Global Earth System Model–Data Integration: Advancing Terrestrial Model Representation of Fundamental Processes

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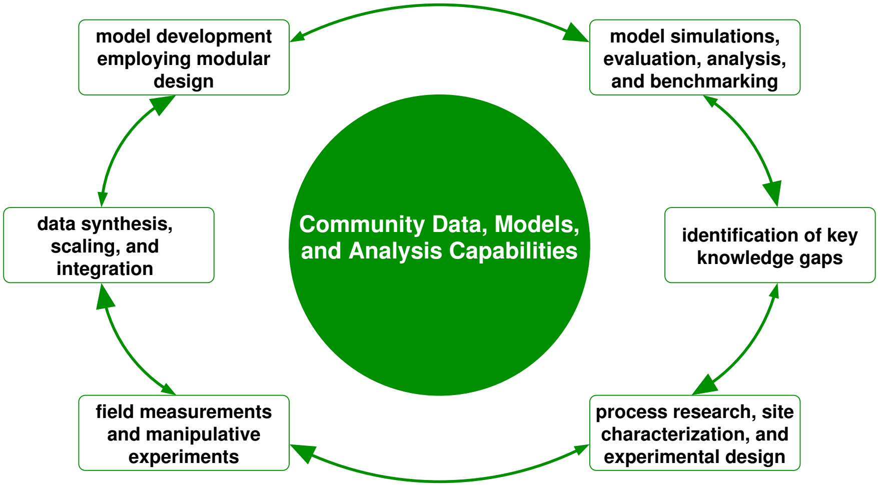
Model, Experiment, and Data Integration Strategy



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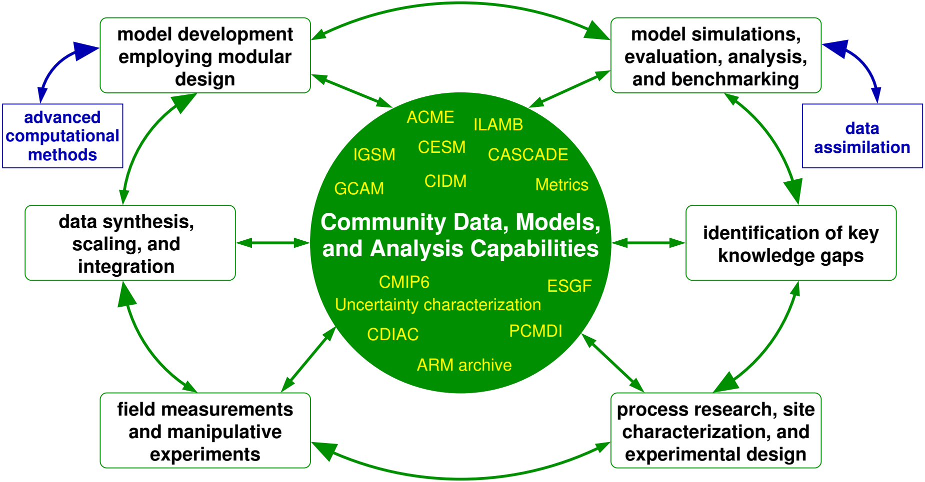
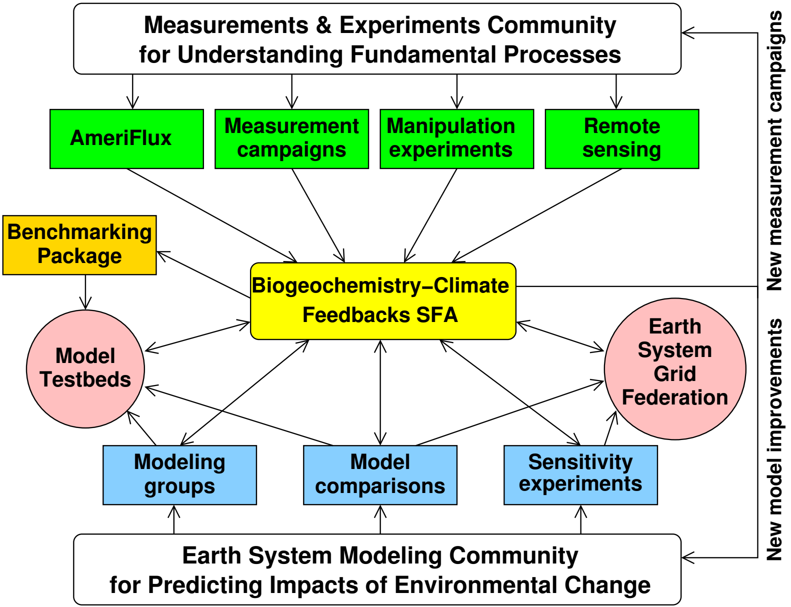


