Land Modeling II: Biogeochemistry and Ecosystems

Adrianna Foster, *Will Wieder, Dave Lawrence, Andy Wood, Bill Sacks, Danica Lombardozzi, Daniel Kennedy, Erik Kluzek, Gordon Bonan, Guoqiang Tang, Jackie Shuman, Katie Dagon, Keith Oleson, Naoki Mizukami, Peter Lawrence, Sam Levis, Sam Rabin, Sean Swenson, Teagan King… and many more!*

11 August 2023

CESM Tutorial

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Land biogeochemistry in CESM

Why?

How?

Uncertainties and future directions

Land biogeochemistry in CESM

Why?

Climate impacts vegetation

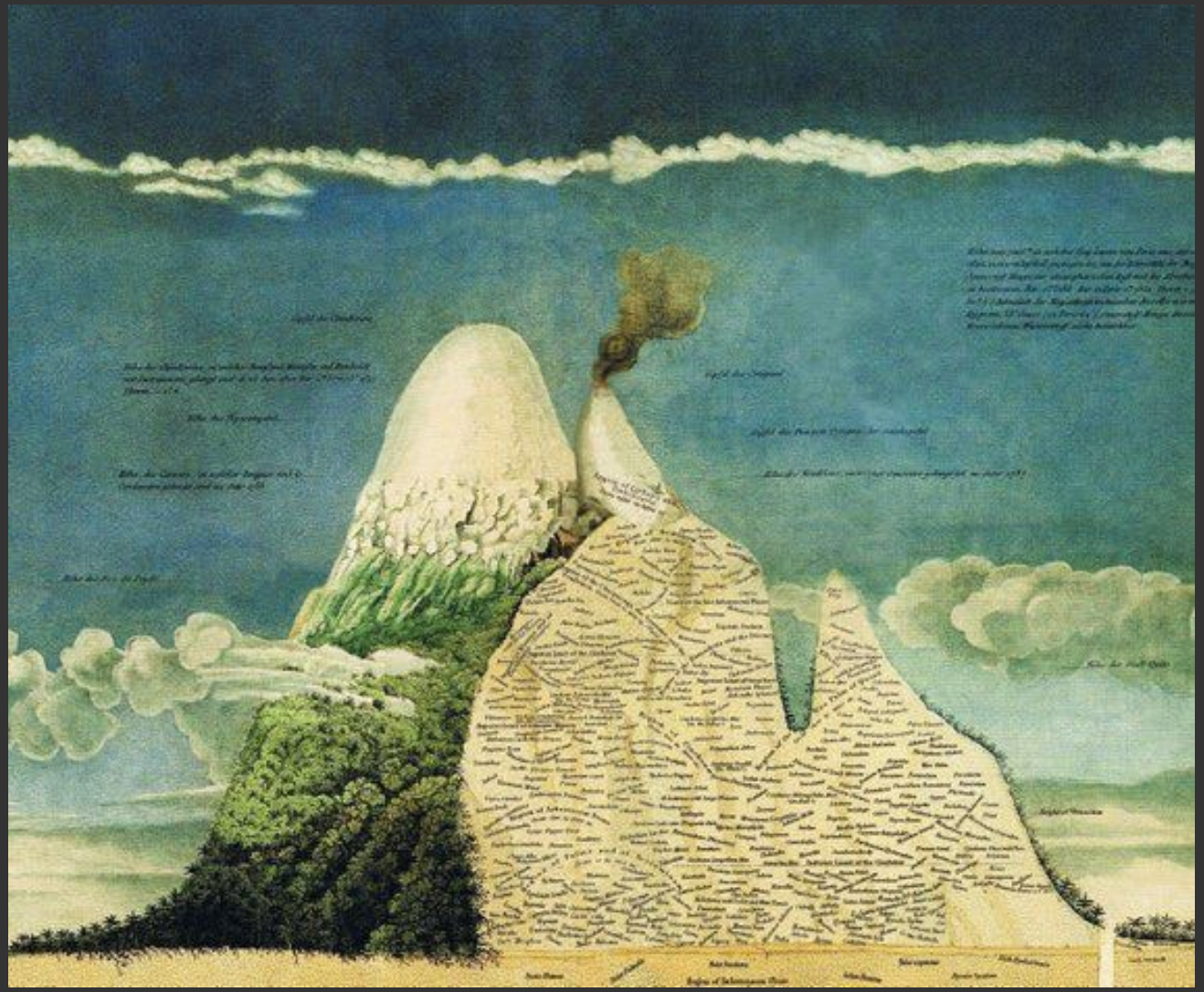
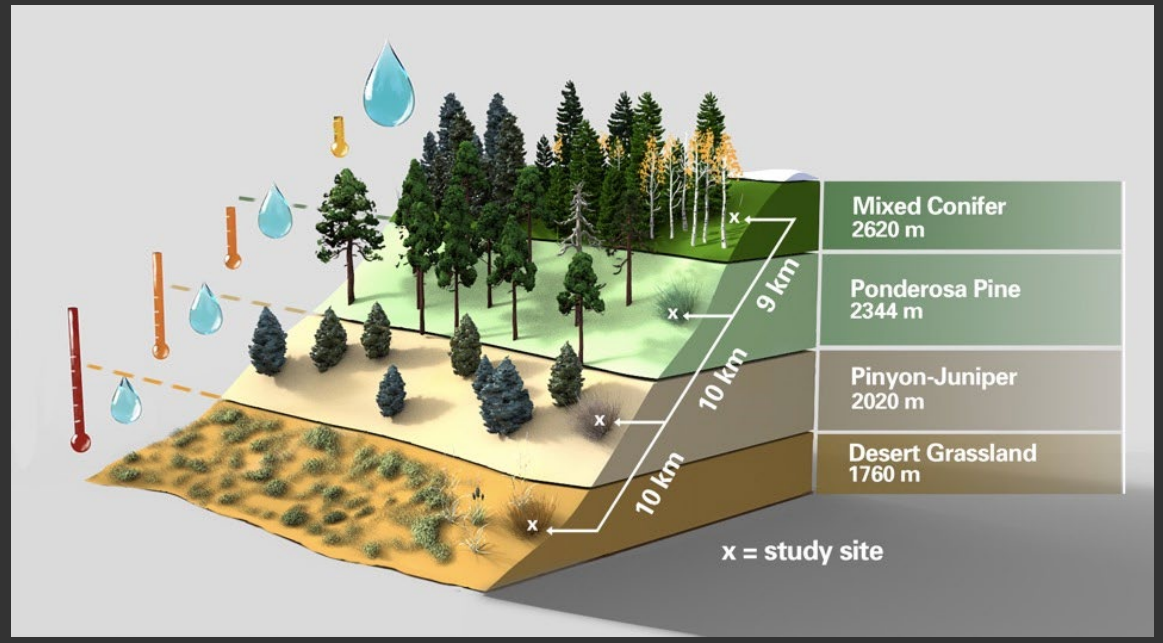


