conductance-based two-source energy balance model (G_c-TSEB). By incorporating optimal stomatal behavior and solar-induced chlorophyll fluorescence, we added effective biophysical constraints to the canopy module of the energy balance model. The soil evaporation is estimated based on the complementary concept and soil temperature, avoiding the need for soil moisture input. As LST is an output variable of the model, G_c-TSEB is able to map spatially and temporally continuous ET, with model parameters calibrated for each grid cell using quality-controlled LST snapshots. Using the contiguous solar-induced chlorophyll fluorescence (CSIF) and MODIS LST, we implemented G_c-TSEB at six flux sites (located in the Mediterranean and other semi-arid regions) and the drylands of Southwest US. The results from site validation yielded an average coefficient of determination (R^2) of 0.77 (0.89), with root-mean-square error (RMSE) of ranging between 0.023 (0.21) and 0.040 (0.49) mm depending on the site, at half-hourly (daily) scale. The ET partitioning was also consistent with model partitioning using the underlying water use efficiency method. Our study demonstrates the power of blending two modeling approaches that are typically separated: latent heat focusing on stomatal conductance and the two-source model focusing on soil and canopy sensible heat fluxes. This modeling approach can be extended for high temporal and spatial resolution ET mapping by collaboratively using remote sensing SIF satellites like TROPOMI, OCO-3, and the upcoming FLuorescence EXplorer (FLEX) mission, along with higher-frequency LST data from geostationary satellites such as GOES and new-generation thermal infrared satellite missions like ECOSTRESS, TRISHNA, LSTM, and SBG.

Key words: Evapotranspiration; energy balance; canopy conductance; land surface temperature; solar-induced chlorophyll fluorescence.

Hydrological Signatures of Agricultural Management

Sara Cerasoli [1], Giulia Vico[2], Amilcare Porporato[3]

[1]*Massachusetts Institute of Technology, Civil and Environmental Engineering, Cambridge, United States of America (cerasoli@princeton.edu)*
[2]*Swedish University of Agricultural Sciences (SLU)*
[3]*Princeton University, Civil and Environmental Engineering, Princeton, USA*

Abstract. Climate change and agricultural management are rapidly altering watershed dynamics, with land use decisions playing a central role in modifying water partitioning at multiple scales. While the Budyko framework effectively describes water-energy relationships in natural systems, managed watersheds often deviate from these patterns due to human interventions, particularly through irrigation. This study develops a process-based extension of the Budyko framework by explicitly incorporating agricultural management into water balance equations. Our approach integrates both stochastic rainfall and irrigation inputs, accounting for different management intensities and climatic conditions. This allows us to predict and explain the systematic shifts in water partitioning observed in managed watersheds. We validate our theoretical predictions using data from agricultural basins spanning diverse climates and management practices - from rainfed to fully irrigated systems. The framework successfully captures how different agricultural strategies modify hydrological patterns, showing strong agreement with observed data across various irrigation methods and intensities. This approach advances our understanding of how land management decisions influence watershed dynamics. The framework's ability to characterize these modifications using minimal parameters makes it particularly valuable for improving land surface models and detecting management impacts through their distinctive hydrological signatures.

Key words: Agricultural water management; Budyko framework; Irrigation

Predicting Wildfire Impacts on Californian Ecosystems using a Terrestrial Biosphere Model Constrained by Remote-Sensing and Ground Measurements

Liling Chang[1], Shaoqing Liu[2], Alexander Antonarakis[3], Marcos Longo[4], Hao Tang[5], John David Armston[6], Ralph Dubayah[6] & Paul Moorcroft[2]

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[2] *Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, Massachusetts*
[3] *Department of Geography, University of Sussex, Falmer, Brighton, UK*
[4] *Climate and Ecosystem Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California*
[5] *Department of Geography, National University of Singapore, Singapore*
[6] *Department of Geographical Sciences, University of Maryland, College Park, Maryland*

Abstract. Wildfires are a key factor in shaping California's forest and woodland ecosystems, influencing their composition, structure, and carbon and water dynamics. These ecosystems have coexisted with fire for centuries. However, the combination of fire treatments and a rapidly changing climate has led to larger and more intense fires during the recent two decades. The future response of these ecosystems to fires under climate change is still uncertain, making accurate predictions essential. In our study, we combine remote sensing data from NASA's Global Ecosystem Dynamics Investigation (GEDI) mission, field measurements from the U.S. Forest Inventory and Analysis (FIA), and the process-based Ecosystem Demography (ED2) model to explore how California's diverse ecosystems might change over the coming decades. Driven by high-resolution downscaled future climate scenarios, we simulate how forest composition and structure shift in response to fire disturbance and how carbon and water fluxes change across an elevational gradient. Our results predict notable changes in forest composition and structure by 2100 within fire-impacted areas, which have important implications for forest management in fire-prone areas.

Key words: *Wildfire Impacts; GEDI; Ecosystem Demography Model.*

Response of Gross Primary Productivity to Water and Heat Stresses in Earth System Models

Yan Chen[1], Anji Seth[1], Guiling Wang[2]

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[2]*School of Civil and Environmental Engineering, University of Connecticut, Storrs, CT; guiling.wang@uconn.edu*

Abstract. The response of vegetation photosynthesis to environmental stresses plays a crucial role in linking carbon and water cycles. Understanding how light use efficiency (LUE), a key indicator of gross primary productivity (GPP), responds to temperature, vapor pressure deficit (VPD), and soil moisture availability (SWA) is essential for predicting future vegetation dynamics. Among these, temperature has a significant impact, with LUE peaking at an apparent optimum temperature (T_{opt}) before declining due to thermal stress. This study evaluates the performance of four CMIP6 Earth system models (ESMs) in (1) capturing the T_{opt} and (2) simulating LUE responses to environmental stresses including heat and drought. Resulting from analysis of T_{opt} show that ESMs use the same temperature response functions for T_{opt} regardless of parameterizations employed, and they effectively capture the LUE response to temperature for C4 plants. However, significant inter-model discrepancies exist in the estimation of T_{opt} for C3 plants. Specifically compared with observations, NorESM2-MM reasonably captures the distribution of T_{opt} but slightly underestimates it in certain regions. CNRM-CM6.1, overestimatesT_{opt}, whereas ACCESS-ESM1.5 underestimates T_{opt} in mid-latitude. Result from the analysis of observed LUE response to stresses shows that in evergreen needleleaf forests (ENFs) and deciduous broadleaf forests (DBFs), temperature and VPD are primary drivers of LUE variations, while SWA has not significant impact. However, in most ESMs, LUE declines as SWA decreases, a pattern that is not observed. The ACCESS-ESM1.5 performs better in capturing the response of LUE to SWA. For C3 grasslands, the observations indicate LUE is jointly regulated by temperature, SWA, and VPD. LUE increases when temperature rises above 4°C but decreases with increasing VPD and declining SWA through physiological response. Heat stress occurs when temperature exceed 32°C. The models represent stomatal conductance differently under high VPD conditions, either to near zero or asymptoting to a constant value. This leads to distortion in the simulation of LUE in the ESMs. Consequently, ACCESS-ESM1.5 simulates observed low LUE values, while other models approach near-zero LUE under extreme VPD conditions. For C4 grasslands, observed LUE is primarily driven by temperature and SWA under moderate VPD conditions, with a clear decline when VPD exceeds 1.2 kPa. While ESMs capture the temperature response pattern, they tend to overestimate LUE sensitivity to VPD at moderate levels and underestimate LUE when VPD is high. In this first examination of ESMs LUE responses at the daily timescale, we find that there are variations among the models in their ability to capture the observed responses. This study highlights key biases in ESMs related to LUE responses, emphasizing the need for improved model representations to enhance model accuracy under varying environmental stresses.

Key words: gross primary productivity, drought, heat stress, earth system models.

