Reducing uncertainties associated with terrestrial carbon cycle-climate system feedbacks: Improved Earth System Model process representation for arctic, tropical, and temperate systems.

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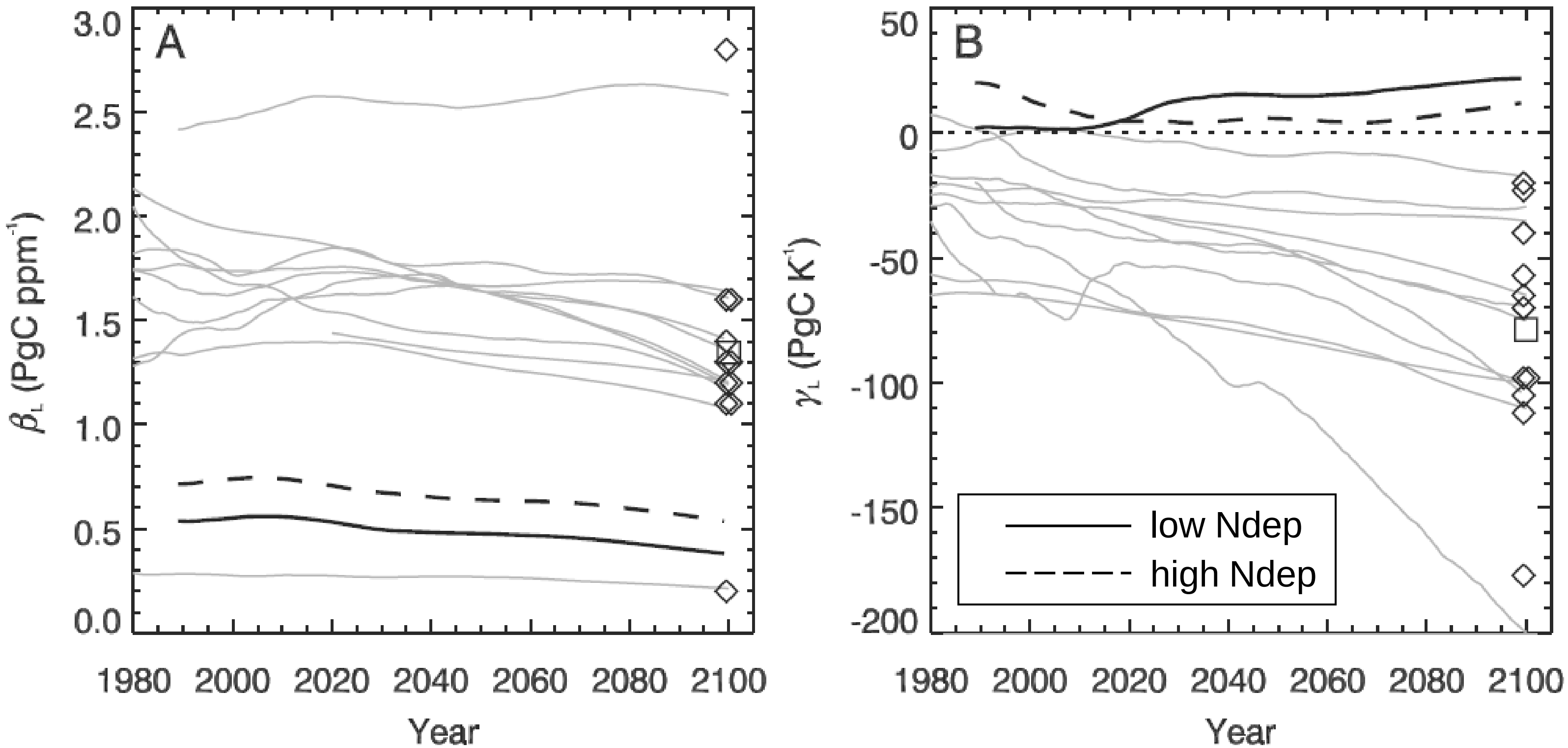
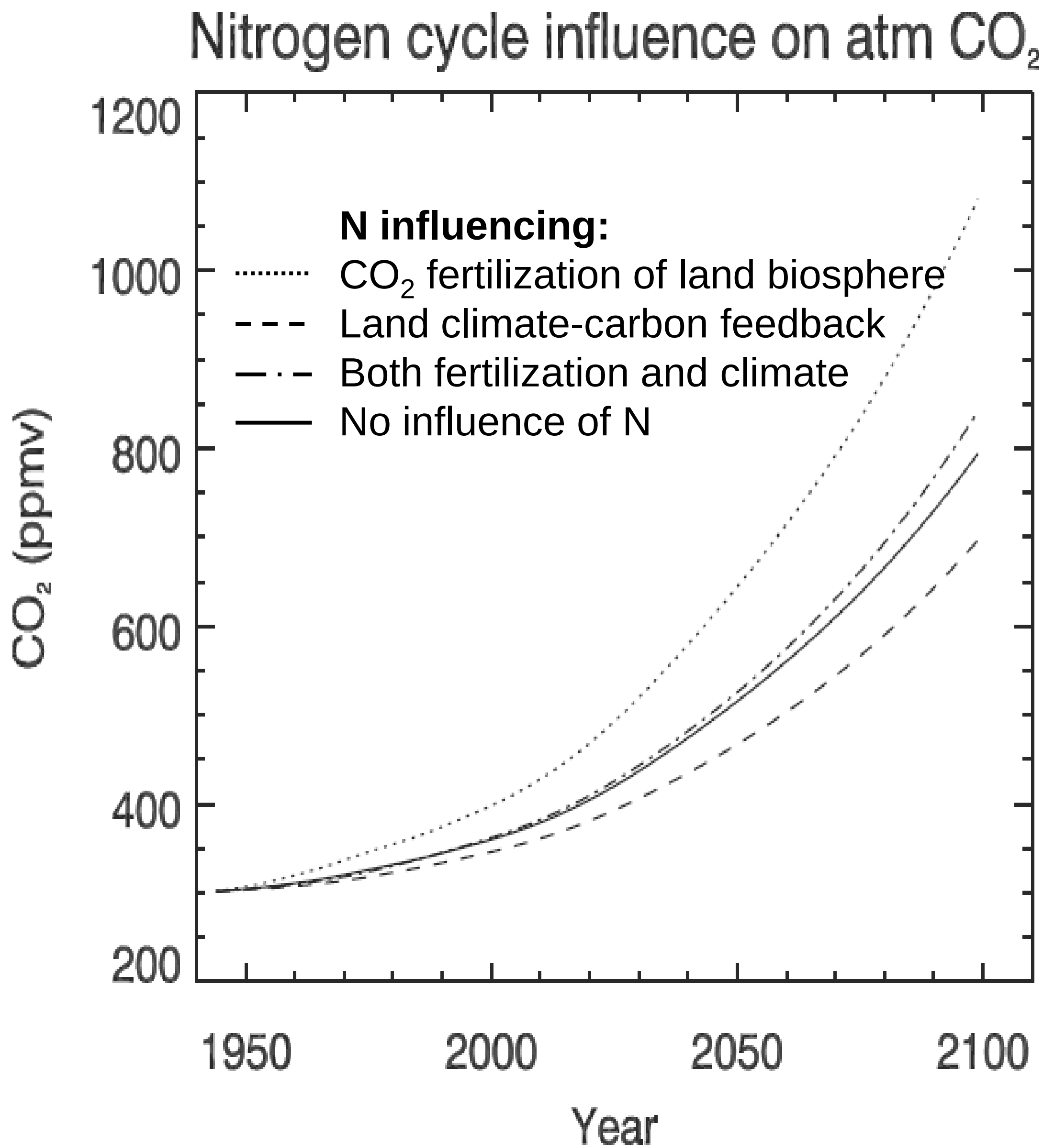
Motivation:
Process understanding suggests large uncertainty in coupled model carbon cycle-climate feedback

Land components of climate-carbon cycle feedback



Thornton et al., 2009



- Our current best terrestrial ecosystem process knowledge is not incorporated in Earth System Models
- There is the potential for large influence of new processes on ecosystem-climate feedback
- We don't have the right diagnostic tools to evaluate the importance and credibility of new terrestrial ecosystem processes at the global scale.

Based on: Friedlingstein et al. 2006, Thornton et al. 2009

Approach

- Prioritize new process representations
- Implement in CLM
- Develop new multi-scale diagnostics
- Evaluate CLM as new processes are coupled
- Extend application of diagnostic tools to CMIP5 models

Project outline

- Tropical Forest (ORNL)
  - Integration of phosphorus with existing C-N coupling in CLM
  - Evaluation against experimental results
- Temperate Forest (LANL)
  - Improvement of ecosystem demography model (ED): nitrogen allocation and hydrology
  - Integration of ED within CLM: PFT cohorts
- Arctic ecosystems (LBNL)
  - Characterize soil C stocks and permafrost state
  - Evaluate candidate belowground models
- Integration (UCI, ORNL, all)
  - Develop new coupled-model diagnostic tools
  - Evaluate CMIP5 model results
  - Exercise and evaluate CESM with new CLM processes

Efforts on Phosphorus cycle

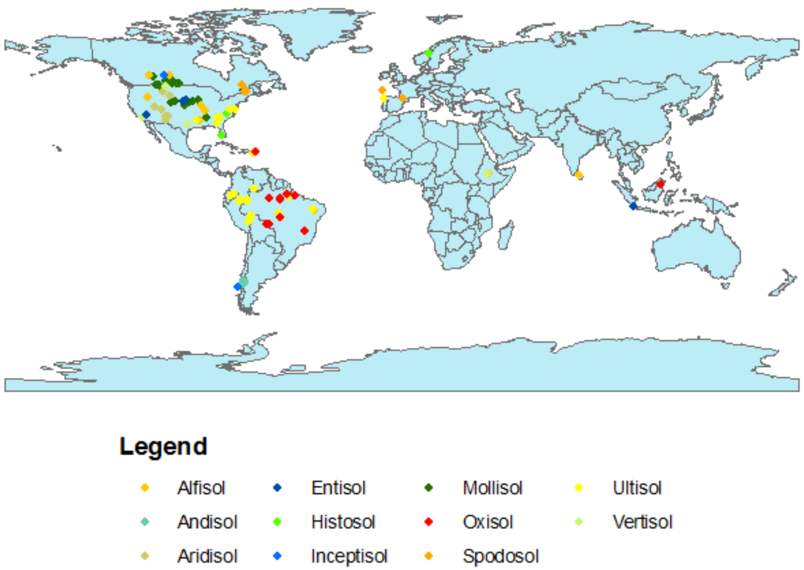
- Building Hedley P database from literature
- Developing spatially explicit global maps of different forms of P to provide initialization data for the global application of terrestrial C-N-P models
- Incorporating P cycle into CLM-CN model

Effort led by Xiaojuan Yang and Mac Post, ORNL

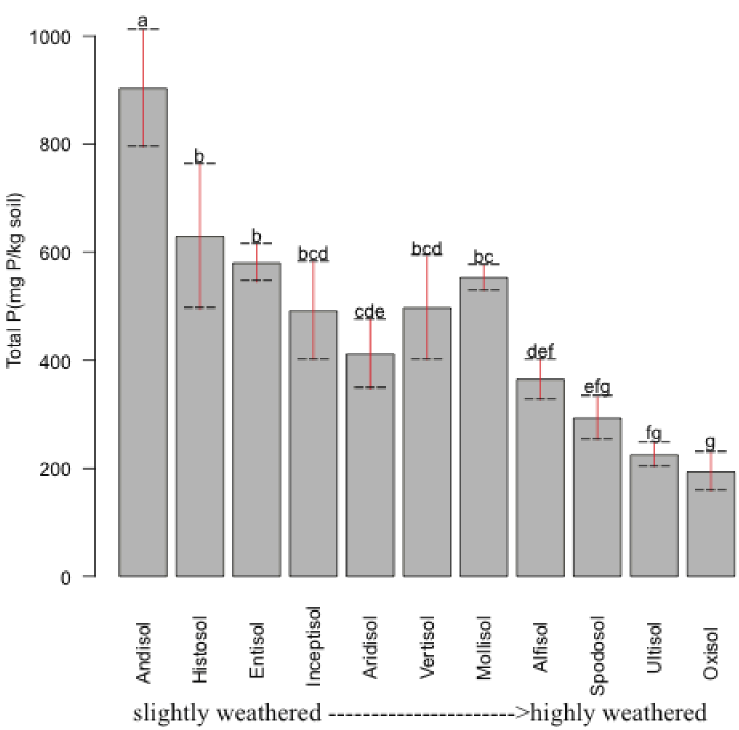
Hedley P database

- 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 stoichimetry in soil organic matter by providing organic C,N,P measurements

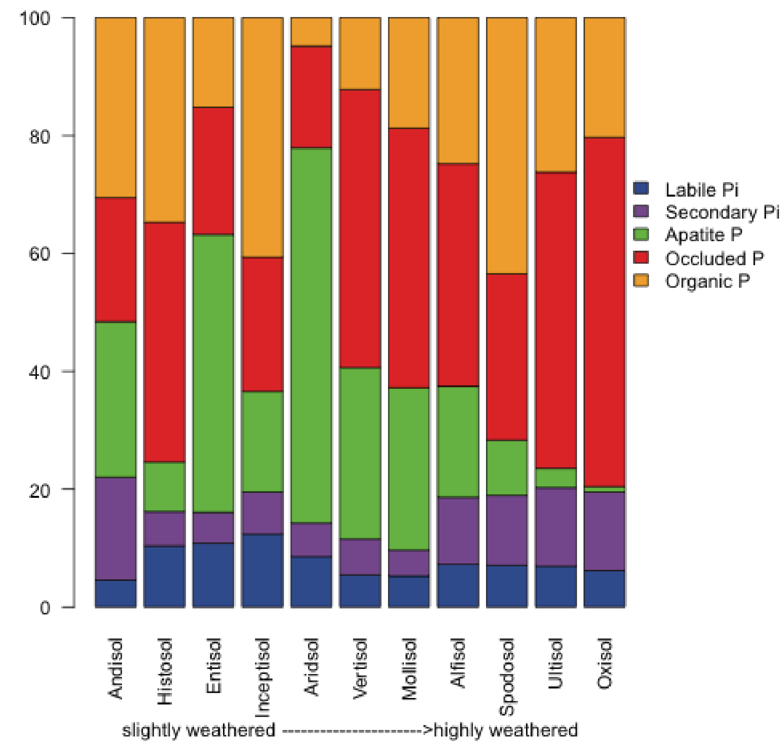
Hedley P database



- **Supports the Walker and Syers(1976)' conceptual model for P transformation during pedogenesis:**
  - ➢Decrease of total P
  - ➢Continual increase and eventual dominance of occluded P fraction
  - ➢First increase and then decrease of organic P fraction

