NOVEMBER 16, 2026

Land Modeling II

Biogeochemistry & Ecosystems

Adrianna Foster
Scientist V, NCAR CGD Terrestrial Sciences Section



This material is based upon work supported by the NSF National Center for Atmospheric Research, a major facility sponsored by the U.S. National Science Foundation and managed by the University Corporation for Atmospheric Research. Any opinions, findings and conclusions or recommendations expressed in this material do not necessarily reflect the views of NSF.

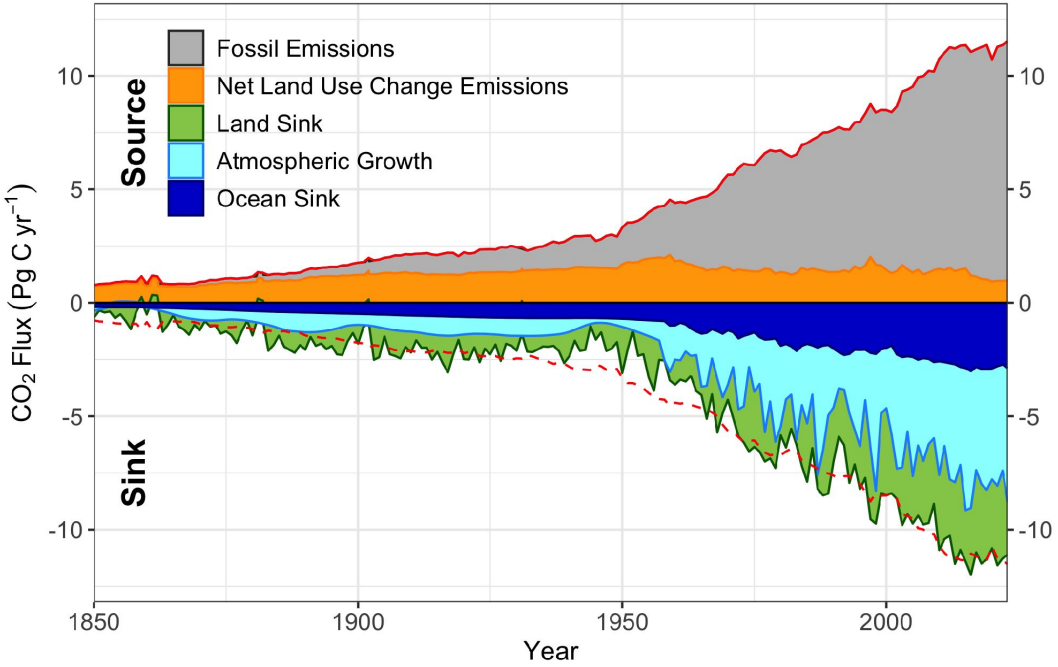
How do ecosystems change when climate changes?



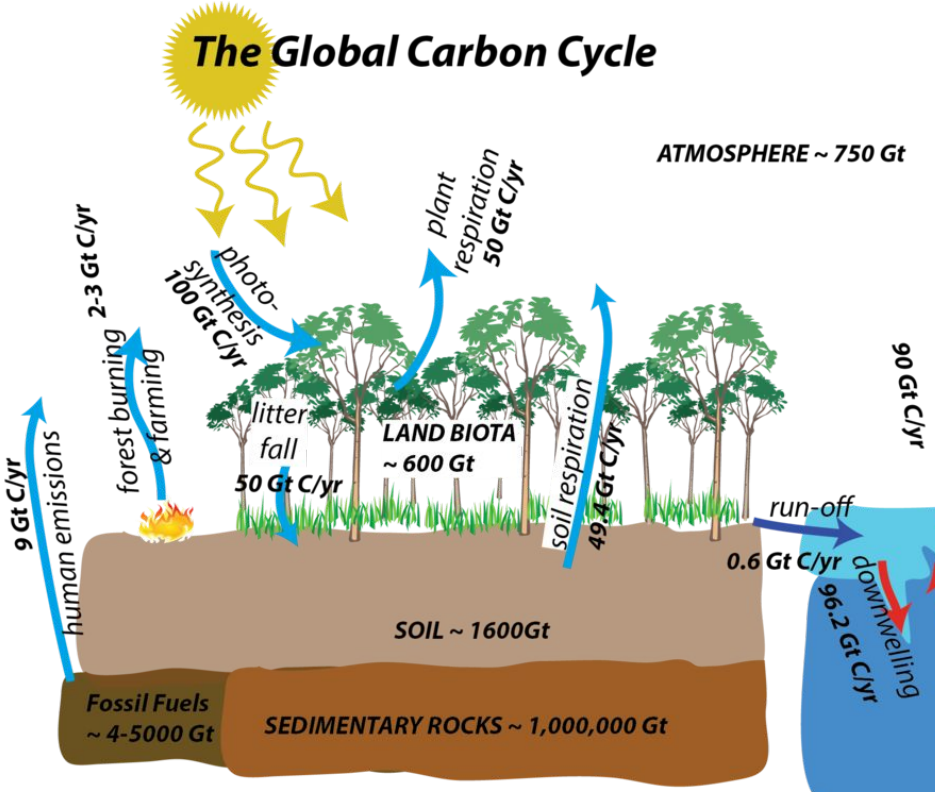
Annual carbon emissions

Annual Carbon Emissions and their Partitioning

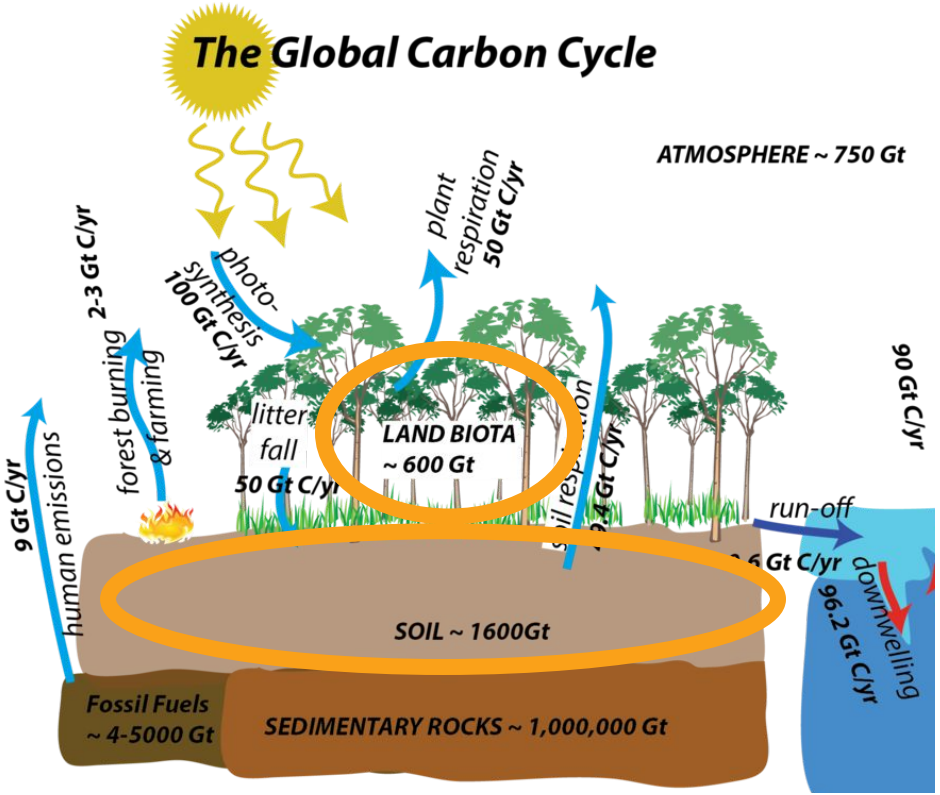
Friedlingstein et al. Global Carbon Budget 2024



Global carbon cycle

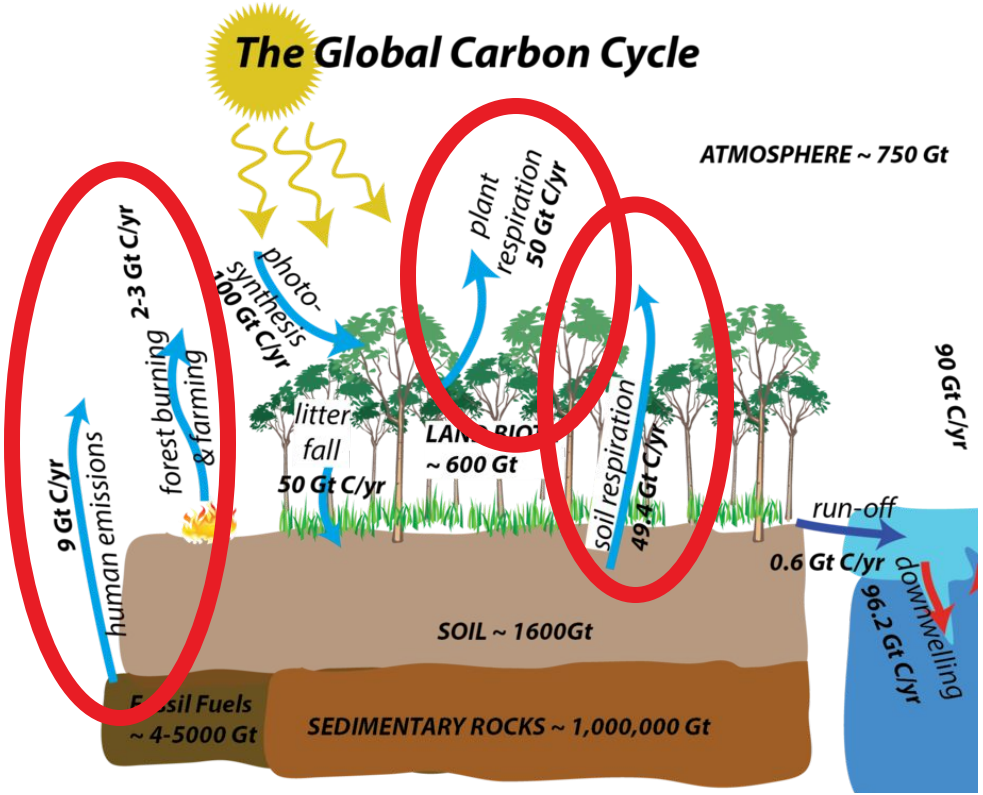


Global carbon cycle



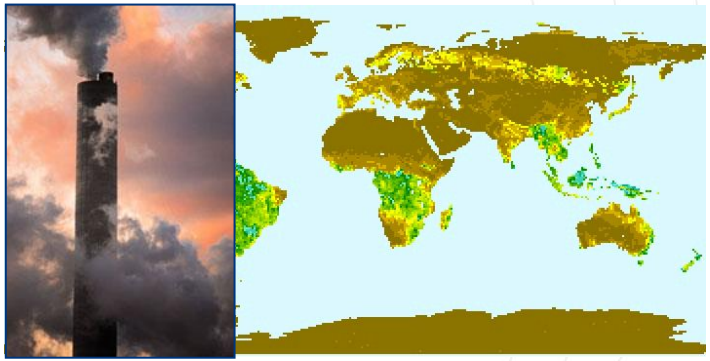
Huge pools

Global carbon cycle

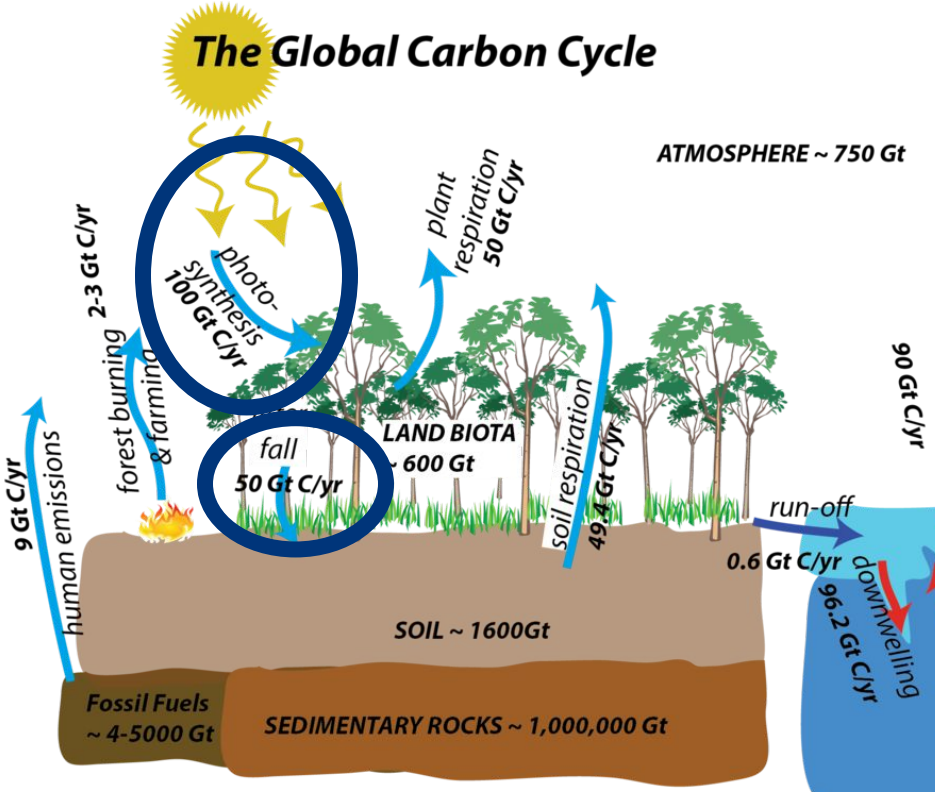


Huge pools

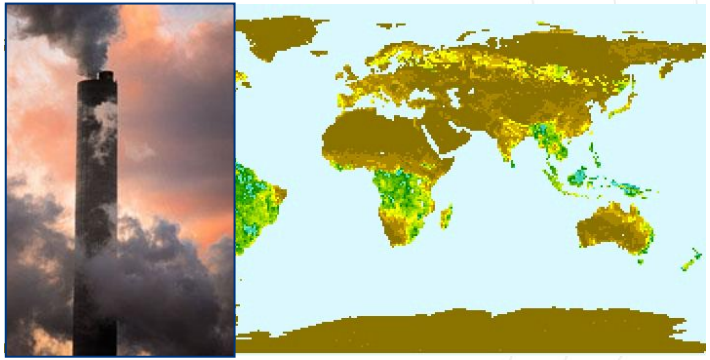
Large fluxes (out)



