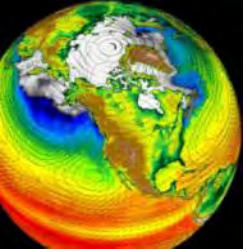
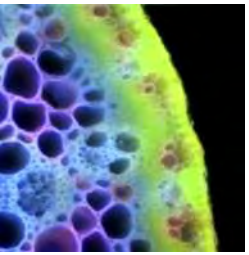



Earth System Modeling updates

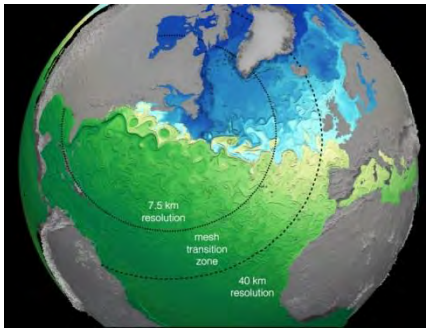
Earth System Science
Principal Investigator Meeting

Dorothy Koch, Program Manager
Earth System Modeling
Climate and Environmental Sciences Division

April 28, 2015

Earth System Modeling (ESM) program

ESM is one of 3 DOE climate modeling programs (ESM, IAR, RGCM)



ESM supports <u>global climate model development</u> to support DOE science and mission

ESM sponsors 3 project-types

- SciDAC-Lab: computational advances in climate modeling (with Advanced Scientific Computing Office) (20%)
- University: SciDAC, paleoclimate (20%)
- ACME: branch of CESM to use DOE computers (60%)

Relation of ESM to ESS and modeling programs

- ESS conducts field and experimental research and constructs process-based models
- ESS and ESM develop global land model parameterizations
- IAR supports societal and energy components
- IAR and ESM collaborate on integration of societal and climate components
- ESM couples (land) components to climate system, conducts hind-cast and projections
- RGCM supports model diagnosis and climate analysis

Accelerated Climate Model for Energy (ACME) Overview

- **Officially launched in July 2014, ACME is a global coupled climate model development project, constructed from existing (Laboratory) projects**
- **ACME branched from the Community Earth System Model (CESM) to:**
  - **effectively use advanced DOE computational facilities, will provide high-resolution coupled climate capability**
  - **address Energy-mission-relevant science**

ACME Science drivers, each has its own experimental design:

