Reconciling Uncertainties in Biogeochemical Interactions through Synthesis and Computation

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U.S. DEPARTMENT of ENERGY

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E3SM All Hands Meeting

Bethesda, Maryland, USA

RUBISCO

EESM-RGMA RUBISCO Science Focus Area (SFA)

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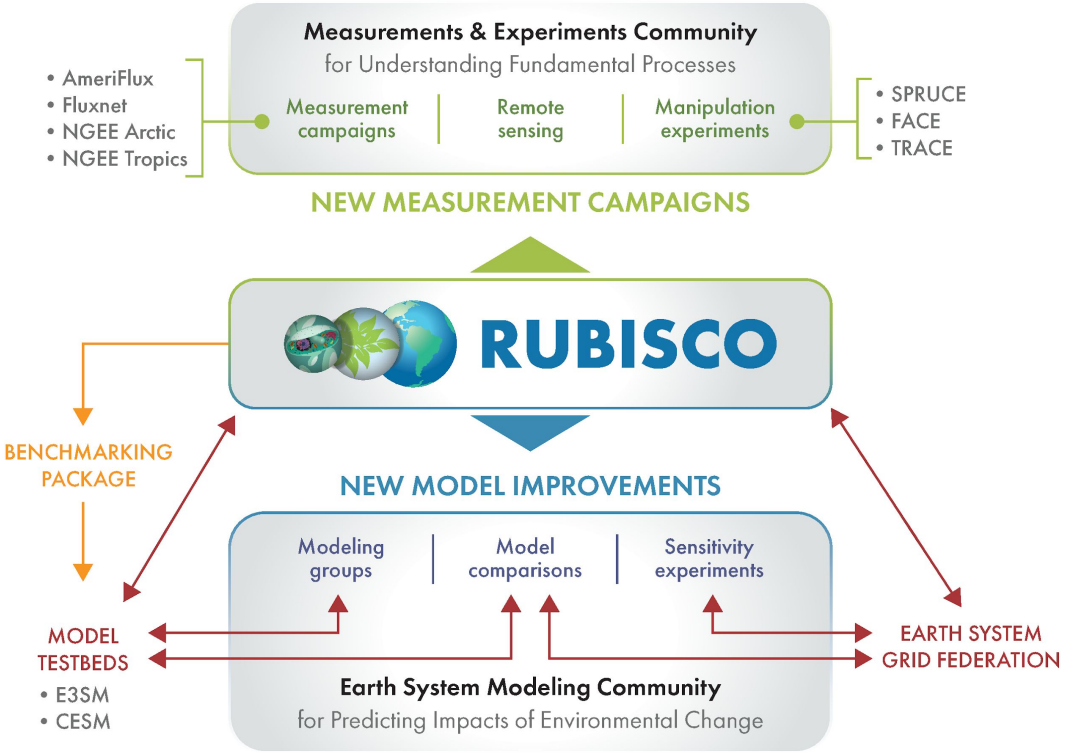
RUBISCO Research Goals