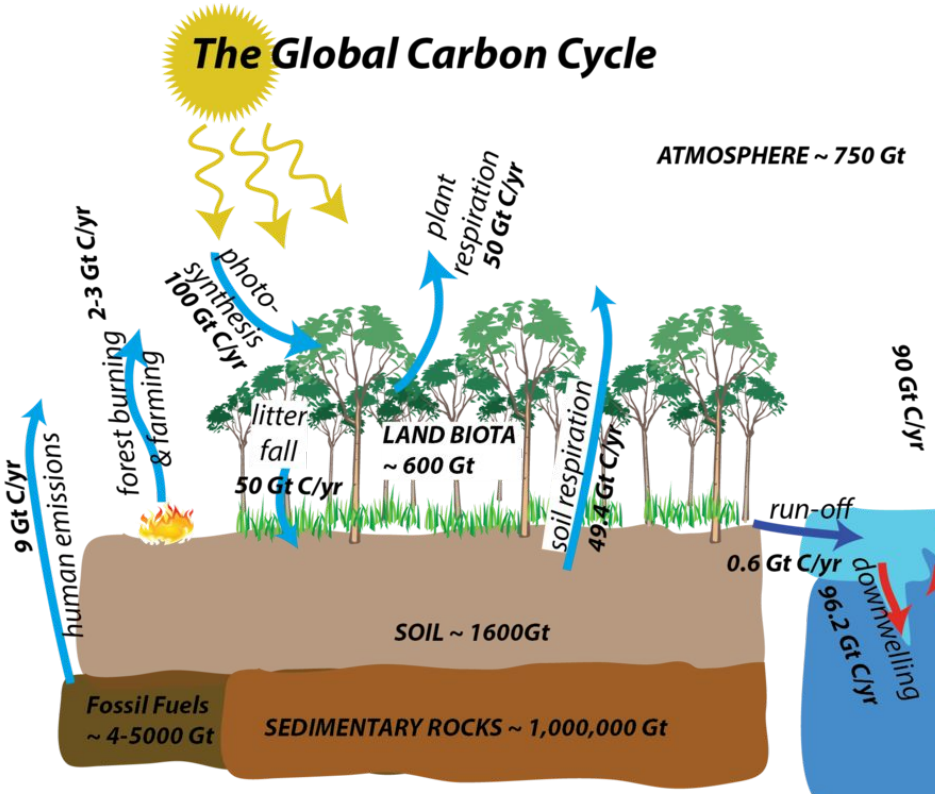
Global carbon cycle



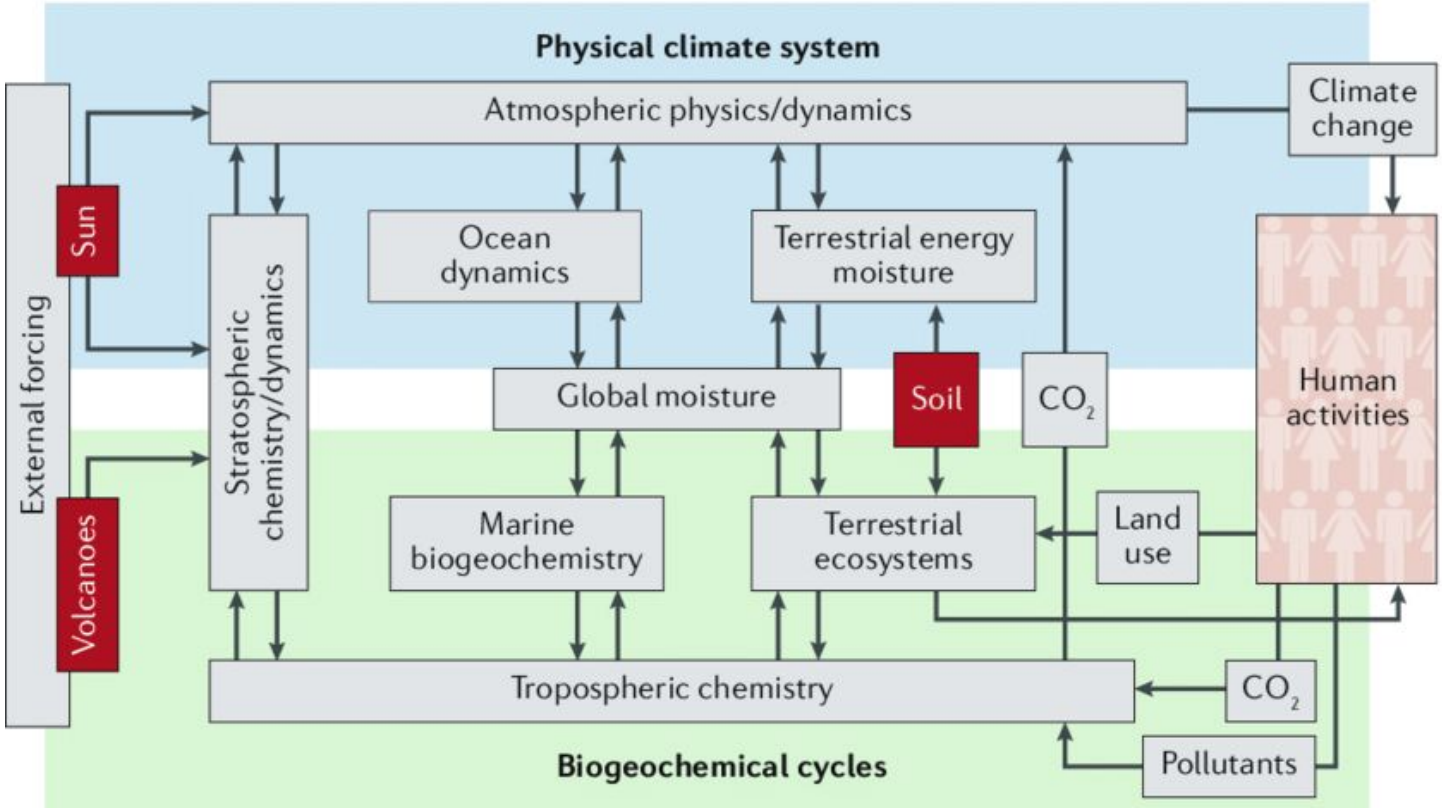
Huge pools
Large fluxes (out)
Large fluxes (in)