KEYNOTE SPEAKER

Lollipops, voxel trees, and slabs of green goo: Incorporating forest structure into Productivity Models

Kyla M. Dahlin[1]

[1]*Department of Geography, Environment, and Spatial Sciences, Michigan State University, kdahlin@msu.edu*

Abstract. The terrestrial biosphere is the largest source of uncertainty in the global carbon budget. We know that Earth system models (ESMs) over-simplify patterns and processes, yet we lack global scale information to constrain these models. This situation is, however, rapidly changing with the development of new observational tools, new ESMs, and new approaches to data analysis. To help constrain and inform ESMs, my group is working to understand ecological diversity at multiple spatial and temporal scales. Over the past several years we have been developing a modeling framework to integrate imaging spectroscopy and lidar data from the National Ecological Observatory Network into a three-dimensional radiative transfer model and a simple model of gross primary productivity. At its core, this project asks the fundamental question: How can we better quantify the globe's myriad dimensions of ecological diversity to improve forecasts of the Earth system?

Key words: temperate forests; biodiversity; carbon cycling; remote sensing

The PEcAn+SIPNET Terrestrial Carbon Cycle Reanalysis of North America: Development and Initial Validation

Dongchen Zhang[1], Michael C. Dietze[1], Chaney Finkeldei[1], Yang Gu, [1] Jonathan Huggins[1], Meng Lai[1], Qianyu Li[2], Shashank Ramachandran[1], Andrew Roberts[1], Shawn Serbin[2], Cameron Webb[1], Klaus Zhang[1]

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[2]*NASA Goddard Spaceflight Center, Greenbelt, MD; shawn.p.serbin@nasa.gov*

Abstract. Improving our ability to understand and predict the dynamics of the terrestrial carbon cycle remains a pressing challenge despite a rapidly growing volume and diversity of Earth Observation data. State data assimilation represents a path forward via an iterative cycle of making process-based forecasts and then statistically reconciling these forecasts against numerous ground-based and remotely-sensed data constraints into a "reanalysis" data product that provides full spatiotemporal carbon budgets with robust uncertainty accounting. Here we report on an >100x expansion of the PEcAn+SIPNET reanalysis from 500 sites CONUS, 25 ensemble members, and 2 data constraints to 6400 sites across North America, 100 ensemble members, and 5 data constraints: GEDI and Landtrendr AGB, MODIS LAI, SoilGrids Soil C, SMAP soil moisture. We also report on an ensemble-based machine learning (ML) downscaling to a 1km product that preserves spatial, temporal, and across-variable covariances and demonstrate the impacts of these covariances on uncertainty accounting. Synergistically, we use the same ML models assess what climate, vegetation, and soil variables explain the spatiotemporal variability in different C pools and fluxes. In addition, we review a wide range of ongoing validation activities, comparing the outputs of the reanalysis against withheld data from: Ameriflux and NEON NEE and LE; USFS Forest Inventory biomass, biomass increment, tree rings, soil C, and litter; NEON soil C and soil respiration. Finally, we touch on ML analyses to diagnose and correct systematic biases and emulator-based recalibration efforts.

Key words: carbon cycle; model-data fusion; remote sensing, hybrid ML data assimilation.

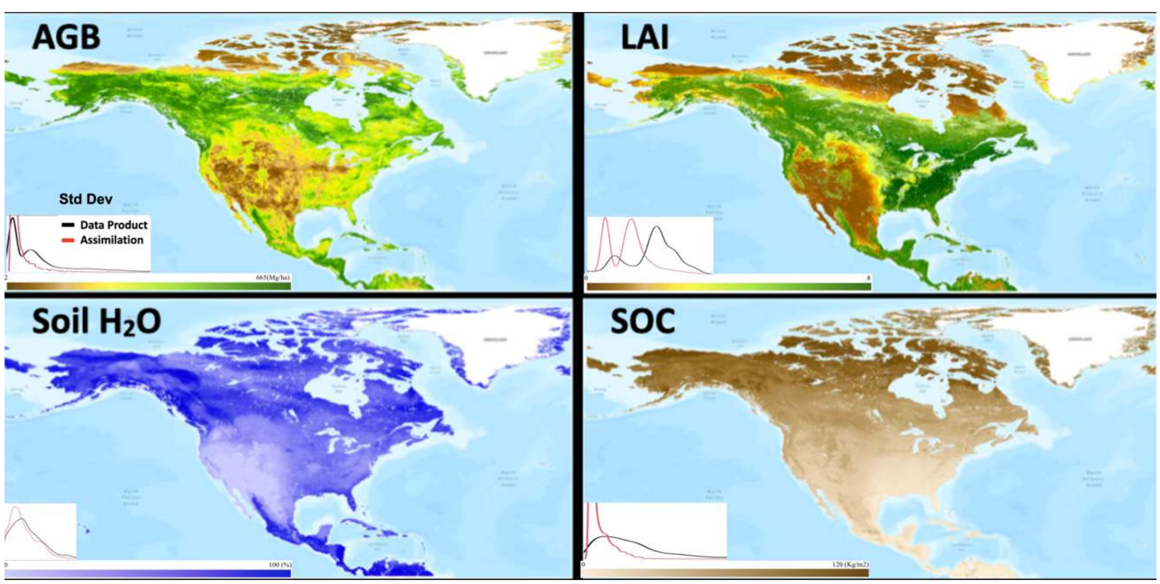

Figure 1. Example downscaled reanalysis maps for June 2021 and associated uncertainty reductions compared to individual data products.

Evaluating Historical Carbon Dynamics of the Terrestrial Ecosystem Model with TRENDY Forcing Using the ILAMB Protocol

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[2]*Department of Land, Air, and Water Resources, University of California – Davis, Davis, CA;* emonier@ucdavis.edu, yanlu@ucdavis.edu, srauschenbach@ucdavis.edu

Abstract. The terrestrial carbon sink accounts for about a third of the CO_2 emitted to the atmosphere, and the annual estimates are largely based on Dynamic Global Vegetation Models (DGVMs). We are running historical global simulations from 1700 to 2023 using the Trends in the Land Carbon Cycle (TRENDY) protocol with the Global Dynamical Structural Terrestrial Ecosystem Model (GDSTEM) and evaluating carbon and water stocks and fluxes using the International Land Model Benchmarking (ILAMB) methodology. The TRENDY runs consist of a pre-industrial run (S0), CO_2-only (S1), CO_2 + climate (S2), and CO_2 + climate + land use and land cover change (LULCC) (S3). The GDSTEM is a biogeochemical model of carbon, nitrogen, and water cycling, and includes a cohort approach to allow for annual land-use transitions that account for forest stand age as well as keep track of soil nutrients. The climate forcing uses the monthly averaged Climatic Research Unit (CRU) Japanese reanalysis (CRU-JRA) at half degree resolution and the land-use forcing is from the Land-use Harmonization (LUH-2) dataset. The ILAMB analysis is performed with the S3 experiment. The other simulations allow us to determine the effects of CO_2, climate, and LULCC, with a particular attention to how each contributes to the model performance. We evaluate the standard ILAMB fields relating to ecosystem, carbon cycle, and hydrology cycle, including key carbon fluxes like Net Ecosystem Carbon Balance (NECB), Net Ecosystem Exchange (NEE), Gross Primary Productivity (GPP), Evapotranspiration (ET), and runoff. This evaluation allows us to examine how well GDSTEM compares to observational datasets as well to other ILAMB models.

We have improved our open nitrogen model, which includes inputs of both symbiotic and nonsymbiotic N fixation, N deposition, N fertilization, and outputs of Dissolved Organic Nitrogen (DON) leaching, Dissolved Inorganic Nitrogen (DIN) leaching, and denitrification. N deposition and N fertilization are from model inputs. N fixation is based on the Cleveland et al. approach as a function of evapotranspiration. Leaching is based on the fractional runoff and the respective nitrogen pools. Denitrification is based on the National Center for Atmospheric Research (NCAR) Community Land Model (CLM) approach of a fraction of the gross N mineralization and excess inorganic N pool. Important constraints need to be included to ensure the N losses do not exceed the amount of inorganic N available, that losses to the vegetation and nitrogen pools remain within reasonable C:N, and that denitrification is larger in arid conditions where there is no leaching if there are continual N inputs. These constraints are particularly important to enable a model to equilibrate under conditions where N inputs do not balance N losses over the hundreds or thousands of years required for equilibration.