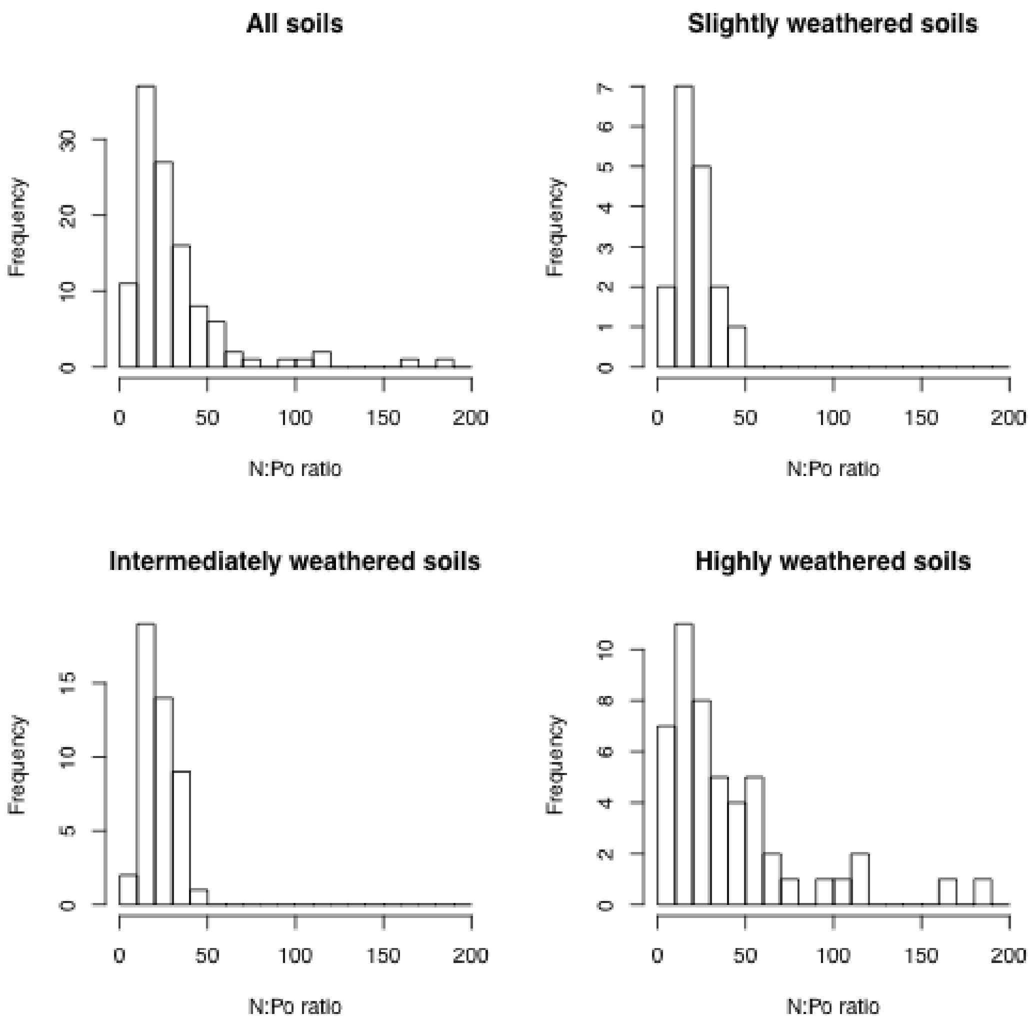


- **But we found persistence of non-occluded P fraction (Labile Pi plus secondary Pi) – dust deposition and dissolution of occluded P?**



Hedley P database

C:N:Po stoichimetry in soil organic matter



- **Carbon and nitrogen in soil organic matter are closely linked in all soils**

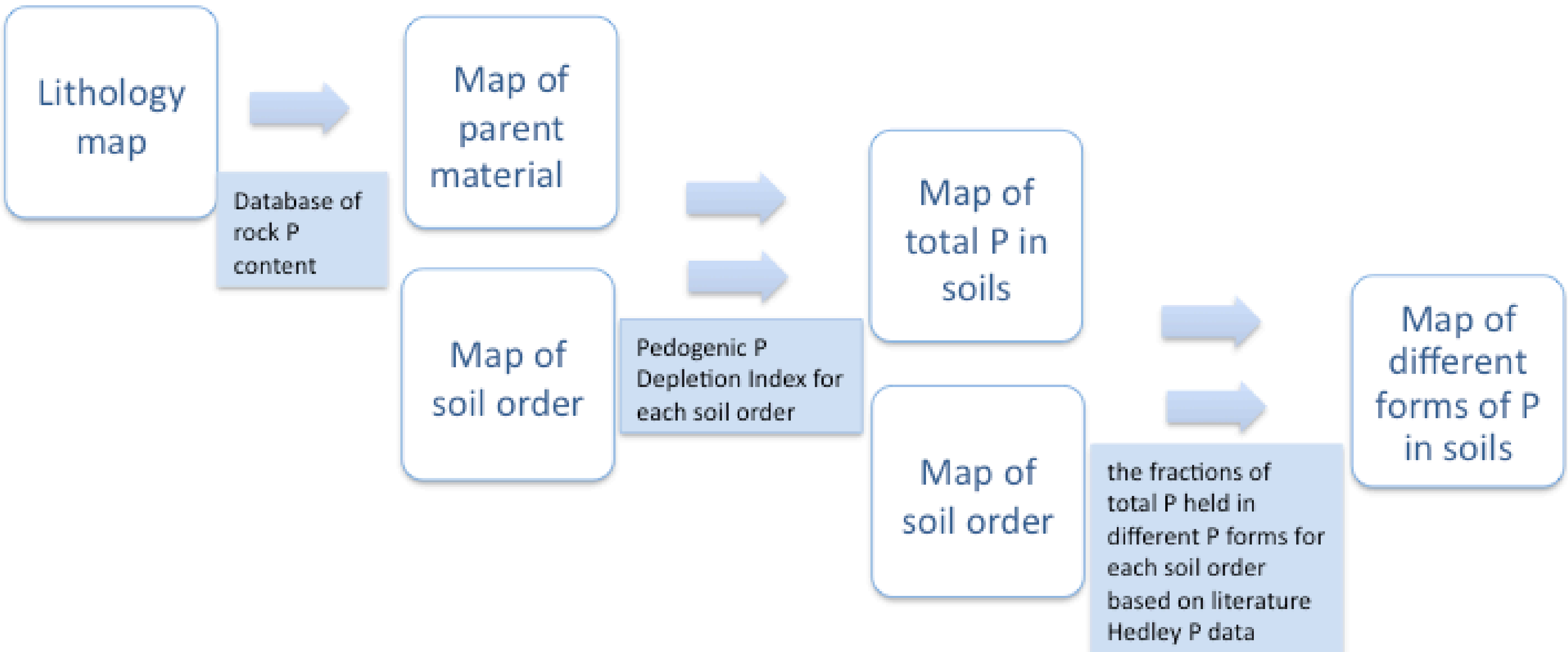
- **The decoupling of P from C and N in highly weathered soils**

    - Larger variation of N:Po
    - Higher mean values of N:Po

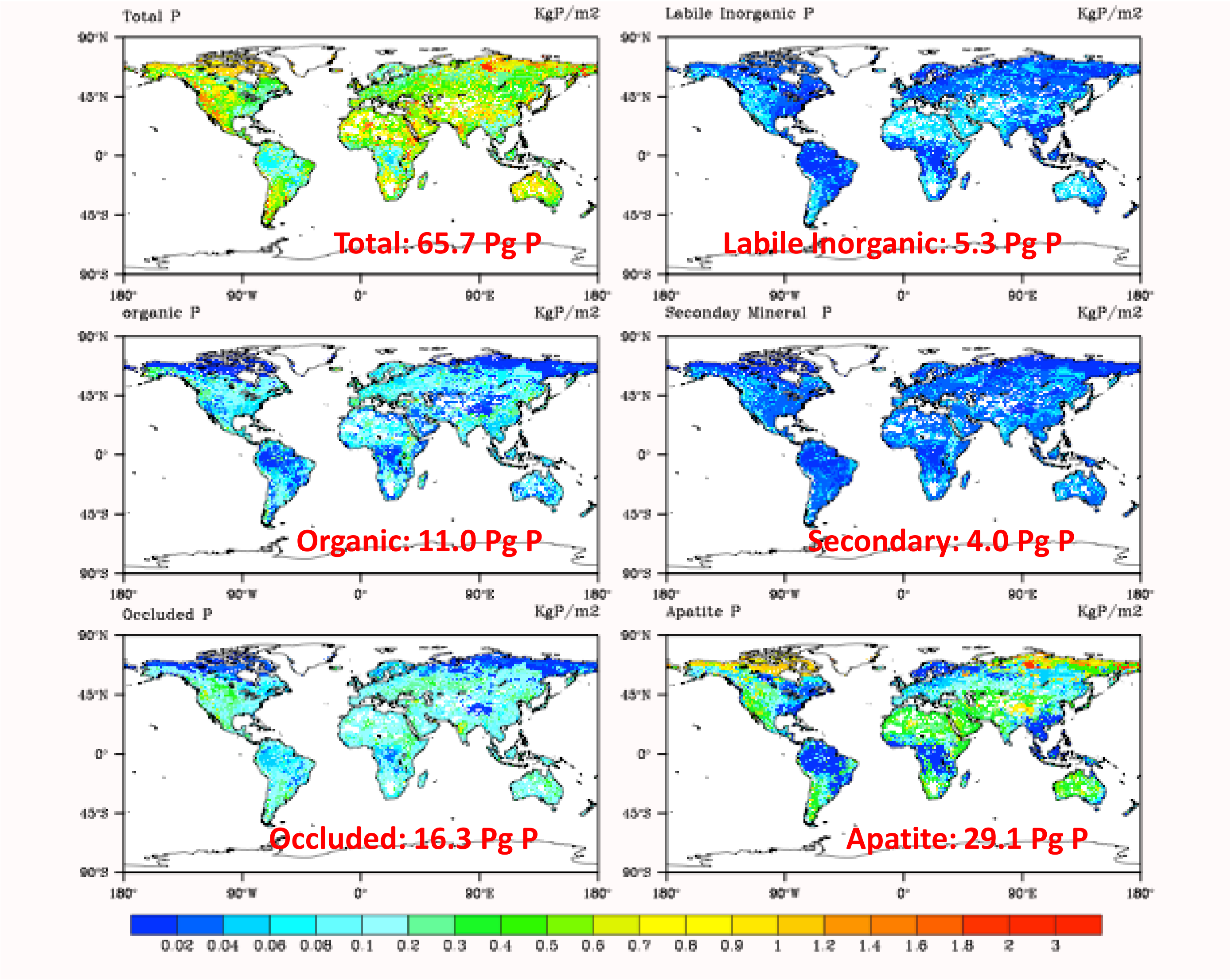
- **Biological and biochemical mineralization of organic P**

- **Another indicator of P limitation in highly weathered tropical soils**

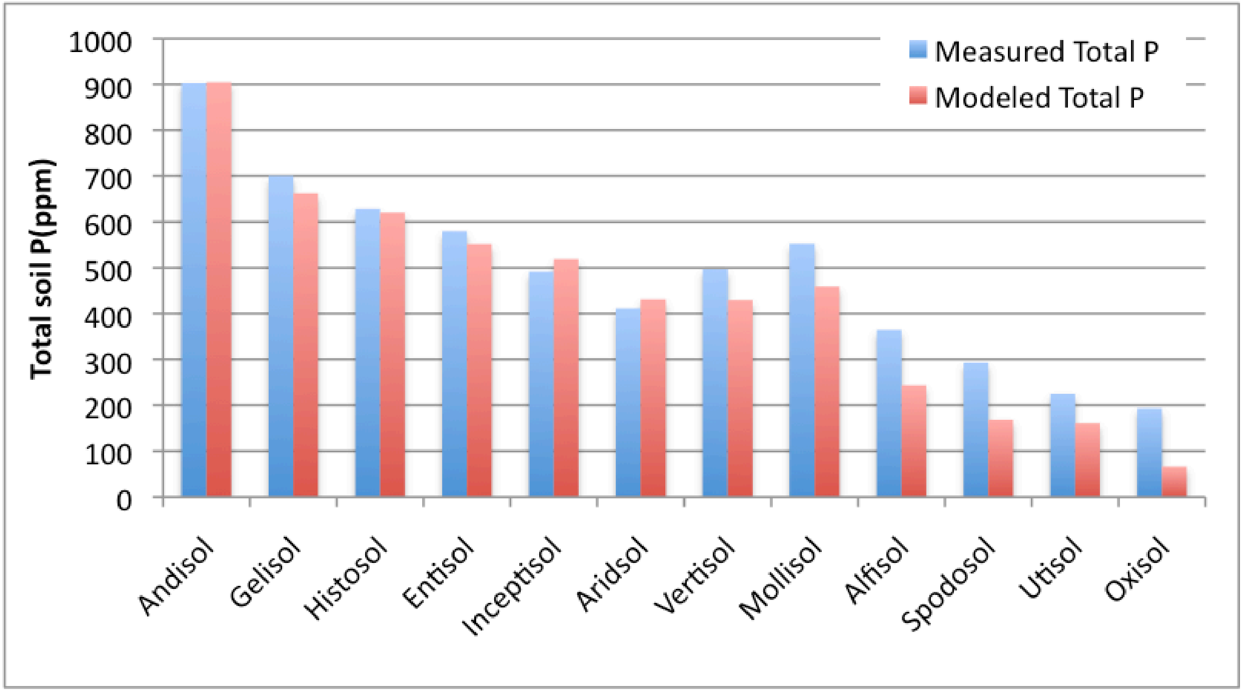
A data based approach for the initialization of various P pools for global models