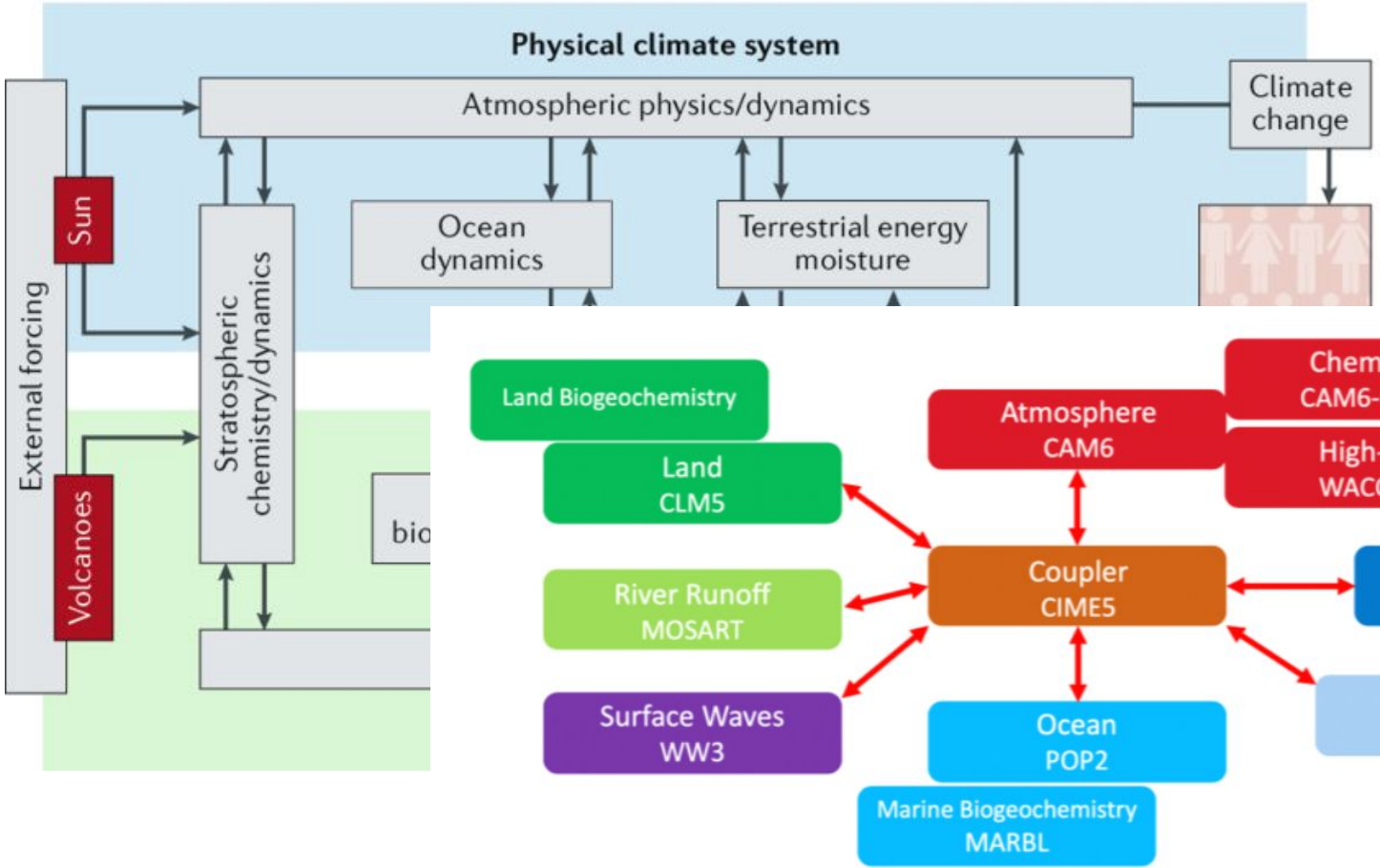
Global carbon cycle

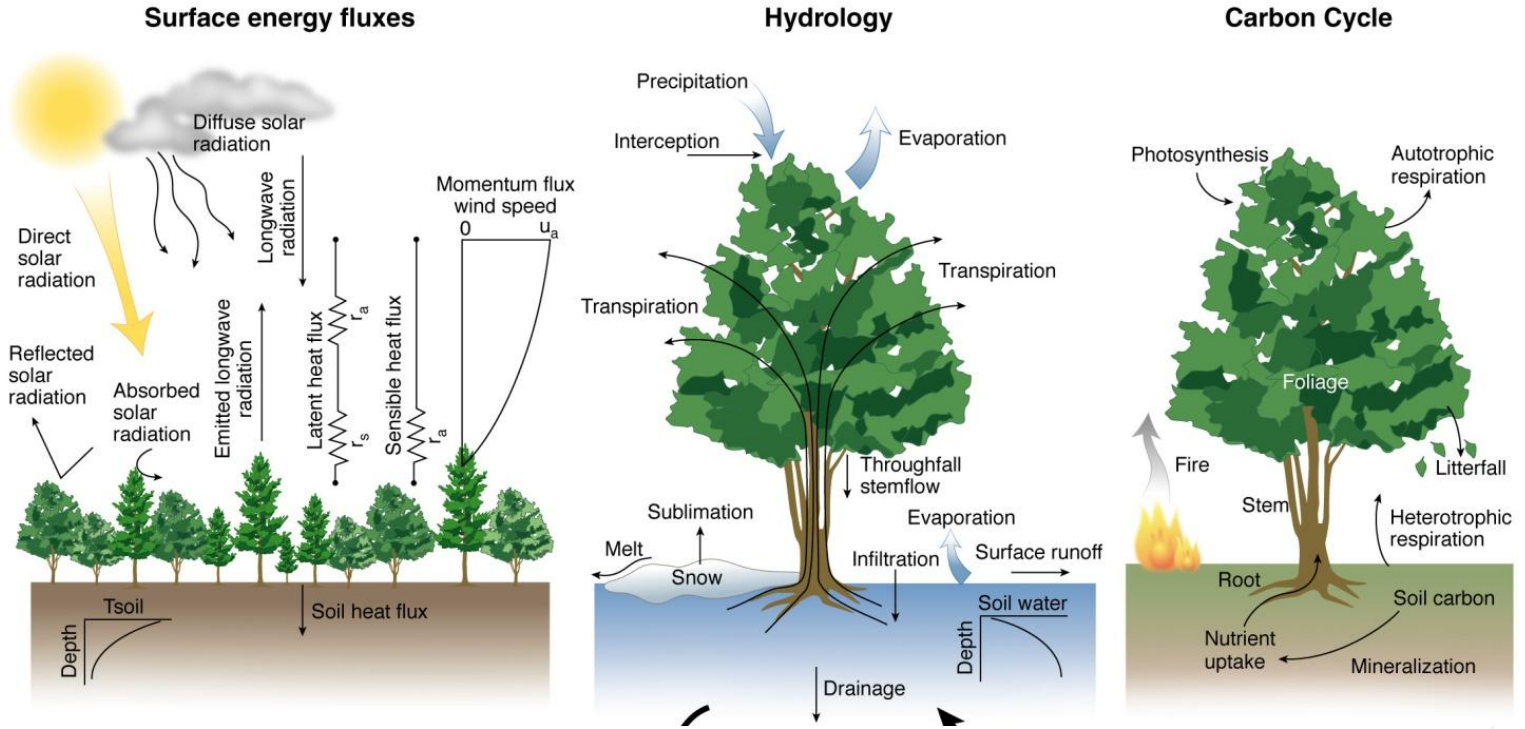


Huge pools
Large fluxes (out)
Large fluxes (in)
Sink = small residual

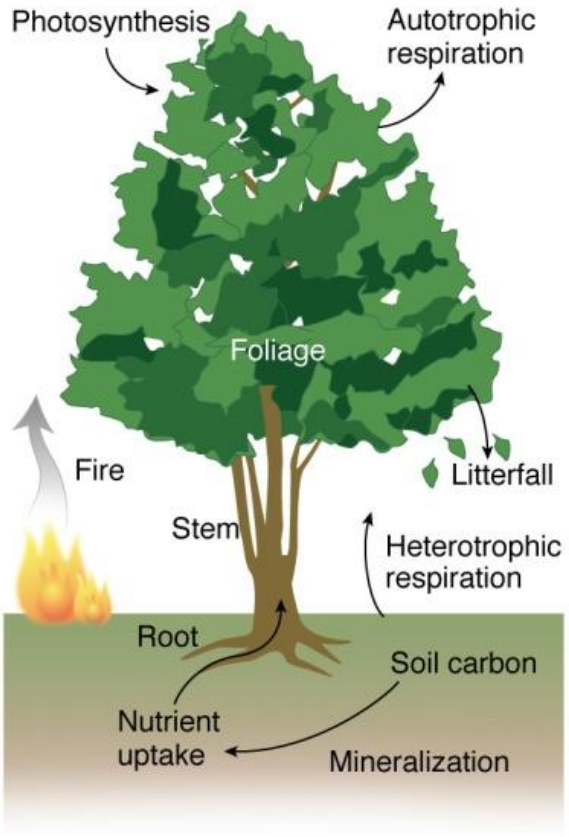


"Bretherton diagram" showing the concept of an Earth System Model

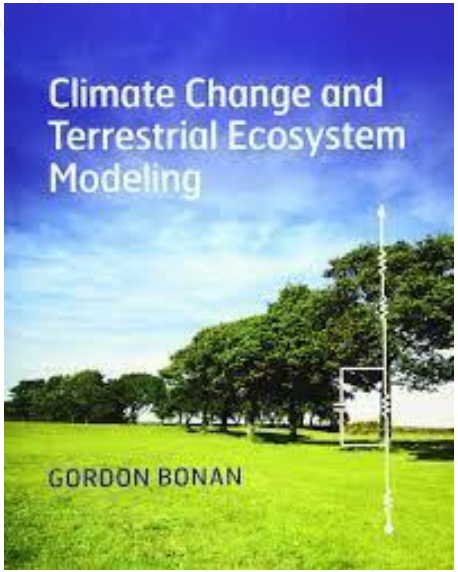

Physical climate system
Atmospheric physics/dynamics
Climate change
Sun
External forcing
Volcanoes
Stratospheric chemistry/dynamics
Ocean dynamics
Terrestrial energy moisture
bio
Land Biogeochemistry
Land CLM5
River Runoff MOSART
Surface Waves WW3
Atmosphere CAM6
Chemistry CAM6-Chem
High-top WACCM6
Coupler CIME5
Sea Ice CICE5
Land Ice CISM2
Ocean POP2
Marine Biogeochemistry MARBL