Biogeochemistry–Climate System Feedbacks



RO6: Nutrient Biogeochemistry

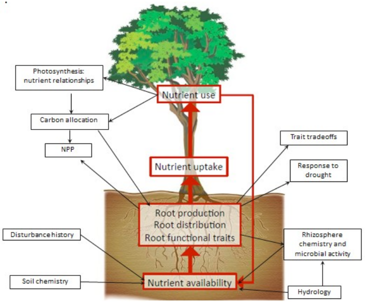
<u>Objective Goals</u>:
Improve understanding and model representation of the factors that control nutrient availability and nutrient controls over forest productivity, plant allocation and turnover, and post disturbance recovery rates.

Focus on P and N-P interactions
Mechanistic understanding
Model-measurement interaction
Develop tools for pantropical scaling
Coordination with other international efforts

Puerto Rico Pilot Study:
Model-guided measurements to link soil chemistry, rhizosphere microbial activity, and root traits with P availability and uptake

APPROACH

Our integrative approach will start with insights from models and model uncertainty and be guided by the need to inform and improve nutrient interactions in models



Our approach separates the strongly linked processes of nutrient availability, nutrient uptake, and nutrient use, and emphasizes the critical role of roots in nutrient interactions

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New Phytologist

Review

Tansley insight

Incorporating phosphorus cycling into global modeling efforts: a worthwhile, tractable endeavor