Distribution of different forms of P in soils

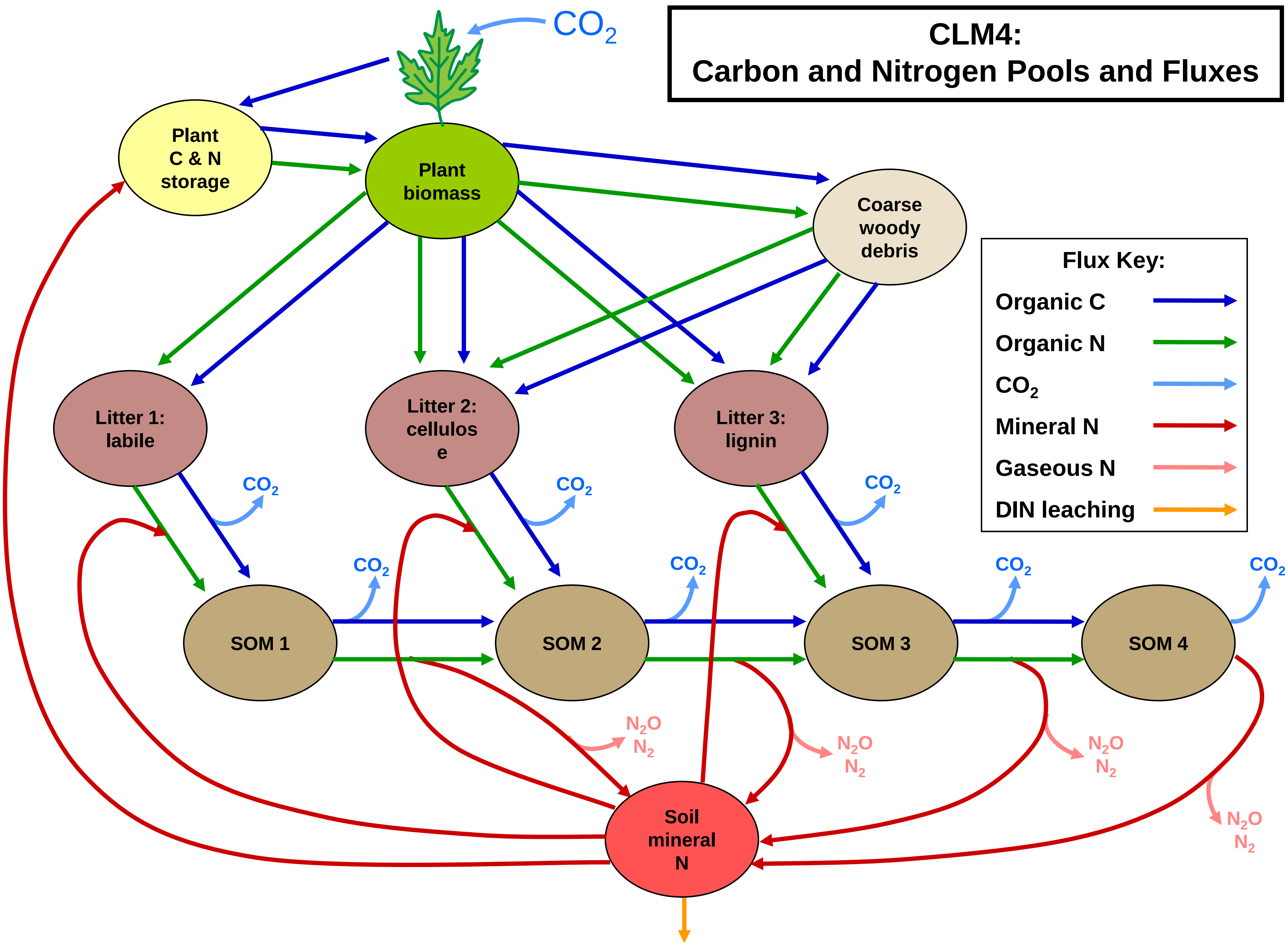


The comparison of estimated total P with field measurement of total P for each soil order



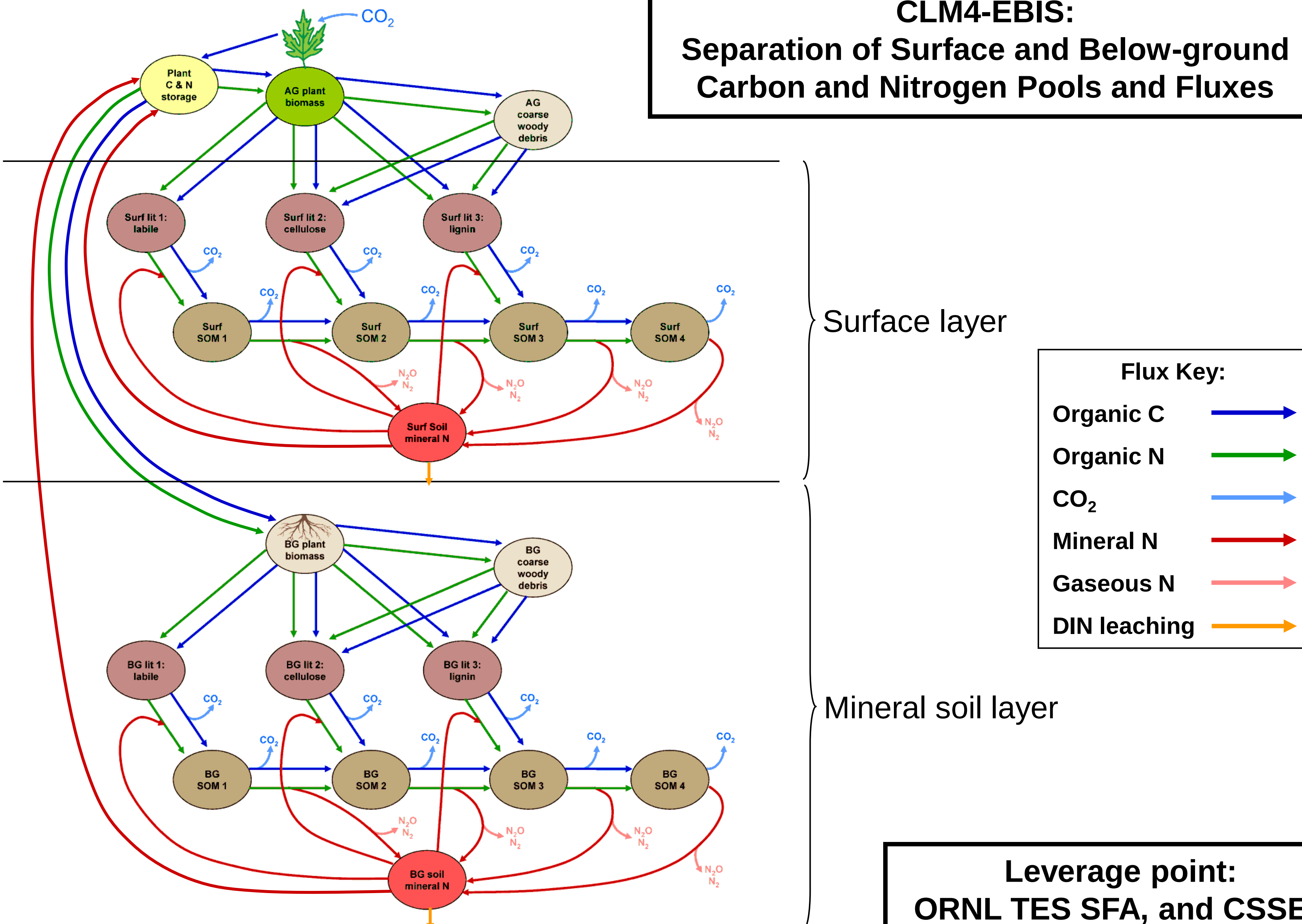
Evaluation of CLM against tropical litter manipulation experiment

- Long-term manipulative experiment altering litter inputs in a mature lowland semi-evergreen tropical forest in Panama.
- 6-year study: aboveground litter removed from one set of plots and added to adjacent plots.
- Found enhanced leaf production on litter addition plots, suggesting alleviation of nutrient limitation
- Highlighted the importance of organic P in supplying tropical forest growth requirements
- Identified priming effect of litter addition on soil respiration
- [Sayer et al., 2011, Nature Climate Change]



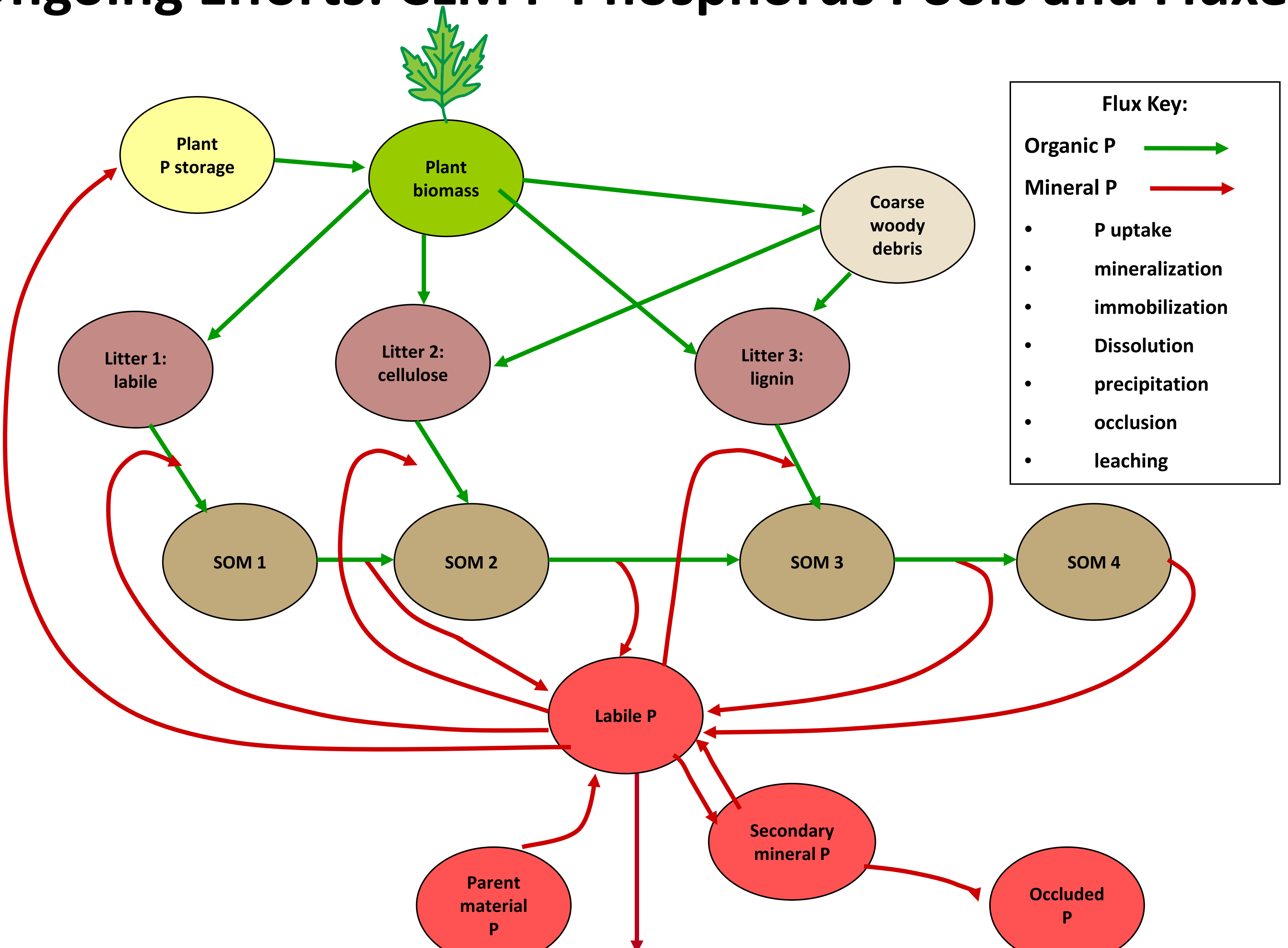
CLM4:
Carbon and Nitrogen Pools and Fluxes
CO_2
Plant C & N storage
Plant biomass
Coarse woody debris
Litter 1: labile
Litter 2: cellulos e
Litter 3: lignin
SOM 1
SOM 2
SOM 3
SOM 4
Soil mineral N
N_2O
N_2
Flux Key:
Organic C
Organic N
CO_2
Mineral N
Gaseous N
DIN leaching

CLM4-EBIS:
Separation of Surface and Below-ground Carbon and Nitrogen Pools and Fluxes