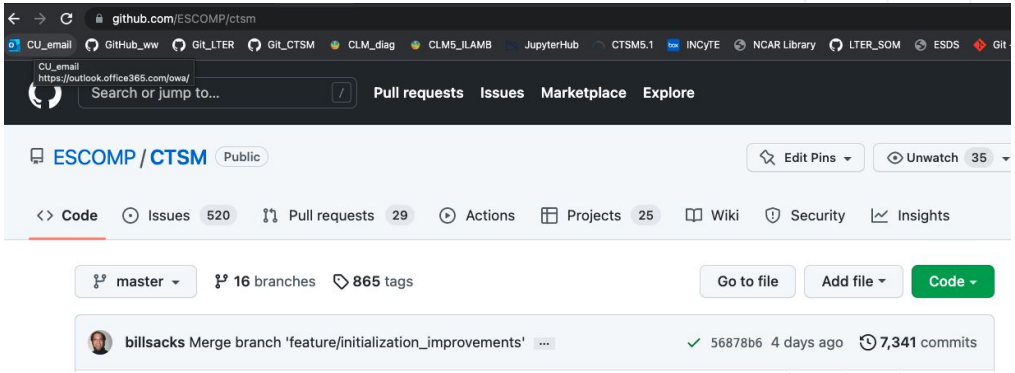


Bonan 2008, Science

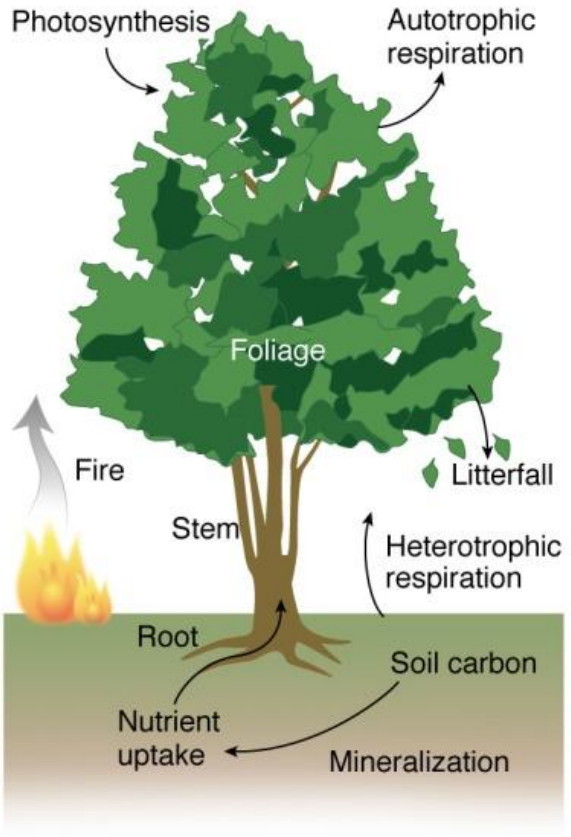


Bonan 2008, Science





https://github.com/ESCOMP/ctsm

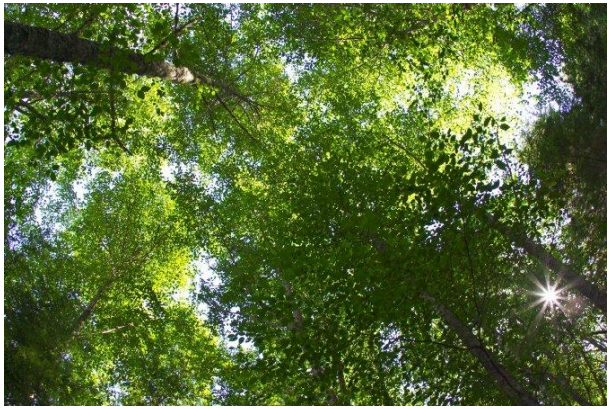


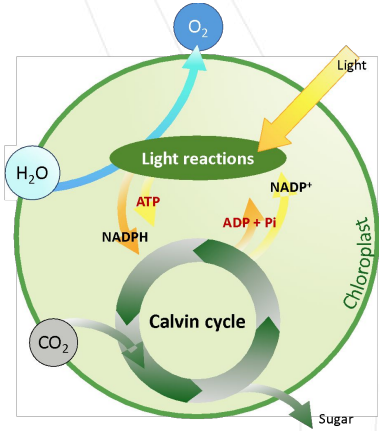
Bonan 2008, Science

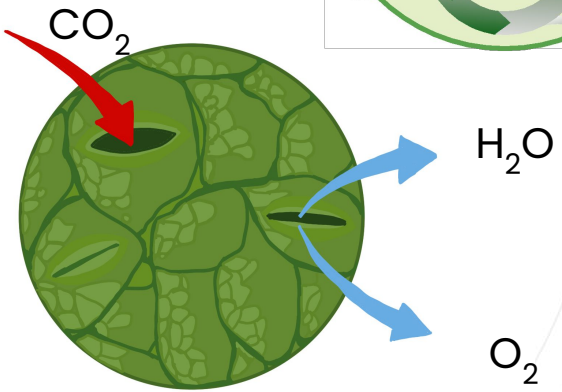
Leaves

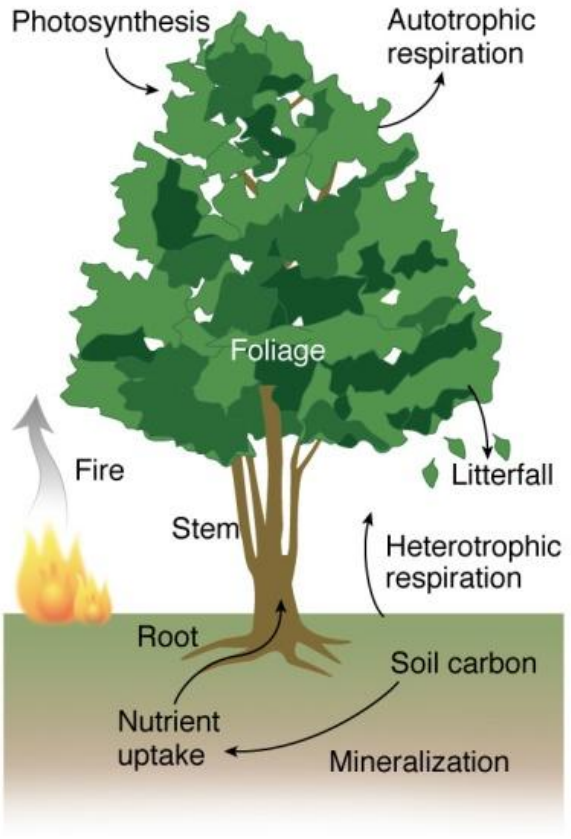
Photosynthesis

Stomatal Conductance









Bonan 2008, Science

Leaves

Photosynthesis

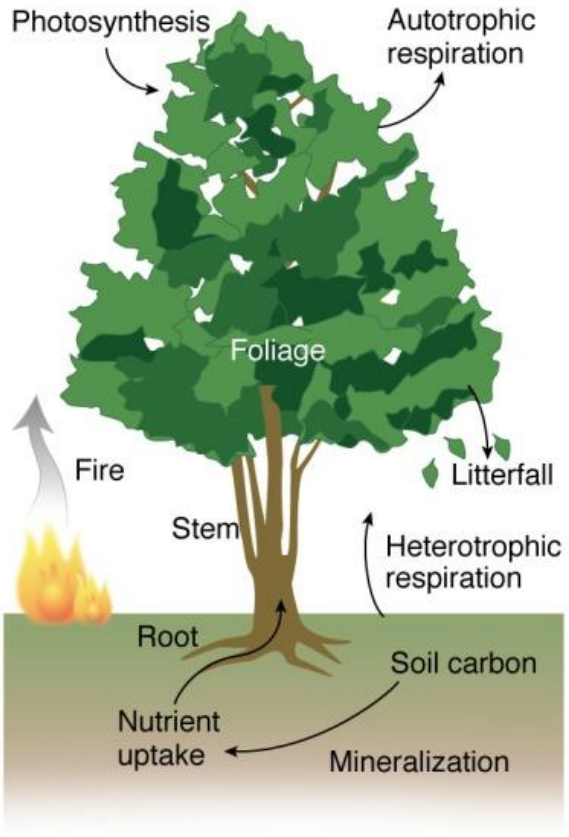
Stomatal Conductance

Canopy & Light

Two-stream radiation approximation, sunlit/shaded leaf

GPP: Gross Primary Productivity





Bonan 2008, Science

Leaves

Photosynthesis

Stomatal Conductance

Canopy & Light

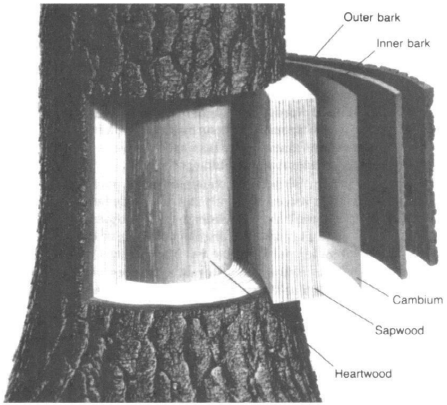
Two-stream radiation approximation, sunlit/shaded leaf

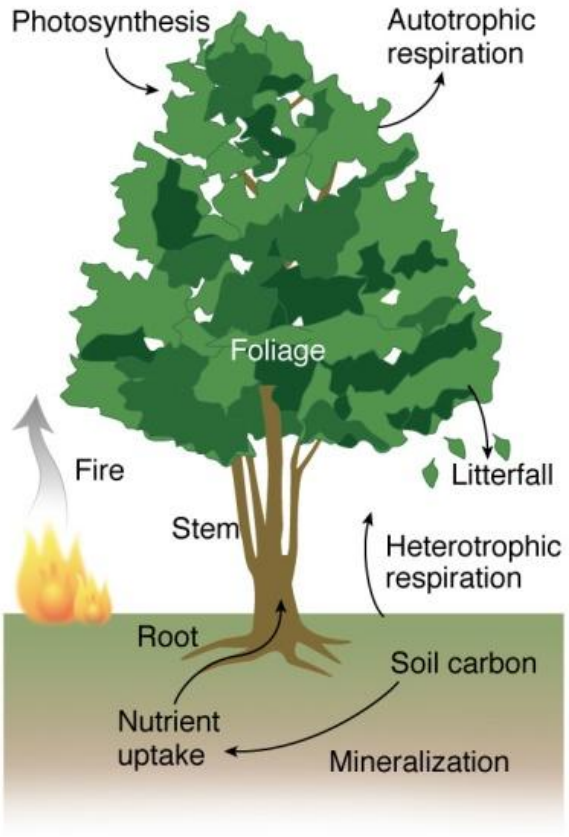
Allocation & Respiration

leaves, wood, roots

AR: Autotropic respiration

NPP: Net Primary Productivity = GPP - AR





Bonan 2008, Science

Leaves

Photosynthesis

Stomatal Conductance

Canopy & Light

Two-stream radiation approximation, sunlit/shaded leaf

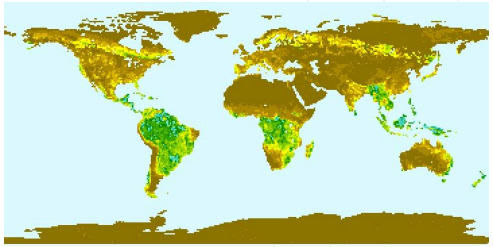
Allocation & Respiration

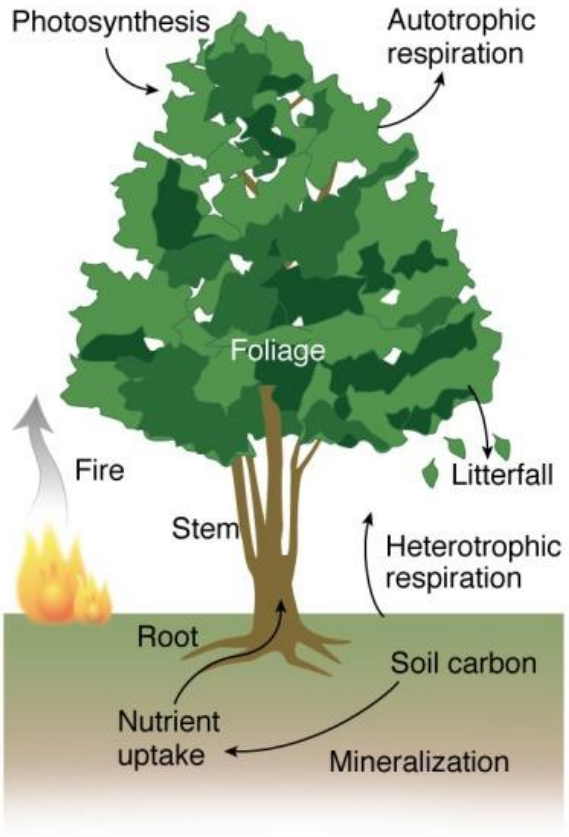
leaves, wood, roots

Phenology & Turnover

mortality, litter, etc.

LAI: Leaf area index





Bonan 2008, Science

Leaves

Photosynthesis
Stomatal Conductance

Canopy & Light

Two-stream radiation approximation, sunlit/shaded leaf

Allocation & Respiration

leaves, wood, roots

Phenology & Turnover

mortality, litter, etc.

Decomposition

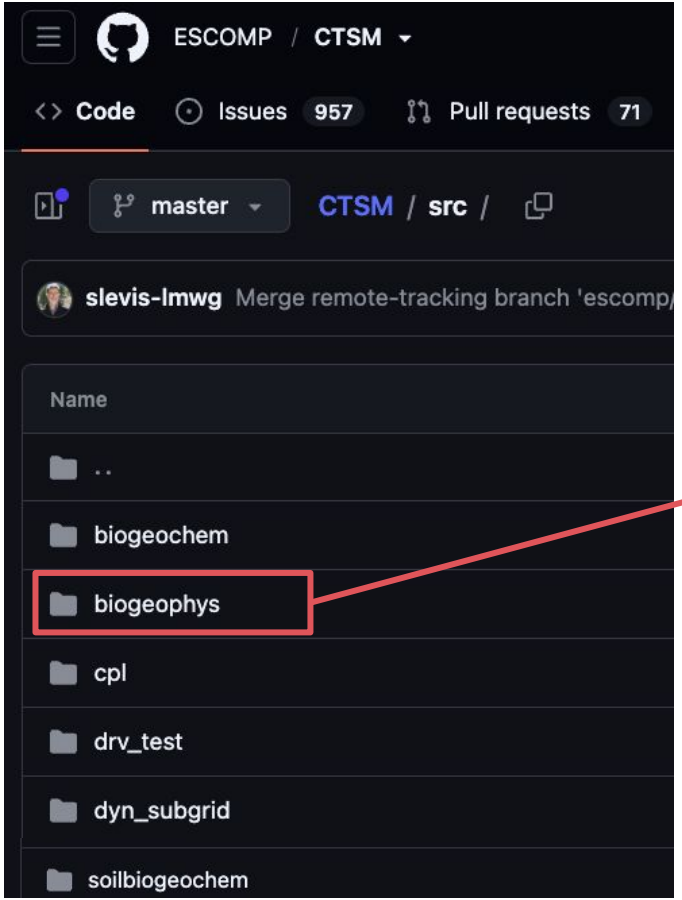
HR: heterotrophic respiration

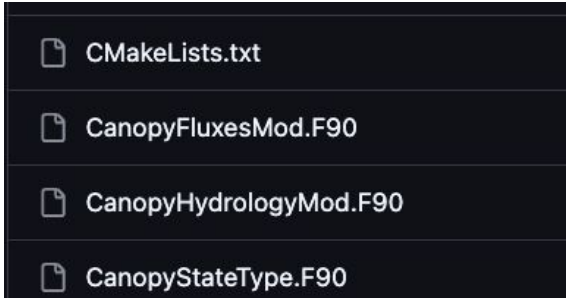


NEP: Net Ecosystem Production = GPP – AR - HR

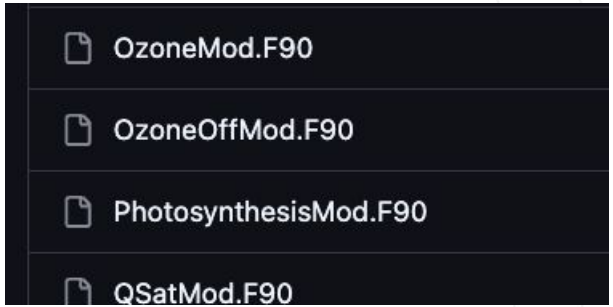
NEE: Net Ecosystem Exchange = NEP – fire loss

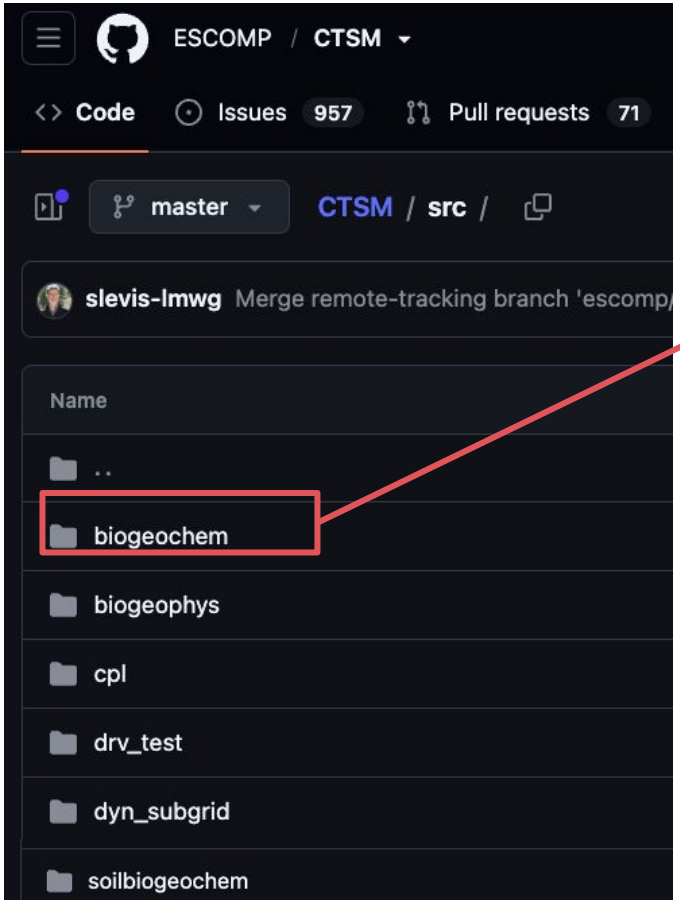
NBP: Net Biome Production = NEE – land use - harvest