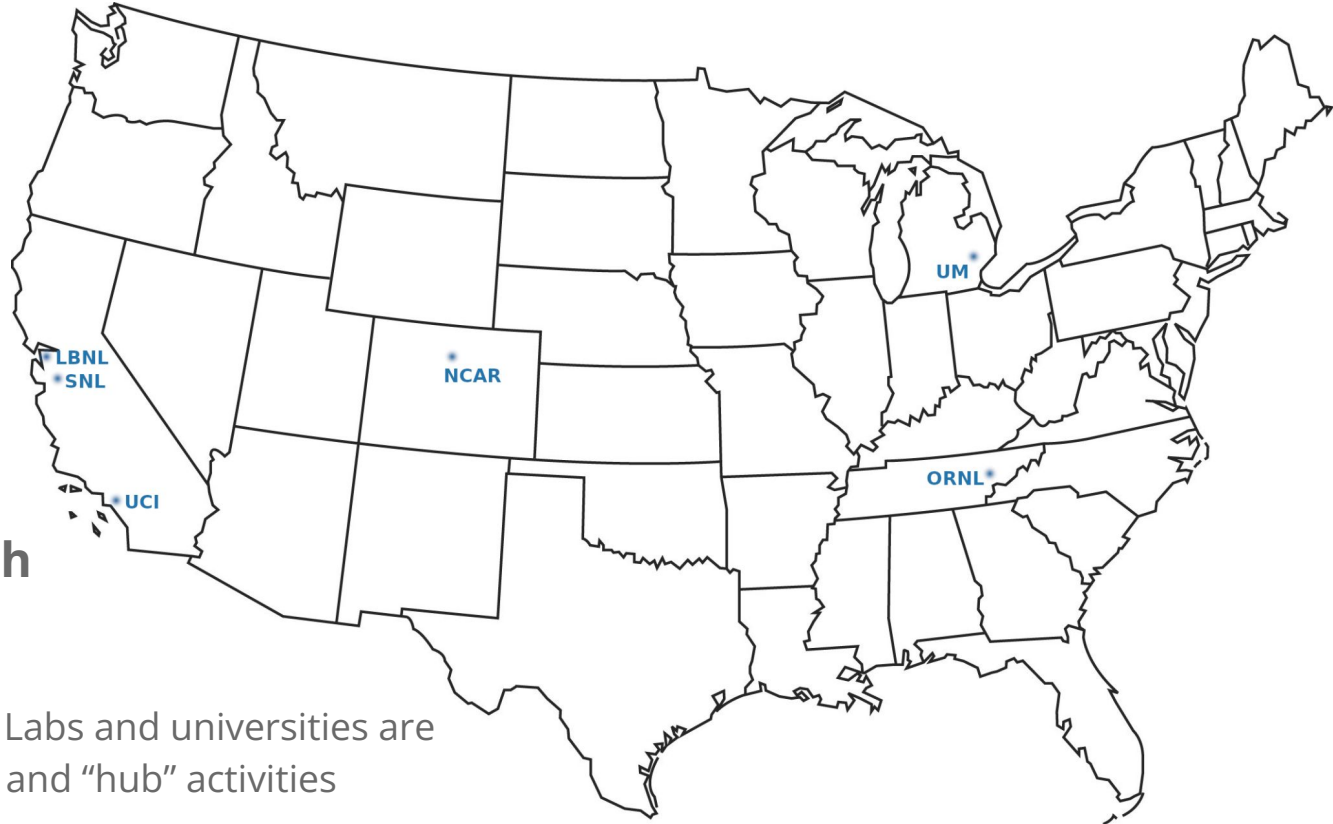
- Identify and quantify interactions between biogeochemical cycles and the Earth system
- Quantify and reconcile uncertainties in Earth system models (ESMs) associated with those interactions

The RUBISCO SFA works with the measurements and the modeling communities to use best-available data to evaluate the fidelity of ESMs. RUBISCO identifies model gaps and weaknesses, informs new model development efforts, and suggests new measurements and field campaigns.



RUBISCO Consists of Six Partner Institutions

- **3 DOE National Labs**
  - Lawrence Berkeley (LBNL)
  - Oak Ridge (ORNL)
  - Sandia (SNL)
- **2 Universities**
  - U. California Irvine (UCI)
  - U. Michigan (UM)
- **National Center for Atmospheric Research (NCAR)**



Collaborations at other National Labs and universities are fostered by our Working Groups and “hub” activities

RUBISCO Phase 3 Research & Development Objectives

1. Pursue **hypothesis-driven research** to quantify uncertainties related to estimates of contemporary terrestrial and ocean processes
2. Apply new advances in the field of **artificial intelligence (AI) and machine learning (ML)** to improve prediction and simulation of biospheric processes
3. Assess the impact of **biogeochemical interactions** on Earth system variability
4. Explore **ecological & hydrological interactions** through simulation, analysis, & benchmarking using the Energy Exascale Earth System Model (E3SM) & CESM
5. Develop & apply our open source **ILAMB and IOMB benchmarking software** tools for evaluation of ESM biogeochemical & hydrological processes
6. Manage **Working Groups** that engage community researchers and RUBISCO scientists in data synthesis, multi-model analysis, and benchmarking
7. Conduct **ensemble and parameter simulations** to explore interactions

Science Questions Span Temporal and Spatial Scales

Science Questions

1. How can observational constraints and models be used to identify and quantify uncertainties in terrestrial and oceanic processes?
2. How can advances in machine learning be leveraged to improve understanding of biospheric processes and their representation in Earth system models?
3. What is the contribution of biogeochemical interactions to future Earth system variability on seasonal, interannual, and decadal timescales?
4. What are the key pathways and strengths of multiscale ecological and hydrological interactions?