*Tableau des Régions é*quinoxiales from Humboldt (1807)



Morrissey et al. (2019) *Nature Ecology and Evolution*

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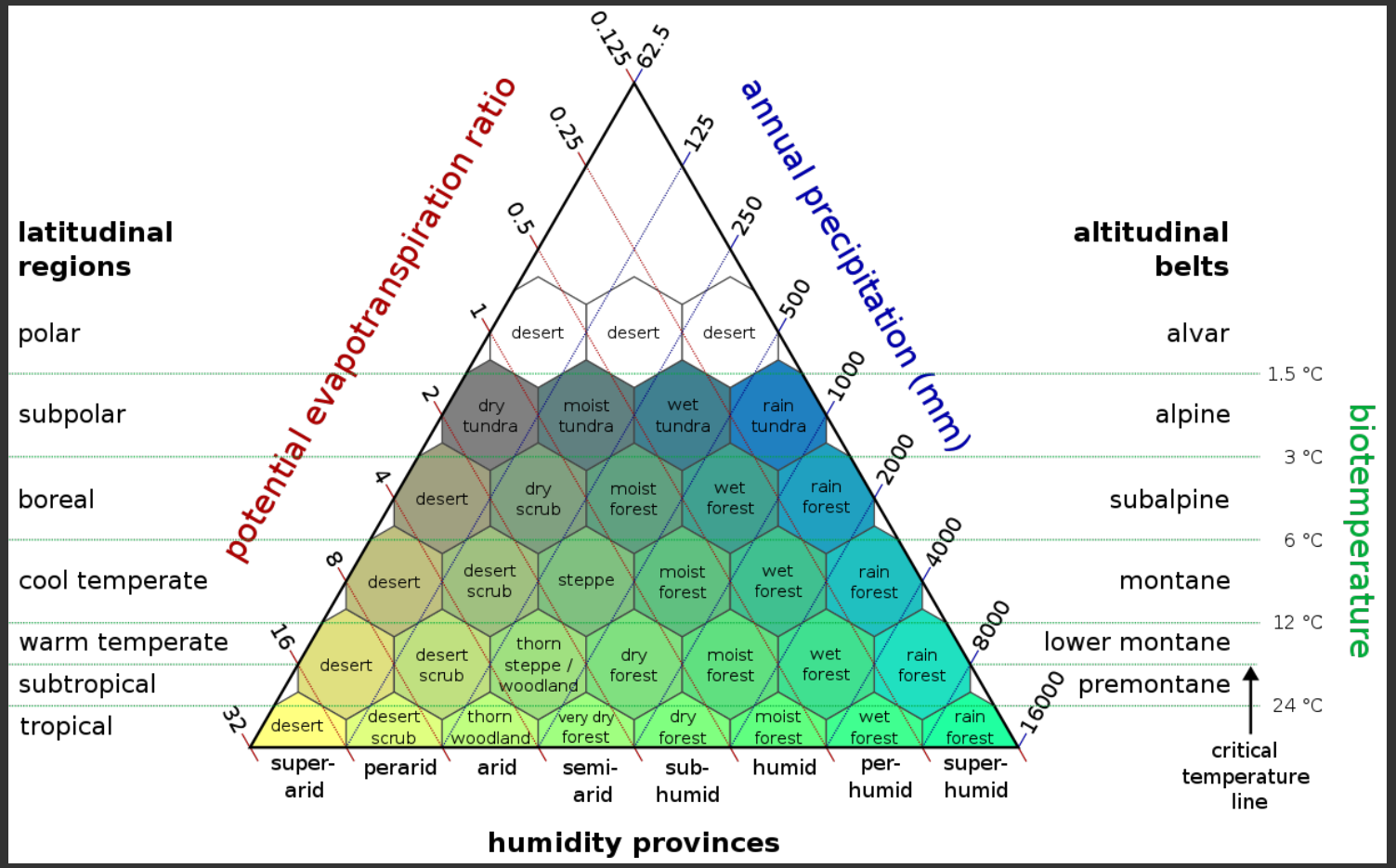
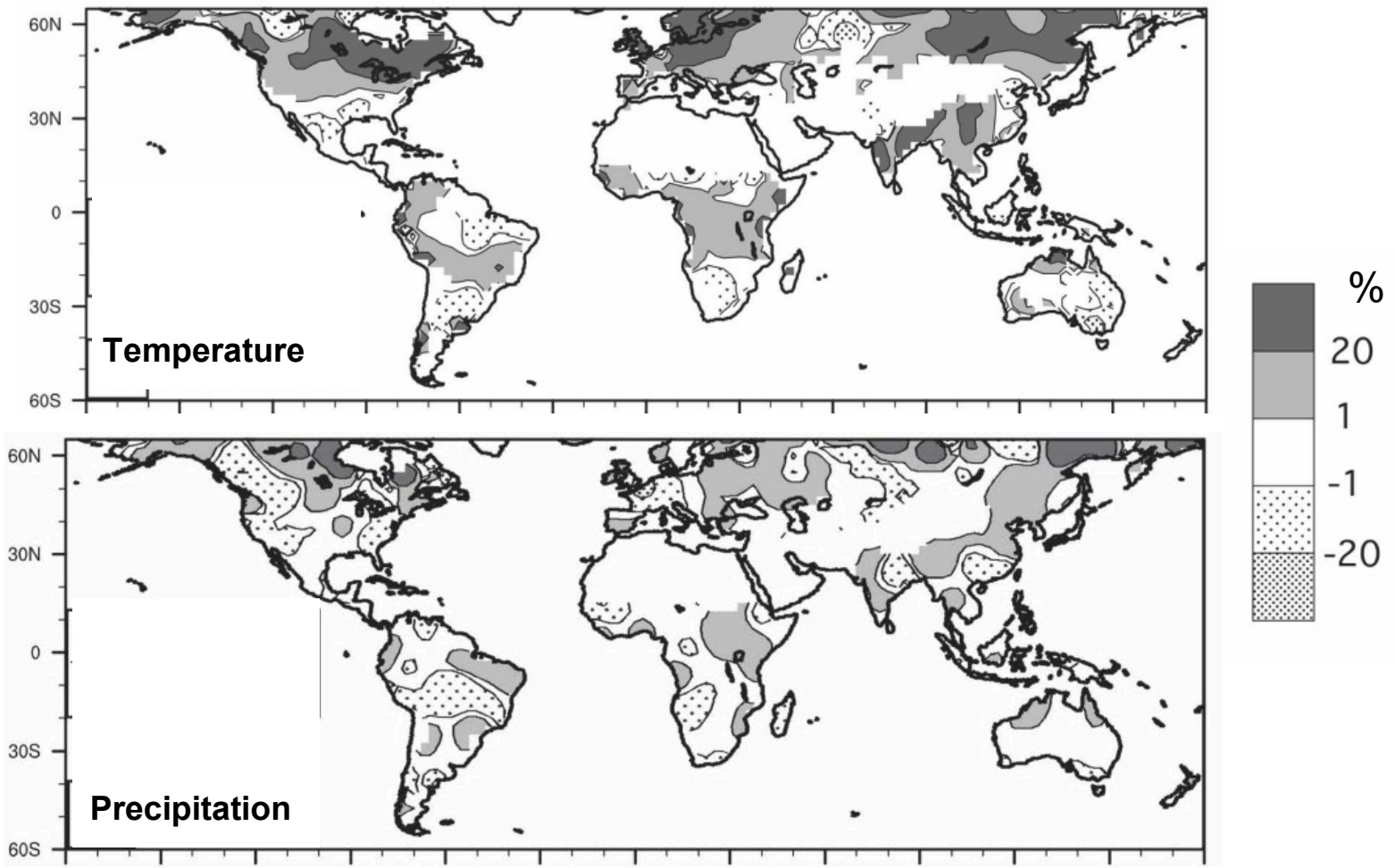