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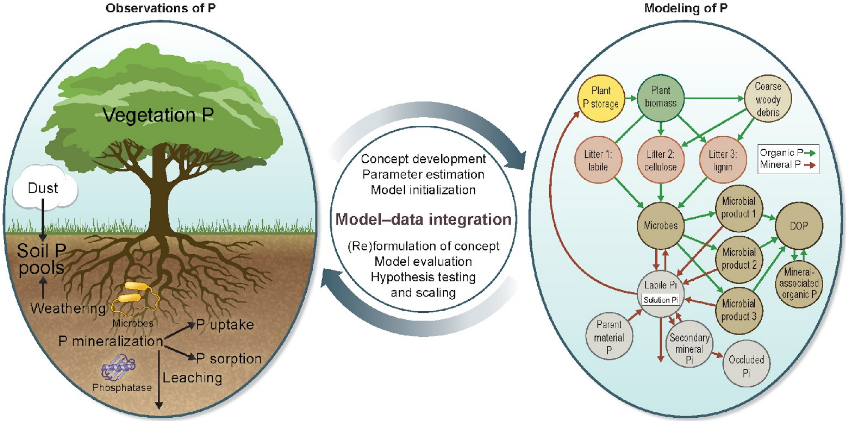
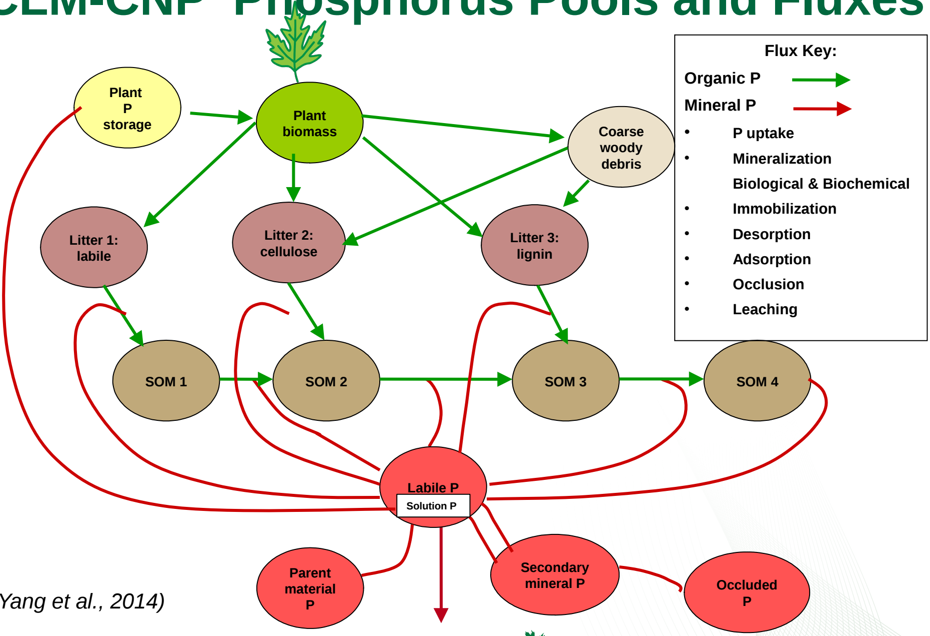
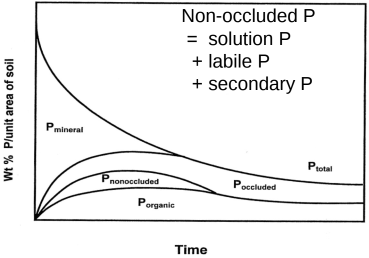


CLM-CNP Phosphorus Pools and Fluxes

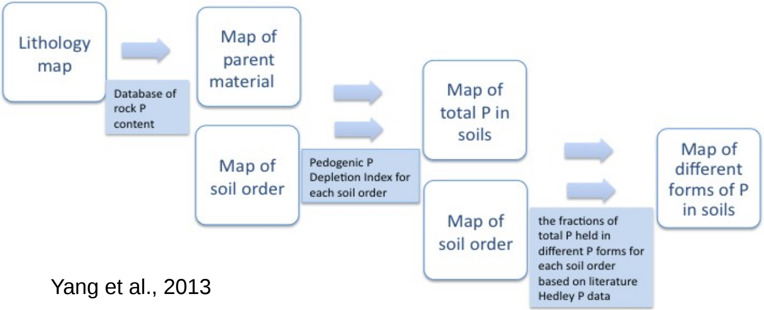


(Yang et al., 2014)

Global P maps – A data based approach

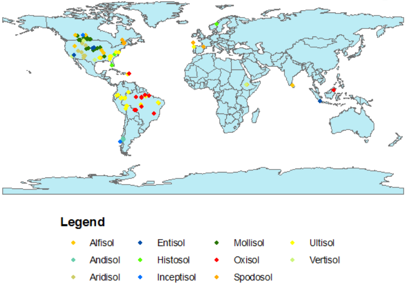


- **Walker and Syers' conceptual model**
- **USDA soil order as an proxy for soil development stages**
- **Chronosequence studies and soil vertical profile P data used to quantify loss of total P for each soil order**
- **Hedley P database to provide the fractions of P in different forms for each soil order**