Community Resource Objectives

1. Advance ILAMB & IOMB
2. Manage SOM, AmeriFlux, and Soil Moisture Working Groups
3. Biogeochemical-water cycle simulations

Wildfire Research

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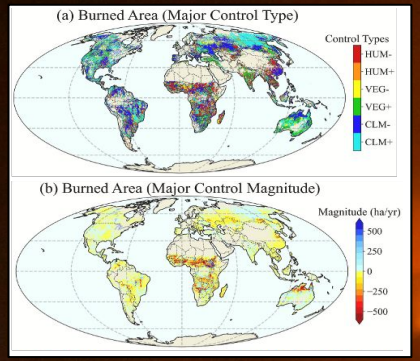
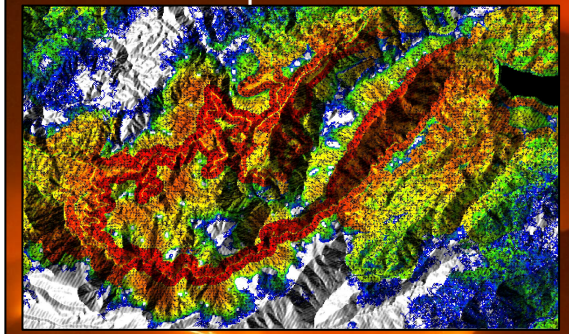
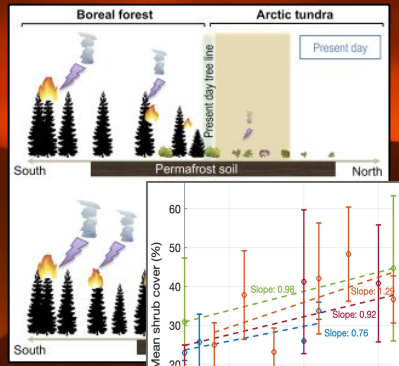
Drivers of Fire Risk