Holdridge life zones

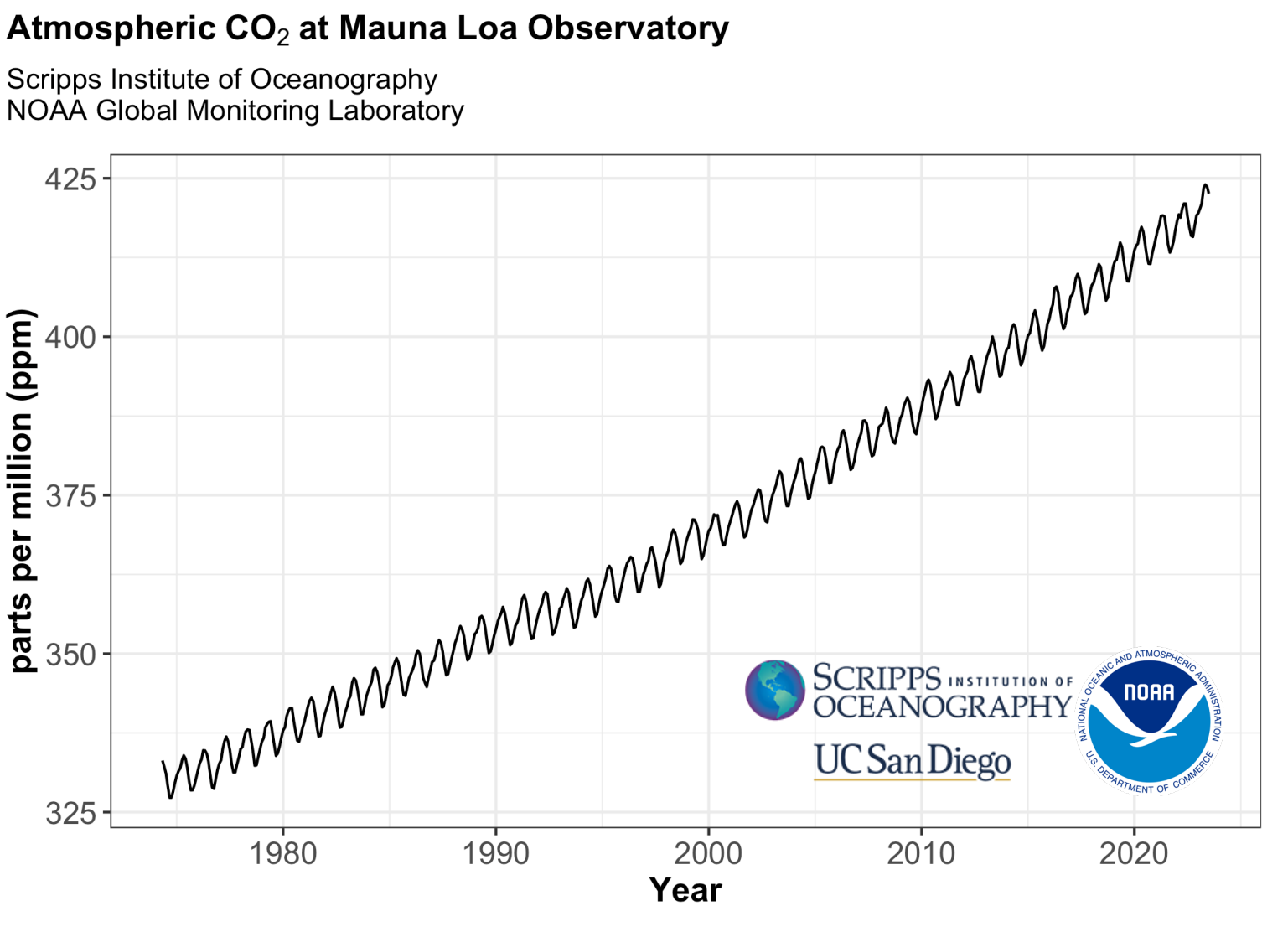
Vegetation impacts climate



Short time scales – dominated by albedo and evapotranspiration

Liu et al. 2006 *Journal of Climate*