Leverage point:
ORNL TES SFA, and CSSEF

Ongoing Efforts: CLM4 Phosphorus Pools and Fluxes



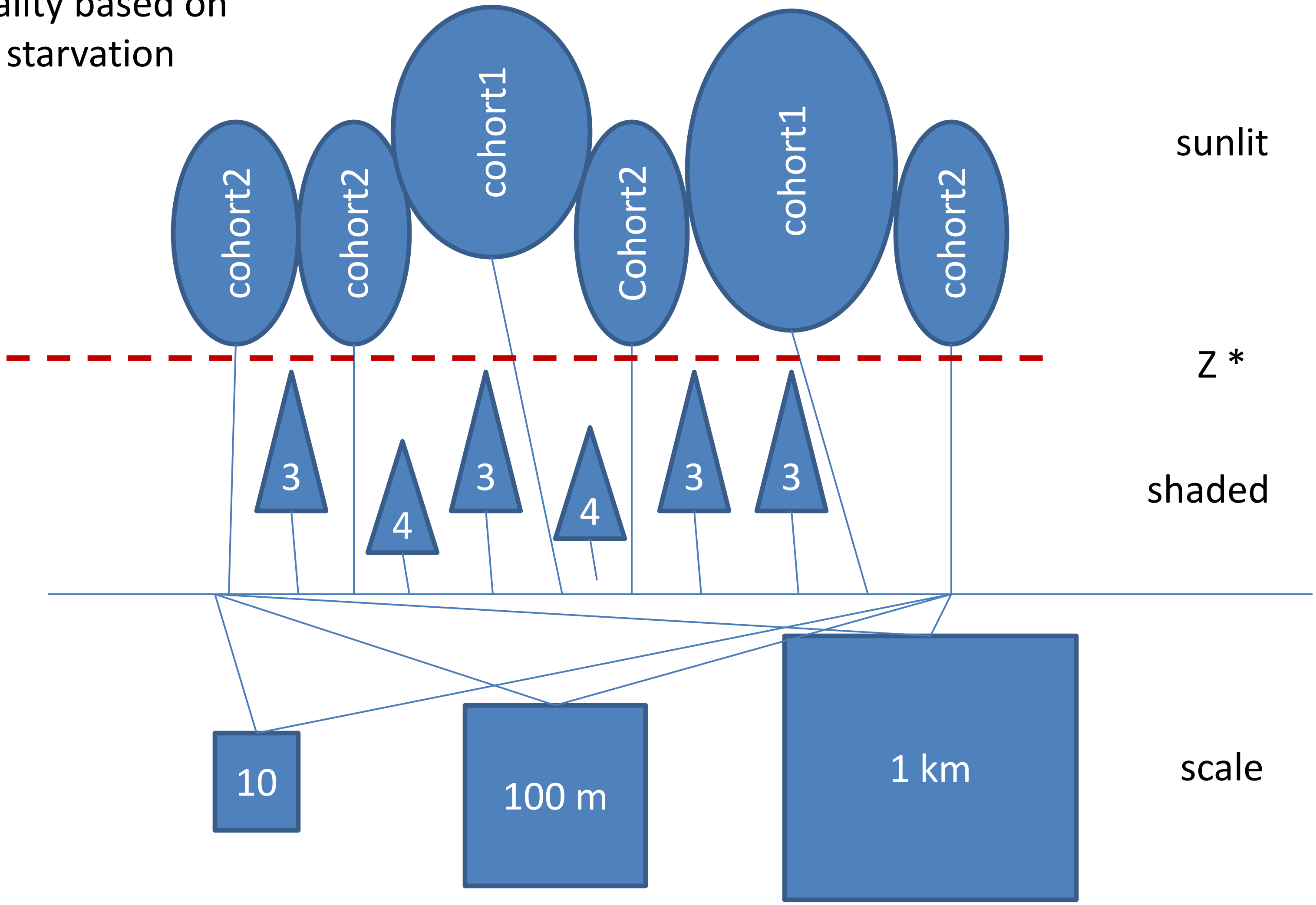
Temperate Forest:

- Improvements in ED
- Coupling CLM + ED

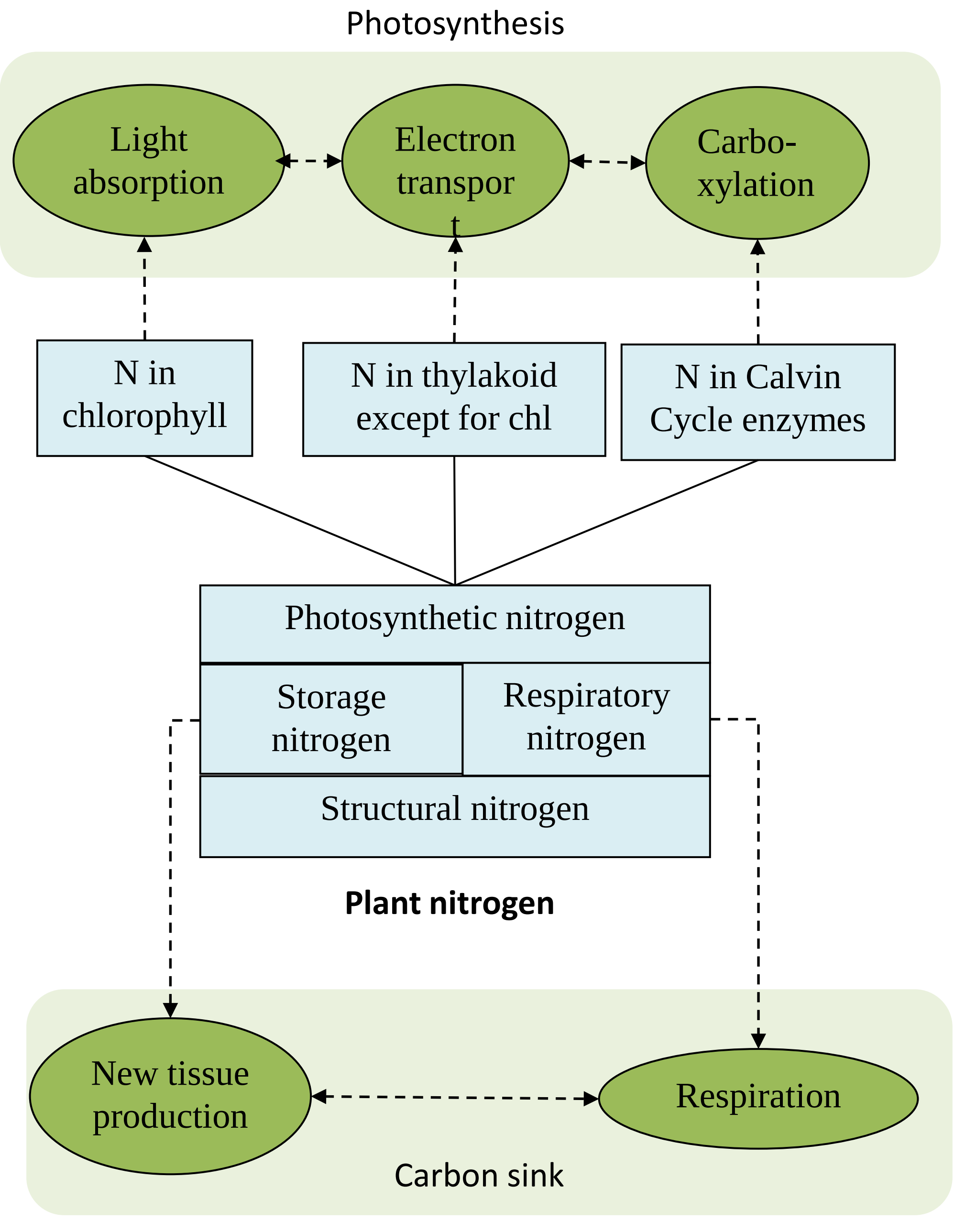
Effort led by Chonggang Xu (LANL), Nate McDowell (LANL) and Rosie Fisher (NCAR)

ED model: Scale and light competition

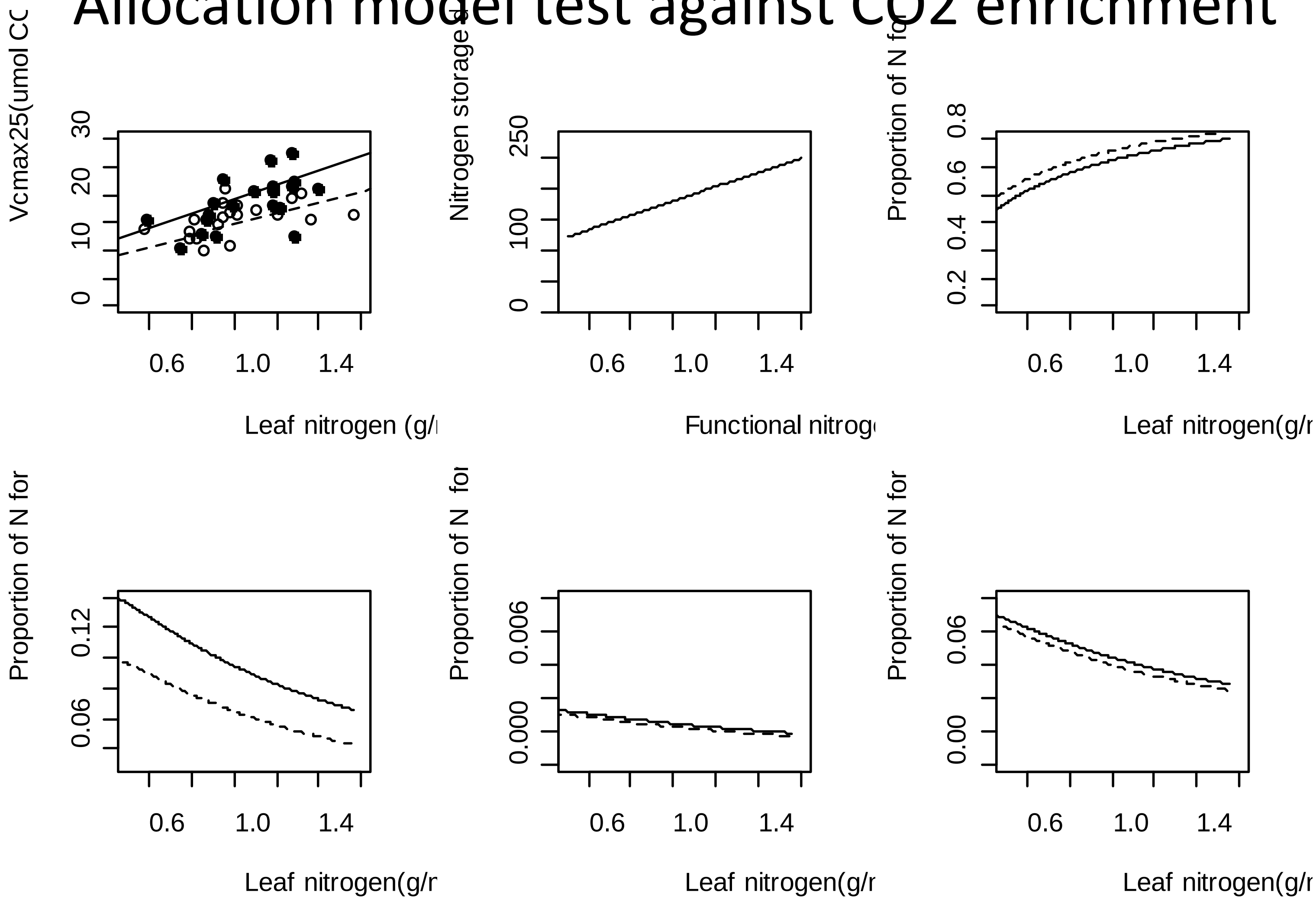
Tree mortality based on carbon starvation



Mechanistic nitrogen allocation model for ED



Allocation model test against CO2 enrichment

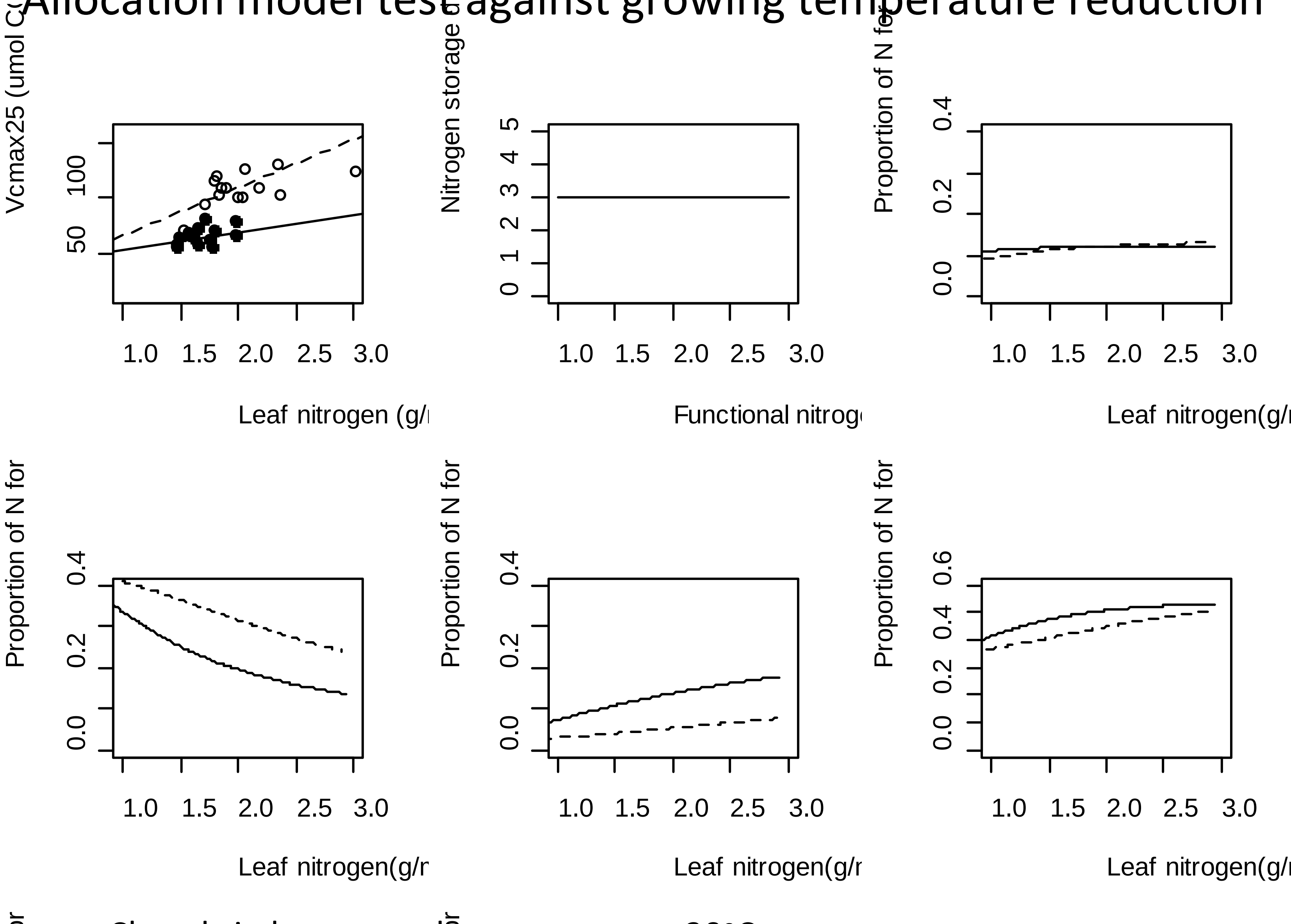


Closed circles---[CO_2]=370 ppm

Open circles- --[CO_2]=570 ppm.

Data are from duke FACE experiment (Crous et al., 2008).