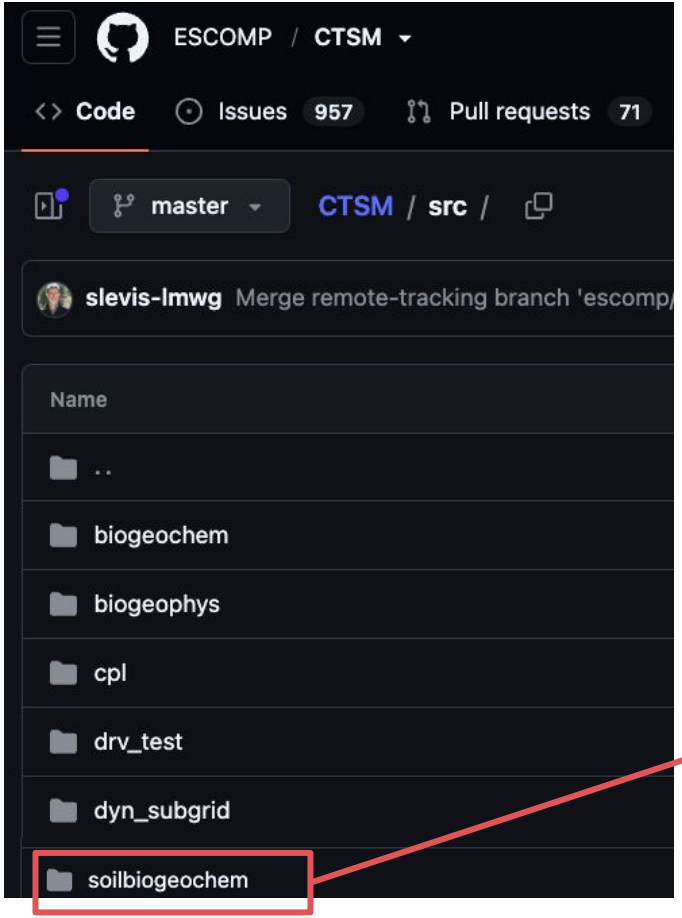
biogeophysics
(Photosynthesis, Canopy Fluxes)





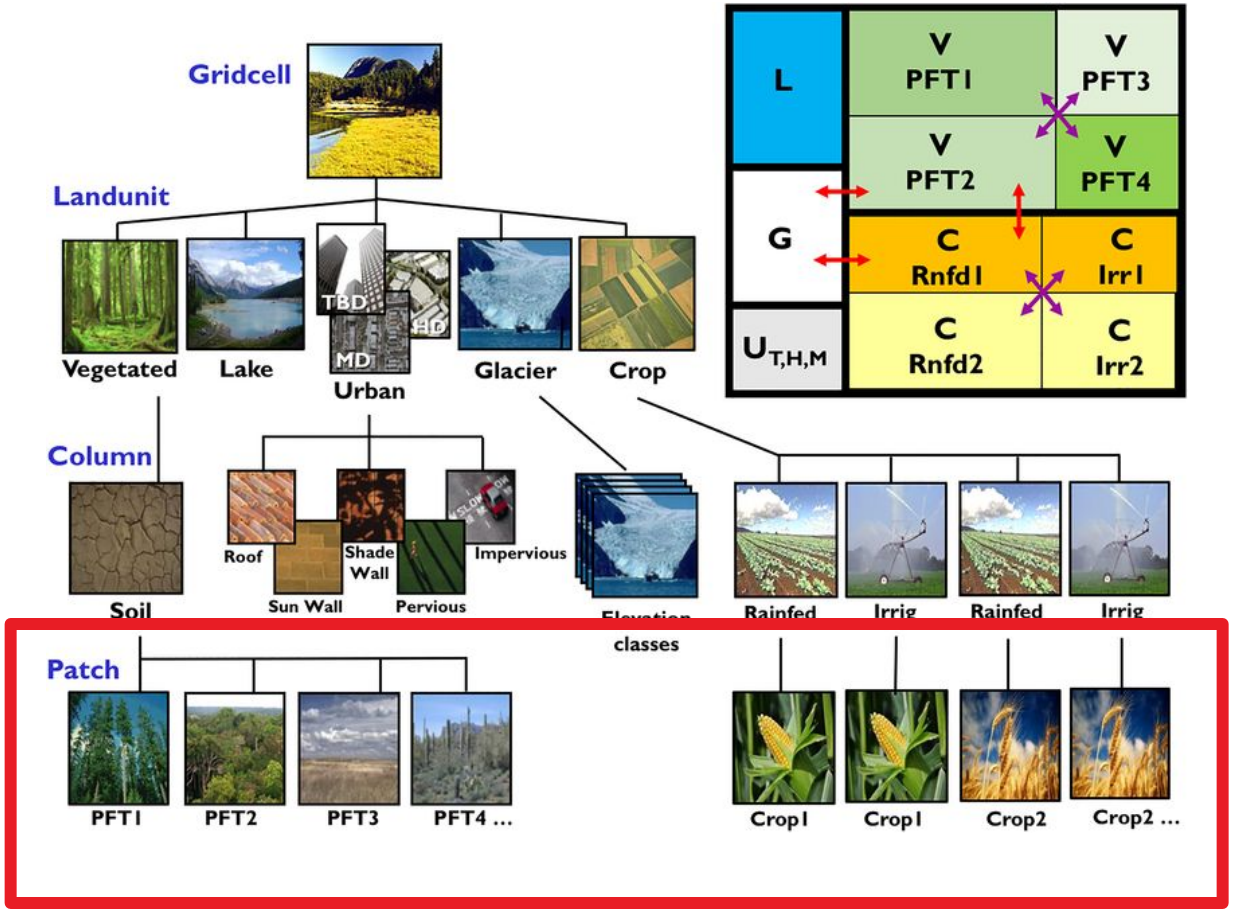
plant biogeochemistry
(Allocation, “CNVeg”, Nutrients, Phenology)

- CNFireLi2024Mod.F90
- CNFireNoFireMod.F90
- CNGRespMod.F90
- CNGapMortalityMod.F90
- CNMRespMod.F90
- CNNDynamicsMod.F90
- CNNStateUpdate1Mod.F90
- CNNStateUpdate2Mod.F90
- CNNStateUpdate3Mod.F90
- CNPhenologyMod.F90
- CNPrecisionControlMod.F90
- CNProductsMod.F90
- CNSharedParamsMod.F90

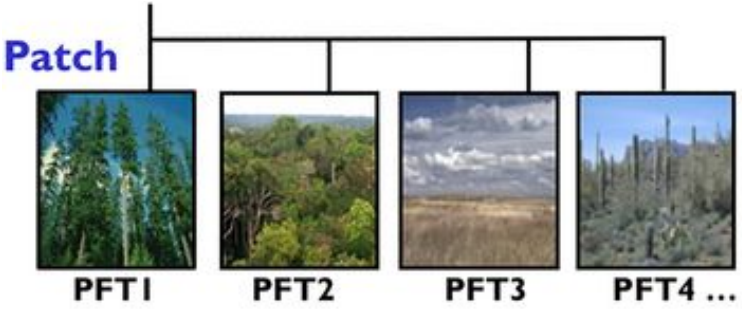


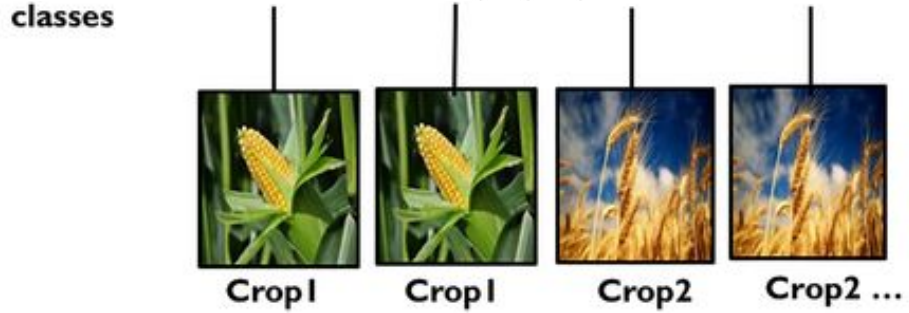


soil biogeochemistry
(Litter, Leaching, Decomposition, CN Matrix)

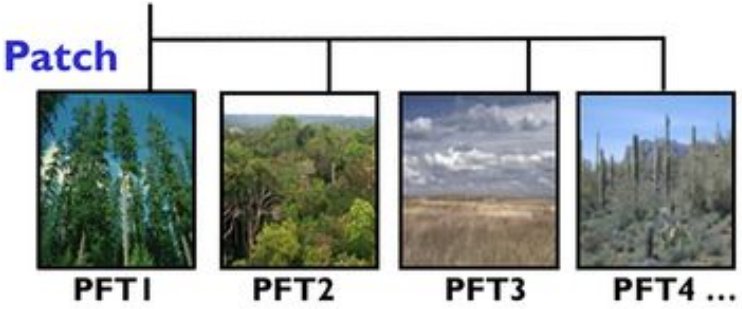


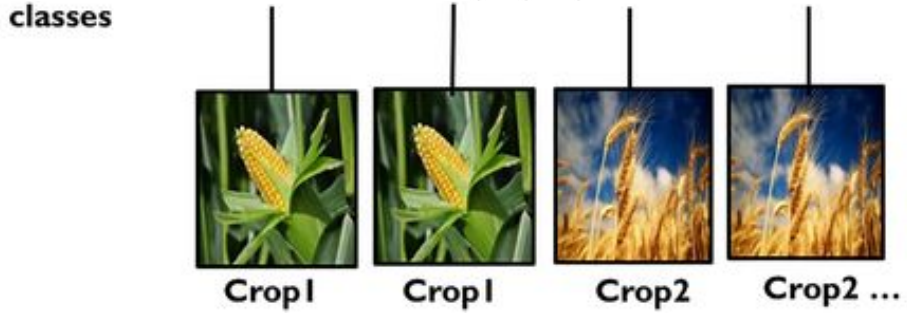
Lawrence et al 2019, JAMES
https://github.com/ESCOMP/ctsm