The Impacts of Wind Disturbances on the Amazon Carbon Sink Through Data-Driven Synthesis

Yanlei Feng[1], J. David Urquiza Muñoz[2,3], Robinson Negron-Juarez[4], Na Chen[1], Jevan B. Yu[1], Daniel Magnabosco Marra[5,2], Jeffrey Q. Chambers[4,6], César Terrer[1]

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Abstract. The Amazon rainforest accounts for approximately a quarter of the global land carbon sink, but its capacity to sequester carbon is declining due to increased tree mortality. Although windthrow events—where convective storms uproot or break trees—have been recognized as a significant driver of mortality, and have recently expanded in both area and frequency, no basin-wide analysis has yet quantified how much aboveground biomass (AGB) carbon is lost in the Amazon from these events. Here, we synthesize data from over 140 windthrow events across Amazonia, integrating remote sensing AGB measurements validated by field measured AGB, to quantify the AGB losses caused by windthrows. We find that windthrows reduce AGB by 9% to 73% within five years across Amazonia, from an average AGB 248 ± 30 Mg ha^{-1} to 177 ± 37 Mg ha^{-1}, with no signs of recovery in this period. Regional variations in AGB loss are linked to tree mortality, proximity to major rivers, and other climate and environmental factors. Upscaling these results, we estimate that all windthrows cause a short-term AGB loss of 0.29 ± 0.063 Pg C per year, comparable to annual losses from other anthropogenic disturbances, including fire and deforestation in the last 20 years. Our findings identify windthrows as a significant driver of Amazon carbon dynamics.

Key words: Climate extremes, Disturbance, Carbon cycle, Amazon forests

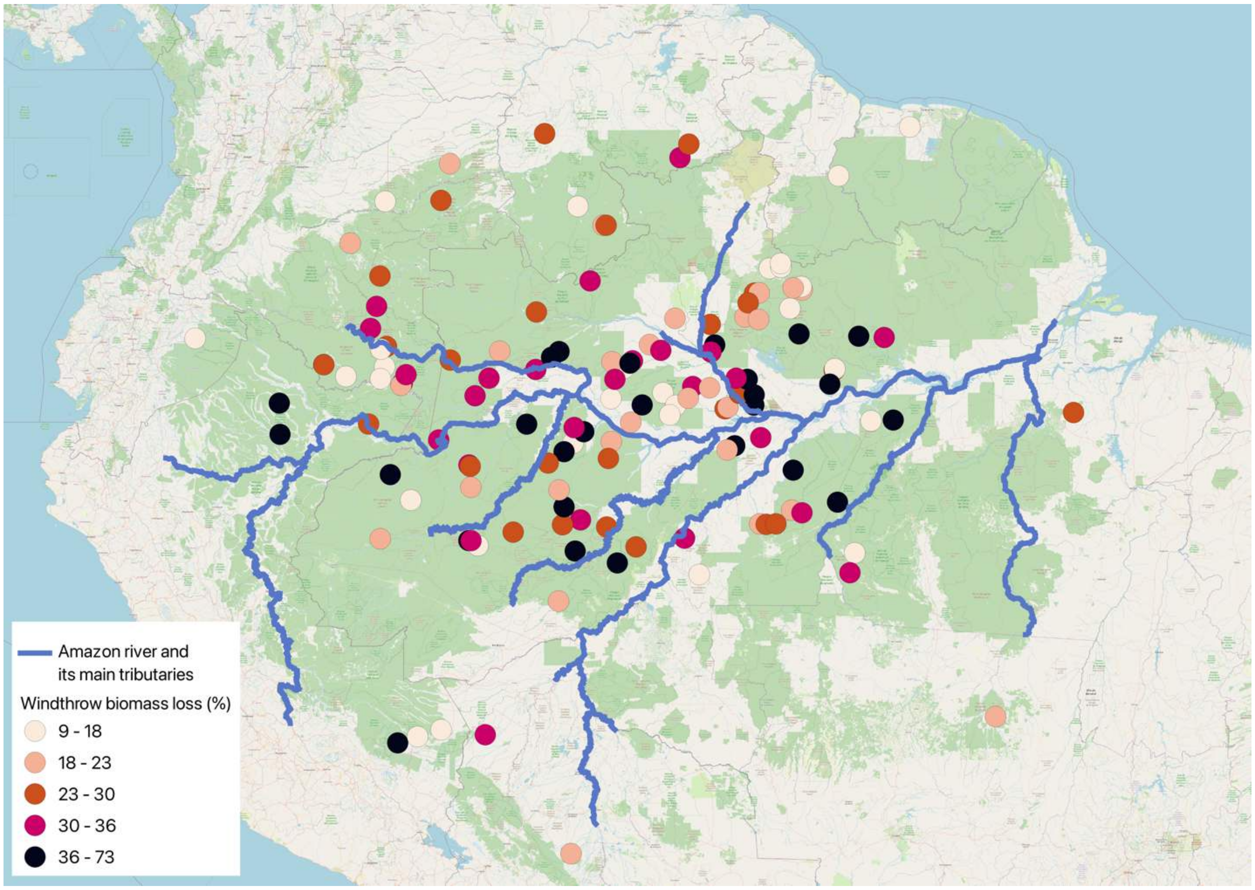

Figure. Spatial variability of AGB loss percentage across Amazonia. Each circle represents a single windthrow event. The colors are grouped so that each group contains an equal number of windthrow events.

Global monitoring of vegetation water dynamics using the microwave backscatter-incidence angle relation

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Abstract. Vegetation plays a key role in the surface-atmosphere interface of the water and carbon cycle. To accurately parameterize and constrain water exchanges at this interface at a global scale, it is important to use globally available observations that relate to the water content of vegetation. Since 2007, the ASCAT scatterometer, which is onboard the Metop satellite series operated by the European Center for Meteorological Satellites, has been observing microwave backscatter. The unique viewing geometry of this instrument ensures a daily near-global coverage of observations from three separate looking angles, with a spatial resolution of roughly 25 km. While dynamics in observed microwave backscatter at a given incidence angle is mostly driven by soil moisture in the topsoil layer, the relation between observed backscatter and the corresponding incidence angle is most related to vegetation structure and water content, due to their attenuation and volume scattering of microwaves. Combining data from multiple overpasses, this relation can be estimated with a sub-monthly temporal resolution. Thus, time series of the backscatter-incidence angle relation observed by ASCAT can be used to globally monitor changes in vegetation water content and structure over the past 18 years. Furthermore, the launch of SCA on Metop-SG ensures data beyond 2040. Recent advances in the understanding and estimation of this relation could improve the representation of short-term changes in the estimated time series. Here, we will present first results from a global analysis of the ASCAT backscatter-incidence angle relation using a novel estimation method. These will be used to highlight the potential to use this unique global dataset to study spatial and temporal variations in vegetation water dynamics.