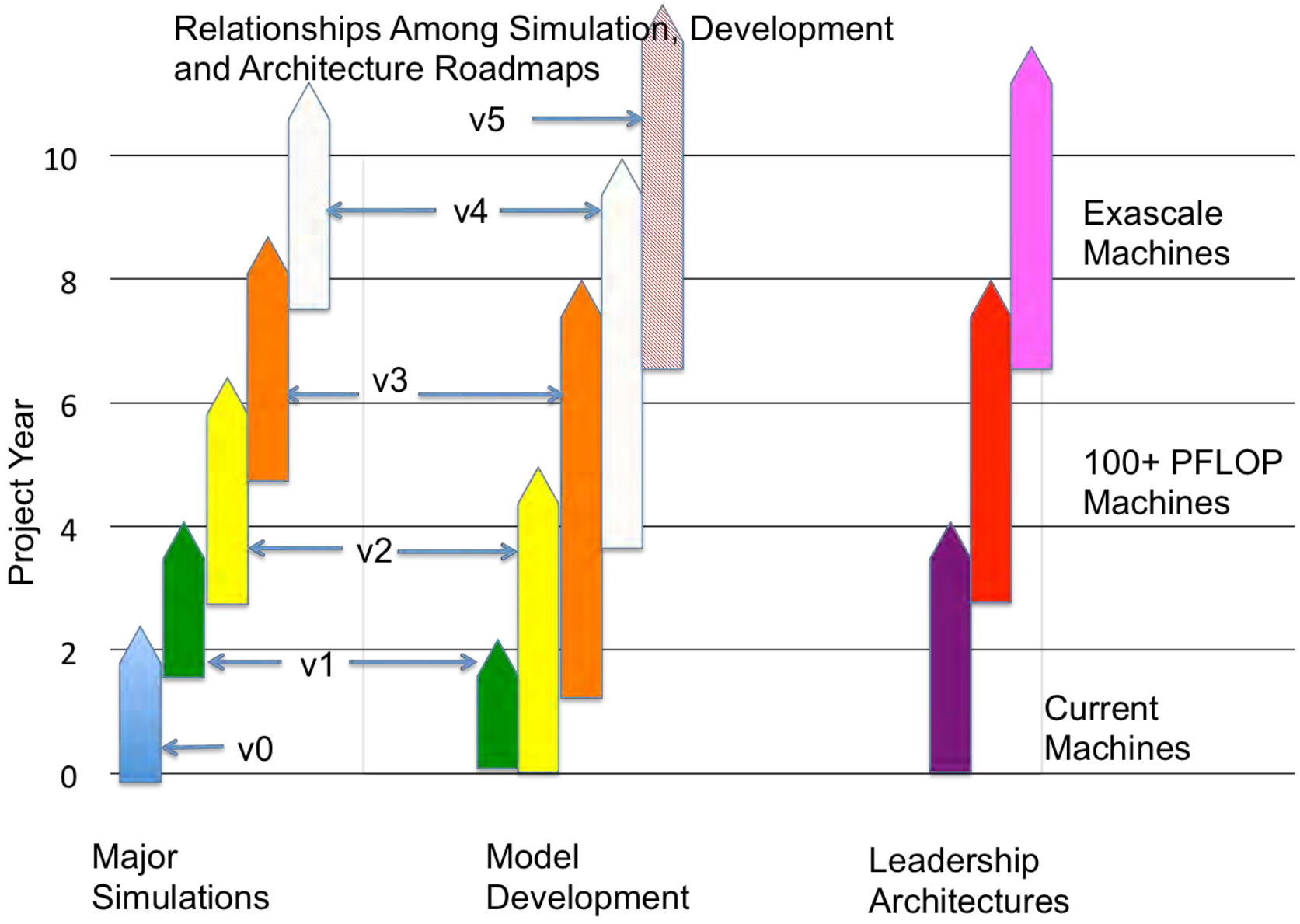
Water cycle: **How do the hydrological cycle and water resources interact with the climate system on local to global scales?** ***Water availability***

Biogeochemistry: **How do biogeochemical cycles interact with global climate change?** ***Carbon cycle***