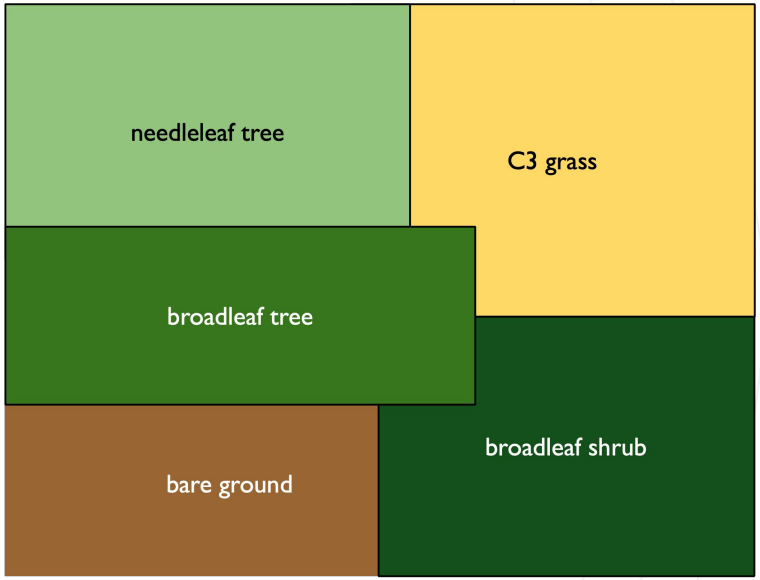




Lawrence et al 2019, JAMES
https://github.com/ESCOMP/ctsm

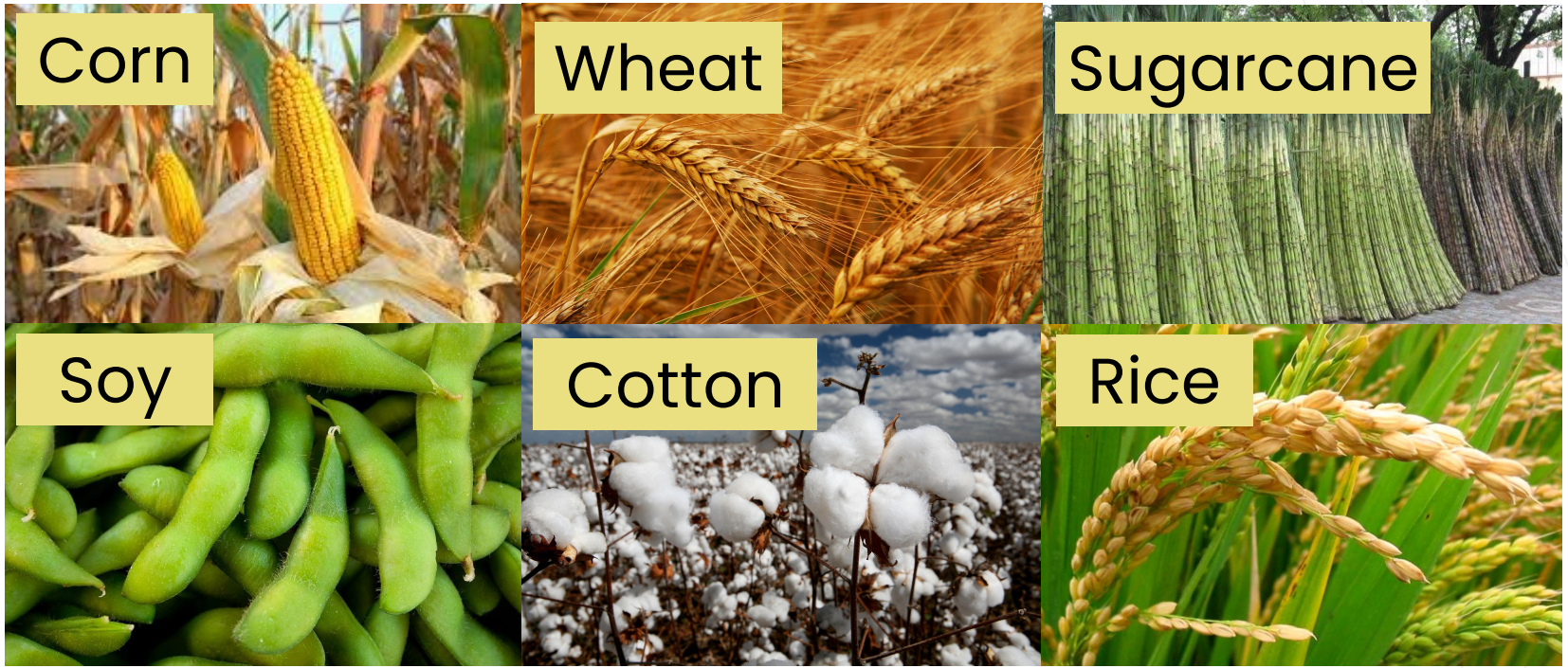






Lawrence et al 2019, JAMES
https://github.com/ESCOMP/ctsm

Agriculture in CLM



Agriculture in CLM

Fertilize



Irrigate



Transient fertilizer and irrigation (1850 – 2100)

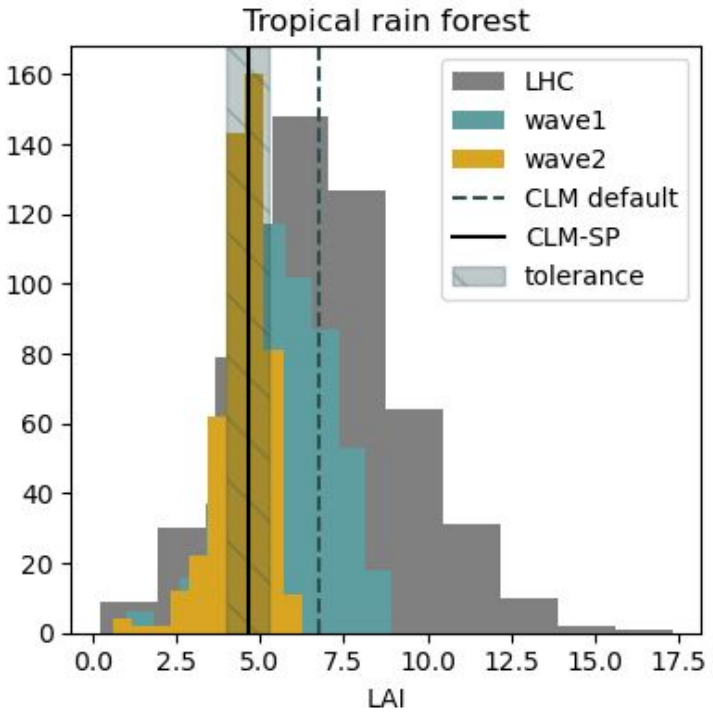
Where do parameter values come from?

Laboratory understanding of plant physiological processes
e.g., Farquhar: Photosynthesis is co-limited by light, energy, export of sugars

Trait databases
e.g., TRY Database (Leaf N and dark respiration)

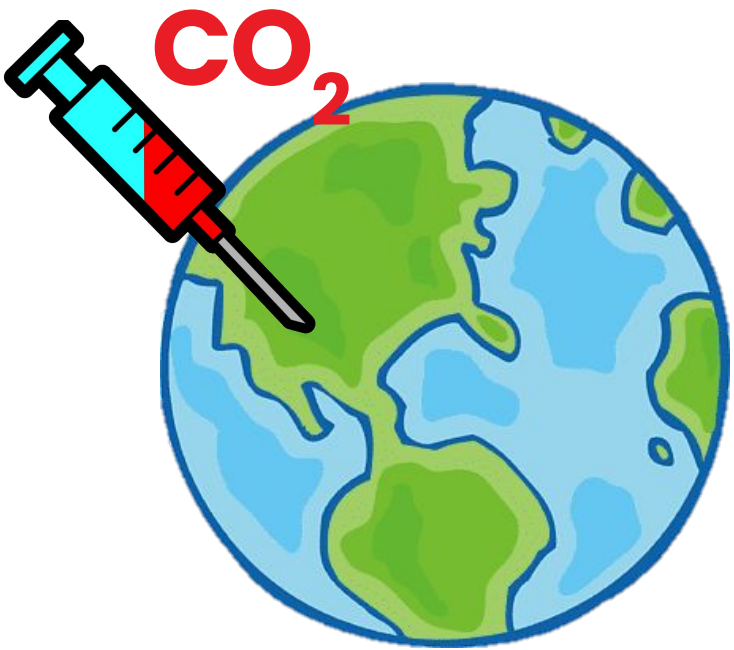
Optimality theory: plants try to optimize things like water use efficiency
e.g., FUN and LUNA modules

Calibration!



Hawkins, et al. in prep

Idealized experiments

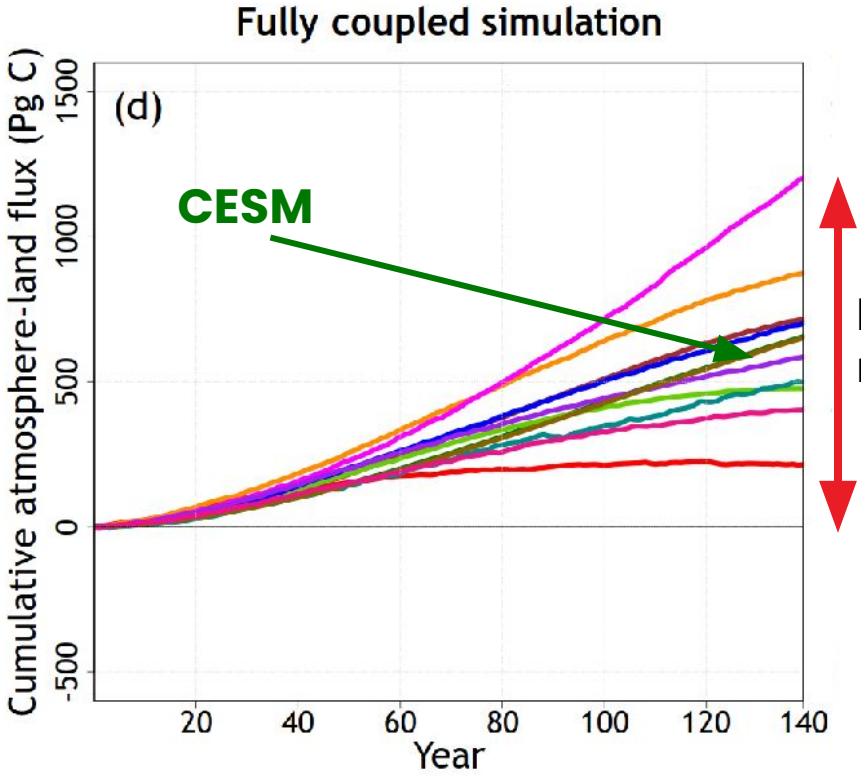


1% CO2 / year
Land & Ocean uptake
Temperature change

Three experiments:

1. Fully coupled
2. Biogeochemically coupled
3. Radiatively coupled

Idealized experiments



large uncertainty in magnitude of land sink

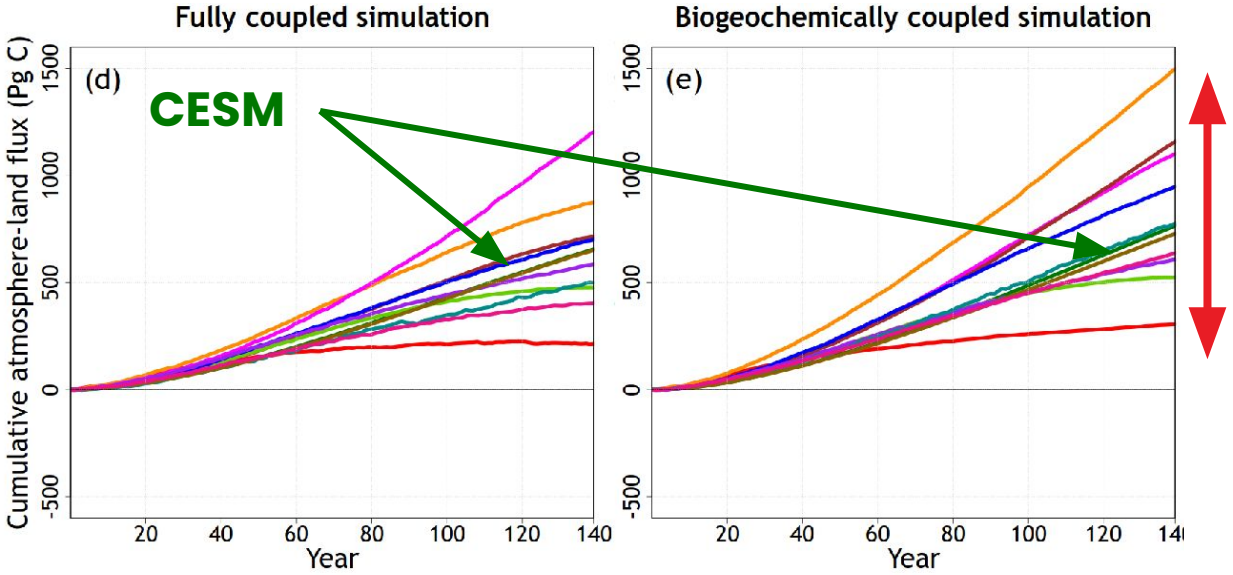
CMIP6 models

- ACCESS-ESM1.5
- BCC-CSM2-MR
- CanESM5
- CESM2
- CNRM-ESM2-1
- IPSL-CM6A-LR
- MIROC-ES2L
- MPI-ESM1.2-LR
- NOAA-GFDL-ESM4
- NorESM2-LM
- UKESM1-0-LL