Yang et al., 2013

Hedley P database

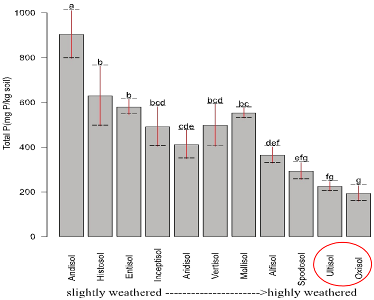


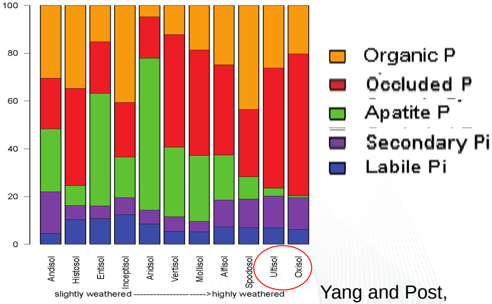
➢ Hedley sequential fractionation method- a useful tool to examine different forms of P in soils (Labile Pi, secondary mineral Pi, apatite P, occluded P, organic P)

➢ 178 soil measurements from literature

➢ Categorized by USDA soil order, useful for understanding of phosphorus transformations as a function of pedogenesis

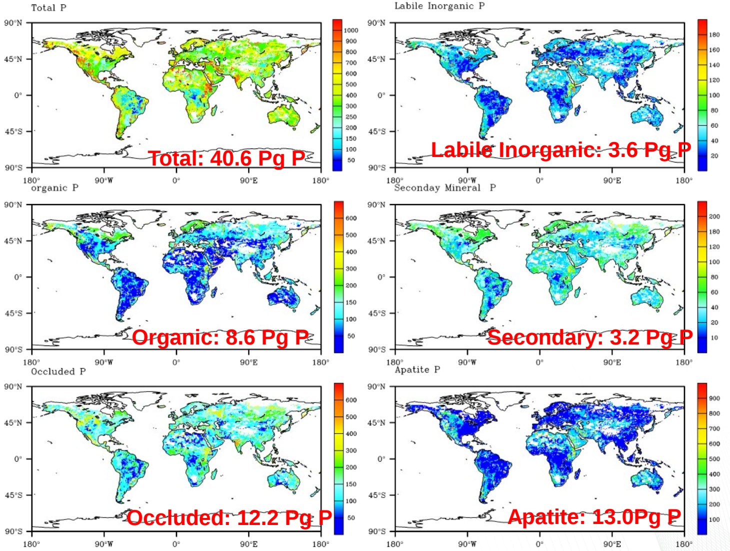
➢ Useful for investigating C:N:P stoichiometry in soil organic matter by providing organic C,N,P measurements





Yang and Post, 2011

P maps for global model initialization



Yang et al., 2013

Calculation of P supply

Model spin-up:

1. start with accelerated decomposition without P limitation to initialize P pools in vegetation and SOM pools using PFT stoichiometry
2. initialize soil inorganic P pools using site observations or parameters based on soil type
3. run normal spin-up with P limitation turned on to allow C, N, and P cycles to equilibrate

Critical model inputs for P supply

- Total soil P
- Rate constants for conversions between inorganic P pools (from literature)
- Smax – the maximum amount of labile P in soil and Ks – empirical constant representing tendency of soil solution P for adsorption (calibrated values, starting from literature)
- Specific biochemical mineralization rate (calibrated)
- Scaling factor for biochemical mineralization

Global model runs -- Grid cell 0.5 degree (~50 x 50 km)