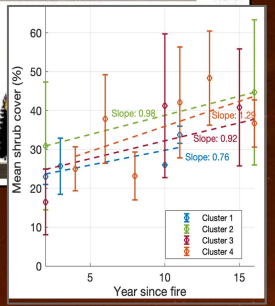


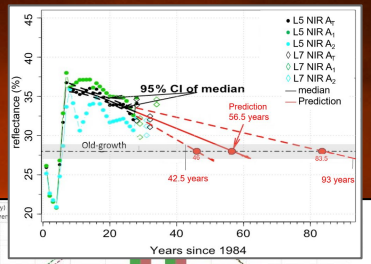
Fuel Connectivity & Fire Exposure/Risk

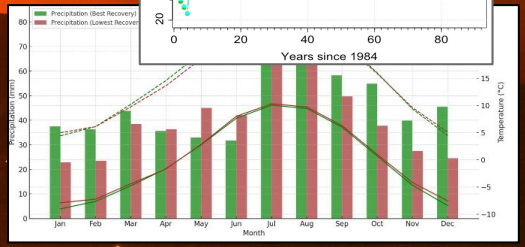


Vegetation Responses to Wildfire

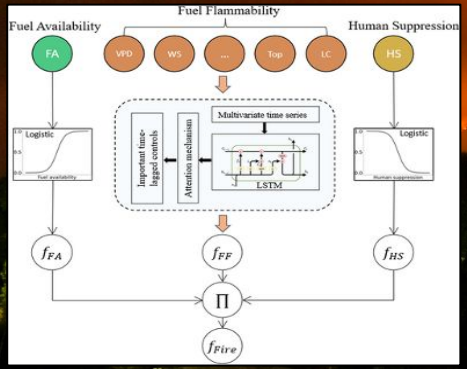




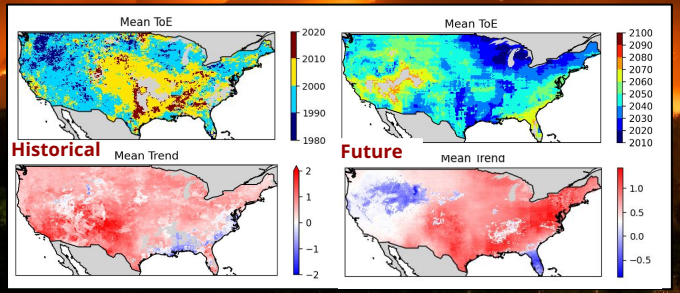




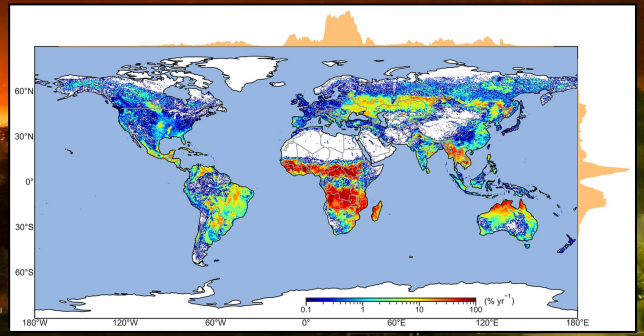
Vegetation Regrowth & Recovery



AI/ML Wildfire Prediction



Changing Fire Weather



Satellite Wildfire Fluxes & Extent

Berkeley Lab

NCAR
National Center for Atmospheric Research

Oak Ridge National Laboratory

Sandia National Laboratories

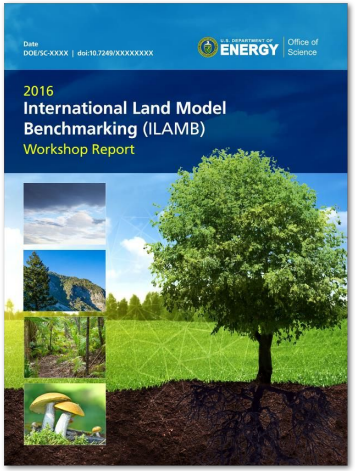
University of California Irvine

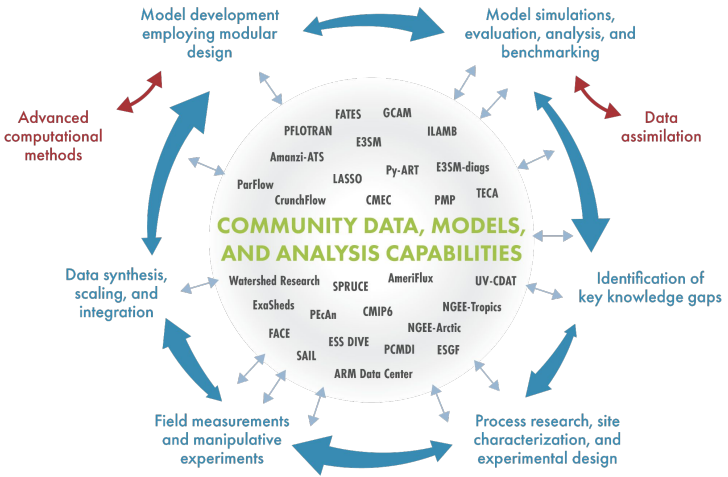
University of Michigan

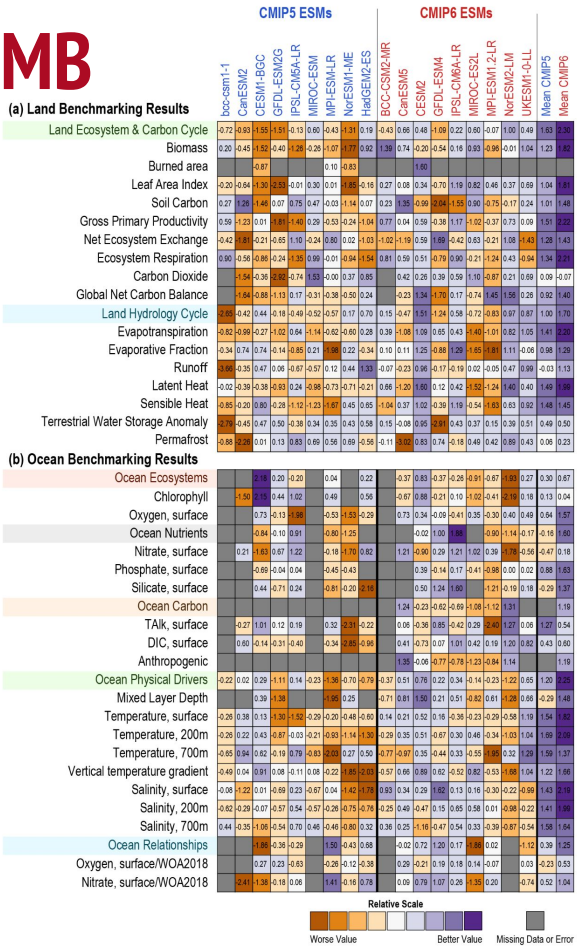
Model Benchmarking with ILAMB & IOMB

RUBISCO leads the development of the International Land Model Benchmarking (ILAMB) and International Ocean Model Benchmarking (IOMB) packages for community multi-model evaluation.