Cumulative land CO_2 sink

Idealized experiments

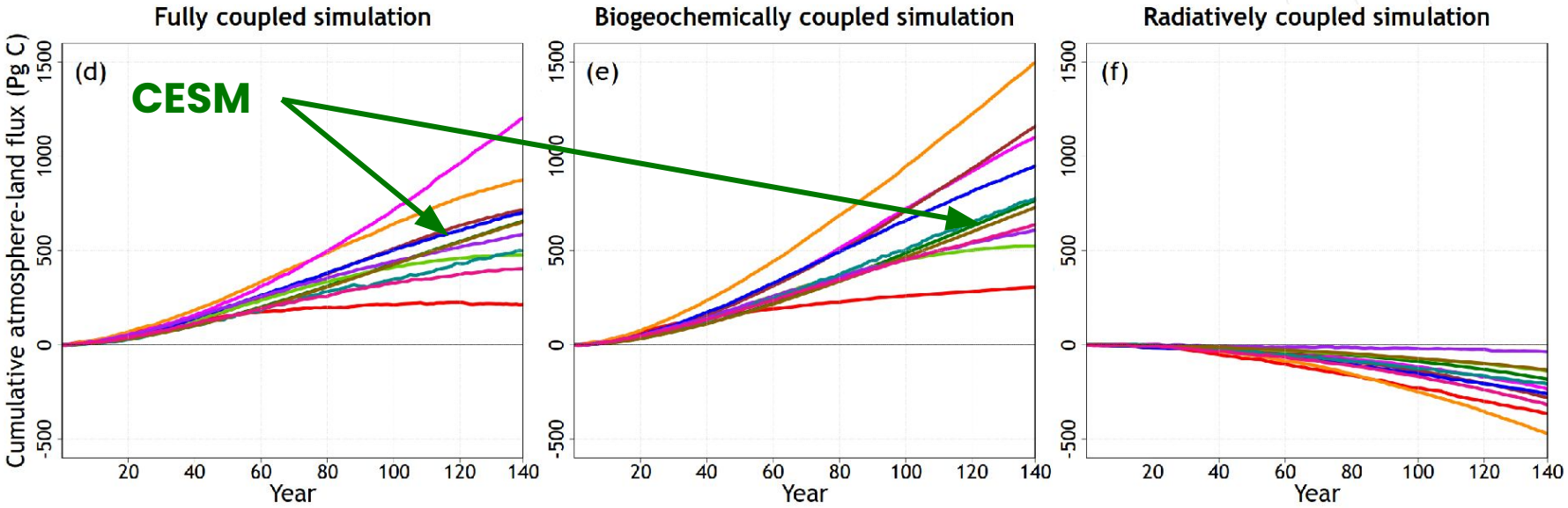
Cumulative land CO_2 sink



still large uncertainty in magnitude of land sink

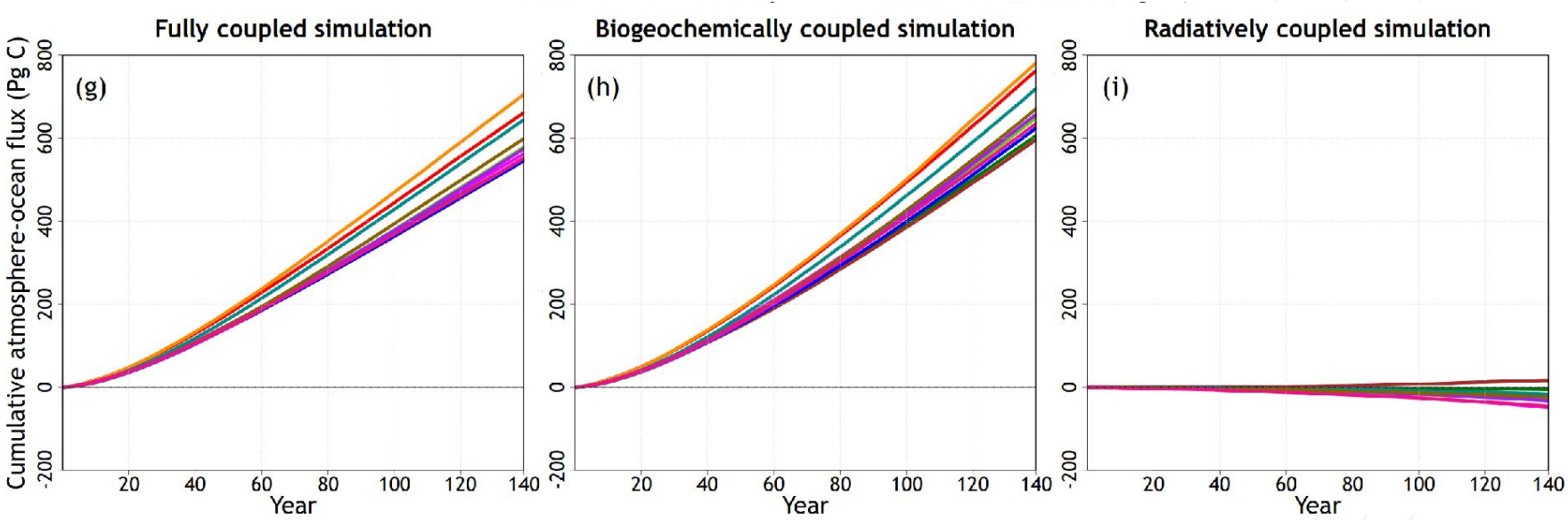
Idealized experiments

Cumulative land CO_2 sink



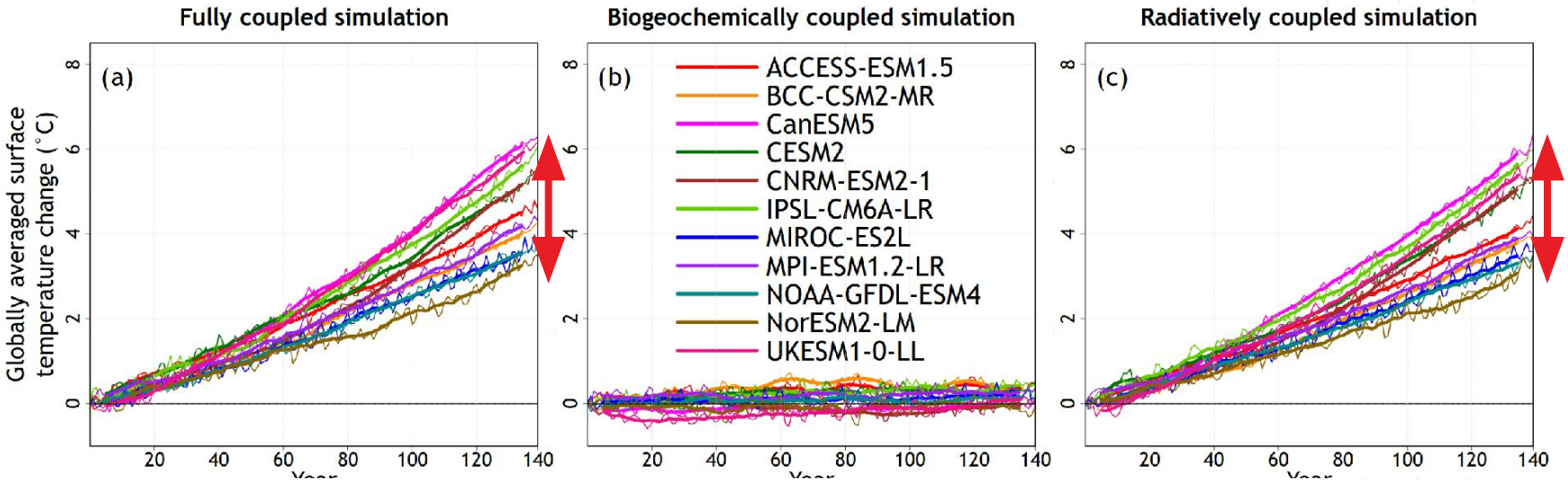
Idealized experiments

Cumulative ocean CO_2 sink

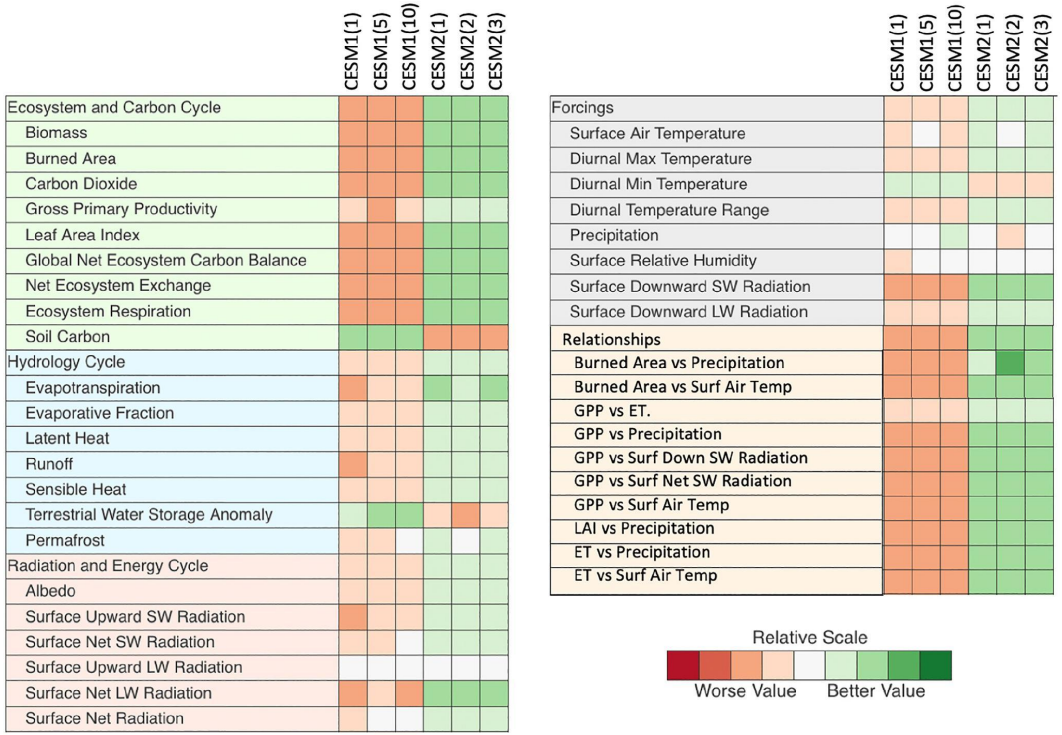


Idealized experiments

Global average surface temperature change (°C)