Key words: Microwave Remote Sensing; Vegetation Water Content; Global

Understand Prescribed Fire and Thinning Effects of Fuel and Wildfire Dynamics in the Sierra Nevada Mixed-Conifer Forest Using a Vegetation Demography Model

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Abstract. Mixed-conifer forests are a dominant vegetation type in the Sierra Nevada mountains, influencing regional carbon and water budges. As fire-prone ecosystems, the Sierra mixed-conifer forests are adapted to frequent, low intensity fires that were ignited by lightning and Native Americans prior to the start of the fire suppression policies in the 20th century. Prior to these policies, fire return interval was generally less than 20 years, resulting in a more open forest structure, and smaller amounts of surface and ladder fuels. Fire exclusion led to denser forests along with changes in species composition. In addition, accumulation of fuels and changing climate together contribute to the rise of extreme wildfire incidents in recent years, impacting forest structure and ecosystem functioning. Fuel treatments, including prescribed fire and mechanical thinning, have been applied to reduce wildfire hazard but with contrasting results documented. It is thus critical to understand how changing climate will interact with forest management to affect vegetation responses and wildfire risk in the long term. As a first step, we implemented a new management fire module in the Functionally Assembled Terrestrial Ecosystem Simulator (FATES), a vegetation demography model. The management fire module adapts existing wildfire code based on SPITFIRE to incorporate effects of fuel load and fuel characteristics, weather conditions, and burning capacity on prescribed fire occurrence and behavior, and resulting impacts on tree mortality and fuel combustion. Using the management fire module and the existing logging module in FATES, we are evaluating FATES at selected sites across the Sierra mixed-conifer forest region to validate model simulations against observed fuel and ecosystem responses to different fuel treatment practices. Preliminary results suggest that using four plant functional types with varying fire response (oak, pine, cedar, fir), FATES with management fire can reproduce forest structure under a frequent, low intensity fire regime consistent with practices prior to 20th c. fire exclusion.
This new management fire module will enable study of how forest and fire management interact with changing climate to affect critical ecosystem structure (e.g. species composition) and processes (e.g. post-management vegetation and fuel dynamics).

Key words: Prescribed fire; Forest thinning; Sierra mixed-conifer forest; Dynamic vegetation demography model.

KEYNOTE SPEAKER

Quantifying and scaling agents of tree death: drones, big trees, and the role of storms

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Abstract. Tree death rates are increasing in many tropical forests, weakening the tropical forest carbon sink and making the future of the tropical forest carbon budget highly uncertain. However, we do not know the primary drivers of tree mortality today, much less why tree mortality rates are increasing or how they will change into the future. Moreover, the largest 1% of trees ("giant trees") are responsible for ca. 50% of biomass carbon stocks and fluxes, but we know so little about their mortality that we cannot precisely estimate the rate of mortality for giant trees for any tropical forest in any given year. To understand the future of the tropical forest carbon sink, we must understand when, where, and why tropical trees die, particularly these giant trees.

Our group is addressing these knowledge gaps using a diverse array of approaches. In particular, we are integrating precision remote sensing systems (e.g., fixed-wing drones and electric field change meters) with forensic field ecology to quantify patterns and proximate drivers of tree mortality. We will present results from these projects and syntheses of existing data, many of which suggest that storm-caused wind and lightning are key drivers of increasing tree death rates and tropical forest change.

Key words: tree mortality, carbon cycling, tropical forest, wind, lightning.

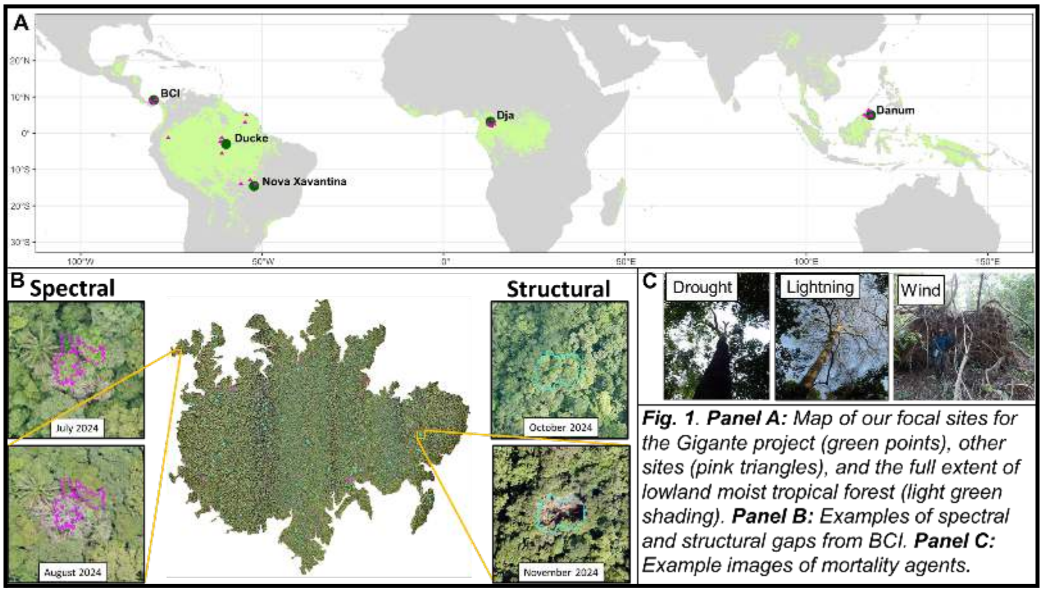

Fig. 1. ***Panel A:*** *Map of our focal sites for the Gigante project (green points), other sites (pink triangles), and the full extent of lowland moist tropical forest (light green shading).* ***Panel B:*** *Examples of spectral and structural gaps from BCI.* ***Panel C:*** *Example images of mortality agents.*

Dryland Forests on the Edge: The Fight for Long-Term Survival in a Changing Climate

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Abstract. The structure and function of woody vegetation are crucial for the provision of ecosystem services in dryland ecosystems. Many drylands face increasing aridity and desertification, raising concerns about their long-term sustainability. Afforestation has been proposed as a strategy to maintain ecosystem function and mitigate climate change effects in these regions. However, the resilience of planted forests under future climatic conditions, particularly in terms of carbon storage and long-term sequestration, remains uncertain.
In this study, we adapted the Ecosystem Demography model (ED2) to simulate the response of an afforested pine forest in a semi-arid region to climate change. Our study focuses on Yatir Forest in the northern Negev, Israel, where the model was initialized with inventory data and constrained by locally measured or derived parameters. We ran a current climate scenario as a single time series and simulated two climate change scenarios using projections from five climate models. This approach allowed us to assess the forest's future viability and the fate of its carbon stocks under different climatic trajectories.
Our findings indicate significant challenges to the long-term sustainability of afforested dryland forests. Pine regeneration is extremely limited**,** with few seedlings establishing and even fewer surviving into larger size classes. Declining leaf area index (LAI) and fluctuating growth rates point to increasing environmental stress, primarily driven by rising temperatures and declining water availability. Additionally, evapotranspiration is projected to increase, while soil moisture declines at all depths, further limiting tree survival.
These trends not only threaten the forest's structure but also its role as a carbon sink. As trees struggle to survive, carbon storage may shift from biomass to soil pools, or be lost to the atmosphere through decomposition and respiration. The long-term persistence of afforested carbon stocks under continued drought remains uncertain, raising concerns about the feasibility of afforestation as a sustainable climate mitigation strategy in semi-arid and arid regions under future climate change.

The Global Soil Carbon Sink: Evidence and Uncertainties from Repeated Soil Carbon Measurements

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Abstract. The terrestrial biosphere has been a net sink of ~30% of annual anthropogenic CO_2 emissions. However, how the land sink is partitioned between plants and soils remains unclear. Changes in plant biomass carbon has been quantified by extensive observation-based analyses, using forest inventory and remote sensing data. In contrast, changes in global soil carbon (SOC) stocks have only been quantified by models, which show a wide range of uncertainty. The lack of observation-based global studies on SOC change limits our ability to benchmark modeled results and predict whether the land sink will persist in future climate scenarios. Here, we collected and synthesized repeated SOC measurements from over 2700 sites to quantify recent changes in natural SOC stocks. We found that young temperate and boreal forests have accumulated SOC since 1986. Old boreal forests have potentially accumulated SOC while old temperate forests have lost SOC since 1986. Ungrazed or lightly grazed temperate grasslands have accumulated SOC since 2000. Besides temperature and precipitation, soil nitrogen content, clay content, pH, and site elevation also influence SOC temporal change. Further, we upscaled these data to estimate the global natural soil carbon sink in recent decades, and compared our results to model outputs for benchmarking. The upscaling process reveals large uncertainties in natural SOC sinks in shrublands, the tropics, and the northern permafrost regions. We therefore advocate for a collective effort to promote open data and more repeated field observations in underrepresented locations outside of North America and Europe. Meanwhile, this dataset opens up the opportunities for model validation and optimization with repeated SOC observations at global scale.