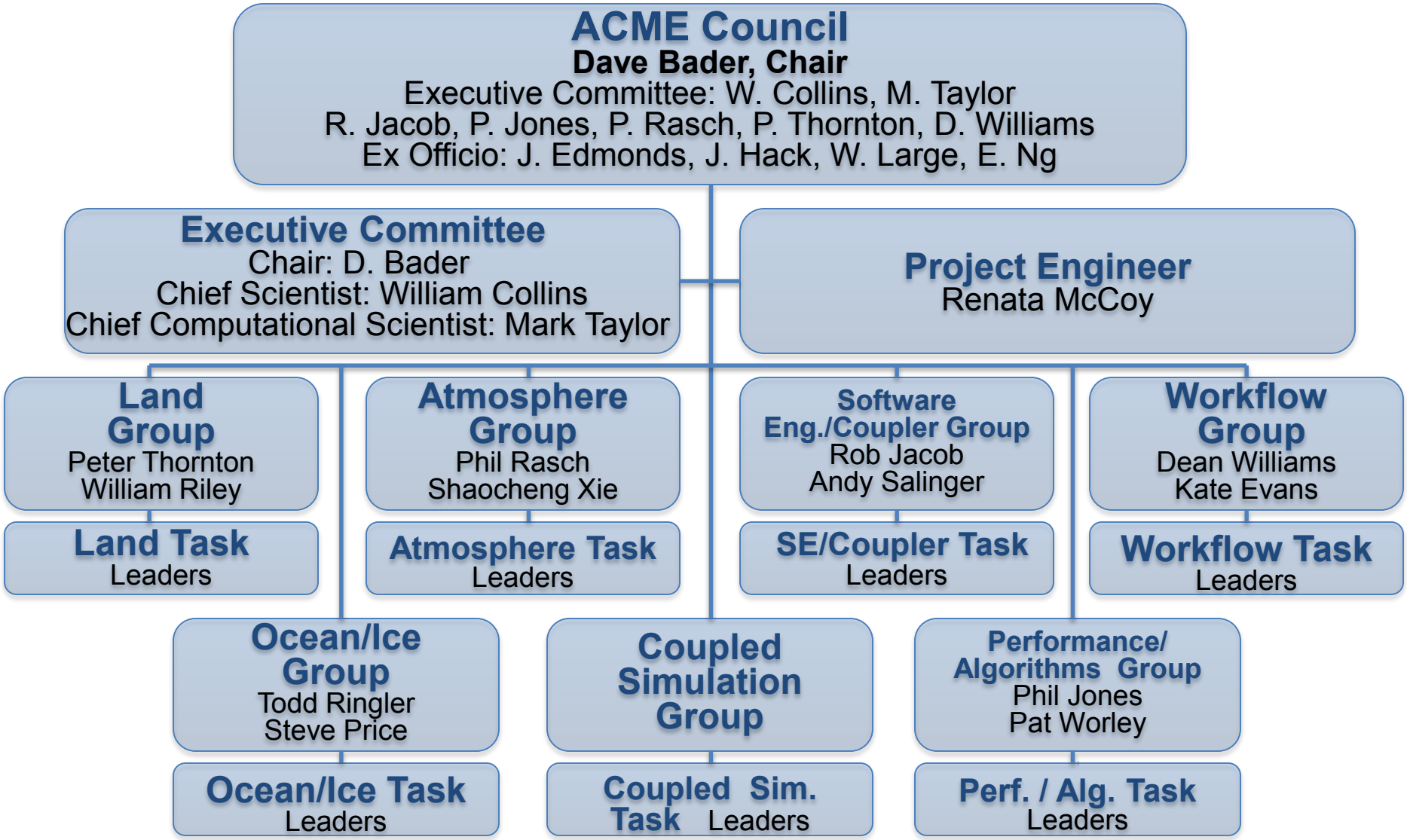
Cryosphere: **How do rapid changes in cryospheric systems interact with the climate system?** ***Sea level rise***