Allocation model test against growing temperature reduction



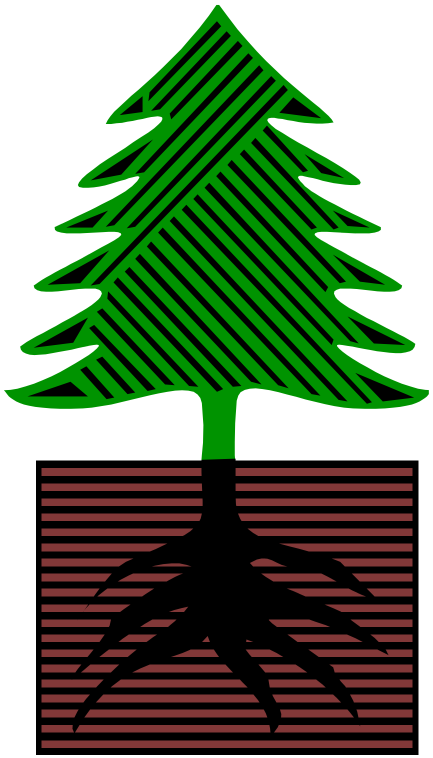
Closed circles---growth temperature =30^{o}C

Open circles-growth temperature=15^{o}C

Data are from Kobayashi et al. (2001).

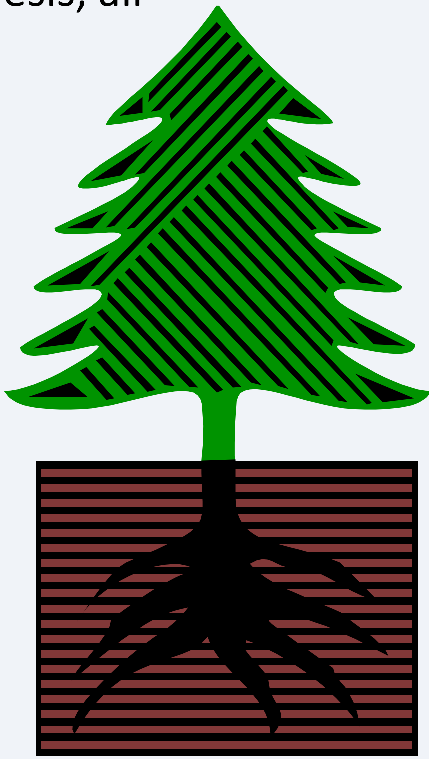
Plant-Soil hydrology for ED

Original:
Transpiration=α Potential transpiration



α is an empirical parameter depending on soil moisture

Improved:
Water demand=f(photosynthesis, air humidity, wind speed)

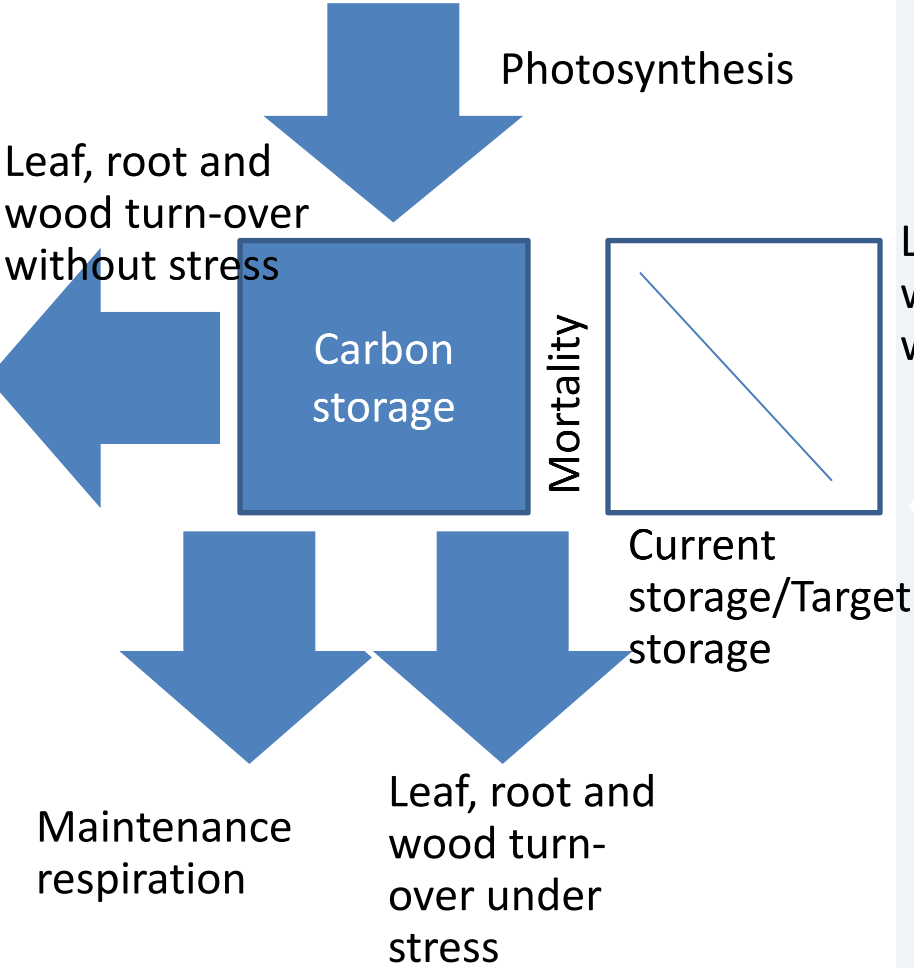


Water uptake= minimum (water demand, water supply)

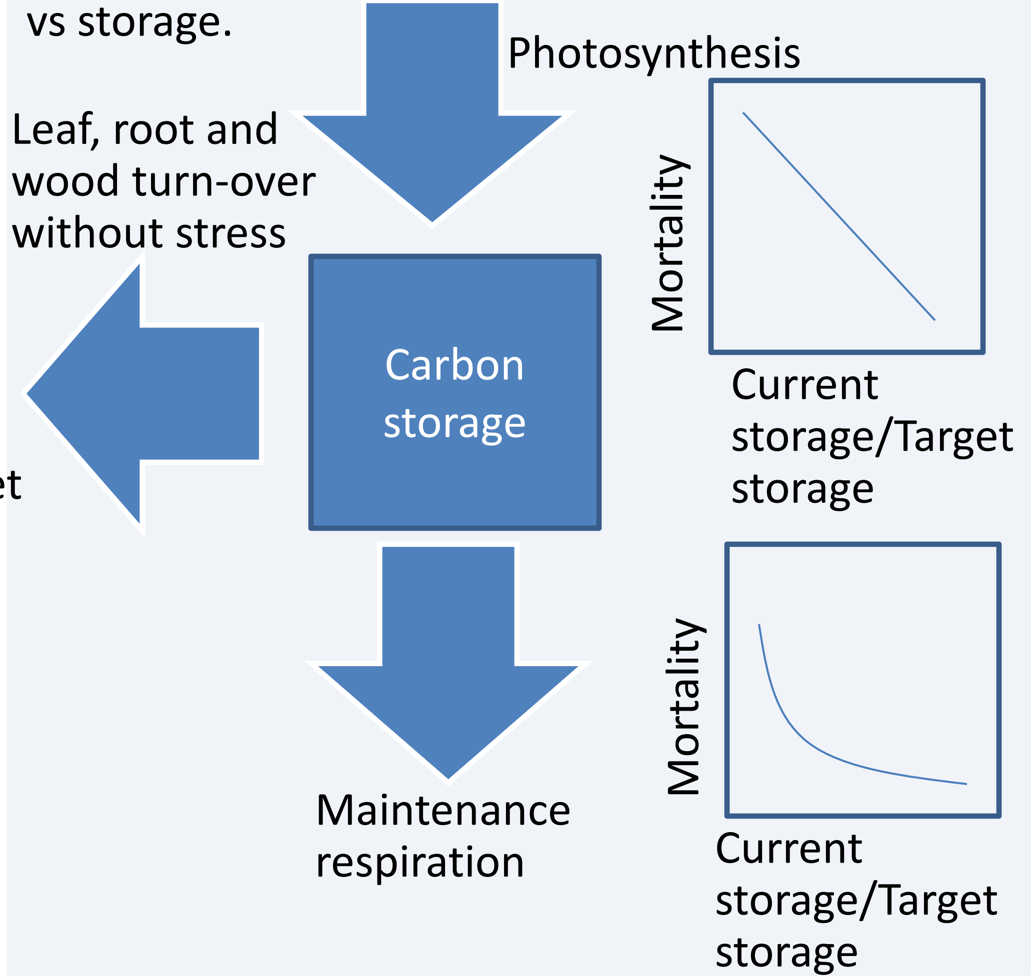
Water supply=f(minimum leaf water potential, soil water potential, sap wood area, root, sap wood and leaf water conductivity)

Tree mortality in ED

Original:

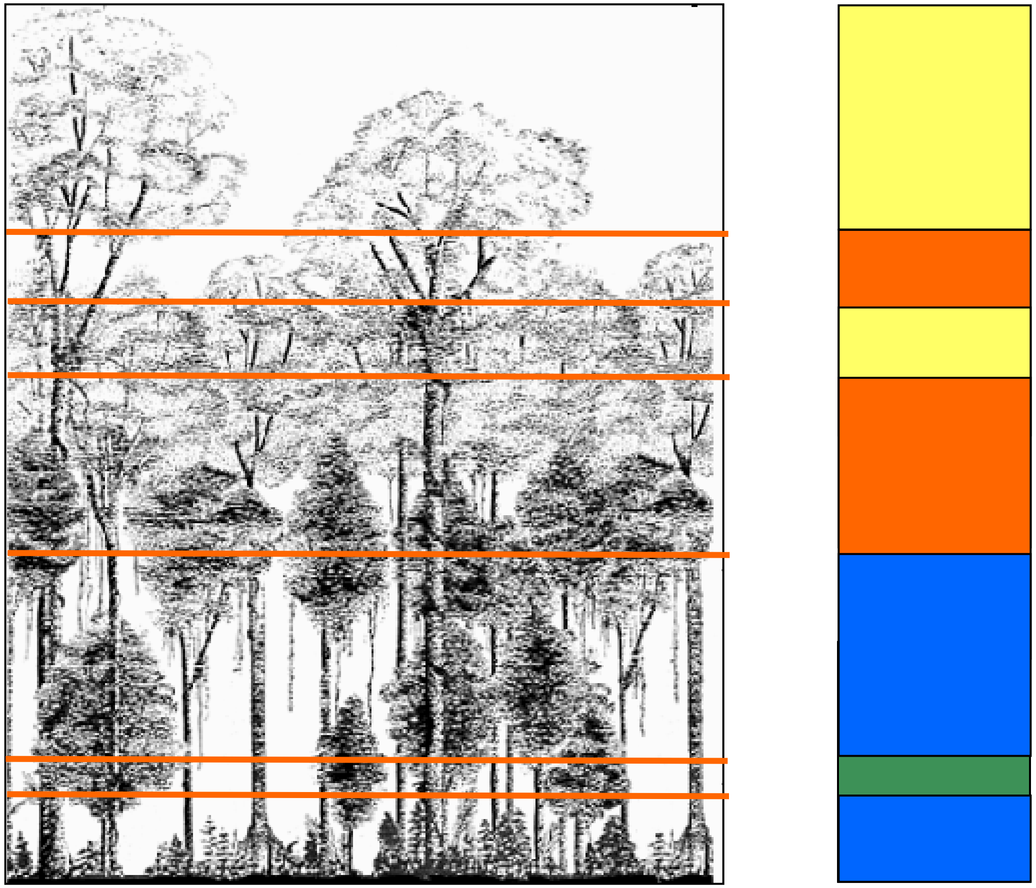


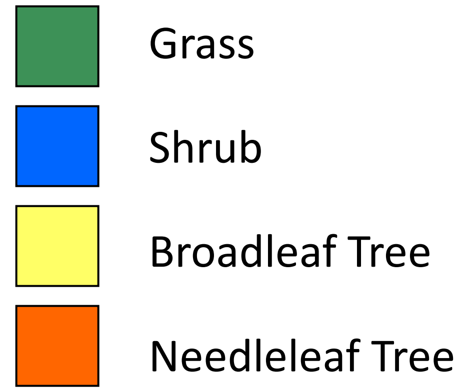
Improved: 1. reduced tree mortality under stress by reduce/stop leaf, root and wood turn-over from storage; 2. Exponential function of mortality vs storage.