Key words: Soil carbon sink; repeated observations.

Phanerozoic Vegetation Boundary Conditions for Climate Feedbacks in Earth System Models

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Abstract. Dynamic global vegetation model (DGVMs) that couple with Earth System Models (ESM) have not yet been widely used in paleoclimate simulation studies to predict climate-consistent vegetation distributions, because few have complete or suitable representation of the numerous processes for reliable prediction of vegetation geographic distributions. Climate simulation studies for different periods of the Phanerozoic typically rely on fossil reconstructions of vegetation maps or off-line estimates from other models. To produce vegetation boundary conditions ("VBCs") (cover type, seasonal leaf area index (LAI), canopy height) for consistent coupled vegetation-climate model simulations, we apply the Koeppen-Geiger system ("KG"), a long-developed geographer's scheme for classifying climate data (observed or simulated monthly surface temperature and precipitation) by the biome types adapted to them. We classify modern observed climatology to regress KG masks on satellite-derived vegetation maps to produce a lookup table (LUT) of subgrid cover fractions of "plant functional types" (PFTs) contained in each KG biome, and accompanying other VBCs for each biome-PFT class and hemisphere. The PFTs are those of the DGVM, the Ent Terrestrial Biosphere Model (Ent TBM), which is the DGVM available in the Resolving Orbital and Climate Keys for Earth and Extraterrestrial Environments with Dynamics (ROCKE-3D) planetary GCM and coupled to its parent Earth System Model (ESM), the NASA Goddard Institute for Space Studies (GISS) ModelE. Ent's 13 supported PFTs are typical of DGVMs, distinguished by photosynthetic pathway (C3, C4), leaf shape (broadleaf, needleleaf), leaf spectral optical properties, growth form (grass/herb, shrub, tree), phenology, environmental tolerances, and other parameters. The scripts generate files of the VBCs formatted for input to the Ent TBM. The LUT then can be used to generate VBCs for alternative climates through regressing the PFT cover fractions and monthly LAI by biome. We present modern Earth climate simulated climatology for 1980-2020 with the Ent TBM coupled to ModelE as 2.5°x2° to evaluate the KG-classified VBCs compared to the detailed satellite-observed VBCs from which the KG classification was derived. We then present an initial estimate of Cretaceous VBCs, predicted from climatology simulated by the ROCKE-3D GCM at 4°x5° with bare soil. The predicted VBCs compare well to fossil estimates, and they will be used as initial conditions for asynchronous equilibration of the VBCs through coupled simulations of Ent TBM and ROCKE-3D. The R and Python scripts to generate the LUT and model input files will be made available for community use.

Key words: dynamic global vegetation model, Ent Terrestrial Biosphere Model, paleo-vegetation, Phanerozoic, ROCKE-3D

The Metabolic Rate of the Biosphere:
Photon Energy Use in Terrestrial Vegetation Biomes

Nancy Y. Kiang[1], **James Lui**[2], **Tori Hoehler**[3], **Christopher Kempes**[4]

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Abstract. How energy utilization by living organisms scales with organism size or mass is the subject of a large literature seeking universal scaling relations or explanations of variants, often as a function of activity levels and environmental factors like temperature. Absorbed photosynthetically active radiation (APAR) is a fundamental quantity that fuels the vast majority of the Earth's biosphere. We investigated if the efficiency of APAR use exhibits scaling relationship at the scale of terrestrial biomes, which are consortia of plant types in ecosystems adapted to different climate types. "Mass-specific power (MSP)" at the biome scale was calculated in various ways, using annual totals per biome and per area of APAR, its fraction utilized in plant photosynthesis (FAPAR), respiration as the metabolic cost, and a variety of biomass estimates. APAR, FAPAR, and autotrophic respiration were simulated using a DGVM, the Ent Terrestrial Biosphere Model, driven by observed meteorology for the period 2000-2009. Biomes were identified utilizing the Koeppen-Geiger classification of the observed climatologies of mean monthly temperature and precipitation. We also classified behavior by the plant functional types (PFT) of the Ent TBM, mixtures of which compose each biome. Global biomass is a poorly constrained quantity, so we examined relationships of the MSP to several different estimates derived from ground inventories and satellite estimates. We found that the quantities per area of each biome remarkably exhibit a log-linear distribution, which also reveals inaccuracies in different biomass estimates. At the scale of individuals, the biomass of individuals separates by the different orders of magnitude of growth form (grass, shrub, tree), and the slope for each PFT appears steeper in more resource-stressed environments. The slopes of these relations identify potential target emergent behaviors for DGVMs to improve parameterizations of the processes of light absorption, respiration, and growth allocation.

Key words: metabolic scaling, absorbed photosynthetically active radiation, biome, plant functional type, dynamic global vegetation model, Ent Terrestrial Biosphere Model

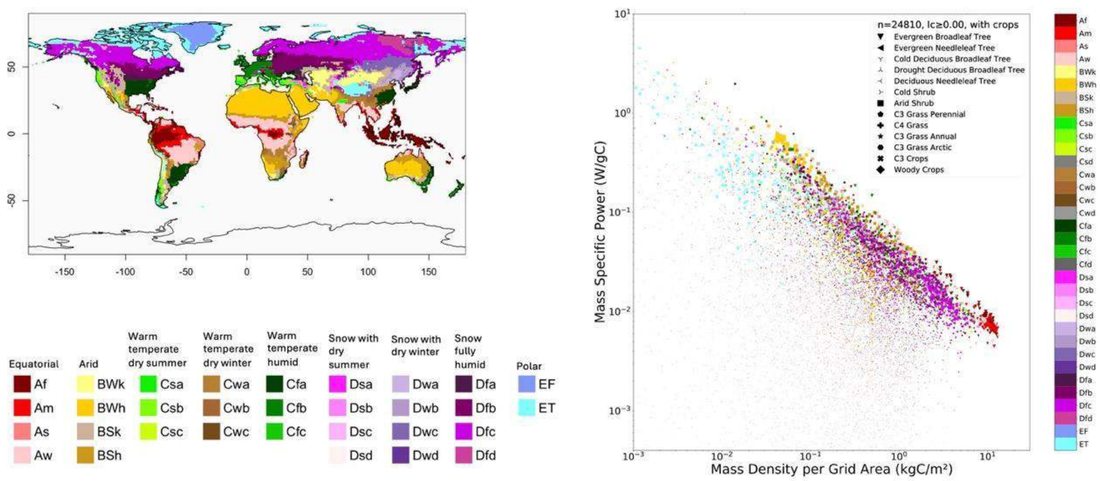

Figure 1. Left: Köppen-Geiger classification of 2000-2009 observed climate from the TRENDY2023 meteorological forcings. Right: Annual average 2000-2009 mass-specific power (Watts APAR/gC biomass) vs. mass density per area (kgC/m^2); MSP is simulated by the Ent Terrestrial Biosphere Model, and biomass is from Spawn et al. (2020), with symbols for PFTs and colors for biome.

CANOPY STRUCTURAL TRAITS AND THEIR HETEROGENEITY: FROM DATA TO MODELS

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Abstract. Canopy structure determines the interception of light and rainfall by vegetation. It is a key factor affecting canopy fluxes of carbon, water, and energy, and the competition among individuals. However, there are limited observations on key canopy structural traits, including leaf angle and clumping, and our understanding of the drivers and ecosystem impacts of the spatial variation of canopy structural traits remains limited. Consequently, these canopy structural traits are not well represented and constrained in dynamic vegetation models.
In this study, we conducted terrestrial laser scanning (TLS) at 10 sites in subtropical and temperate forests across environmental gradients in the Eastern United States. At each site, we estimated the vertical profiles of plant area, leaf area, leaf angle, and clumping, and calculated various canopy structural traits. We found higher leaf area index was associated with more vertical leaves; at drier sites, leaves at the top layer are more vertical than leaves at the bottom layer. We also conduct model simulations to investigate the impact of canopy structural traits and their vertical variations on canopy fluxes and ecosystem dynamics. Preliminary results showed that considering the vertical variation of leaf angle can lead to 10% differences in canopy photosynthesis and latent heat flux. This work enhances our understanding of the coordination of canopy structural traits, and it is a step toward improving the parameterization of canopy structural traits in dynamic vegetation models.