We used ILAMB and IOMB to evaluate multiple generations of Earth system models





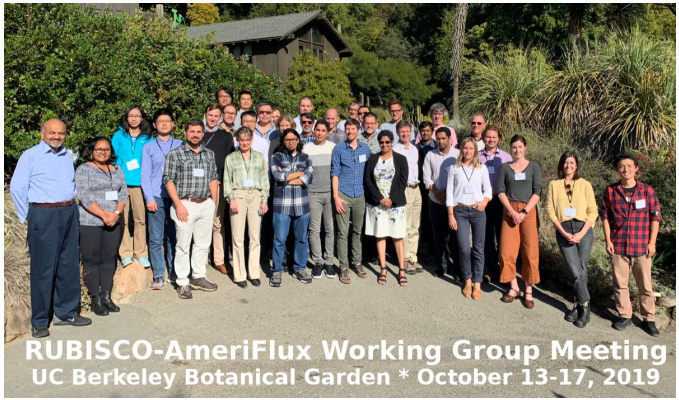


RUBISCO Leadership of Community Working Groups

RUBISCO Soil Moisture Working Group

- Synthesizing global soil moisture data from in situ and remote sensing
- Developing metrics for model evaluation of vertical distribution of moisture

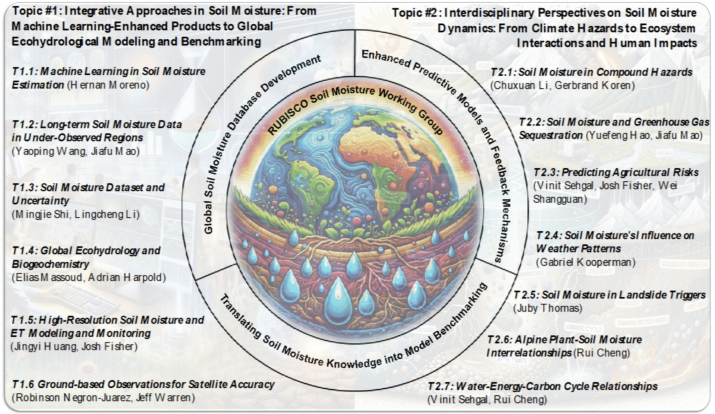
★ Partnership with NASA



RUBISCO Soil Organic Matter Working Group

- Synthesizing SOM measurements and applying machine learning to produce gridded data
- Developing metrics and evaluating microbially explicit decomposition models

★ Partnership with ESS projects and potentially BSSD projects



RUBISCO-AmeriFlux Working Group

- Synthesizing eddy covariance data to provide observational data
- Analyzing responses to disturbance and variability
- Developing metrics for model evaluation and constraints