Ecosystem Demography Model (ED)

Moorcroft, Hurtt and Pacala. (2001)



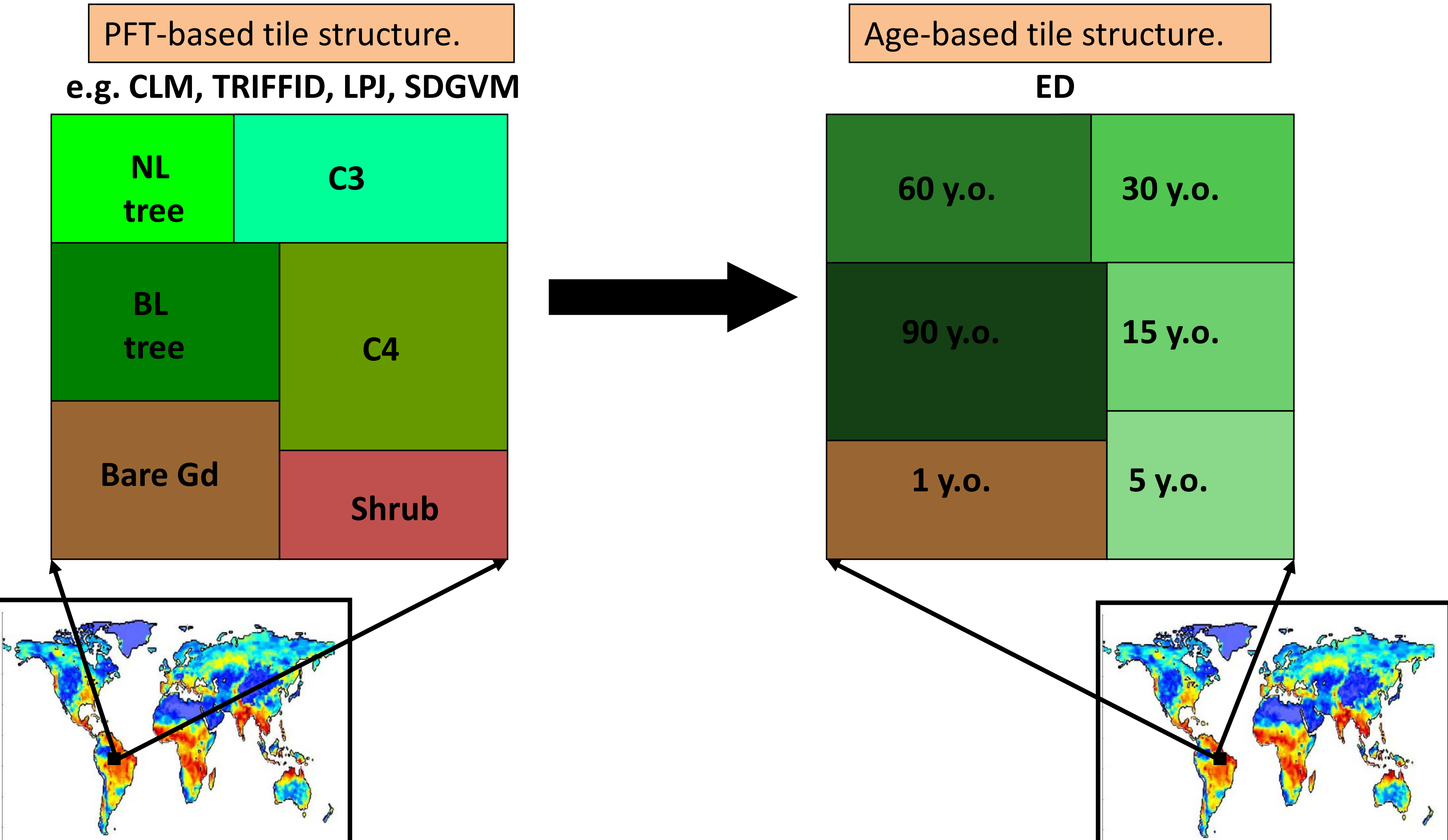


'Cohorts' of trees,
Binned according to:

1. Plant type
2. Height
3. Successional stage

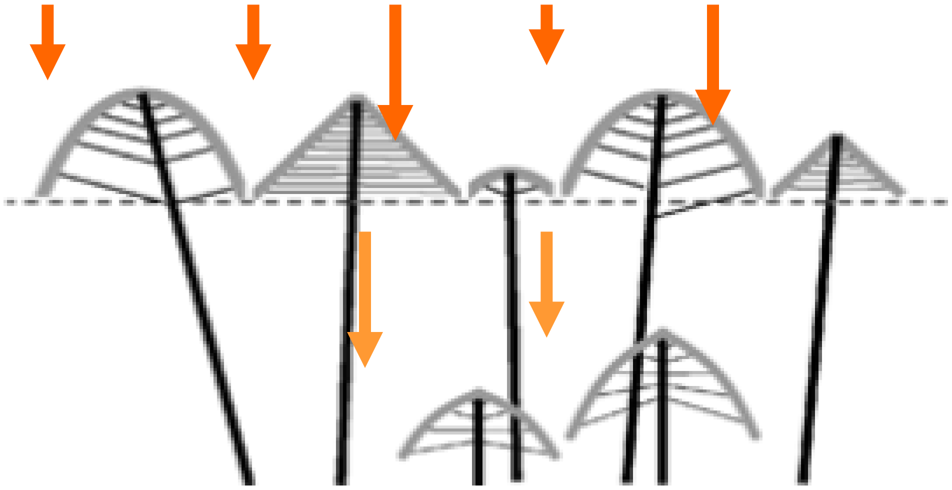
Ecosystem Demography Model (ED)

"Size-and-age structured approximation of a gap model"



Implementation of competition for space in ED (required to simulate long term coexistance)

- ‘Perfect Plasticity Approximation’ (PPA)
  - Tree canopies are are ‘perfectly plastic’ and fill in all the gaps.
  - Tree canopy splits into distinct layers.
- Canopy trees : 100% light on top leaf surface
- Under-story trees : All have the same light environment

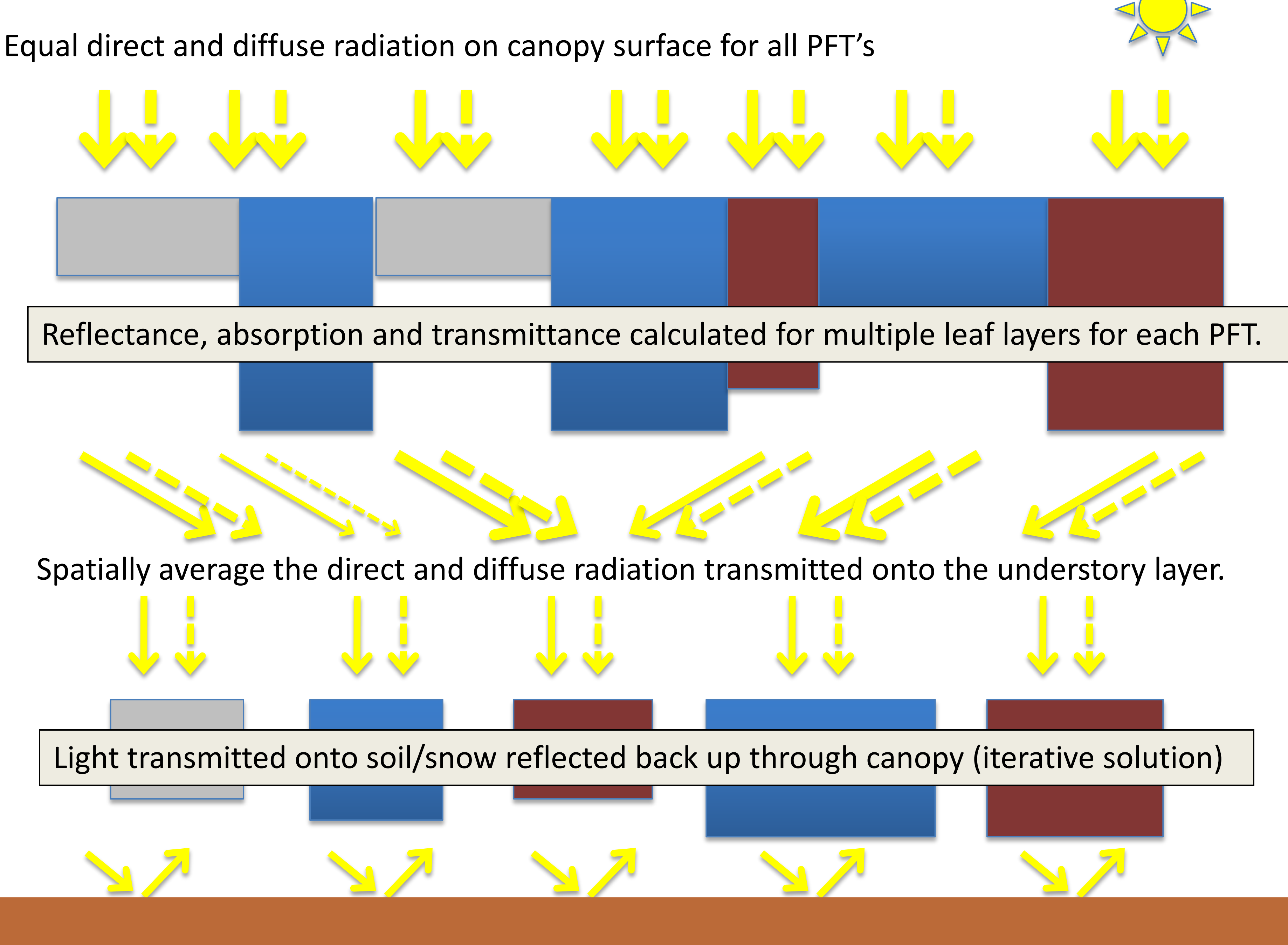


Purves et al., PLOS One 2007. Fisher et al. New Phytologist 2010.

Radiation and photosynthesis in ED-CLM

- CLM uses a ‘two-stream’ approximation to estimate absorption, reflectance and transmittance for ‘big leaf’ (one layer) canopies.
- ED requires that we have a vertical light profile to simulate vertical competition
- Using the two-stream approximation is thus overly complex, and it cannot be used for the multi-PFT canopy in the ED-PPA model
- Thus, we propose to use the Norman et al. (1979) explicit radiation scheme
- This scheme calculates transmittance, reflectance and absorption directly at each layer for direct and diffuse (& NIR and visible) light.
- An iterative solution is required to absorb all the radiation which bounces up (and down) off the soil and leaf surfaces.

Norman Radiation scheme as implemented in ED-CLM.



Next steps for CLM-ED

- Multi-layer Nitrogen limitation (if there isn't enough N, which PFT and /or leaf layers are affected?)
- Land-use change (pasture/crops) representation
- Coupling to fire model.
- Expand PFT range using GLOPNET/TRY databases.
- Benchmarking with expanded iLAMB database.

Active Layer and Permafrost SOC Stocks in Arctic Soils: Measurements, Modeling, and Uncertainty

Umakant Mishra,
Charles D. Koven,
William J. Riley
LBNL

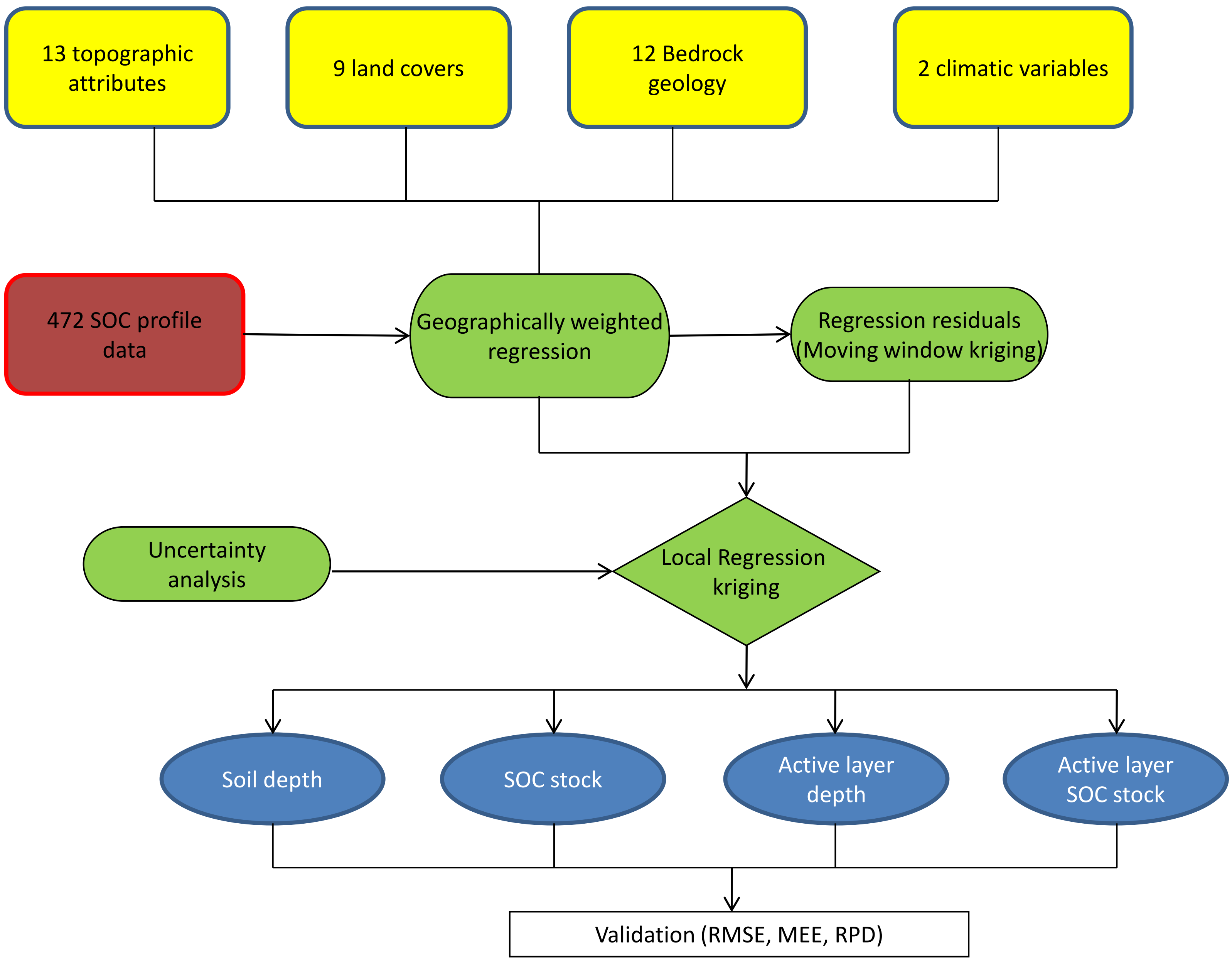
Goals

- Characterize high-resolution maps of soil C stocks and permafrost state
  - Test ability of current LSM's to replicate observations
  - Identify uncertainty, dominant drivers of heterogeneity, and vulnerability of SOM

Methods

- Applied GIS-based analysis with 472 pedon observations to generate soil C maps
- Compare default and new CLM4 belowground C cycle model predictions
  - Stocks and dominant drivers of heterogeneity
  - Investigating uncertainty and scaling methods

GIS Model Methodology

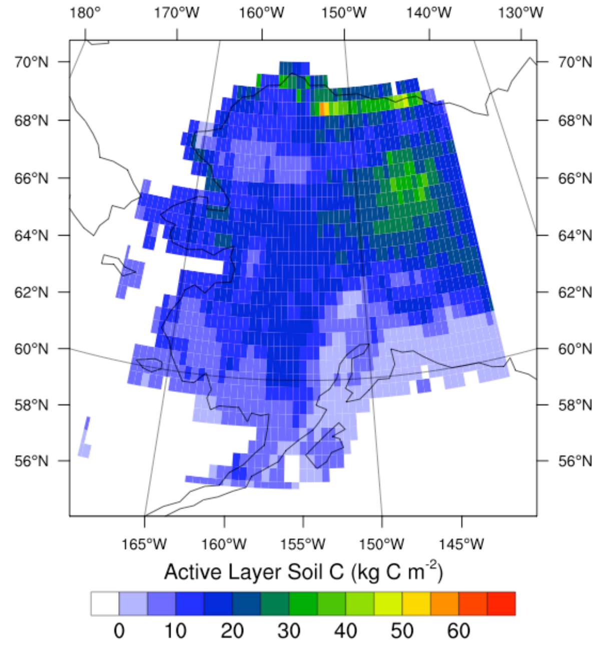


Alaska Active Layer Depth and SOC Stocks from GIS Pedon analysis

Dominant predictors:
Latitude
Precipitation
Barren
Bedrock type

Dominant predictors:
CTI
Specific catchment area
Precipitation
Temperature
Scrub
Herbaceous
Barren
Bedrock type

Comparison of GIS Soil C mapping and CLM4-Vertical Soil C predictions for Active Layer C stocks



•Overall CLM soil C still underestimated
•Maxima in NE Alaska captured
•Maxima in SW Alaska not captured—likely due to lack of peatland processes

Leverage point:
IMPACTS

Coupled model evaluation

- Develop new metrics
- Apply to CMIP5 database (including default CESM1)
- Evaluate CESM with new CLM as development progresses.