ACME
Accelerated Climate Modeling for Energy

ACME development Roadmap



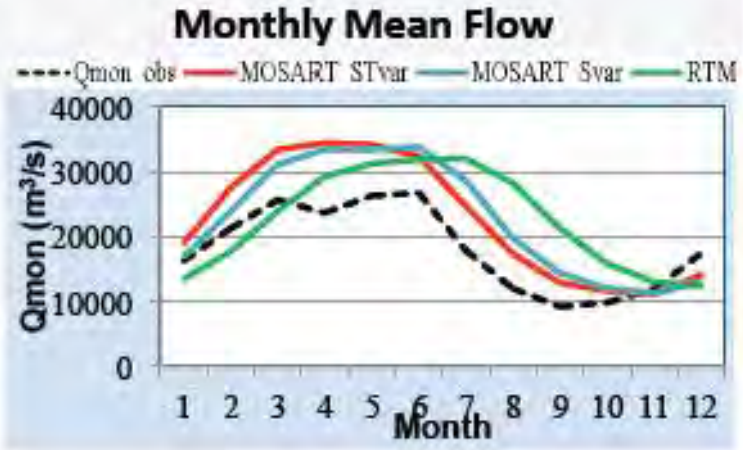
ACME management structure



Water Cycle Experiment Strategy

Seasonally inundated river basins in central Amazon

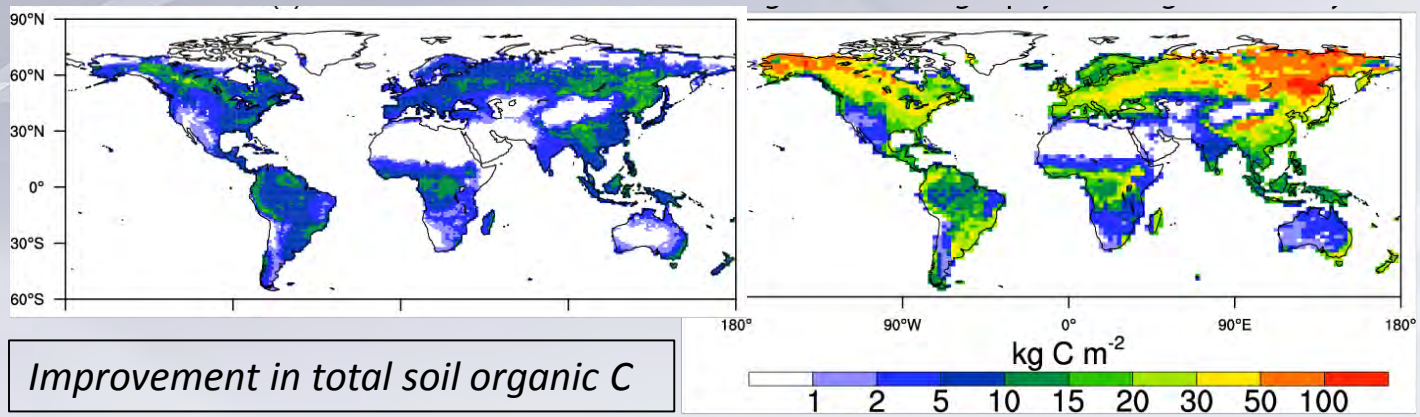
- **Explore the role of physical processes and parameterization in climate models influencing river flow and fresh water supply.**
- **Produce accurate simulation of river flow for major river basins: Mississippi, Amazon, Ganges**
- **These basins represent very different:**
  - Climatic and hydrologic regimes
  - Large-scale ocean-atmosphere interactions
  - Regional land-atmosphere interactions
  - Local human activities



ACME Accelerated Climate Model for Energy

U.S. DEPARTMENT OF ENERGY

Biogeochemical Experiments



Improvement in total soil organic C

Science Question

- What are the impacts of nutrients on terrestrial C-Climate feedbacks?

Motivation

- Globally, many ecosystems are N, P, or N and P limited
- Current nutrient-enabled models show poor performance compared to observations

Goals

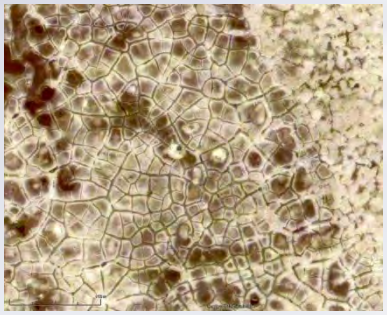
- Quantify impacts on C-climate system feedbacks by nutrients (nitrogen, phosphorus)
- Investigate structural uncertainty in representations of nutrient controls on C-cycle dynamics