Calculation of P demand and limitation

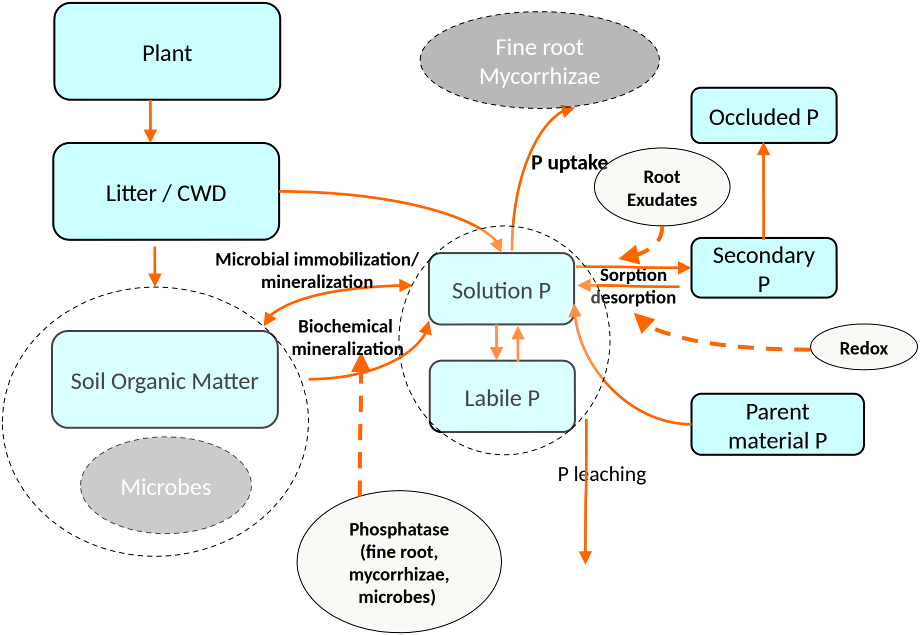
P demand = plant + microbial demand

- Plant P demand is the amount of P needed for the allocation of new growth to various tissues based on specified C:P ratios and allometric parameters
- P demand from soil = total plant demand – P flux from retranslocated P pool
- P demand for microbial immobilization is sum of all potential P immobilization fluxes during SOM decomposition
- If soil solution P pool < total P demand, plant and microbial limiting factors are equal to P_{sol}/demand.
- Either N or P will limit GPP, but this can vary with each time step

Inputs needed:
- Stoichiometric constants for dominant PFT
- Allometric constants for dominant PFT

Critical model uncertainties

- Stoichiometric constants for dominant PFT
- Total soil P
- Rate constants for conversions between inorganic P pools (from literature)
- S_{max} – the maximum amount of labile P in soil and Ks – empirical constant representing tendency of soil solution P for adsorption (calibrated values, starting from literature)
- Specific biochemical mineralization rate (calibrated)
- Scaling factor for biochemical mineralization


Plant
Litter / CWD
Fine root
Mycorrhizae
P uptake
Root
Exudates
Occluded P
Secondary
P
Sorption
desorption
Redox
Microbial immobilization/
mineralization
Solution P
Biochemical
mineralization
Labile P
Soil Organic Matter
Microbes
Parent
material P
P leaching
Phosphatase
(fine root,
mycorrhizae,
microbes)

Matching measurements to model uncertainties

Measurements in Puerto Rico to inform the model

- Total soil P (organic + inorganic + microbial)
- Langmuir equation parameters for sorption-desorption
- Biochemical mineralization parameters
  - Phosphatase activity
  - Root and mycorrhizae distribution and activity

Measurements to inform model development

- P uptake
- Redox and pH conditions that affect sorption-desorption
- P effects on N fixation

Measurements to support development of ED framework

- Root traits associated with P availability and P uptake
- Root depth distribution
  - Aboveground traits (e.g., foliar P, spectral signatures) that correlate with belowground activity

Three sites identified with contrasting P availability

<u>Day 2</u>

- Visited two areas with contrasting parent material – El Verde and Icacos
- Identified areas with contrasting P availability where we can initiate research

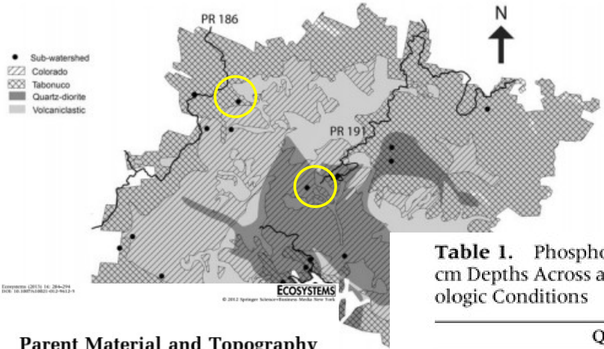


Figure 1. Location of the sub-watersheds within the Luquillo Forest. *Light gray* indicates VC and *dark gray* indicates QD, *crosshatched pattern* indicates Colorado forest and *striped pattern* indicates Tabonuco forest.