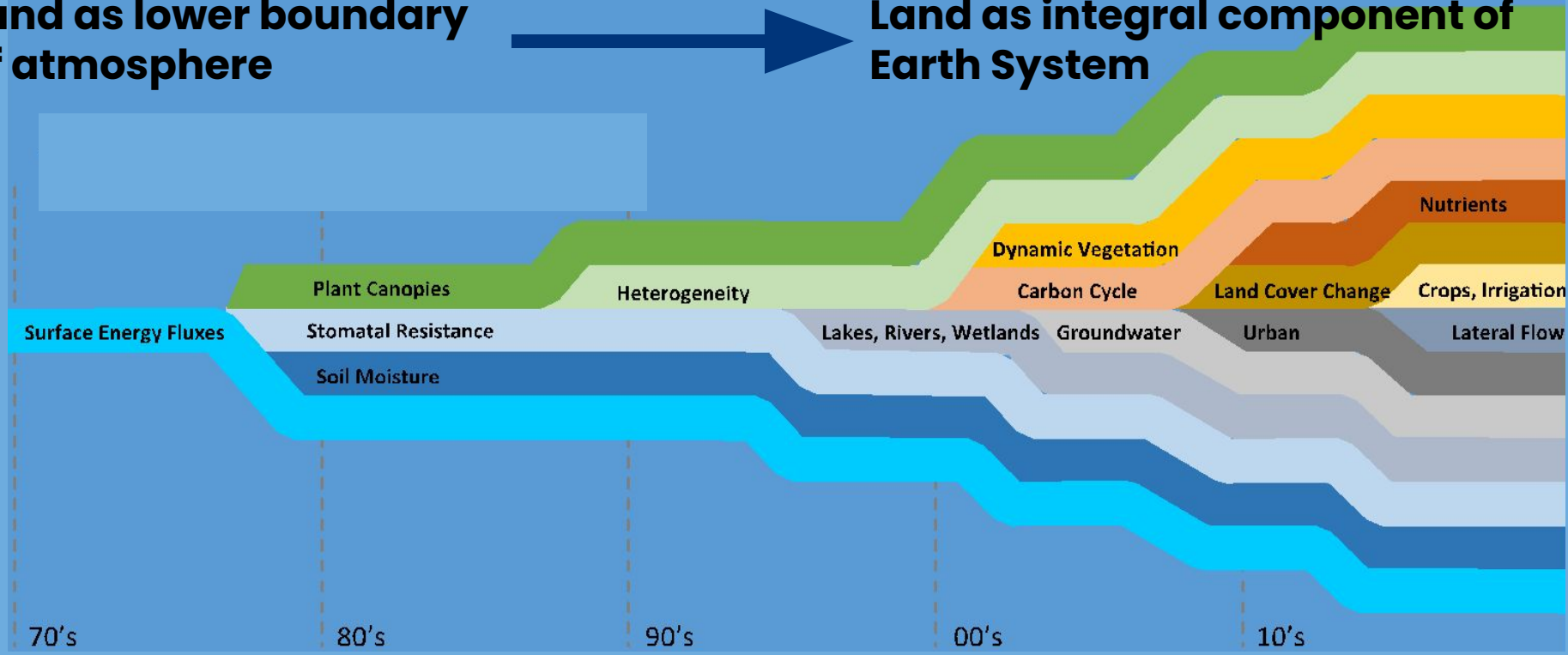
Representing the land

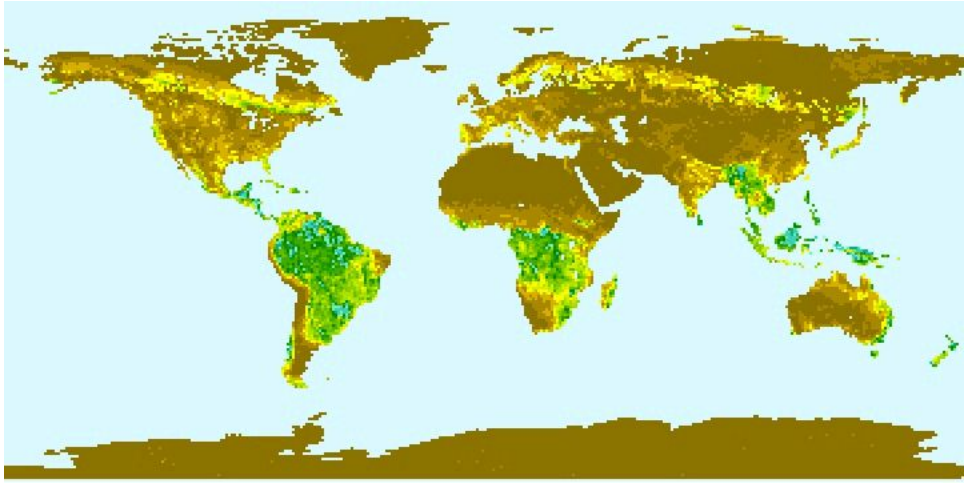


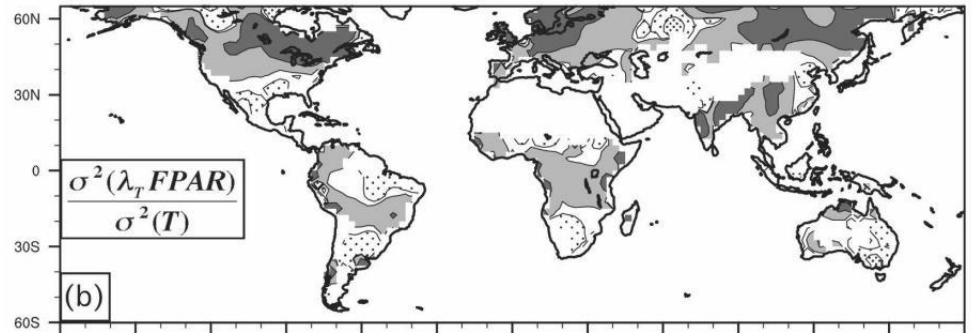
ILAMB – International Land Model Benchmarking package

the Evolution of land modeling

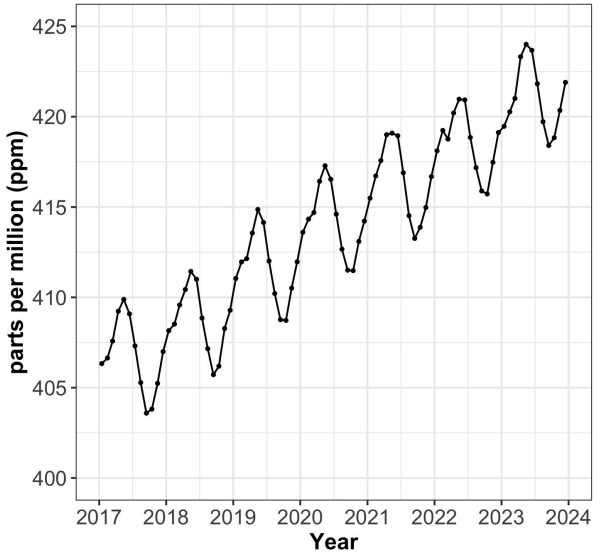
Land as lower boundary of atmosphere → **Land as integral component of Earth System**





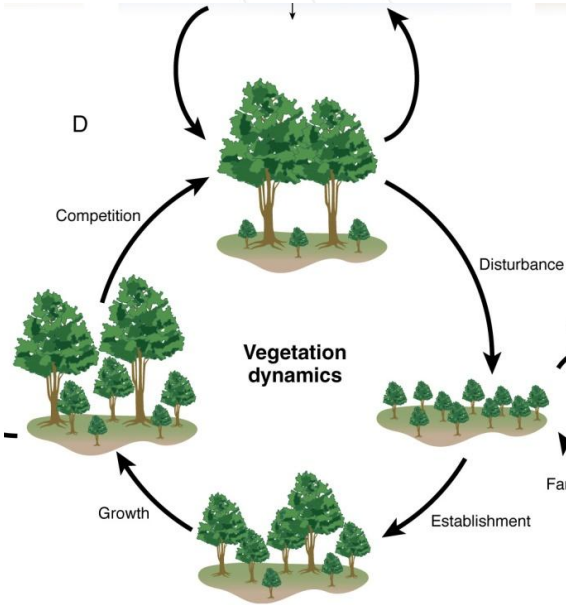


Recent monthly mean CO_2 at Mauna Loa Observatory



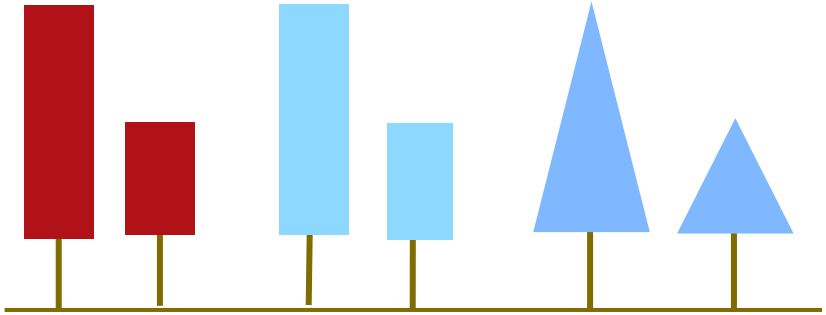
Forests are a mosaic of patches





FATES: Functionally Assembled Terrestrial Ecosystem Simulator

FATES

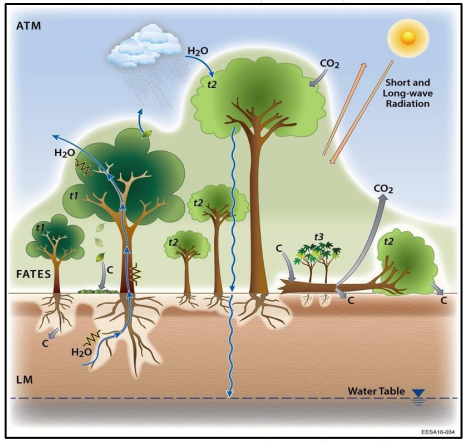


cohort-specific model

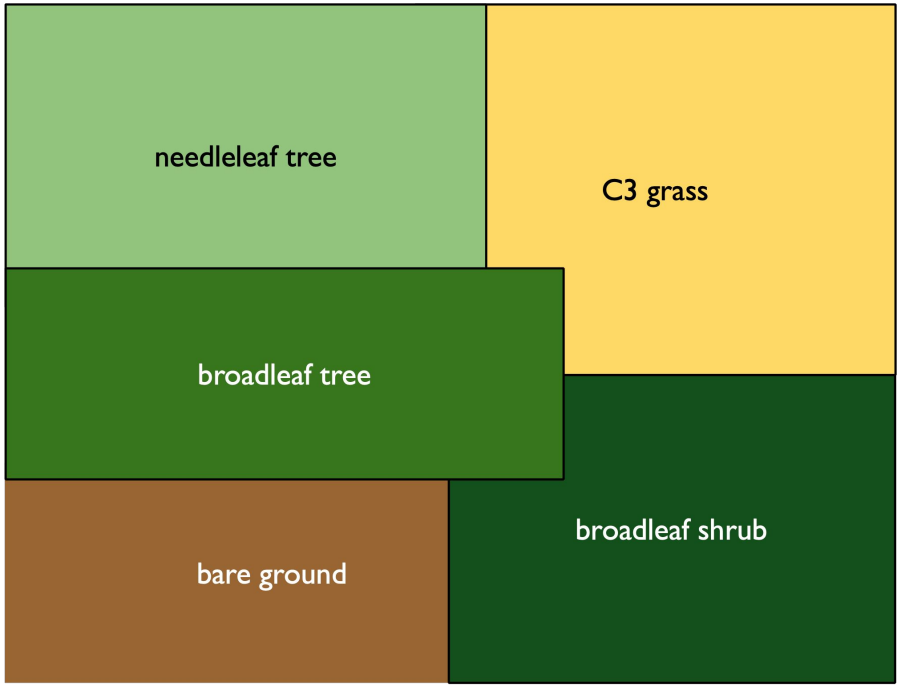
30-minute photosynthesis and fluxes

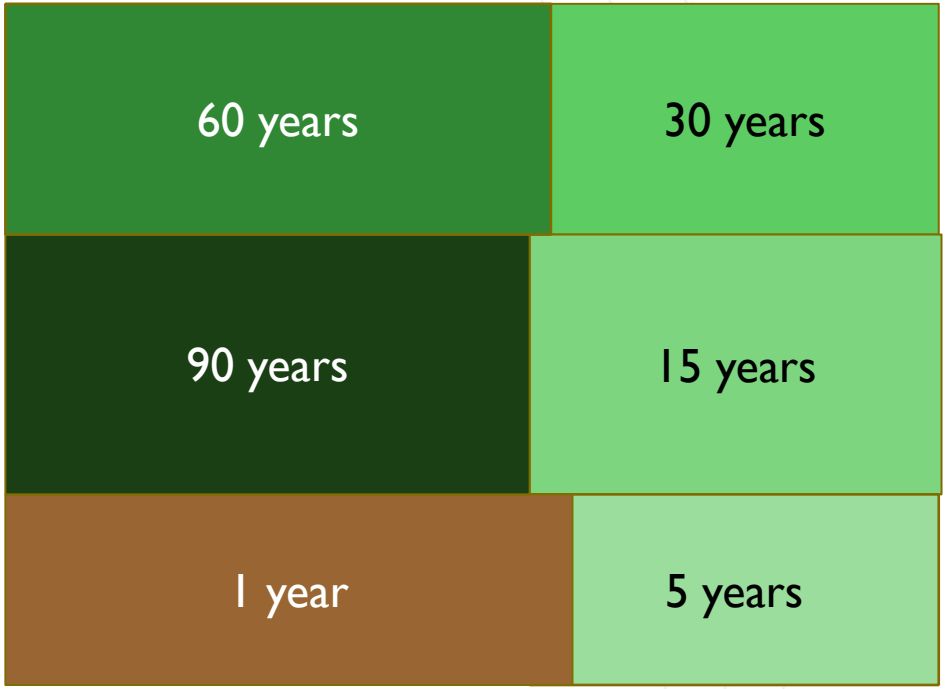
daily growth and allocation

dynamic vegetation!



Tiling differences



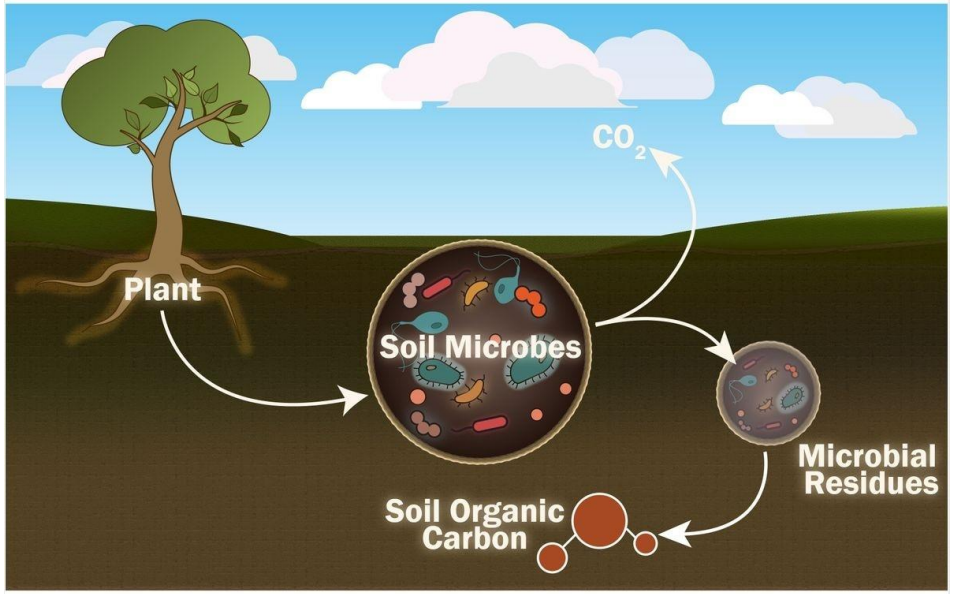


Tiling differences

Each tile contains cohorts of plants of different PFT and size

MIMICS: modeling microbial controls on soil carbon dynamics

Soil C model that considers relationships among litter quality, functional tradeoffs in microbial physiology, and microbial byproducts



More accurately represents C response to N enrichment

Community LAND MODEL DEVELOPMENT



