ACME-Land development approach

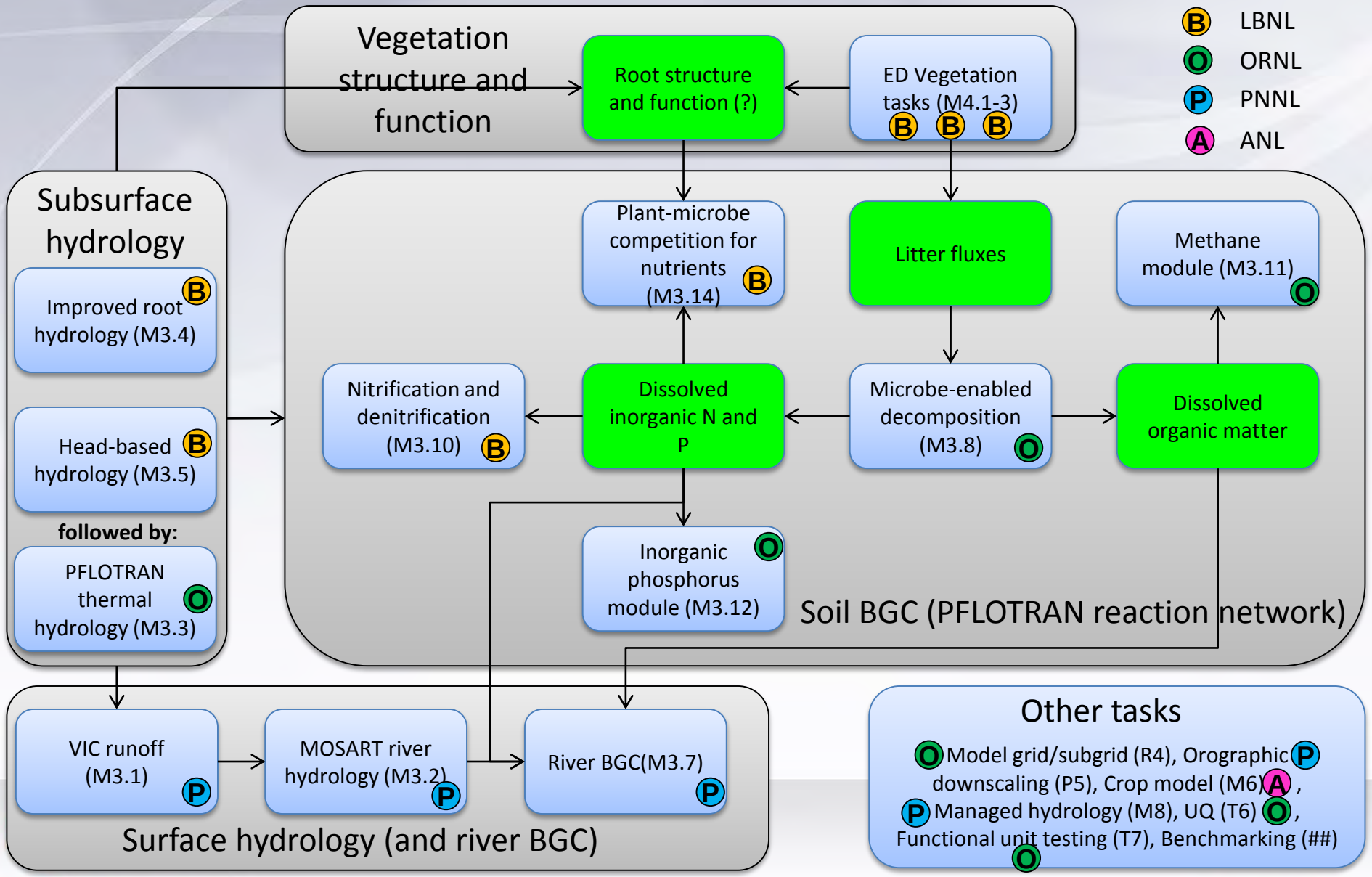
- Goals
  - Modularity of Land components within a software architecture
  - Develop new capabilities to be deployed in increments (Version 1, Version 2, etc.)
  - Evaluate Land as single component and within the coupled framework, developing new metrics as required by ACME science

Major land development tasks

- Hydrologic processes: uses basin, sub-basin gridding
  - Subsurface thermal hydrology
  - Runoff parameterizations
  - River and floodplain parameterizations
- Vegetation processes
  - Age-class and time since disturbance
  - Vertical canopy interactions
  - Root hydrology and rooting dynamics
- Biogeochemical processes
  - Riverine biogeochemical processes and transport
  - Prognostic phosphorus cycle
  - Explicit microbes
- Coupled system processes
  - Orographic downscaling
  - Human-land interface (crops, hydrology)
- Model evaluation and uncertainty quantification
- Code architecture, functional unit testing



Modular interface design



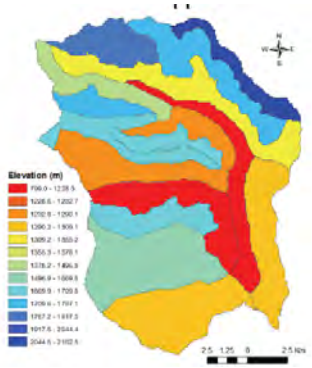
Pending societal/energy ACME component

- Proposal under development to incorporate societal/energy component into ACME, mainly part of the land:
  - Include GCAM Integrated Assessment – ACME linkages (from previous iESM project)
  - Carbon cycle GCAM-ACME synthesis
  - Biofuel crops
  - Water management
- We are considering co-development of the ACME-land model with the Integrated Assessment Research program, for better integration of Human and Natural systems