Temperature Dependence of Heterotrophic Respiration

$$R_h = C_{bg} k_0 Q_{10}^{\left(\frac{T-T_0}{10}\right)}$$

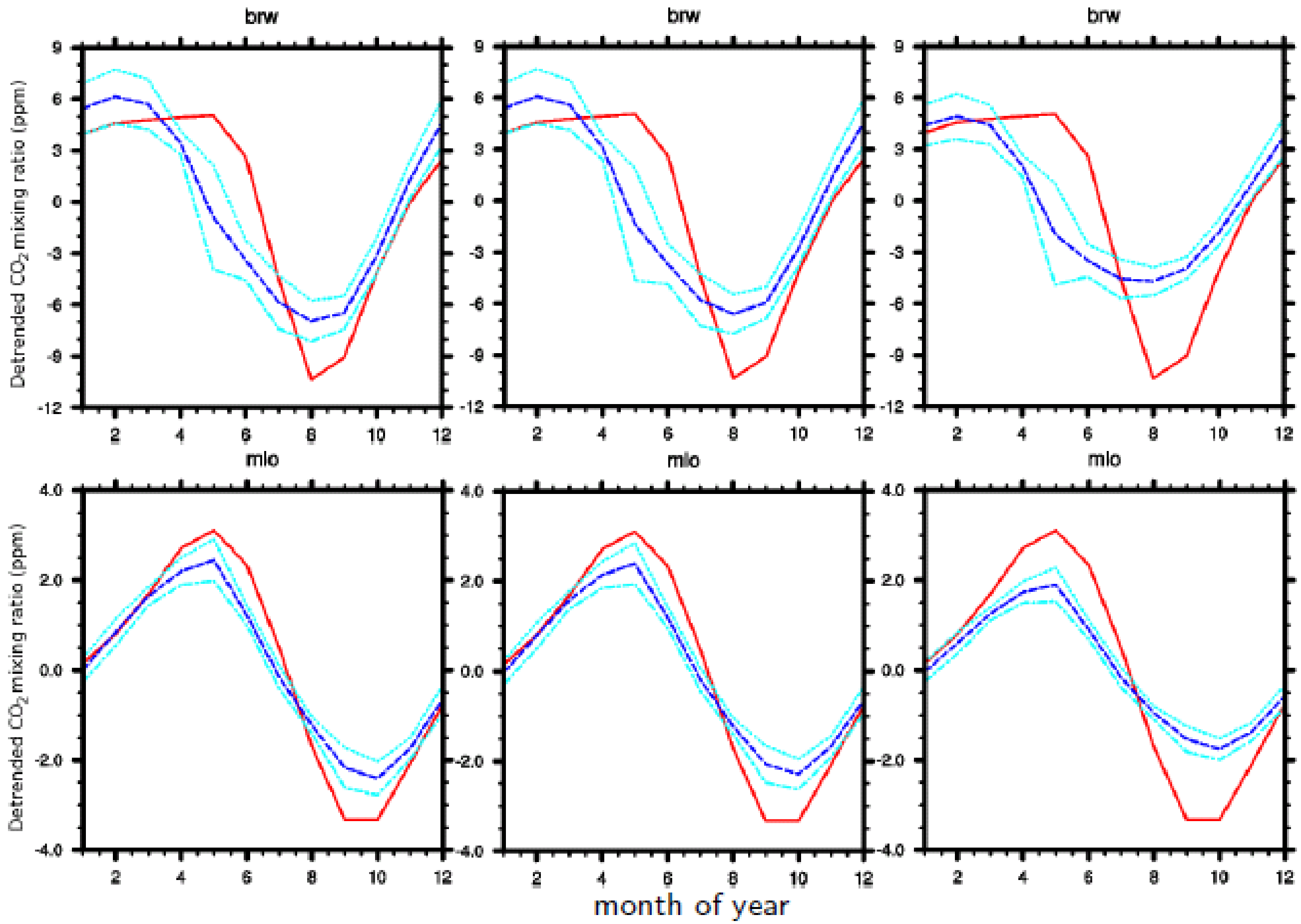
$Q_{10} = 1.5$ $Q_{10} = 2.0$ $Q_{10} = 3.0$

Barrow (BRW)

71.32° N, -156.61° E

Mauna Loa (MLO)

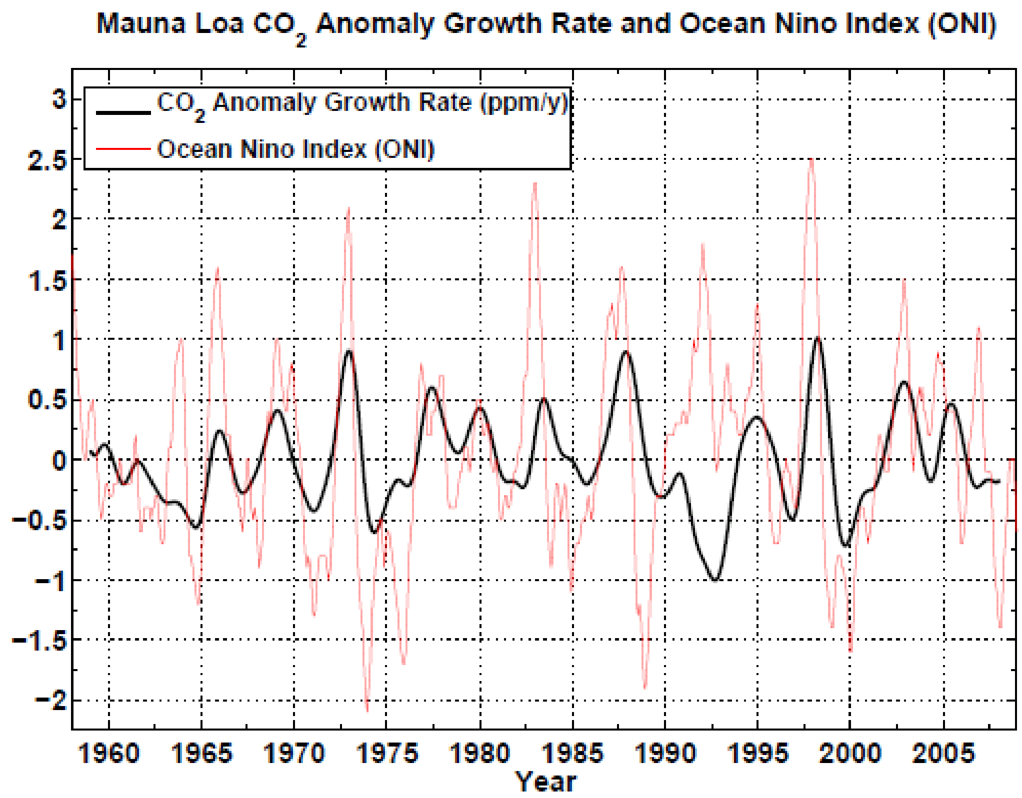
19.54° N, -155.58° E



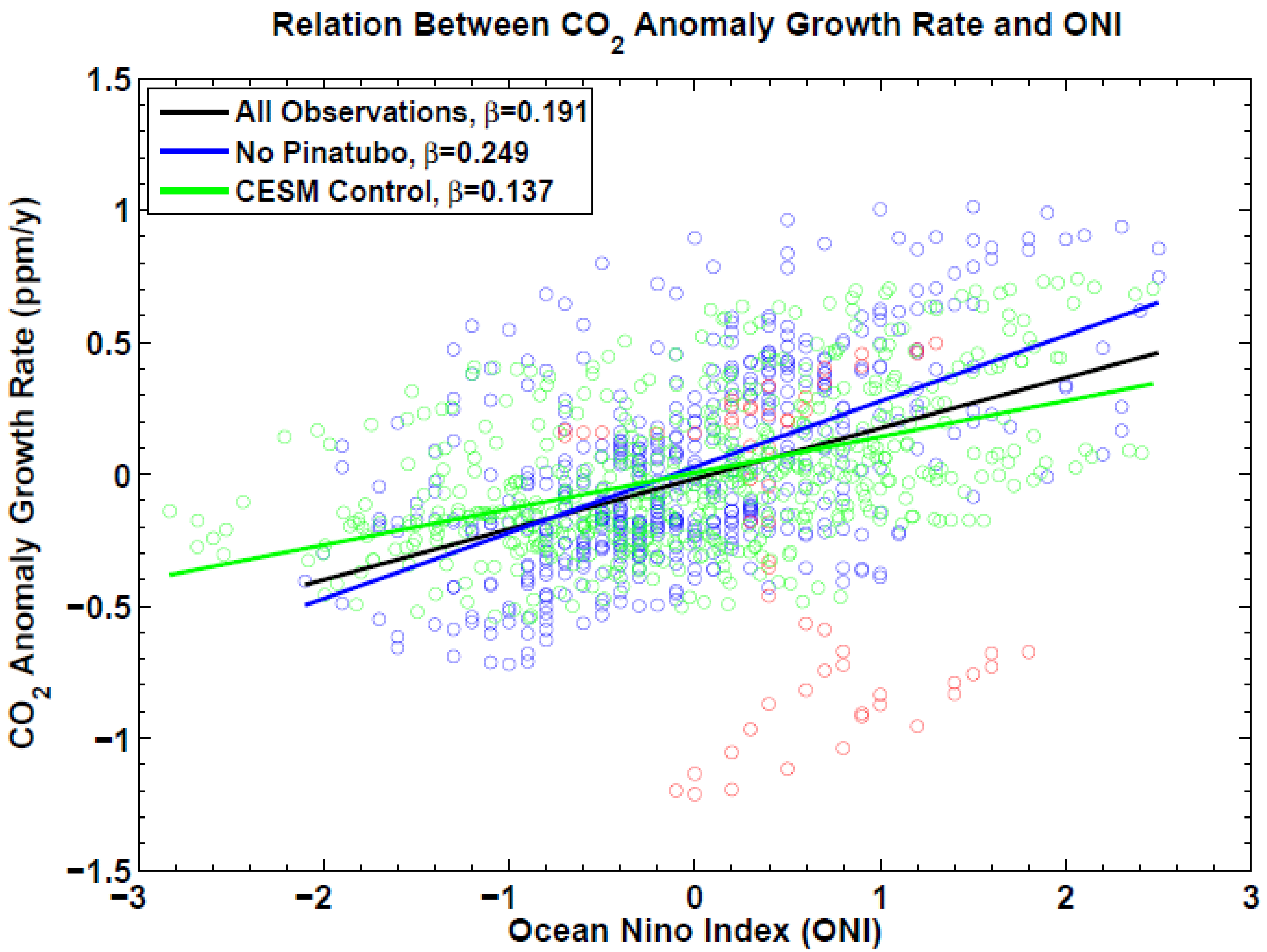
GLOBALVIEW-CO2/TRANSCOM impulse response function (TIRF), CLM4/Mean TIRF, CLM4/TIRF bounds

A New Metric for Evaluating Variability of CO_2 with ENSO

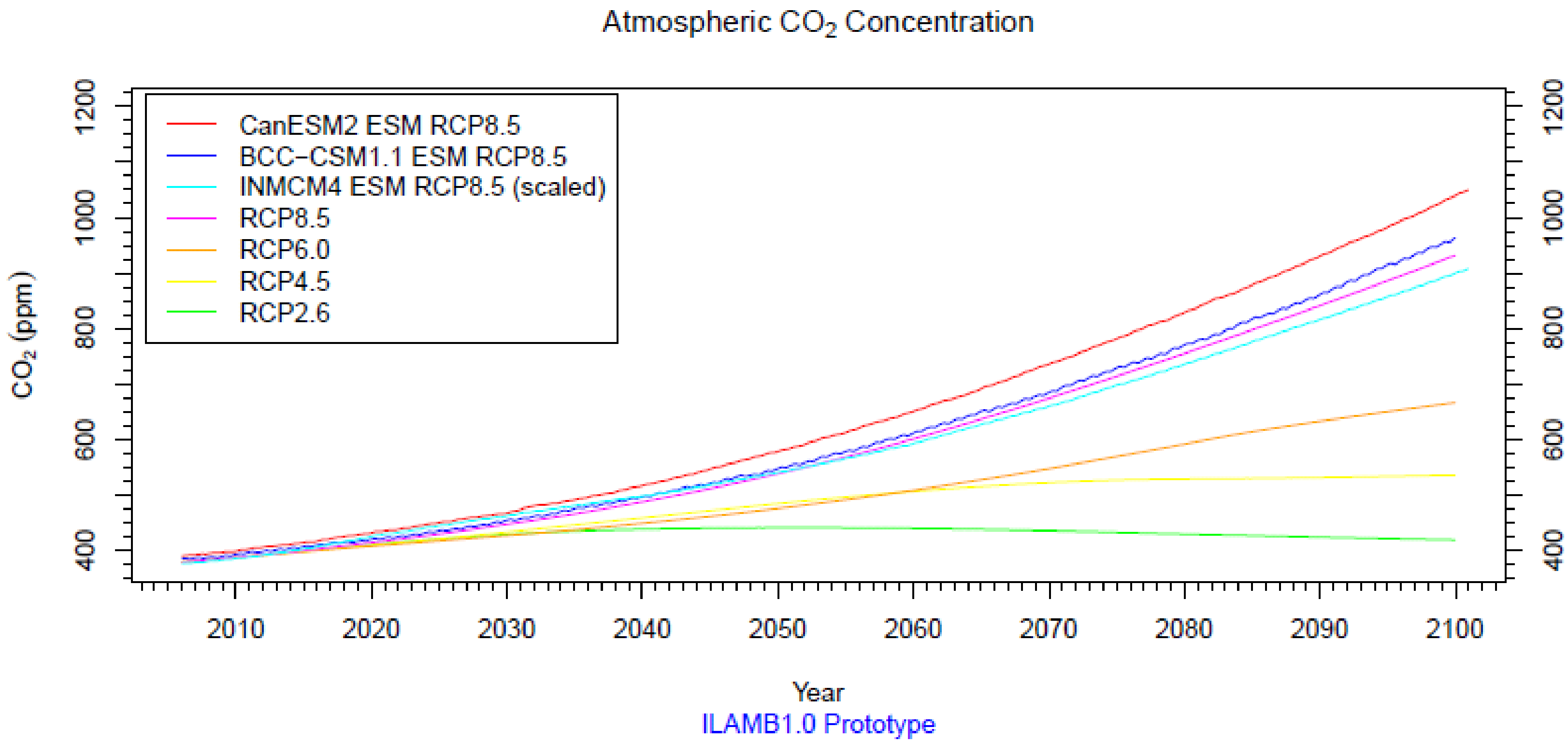
The relationship between El Niño-Southern Oscillation (ENSO) and observed CO_2 anomalies at Mauna Loa may be exploited to evaluate ocean and terrestrial model responses.