Key words: canopy structure; terrestrial laser scanning; leaf angle; canopy models.

Impacts of Multilayer Canopy and Cohort-Based Representation on Modeled Ecosystem-Scale Evapotranspiration

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Abstract. Many land surface models represent plant canopies as a uniform single-layer foliage, commonly referred to as the big-leaf model. Recent advances in model development have enabled more detailed and realistic representations of canopy structure and composition. For instance, the Community Land Model (CLM) allows a multilayer canopy structure, while the Functionally Assembled Terrestrial Simulator (FATES) and other dynamic vegetation models incorporate cohort-based representations. These advanced approaches allow for more accurate estimations of radiative transfer, microclimate, and hydraulic architecture within the canopy. However, it remains unclear under what conditions multilayer or cohort-based representations outperform a big-leaf model in estimating evapotranspiration (ET) at the ecosystem scale how ecosystem structure regulates ET. To address these questions, we conducted model experiments across multiple forest sites within the AmeriFlux network. We compared: (1) big-leaf versus multilayer configurations of CLM, and (2) two reduced-complexity modes of FATES—one equivalent to a big-leaf representation and the other incorporating cohort-based structure and composition. using observed leaf area density profiles from the Global Ecosystem Dynamics Investigation (GEDI) for each site. Key hydraulic and radiative transfer parameters critical to ET estimation were identified and optimized for each model configuration. Initial results indicate that the multilayer CLM improves ET estimation under high vapor pressure deficit and low soil moisture. Compared to the big-leaf canopy, the multilayer canopy mitigates plant water and heat stresses, maintaining higher leaf water potential and lower leaf temperature under identical air temperature and soil moisture. Similarly, the cohort-based FATES shows significant differences in estimated ET compared to its big-leaf counterpart, particularly under low soil moisture conditions. The findings highlight that ET and plant stresses are substantially modulated by canopy structure under the same physical climate conditions. The results are expected to provide a benchmark for ET estimation across models of varying structural complexity, ultimately contributing to improved large-scale ET predictions.

KEYNOTE TALK

AI-facilitated scientific discovery from big data and process-based modeling

Yiqi Luo[1]

[1]Cornell University

Abstract. Artificial intelligence (AI) is powerful in uncovering hidden patterns and adaptively learning nonlinear relationships within intricate ecological systems from big data. However, different methods such as random forests and neural networks are mostly based on black-box structures, causing substantial difficulty in interpreting their predicted results. On the other hand, process-based modeling mathematically conceptualizes mechanistic understanding of investigated systems dynamics, thus guaranteeing full interpretability to their simulations. However, no matter how detailed processes of a system are represented, a lack of considering those processes' environmental dependence always leads to poor performance in representing real-world observation using process-based models. This presentation shows how process-guided machine learning leverage the best parts of AI and process-based modeling to facilitate scientific discovery and deepen mechanistic understanding of ecological systems. Our examples from research on soil carbon dynamics and forest dynamics demonstrates that process-guided AI methods not only can represent real-world observations very accurately but also pave the way for more mechanistic understanding of ecological and agriculture systems from big data.

ENVIRONMENTAL DRIVERS OF TROPICAL TREE GROWTH: MODEL-DATA COMPARISON AT A WET TROPICAL FOREST

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Abstract. Tropical forests are experiencing rapid environmental changes, and understanding the environmental sensitivity of tropical tree growth is fundamental for predicting regional and global forest carbon sink. Tropical tree growth is often assumed to be limited by photosynthesis, and the environmental drivers of this source limitation are well-documented. Meanwhile, woody growth may also decouple from photosynthesis and exhibit distinct environmental responses due to sink limitation, but few studies have examined its environmental sensitivity in tropical forests, since direct observations of woody growth are limited. Here we compared the environmental sensitivity of tree growth simulated by the Ecosystem Demography Model version 2.2 (ED2) to dendrometer observations of diameter at breast height (DBH) in a tropical wet forest in Luquillo, Puerto Rico. We used net primary productivity (NPP) to characterize simulated source limitation and defined a metric named cumulative leaf water potential to represent modeled sink limitation. Simulated daily NPP responded positively to light and soil moisture, and it decreased substantially with increasing vapor pressure deficit (VPD) at high VPD. Simulated cumulative leaf water potential declined at higher light level and VPD, and it increased with soil moisture. While observed DBH growth was not affected by light level, modeled DBH growth increased with light level. Besides, modeled DBH growth was fastest at intermediate VPD, whereas observed DBH growth declined consistently with higher VPD. We concluded that, in contrast to the observed dominant effect of water availability and thus sink limitation on tree growth, the modeled woody growth is less constrained by water stress and is largely source-limited, suggesting that vegetation models need to better represent sink activity to accurately predict the environmental sensitivity of tropical tree growth.

KEYNOTE SPEAKER

EMERGENT SIMPLICITY OF CONTINENTAL EVAPOTRANSPIRATION

Kaighin A. McColl[1,2], Shiliu Chen[1,3], Angela J. Rigden[1,4], Alexis Berg[1,5]

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Abstract. Evapotranspiration (ET) is extraordinarily difficult to model because it depends, in part, on heterogeneous land surface features -- such as soil moisture, land cover type and plant physiology -- resulting in substantial disagreement between models. This poses a major challenge for projecting changes in the continental water cycle. By leveraging the fact that the land and atmosphere are tightly coupled in many continental environments, we show that the evaporative fraction (ET as a proportion of available energy at the surface) can be estimated across a broad range of water- and energy-limited conditions using a simple, closed-form equation with no free parameters and no land surface inputs; only air temperature and specific humidity observations are required. The method is based on a recent theory of land-atmosphere coupling ('surface flux equilibrium' or SFE), which we here evaluate using multi-scale observations and climate models. The equation performs well when compared to daily eddy covariance measurements at 76 inland continental sites, with overall prediction errors indistinguishable from errors in the measurements themselves, despite substantial variability in surface conditions across sites. When evaluated against multiyear mean annual ET obtained from catchment water balance estimates from 221 catchments across the United States, the resulting error statistics are comparable to those in the catchment water balance estimates themselves. The theory is also reproduced well within a broad selection of CMIP6 climate models. In total, these results reveal an emergent simplicity to continental ET, in which land-atmosphere coupling efficiently embeds land surface information in the near-surface atmospheric state on daily to monthly time scales. This result allows ET to be studied globally using weather data, which have much greater spatial and temporal coverage compared to current ET observation networks. Since lack of observations has been a major limitation in studying ET, this work opens up new opportunities for constraining projected changes to the continental water cycle.

Key words: evaporation; transpiration; land-atmosphere interactions.

ENHANCED LOCAL SURFACE WARMING EFFECTS OF DEFORESTATION ACROSS THE GLOBE

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** Corresponding Authors*
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Abstract. Forests play a critical role in regulating our planet's climate, not only serving as a carbon sink but also moderating local temperatures. They exert a temperature-buffering effect, cooling the land surface in warm regions and warming it in cold regions. Previous studies have assumed this pattern is fixed. However, as global temperatures rise, the biophysical effects of forests may also shift. If a region's background climate dictates whether forests warm or cool the surface, then a warming climate could amplify forest warming effects.
In this presentation, I will synthesize findings from our recent study that:
1) Examine the relationship between local land and air surface temperature changes and forest cover changes in the past decades globally, showing that forest loss causes cooling in high-latitude regions but warming in most other regions.
2) Investigate how changes in background climate are altering the biophysical impacts of forests, showing that as the climate warms, the warming effect of deforestation is increasing.
Our findings show that in many high-latitude forests, the prior cooling effect has weakened or even shifted to a warming effect, highlighting the need to account for these changes in climate models.