ACME
Accelerated Climate Modeling for Energy

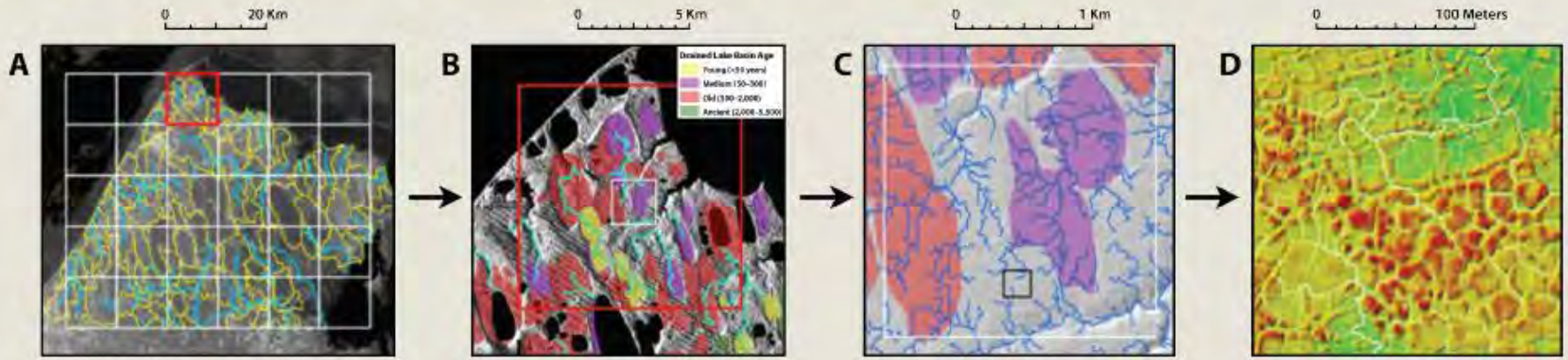
NGEE – ACME connections

- **CLM-PFLOTRAN developed by NGEE-Arctic (phase 1), global implementation under ACME**
- **NGEE-Arctic (phase 2) proposes to use the basin-sub-basin grids and the subgrid orographic downscaling from ACME**
- **NGEE Tropics, NGEE Arctic and ACME will collaborate on ED and trait-based approaches for modeling**



Sub-basin land grid
Columbia river basin

Hydrologic and Geomorphic Features at Multiple Scales. *At the scale of (A) a high-resolution ESM, (B) a single ESM grid cell, (C) a 2 × 2 km domain of high-resolution Light Detection and Ranging (LiDAR) topographic data, and (D) polygonal ground. Yellow outlines in panel A show geomorphologically stable hydrologic basins, connected by stream channels (blue). Colored regions in panels B and C show multiple drained thaw lake basins within a single 10 × 10 km grid cell (B) or a 2 × 2 km domain (C), with progressively more detailed representation of stream channels (blue). Colors in panel D represent higher (red) to lower (green) surface elevations for a fine-scale subregion, with very fine drainage features (white). [Los Alamos National Laboratory, University of Alaska Fairbanks, and University of Texas at El Paso]*



How to engage with ACME?

Talk to Land Group Leads: Peter Thornton and Bill Riley and Task Leads (next slide)

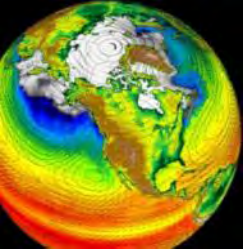
See the project website for more information
http://climatemodeling.science.energy.gov/projects/accelerated-climate-modeling-energy

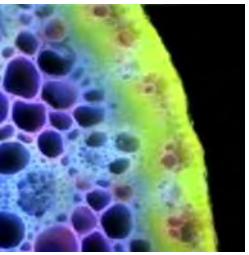
ACME Land Tasks (and Leads)