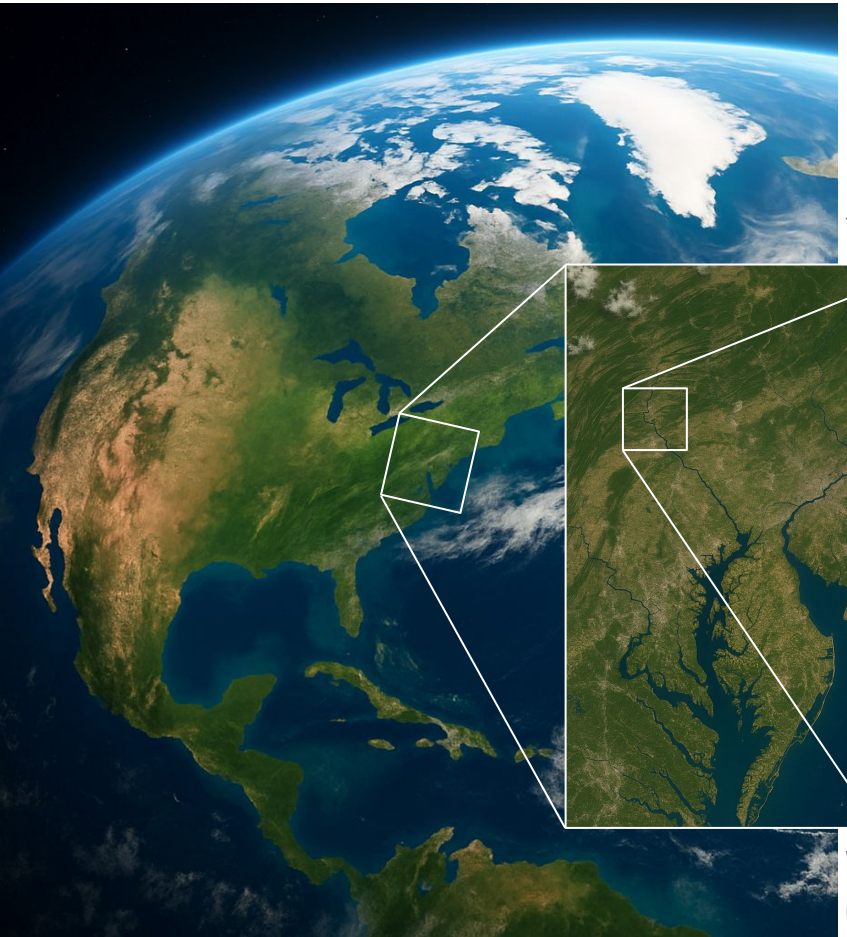
★ Partnership with AmeriFlux Project

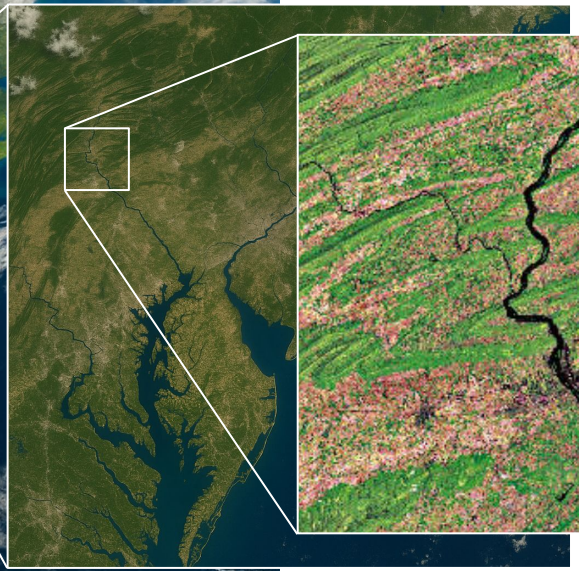
Berkeley Lab · NCAR National Center for Atmospheric Research · Oak Ridge National Laboratory · Sandia National Laboratories · University of California Irvine · University of Michigan

Test Bed for Terrestrial Biogeochemical & Water Cycles

Continental-scale test bed utilizes E3SM and performs top-down scaling to the watershed level

Framework adds representation of vegetation & biogeochemistry absent in traditional hydrological models