Key words: biophysical effects of forests, forest cover change, surface energy balance.

KEYNOTE TALK

DEMOGRAPHIC CONTROLS ON FOREST DYNAMICS: FROM LEAF PHYSIOLOGY TO LARGE TREE MORTALITY

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Abstract. The growth and survival of individual trees define forest structure and carbon sequestration at the local to regional scale. Demographic rates themselves emerge from complex interactions between traits, physiological pathways, and environmental conditions. Understanding the future role of forests in the terrestrial biosphere requires improved understanding of the drivers of demographic diversity within and across forests, as well as improved representation of these processes in vegetation models. In this talk, I will present work combining development of the vegetation demographic model FATES with analysis of large forest inventory datasets and address questions such as how does demographic composition shape forest structure and function? How do patterns of large tree mortality modulate forest response to CO_2 fertilization? And how does the scaling of key physiological processes from the leaf to the canopy impact simulated dynamics? A central theme will be the integration of field data with model development in order to further our understanding of forest response to global change.

Extracting Cohort-Level Vegetation Structure from GEDI Lidar Waveform Data Using a Geometric-Optical Radiative Transfer Model

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Abstract. The Global Ecosystem Dynamics Investigation (GEDI) mission provides full-waveform lidar measurements of forest vertical structure across temperate and tropical regions between 51.6° N and S latitude. While GEDI-derived vertical foliage profiles help estimate light transmission and absorption, commonly used vegetation height metrics primarily represent laser energy distribution rather than direct physical vegetation traits, limiting their application to statistical biomass estimation models. However, extracting cohort-level stem density and biomass directly from lidar waveform data is crucial for improving vegetation dynamic models for carbon assessments and fire fuel modeling.

This study investigates the feasibility of deriving cohort-level stem density and biomass from GEDI waveform data using the Geometric-Optical and Radiative Transfer (GORT) model. Forward simulations of the GORT model in multi-cohort mode demonstrated strong agreement between modeled and observed foliage profiles, gap probabilities, and waveform characteristics using lidar and vegetation survey data from the National Ecological Observatory Network (NEON) TEAK site. The GORT model was then inverted to estimate cohort stem density and biomass (Fig. 1), with validation performed using field-measured vegetation structure and biomass data from the NEON TEAK site.

Key words: Cohort stem density; biomass; lidar waveform

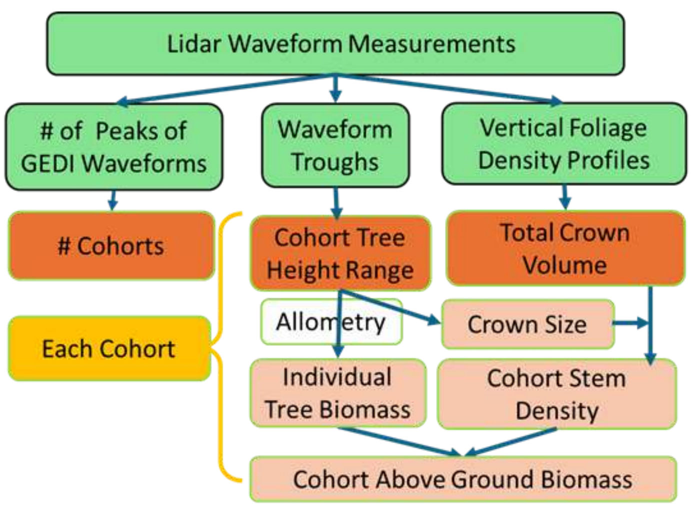

Figure 1. Flowchart to extract cohort-level stem density and biomass density using lidar waveform measurements.

Evaluation of a GEDI waveform-based biomass density model in tropical forests

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Abstract. This study evaluates the performance of a globally generalized lidar waveform-based above-ground biomass density (AGBD) model in tropical forests of Gabon, Central Africa. The model was applied at the regional level using Land Vegetation and Ice Sensor (LVIS) lidar waveform data from four sites in Gabon and at the national level using Global Ecosystem Dynamics Investigation (GEDI) waveforms. Three height scaling exponent (HSE) values—1.146, 1.35, and 1.68—derived from global and local vegetation structure datasets were tested. The model demonstrated consistent accuracy across these HSE values, achieving RMSE = 40.64 - 44.03 Mg ha^{-1}, NRMSE = 0.15 - 0.16, and R^2 = 0.91 - 0.9 at the hectare level compared to field measurements, highlighting its robustness. It also outperformed two biomass products derived from LVIS and small-footprint lidar data and GEDI L4A product. Incorporating wood density further improved model performance, reducing RMSE from 57.66 Mg ha^{-1} to 40.38 Mg ha^{-1}, NRMSE from 0.21 to 0.15, and increasing R^2 from 0.82 to 0.91 for the run with HSE = 1.35. The model performed significantly better with LVIS data than with GEDI data, likely due to differences in lidar and field data collection times, as well as sensor noise and geolocation errors in GEDI data. Additionally, the generalized waveform-based model outperformed the existing GEDI L4A biomass product. These results demonstrate the potential of the generalized GEDI waveform-based AGBD model to enhance biomass density estimation in tropical forests using GEDI satellite data, supporting REDD+ initiatives.

Key words: GEDI; lidar waveform; biomass; REDD+.

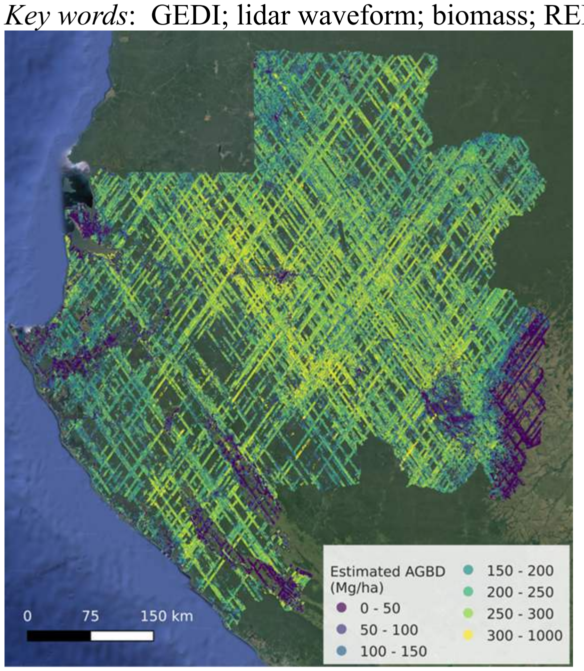

Figure 1. National GEDI footprint level (25 m diameter) above-ground biomass density map for Gabon using all the GEDI waveform data (2019-2024) with all power beams generated using the waveform-based biomass density model.