Task	Task Lead
Land model architecture: definition of requirements and tasks	Peter Thornton
ACME Land Model benchmarking	Forrest Hoffman
Land BGC 3-year Experiment	Bill Riley
Implement new model architecture: grid, subgrid, data structures	Forrest Hoffman
Implement new model architecture: module interfaces, unit testing framework	Dali Wang
Implement uncertainty quantification framework	Khachik Sargsyan
Implement orographic downscaling	Ruby Leung
Implement runoff partitioning based on VIC	Maoyi Huang
Implement river routing, inundation, and water temperature based on MOZART	Ruby Leung
Implement thermal hydrology model based on PFLOTRAN	Jitendra (Jitu) Kumar
Implement improved root hydrology	Gautam Bisht
Implement head-based hydrology solver	Gautam Bisht
Implement riverine biogeochemistry	Hong-Yi Li
Implement explicit microbes and dissolved organic matter	Gangsheng Wang
Implement improved nitrification, denitrification, and N fixation	Bill Riley
Implement improved methane dynamics	Gangsheng Wang
Implement prognostic phosphorus cycle	Xiaojuan Yang
Implement improved plant-microbe competition for nutrients	Bill Riley
Implement vegetation age, size-class, and time-since disturbance	charlie koven
Implement vertical canopy interactions	charlie koven
Implement improved vegetation mortality and recovery	charlie koven
Implement improved crops and crop management practices	Beth Drewniak
Implement managed hydrologic system	Ruby Leung

Additional ESM supported Land-projects

- Scale-Aware, Improved Hydrological and Biogeochemical Simulations of the Amazon Under a Changing Climate (Shen)
- Global land model development: time to shift from a plant functional type to a plant functional trait approach (Reich)
- Quantification of Land-Use/Land Cover Change as Driver of Earth System Dynamics (Hurtt)
- Major improvements on the longwave radiative interactions between surface and clouds in the Polar Regions in Atmospheric global (Huang)
- Improving Land-Surface Modeling of Evapotranspiration Processes in Tropical Forests (Miller)
- Developing Global Simulation of Drought-associated Vegetation Mortality within the Community Land Model (McDowell; co-sponsored with TES and RGCM)
- A Multiscale Reduced Order Method for Integrated Earth System Modeling (Pau, Early Career Award)




Thank you!

Dorothy.Koch@science.doe.gov

ACME:
http://climatemodeling.science.energy.gov/projects/accelerated-climate-modeling-energy

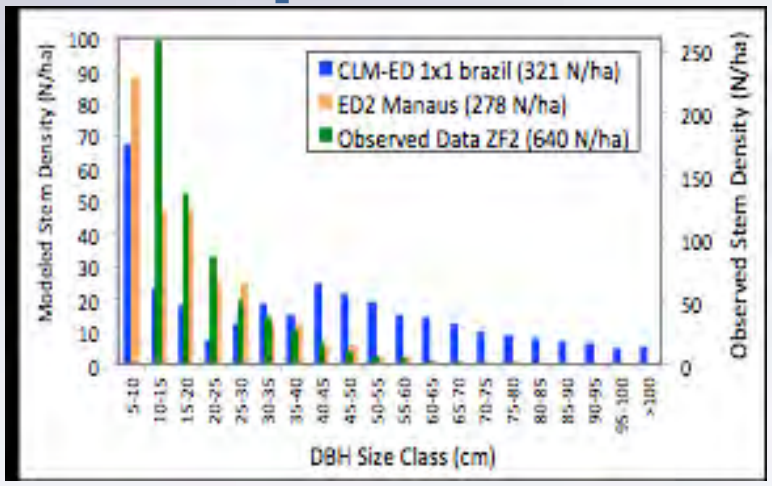
Earth System Modeling:
http://science.energy.gov/ber/research/cesd/earth-system-modeling-program/