Simulates vegetation, soil health, and water

Represents disturbances

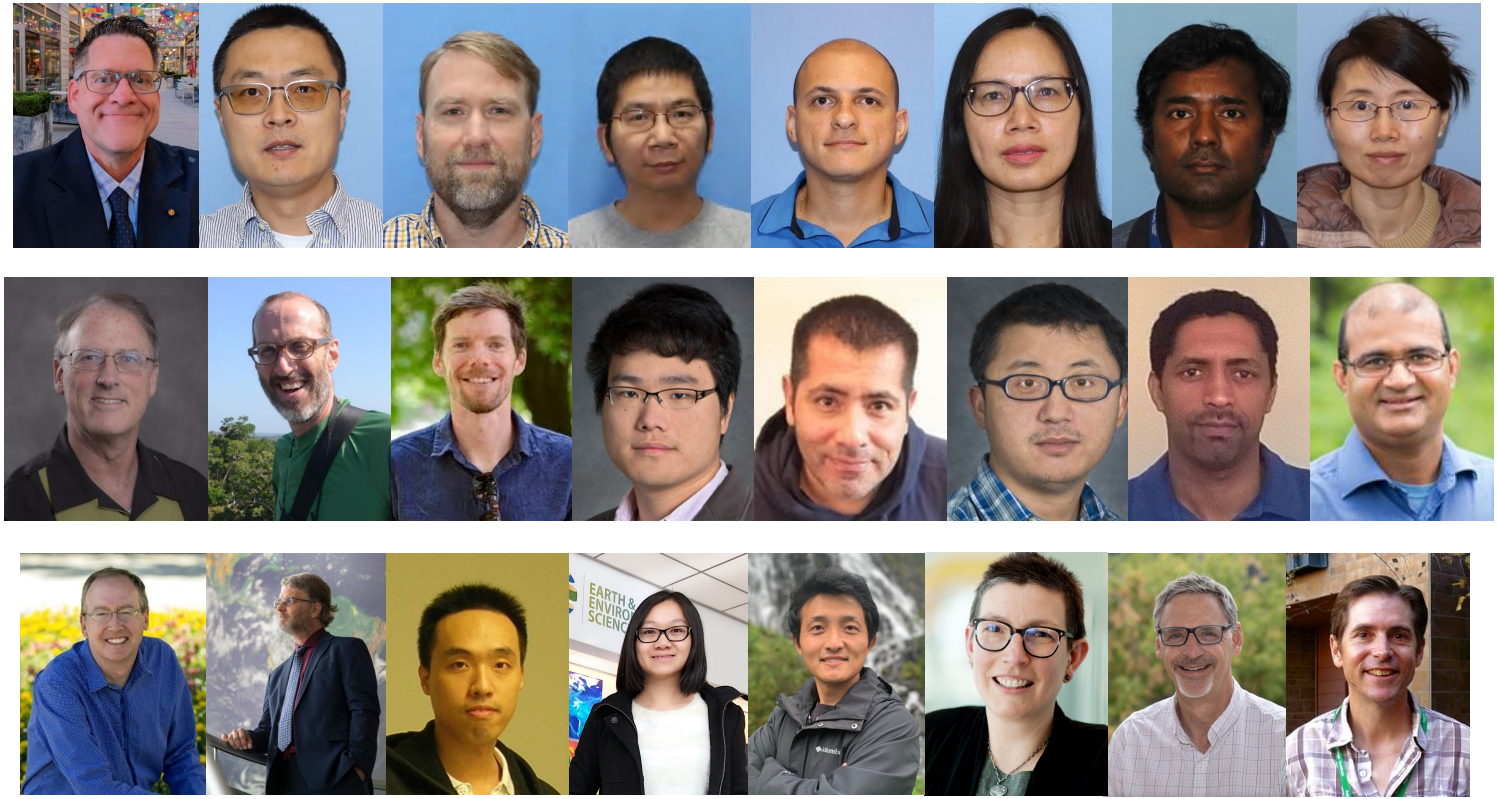
Predicts impacts on energy systems and urban areas

Watershed level uses watershed models (ATS, PFLOTRAN) as a calibration at the finest scale

Additional EESM, EESSD, and BER Collaborations

- **RGMA University Projects:** *Nathan Collier, Forrest Hoffman, Charlie Koven, David Lawrence, and Jim Randerson* – model simulation, evaluation, and metrics development
- **E3SM:** *Qing Zhu and Xiaojuan Yang* – ELM model development, nutrient dynamics
- **InteRFACE:** *Jitu Kumar* – Land model evaluation
- **NGEE Arctic:** *Forrest Hoffman, Charlie Koven, Jitu Kumar, Zelalem Mekonnen, Jing Tao, and Chonggang Xu* – co-leading Data Synthesis & Evaluation Cross-cut and Dynamics & Disturbance Cross-cut, remote sensing data synthesis
- **NGEE Tropics:** *Charlie Koven, Chonggang Xu, and Xiaojuan Yang* – Project and modeling leadership, simulation and analysis
- **AmeriFlux:** *Trevor Keenan* – Science applications of eddy covariance data
- **ESGF2-US:** *Forrest Hoffman, Jitu Kumar, Nathan Collier, Elias Massoud, and Min Xu* – Project leadership, software infrastructure, and data management
- **Joint BioEnergy Institute (JBEI):** *Umakant Mishra* – Agroecosystem modeling

Project Personnel Across Institutions



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