ECOSYSTEMS

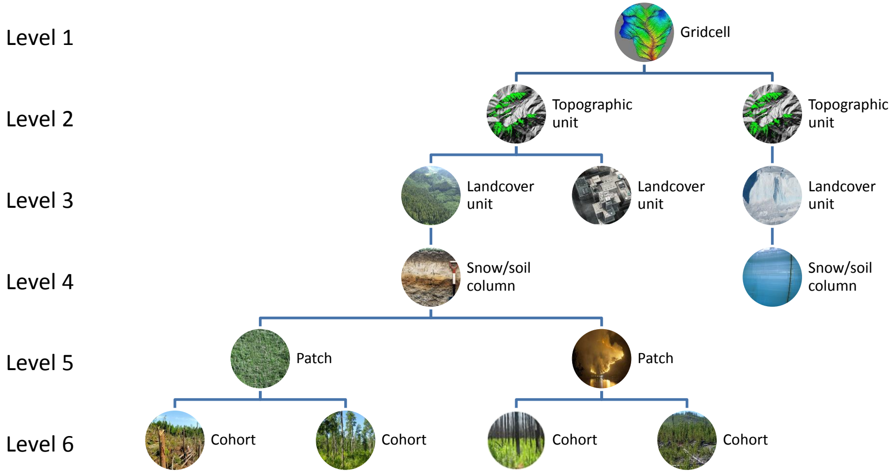
Parent Material and Topography Determine Soil Phosphorus Status in the Luquillo Mountains of Puerto Rico

Susanna M. Mage[1] and Stephen Porder[2]*

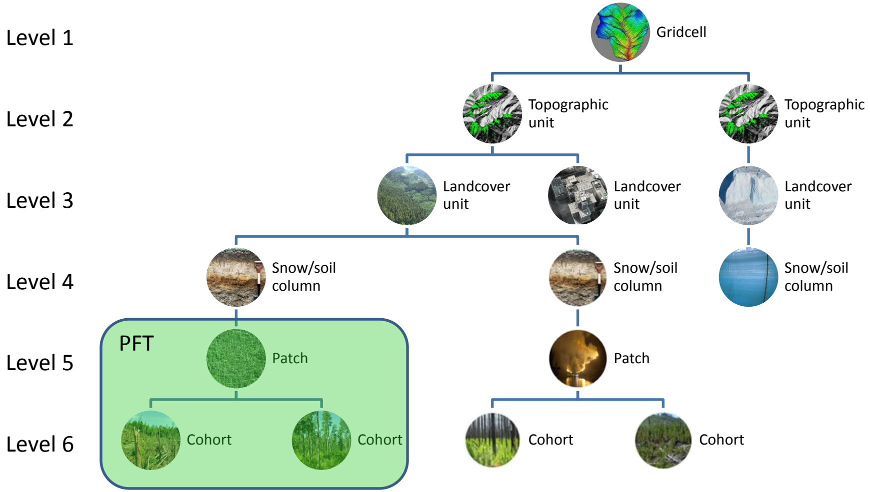
Table 1. Phosphorus Fractions (ppm) from 0–50-cm Depths Across a Matrix of Topographic and Lithologic Conditions

	Quartz diorite	Volcaniclastic
Total P	$R^2 = 0.62$	
Ridge	140 ± 23a	290 ± 15c
Slope	170 ± 31ab	280 ± 20bc
Valley	170 ± 25ab	410 ± 43d

ALM subgrid hierarchy (example with ED active): One column per landunit, multiple patches per column