Characterizing Spatiotemporal Drivers of European Spongy Moth Defoliation Using A Novel Satellite-Based Algorithm

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Abstract. European spongy moth (ESM) is a major outbreaking forest pest in the northeastern US, causing significant defoliation and forest health concerns. However, quantifying the extent of ESM defoliation is challenging due to its spatial patchiness and ephemerality early in the growing season, which limits our understanding of its spatiotemporal patterns and drivers. Here we developed a novel algorithm to quantify ESM defoliation using satellite-based vegetation greenness time series over short time scales (<= 5 years). Our approach robustly removes seasonal trends by determining the linear greenness decline within the growing season based on Theil-Sen regression and further separates anomalies due to defoliation, phenological changes, and forest harvesting. Evaluation over two regions with expert defoliation labeling demonstrated that applying our approach to Sentinel-2 imagery achieved high overall accuracy (OA = 0.85). We then estimated annual defoliation at 10m spatial resolution from 2019-2023 over New York state, which has recently experienced several large-scale outbreaks. Our results captured general patterns and trends found in aerial survey data but also highlighted the low fine-scale precision in aerial surveys. Analyses of potential drivers showed that deciduous forests were more likely to be defoliated, aligning with known ESM feeding preferences. Defoliation extent was also negatively correlated with mean precipitation and precipitation anomaly, highlighting the importance of moisture in driving ESM outbreaks. This study provides a new scalable approach to detect ephemeral and sub-seasonal changes in forest ecosystems and represents an important first step in harnessing Sentinel-2 imagery to improve predictive understanding of defoliation from ESM and other forest pests, addressing an urgent need in forest health monitoring and management as insect outbreaks are likely to increase in range and frequency in response to climate change.
Key words: defoliation, *Lymantria dispar dispar*, insect outbreaks, spatiotemporal, remote sensing

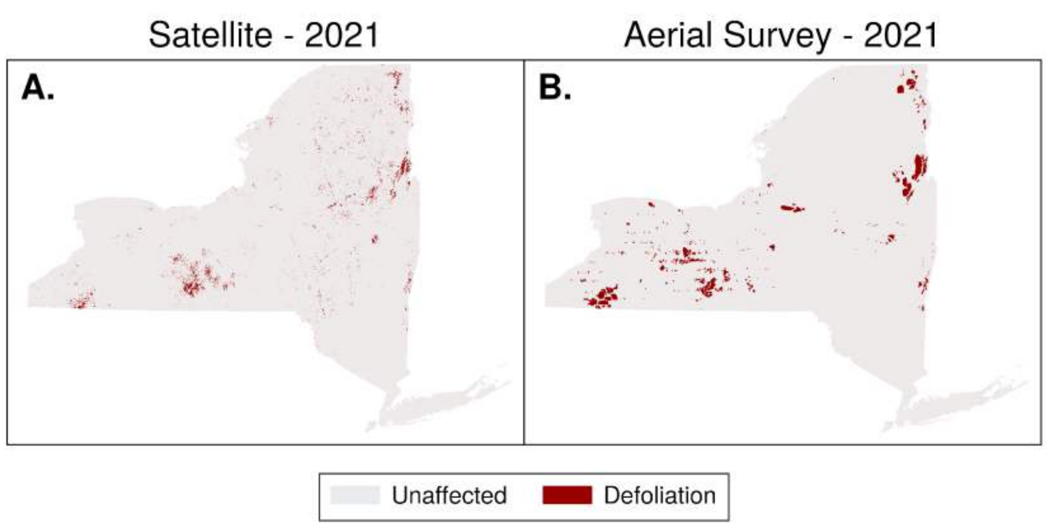

Figure 1. Satellite-based defoliation estimates across New York state in 2021 compared to corresponding aerial survey measurements.

Scaling Roles of Water-Use Efficiency and Leaf Area in Large-Scale Water/Carbon Coupling

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Abstract. The terrestrial water and carbon cycles are linked by many physical processes, perhaps most obviously by (a) conversion of carbon, water, and nutrients into vegetation biomass when conditions favor growth, and (b) the bidirectional fluxes of gaseous water and carbon dioxide through plant stomata. Interestingly, these two mechanisms have different water/carbon covariance signs--a mutual gain of water and carbon for growth (positive correlation) and an exchange of water for carbon for sea-level gas exchange. These can be quantified more precisely using the dynamics of leaf area metrics and water-use efficiency. Here we demonstrate that the differing signs of covariation between these carbon uptake mechanisms and water supply lead to three possible situations: (1) WUE dynamics could tend to dominate growth/decay dynamics, leading to positive feedbacks in the water-carbon balances, (2) growth and biomass loss could dominate WUE, leading to stabilizing patterns of water-carbon behavior, or (3) the two could negate each other making each ecosystem unique in water-carbon behavior. We show that the 2nd of these appears to be true at landscape scales, and at timescales pertinent to the global carbon cycle. We also suggest that this implies that the linkages between water and canopy structure are critically under-represented dynamically in our best models of the Earth system. This casts doubt on our ability to predict future carbon cycle scenarios and climate-biosphere feedbacks.

Key words: water; carbon; coupling; dynamics; scaling.

Laboratory measurements of bryophyte carbonyl sulfide fluxes

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Abstract. Carbonyl sulfide (COS) is a potential tracer gas for terrestrial carbon uptake, as it is taken up by plants during photosynthesis along similar pathways to CO_2. The COS fluxes of other ecosystem components must be known in order for COS to be used to estimate gross primary production. Bryophytes, such as mosses and liverworts, have COS fluxes that are relatively understudied. Their fluxes may respond to environmental variables such as moisture and temperature.

This work presents results of laboratory experiments that investigated these relationships and addresses the uncertainty in bryophyte COS fluxes. Bryophyte samples were collected at a wetland in Harvard Forest, MA (a transition hardwood forest). A quantum cascade laser (QCL) was used to measure COS and CO_2 fluxes from the collected samples during laboratory manipulations of temperature.

Advancement in Field UV-VIS-NIR Spectroscopy of Soil and Clay Minerals

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Abstract. Soil mineral detection is a critical metric in environmental, geological, and soil research today. Most soils are a mixture of organic material, clay, sand, and silt. Due to their large surface area and negative charge clays play a critical role in nutrient availability. Common plant nutrients are positively charged, such as CA++, Mg++, K+ and Na+. The ability to hold and store positively charged ions is called cation exchange capacity (CEC). Clay also acts as a binder for soil particles, helping soil hold moisture and reduce nutrient loss due to leaching. The most common clay minerals in soil include kaolinite, illite, and montmorillonite. We also selected Kaolinite and Halloysite for comparison due to their chemical and spectral similarities. Typical soil sampling necessitates expensive or tedious lab analysis. This is commonly done with an XRD that involves grinding the sample down to a powder significantly manipulating it. Another challenge is that typical soils are dark decreasing the reflectance signal when conducting field spectroscopy. To address this problem, we deployed Spectral Evolutions NaturaSpec series to maximize signal to noise ratio and spectral resolution as well as demonstrate added utility in field soil spectroscopy. Spectral Evolutions field spectroradiometers combined with the contact probe, benchtop probe, and EZ ID software allows unmixing of signal and identification of clay minerals without manipulating the sample. The samples with Kaolinite, halloysite, montmorillonite, and illite were analyzed at various concentrations in soil. EZ ID is a software that allows for the targeting of absorption features in optically complex spectra allowing for the unmixing of soil spectra to target and identify clay spectra. These tests were conducted with instruments with varying spectral resolutions and sensitivities to show the effectiveness across resolutions. These methods are nondestructive in-situ measurements. In this study we present novel methods of spectrally unmixing soil reflectance to identify clay minerals without sample processing as well as explore different resolution spectrometers' ability to identify these minerals.

Key words: UV-VIS-NIR, Soil, HYPERSPECTRAL, SPECTROMETER, REFLECTANCE

Toward a global generic tree biomass allometry: convergence in aboveground biomass scaling to tree size and wood density across biomes

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Abstract. Aboveground biomass (AGB) scaling to tree size, also known as AGB allometry, is pivotal to predicting forest carbon stock and dynamics. However, the existence of general principles underlying AGB allometry across species and biomes remains unclear. Here, we compiled a data set of 22524 individual tree biomass measurements from boreal to tropical forests and investigated the dependence of AGB on tree diameter, height, and wood density. Our analysis revealed the AGB scaling in log-space is quasi-linear to diameter yet nonlinear for height and wood density. Climate and lineage do not affect the scaling except for difference between angiosperms and gymnosperms. We further demonstrated that a generic biomass allometry model could achieve comparable predictive performance as existing species- and biome-specific models but predicted biomass stock with low uncertainty in tropical forests. Our study highlights global convergence of tree biomass scaling to size and wood density and provides parsimonious yet robust models for estimating and modeling forest biomass globally.

Key words: tree biomass, allometry, scaling, wood density, tapering, forest carbon

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