Vegetation impacts climate

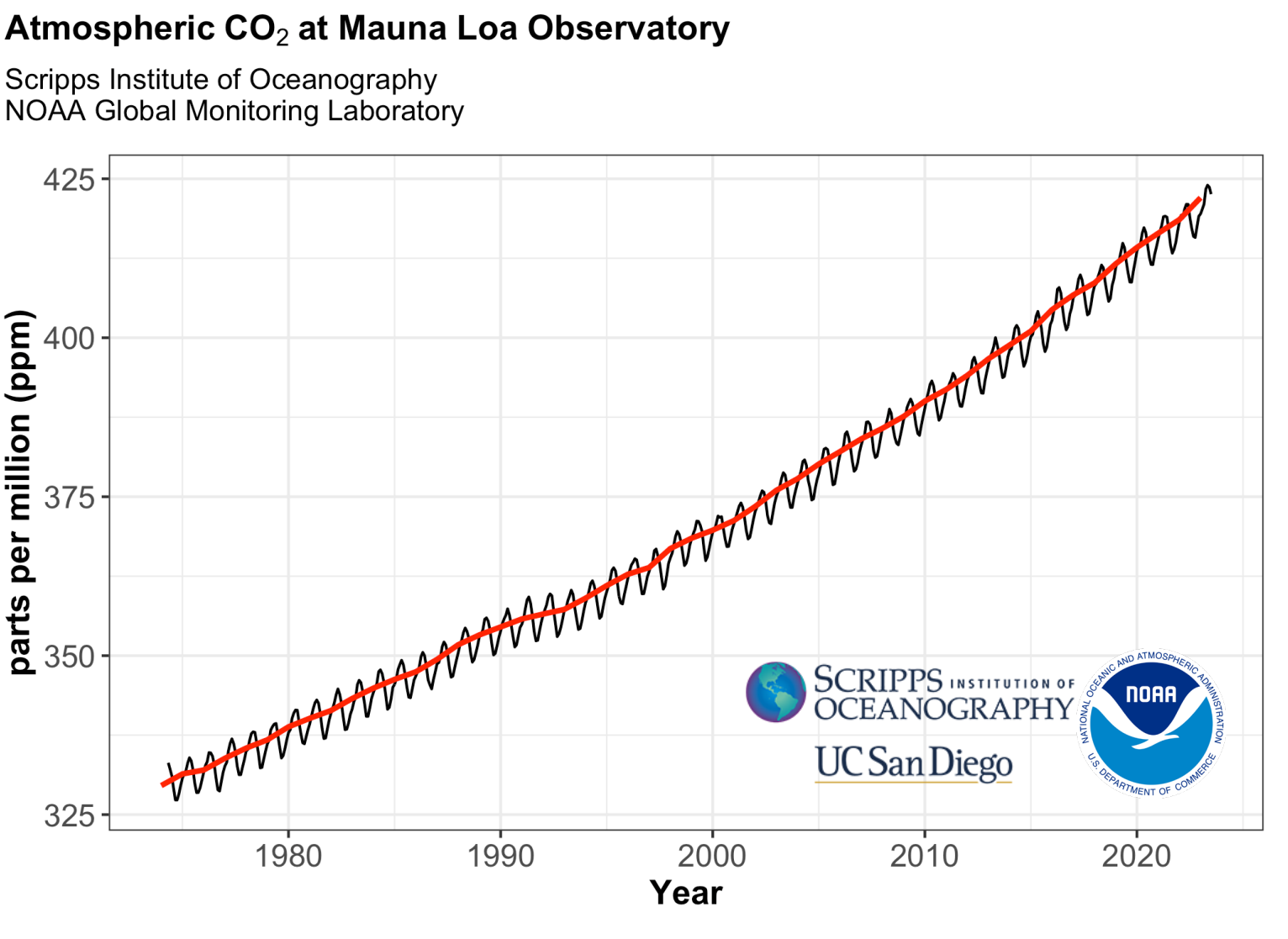


https://gml.noaa.gov/ccgg/trends/mlo.html

Longer time scales

fate of carbon

Vegetation impacts climate