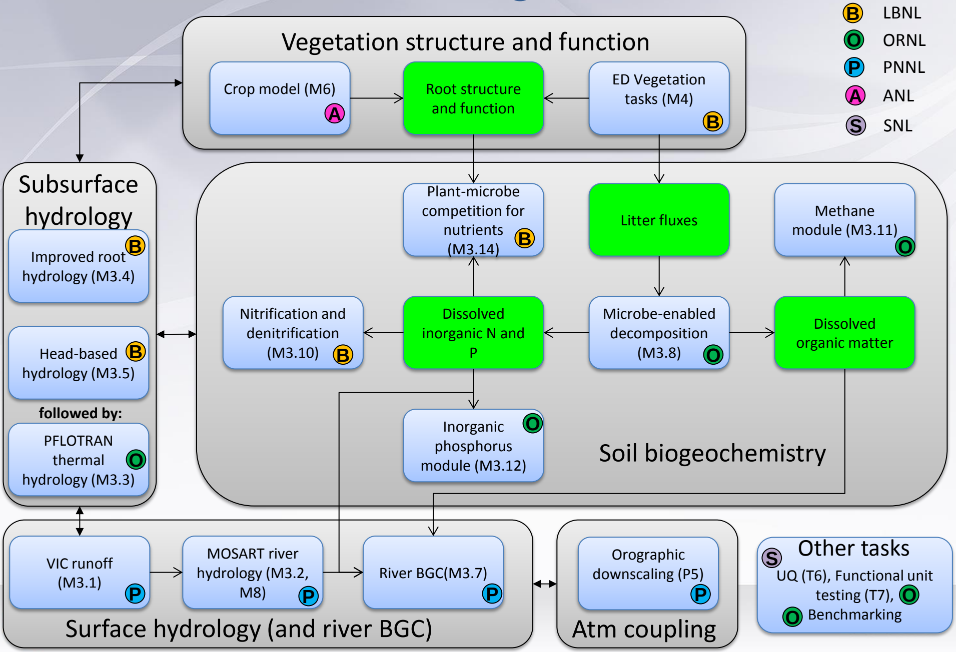


ALM sub-grid hierarchy (example without ED): Multiple columns per landunit, one patch per column



Without ED…

ACME-LM: Modular Design and Tasks



ACME V1 Coupled Experiments

- Biogeochemistry experiment
  - Evaluate the influence of phosphorus cycle on BGC feedbacks
  - Evaluate alternative representations of plant-microbe competition for nutrients
- Water cycle experiment
  - Evaluate the influence of orographic downscaling on land-atmosphere interactions
  - Evaluate improved parameterizations for clouds, aerosols, and cloud-aerosol interactions
- Cryosphere experiment
  - Investigate Antarctic ice sheet melt, destabilization, and sea-level rise
  - Eddy-resolving ocean captures details of circumpolar circulation

ALM developments for V1
(applicable experiment: WC, BGC, or ALL)

- Common architecture (ALL) *
- Orographic downscaling (WC)
- Variably saturated flow - VSF (WC)
- Coupled C-N-P cycles (BGC) *
- PFLOTRAN BGC interface (BGC) *
- Alternative plant-microbe competition - ECA (BGC)
- Initial crop model improvements (ALL)
- MOSART river routing - uncoupled (ALL)
- UQ framework (ALL)
- Evaluation / benchmarking framework (ALL) *
- Functional unit testing framework (ALL) *

(* indicates ORNL task lead)

ALM developments for V2

- VIC-based runoff
- MOSART river routing – coupled
- Managed hydrology
- Riverine biogeochemistry
- Improved soil thermal hydrology – PFLOTRAN *
- Improved root hydrology
- Explicit microbes, methane model *
- Nitrification, denitrification, N-fixation
- Ecosystem demography – ED
- Additional UQ
- Additional evaluation / benchmarking *
- Human dimensions (pending)