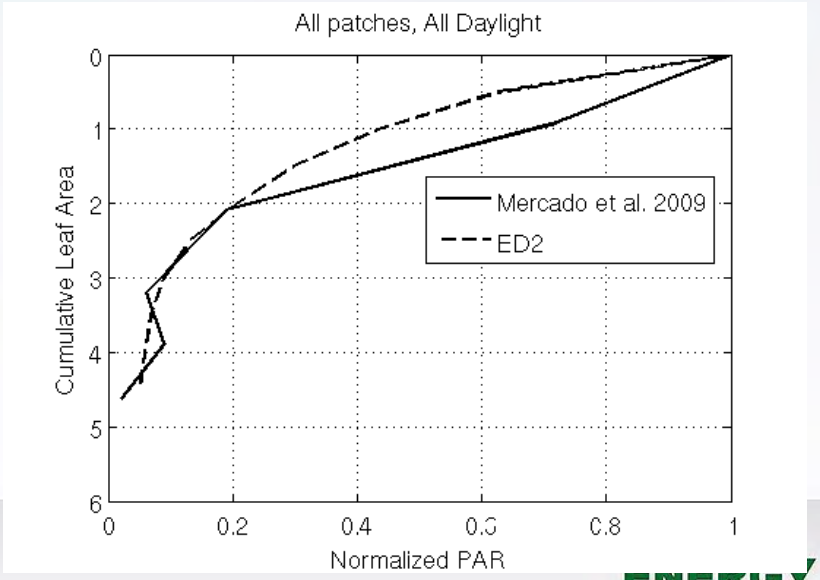
Early Progress: Hydrology

- MOSART added inundation, tested over Columbia River Basin
  - Managed hydrology: Reservoir operation and water balance tested in this framework
- Head-based hydrology tested on benchmark problems
- PFLOTRAN surface meshing procedure complete, and generalization of 3D code to 1D implementation for global runs
  - Regional and global testing underway
  - Code reduction to reduce PFLOTRAN build complexity underway

Early Progress: Vegetation processes

- CLM-ED being exercised in point and regional modes
  - Identified biomass bias
  - Improved canopy height and leaf area distributions
  - Improved radiative transfer for photosynthetically active radiation
- Crops:
  - Rooting dynamics complete
  - Phenology improvements underway





Early Progress: Biogeochemistry

- Prognostic phosphorus cycle model implemented in ACME code base
  - Site, regional, and global testing underway
- Explicit microbe model constructed, testing underway
  - Includes methanogenesis, menthanotrophy
- New nitrogen cycle algorithms being evalauted
- New model for competition for limiting nutrients developed and tested (Equilibrium chemistry approach, or ECA)
- Biogeochemistry component of PFLOTRAN now coupled to CLM
  - Can reproduce functionality of CLM4.5 BGC
  - Modular interface to thermal/hydrology state
  - Configurable to represent ECA approach to nutrient dynamics

Progress: Other highlights

- Uncertainty quantification task focused on model spinup bottleneck
  - New approach reduces model execution time for complete spinup by a factor of 5-10.
  - Spinup approach sensitive to climate
  - Added coarse woody debris pools to accelerated spinup
  - This development will allow significantly more and better simulation experiments, improving model parameterization
- Land model benchmarking has focused on synthesis of nutrient and carbon cycle datasets, in anticipation of the BGC 3-yr experiment.

Development Plans: V1 (by end of 2015)

- New grid/sub-grid architecture, coordinated with atmosphere, land ice
- Orographic downscaling
- Head-based hydrology
- Coupled C-N-P cycles
- ECA method
- Some improvements in crops and managed hydrology
- *Maybe* some components of ED
- *Maybe* some components implemented in PFLOTRAN biogeochemistry framework

Development Plans: V2 (by end of Q12)

- PFLOTRAN biogeochemistry framework
  - Explicit microbial model
  - Improved methane model
  - Phosphorus cycle model
  - Improved nitrogen model (nitrification/denitrification)
  - Switchable options for plant-microbe nutrient competition
- Ecosystem Demography integration
  - Age and size classes
  - Improved mortality
  - Improved vertical canopy
  - Improved leaf physiological traits
- PFLOTRAN thermal hydrology
- River biogeochemistry
- Improved crops, expanded crop types
- Expanded benchmarking and uncertainty quantification