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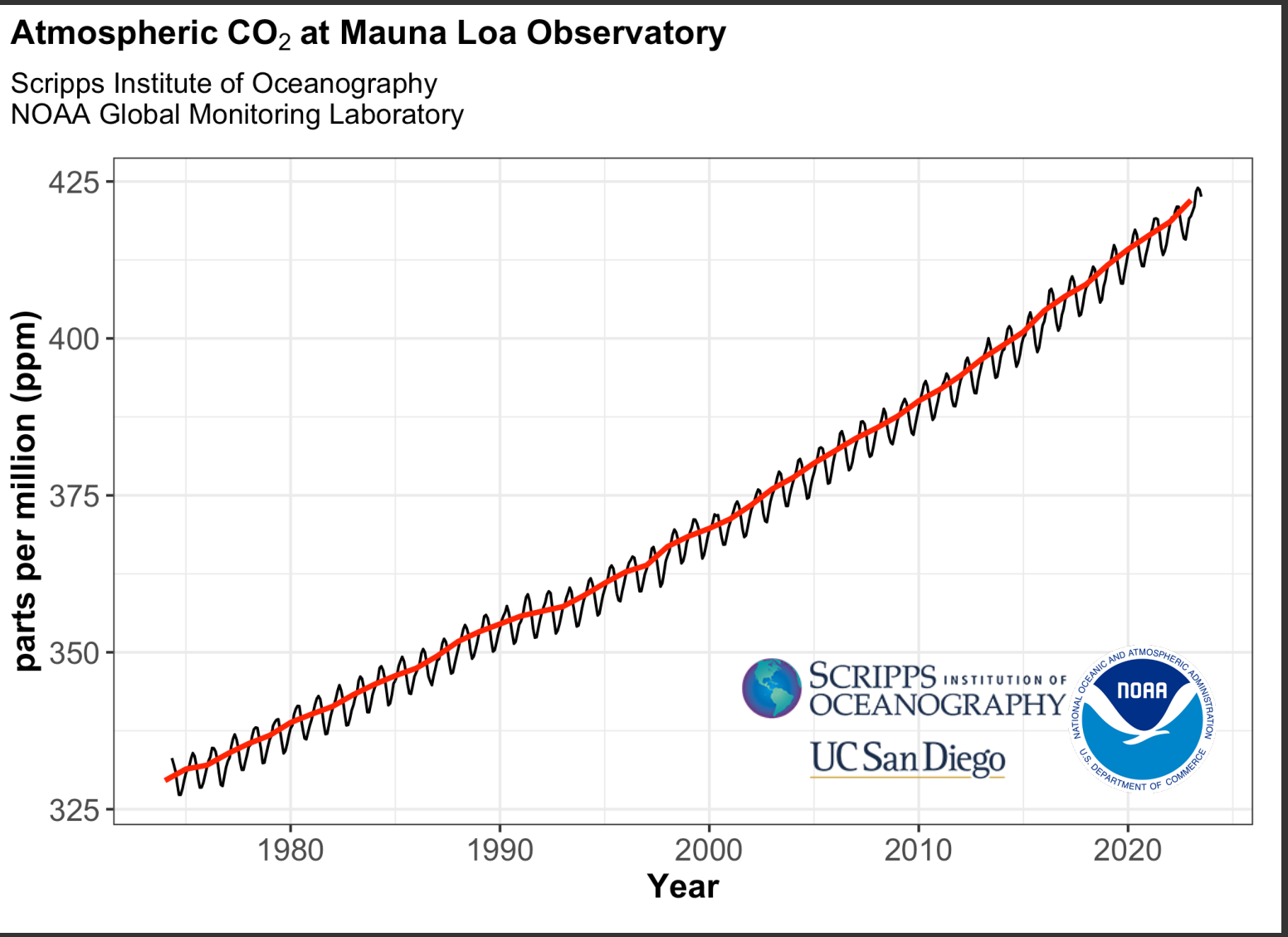
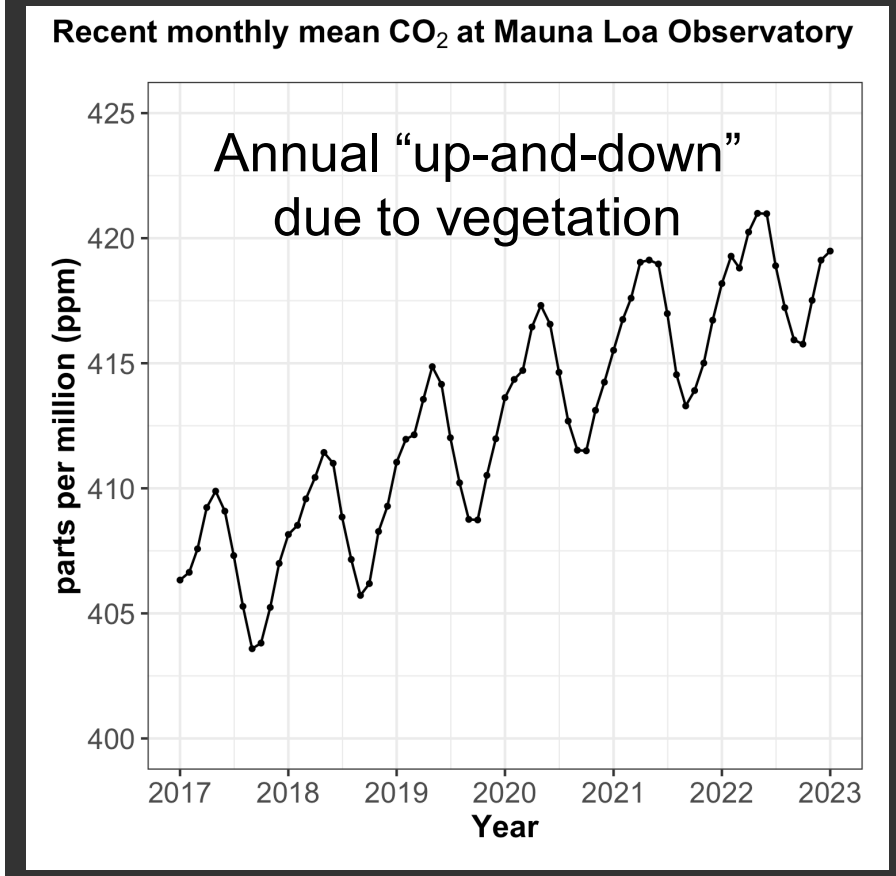
Upward trend due to human activities