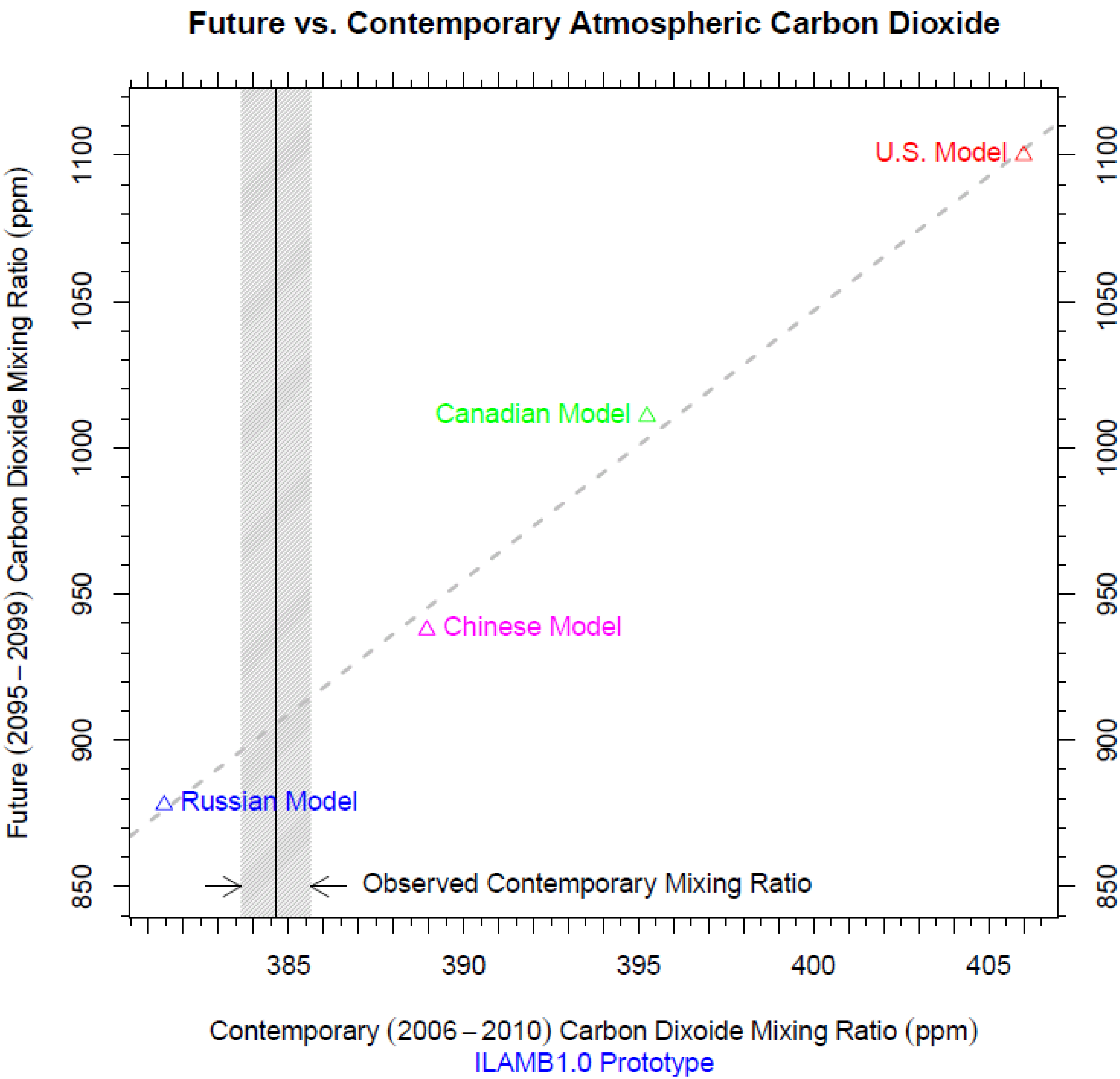
CESM vs. Observations



CMIP5 ESM Model Comparison

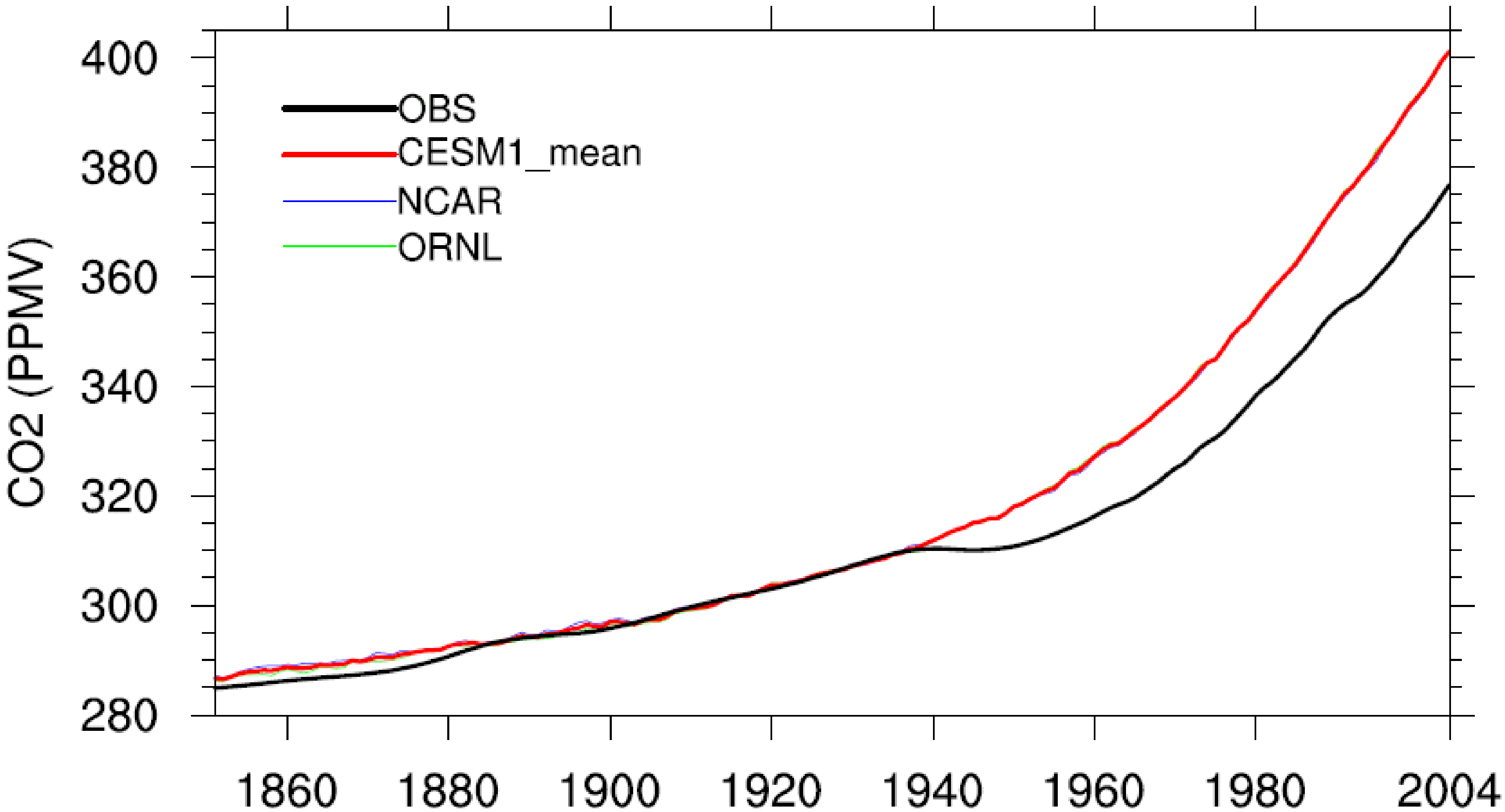


Initial evaluation of the CO_2 trajectories of the Earth System Models (ESMs) is being performed as results appear on the Earth System Grid (ESG).



Future vs. Contemporary Atmospheric Carbon Dioxide
U.S. Model
Canadian Model
Chinese Model
Russian Model
Observed Contemporary Mixing Ratio
Future (2095 – 2099) Carbon Dioxide Mixing Ratio (ppm)
850
900
950
1000
1050
1100
385
390
395
400
405
Contemporary (2006 – 2010) Carbon Dixoide Mixing Ratio (ppm)
ILAMB1.0 Prototype

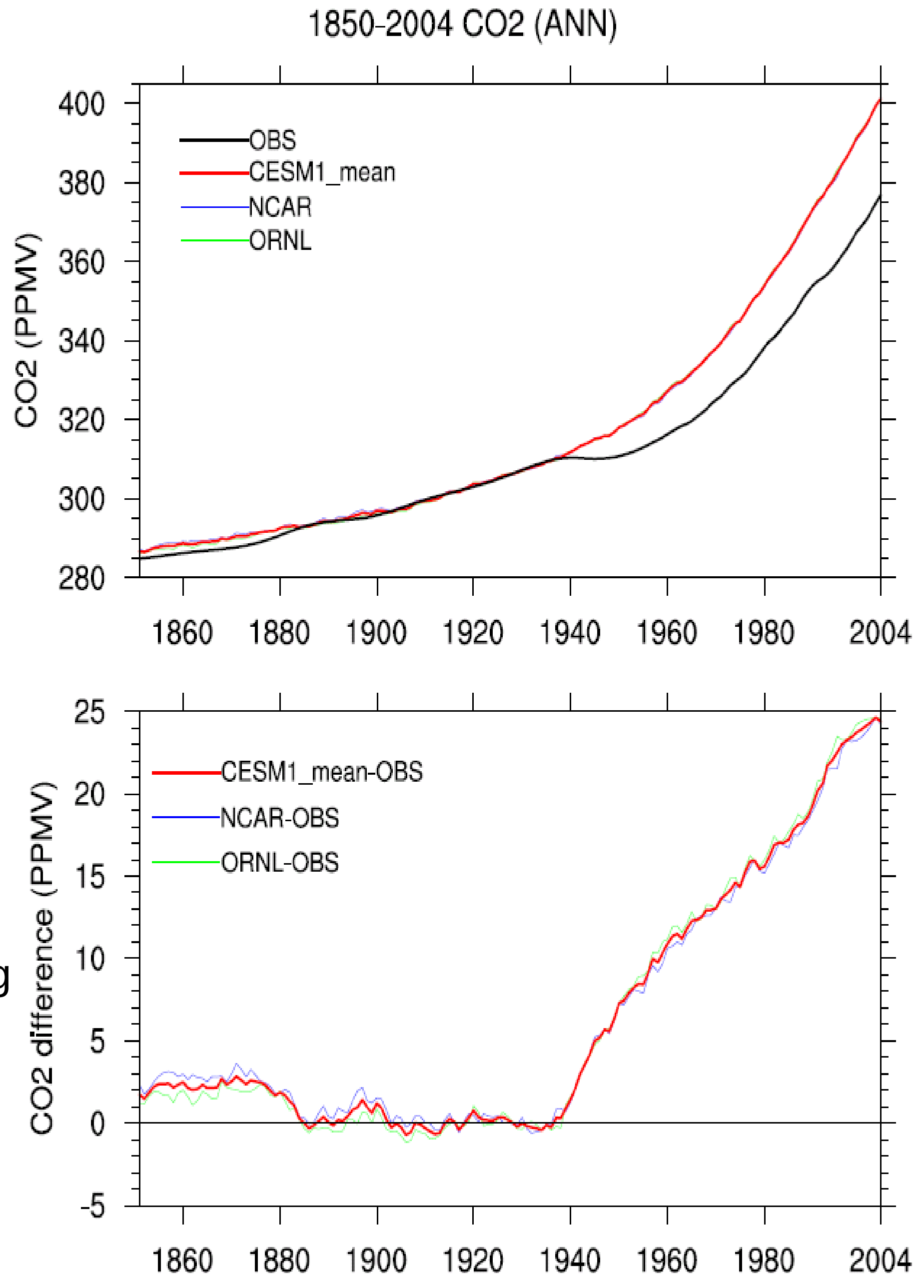
Assessment of bias in global mean CO_2 concentration



What's wrong with this picture?

- Observed CO_2 concentration is biased
  - Ice core / instrument transition?
- Fossil fuel emissions are biased
  - Emissions forcing too high during WWII?
- Land use / land cover change data are biased.
  - Forest harvest too high? Regrowth too small?
- Model is biased
  - Internal climate variability?
  - Low land and/or ocean sensitivity to rising CO_2?
  - Response to harvest too strong?
  - Regrowth response too weak?

Leverage point:
ORNL TES SFA



Next steps:

- Year 2
  - Complete new process integration in CLM4
  - Evaluate new process representation against plot-level observations/experiments
  - Continue development of new global metrics
  - Evaluate CMIP5 models against new global metrics
  - Commence coupled model integration
- Year 3
  - Continue development of new global metrics
  - Finish coupled model integration
  - Evaluate new CESM against new global metrics