Vegetation impacts climate





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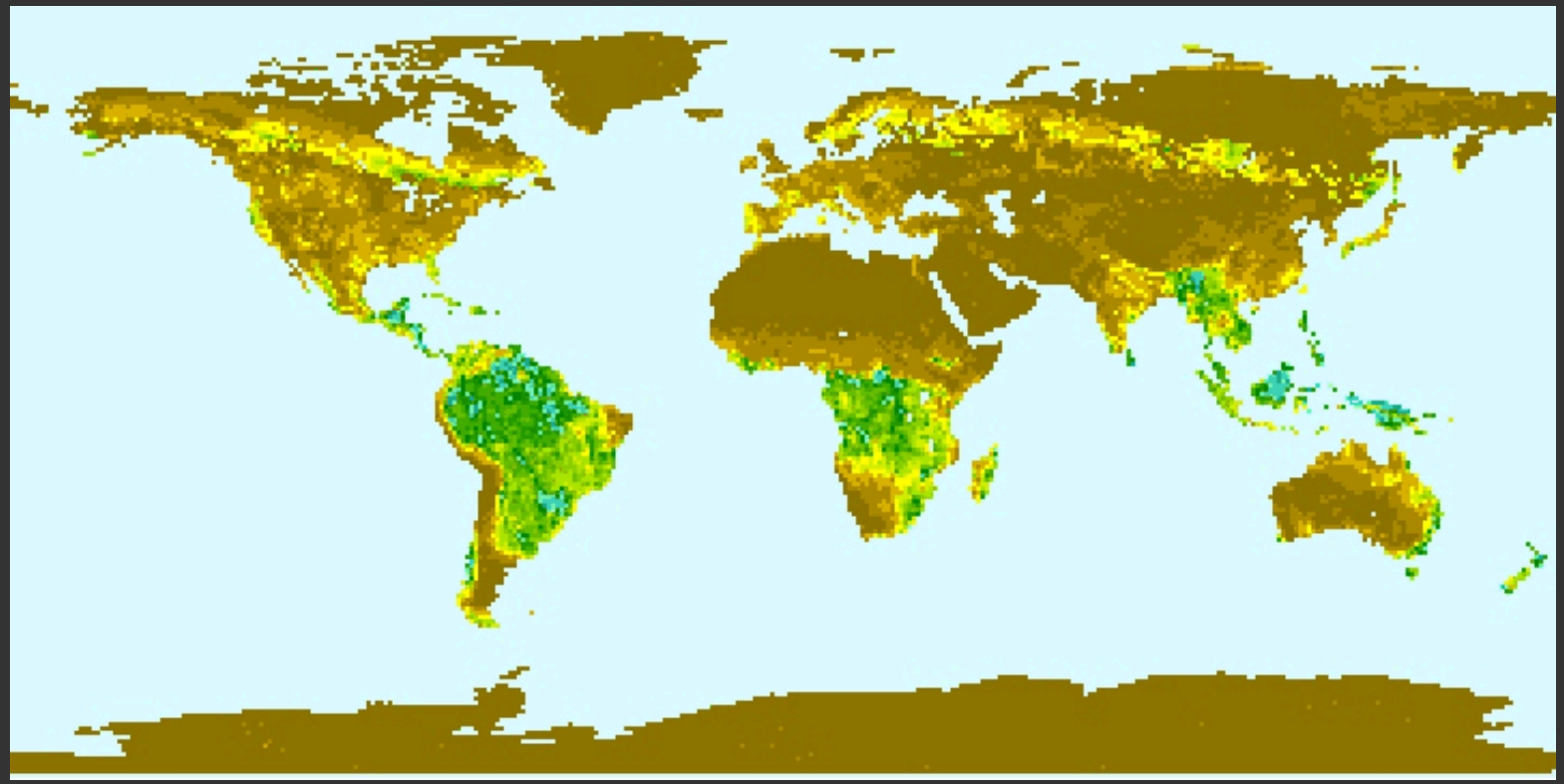
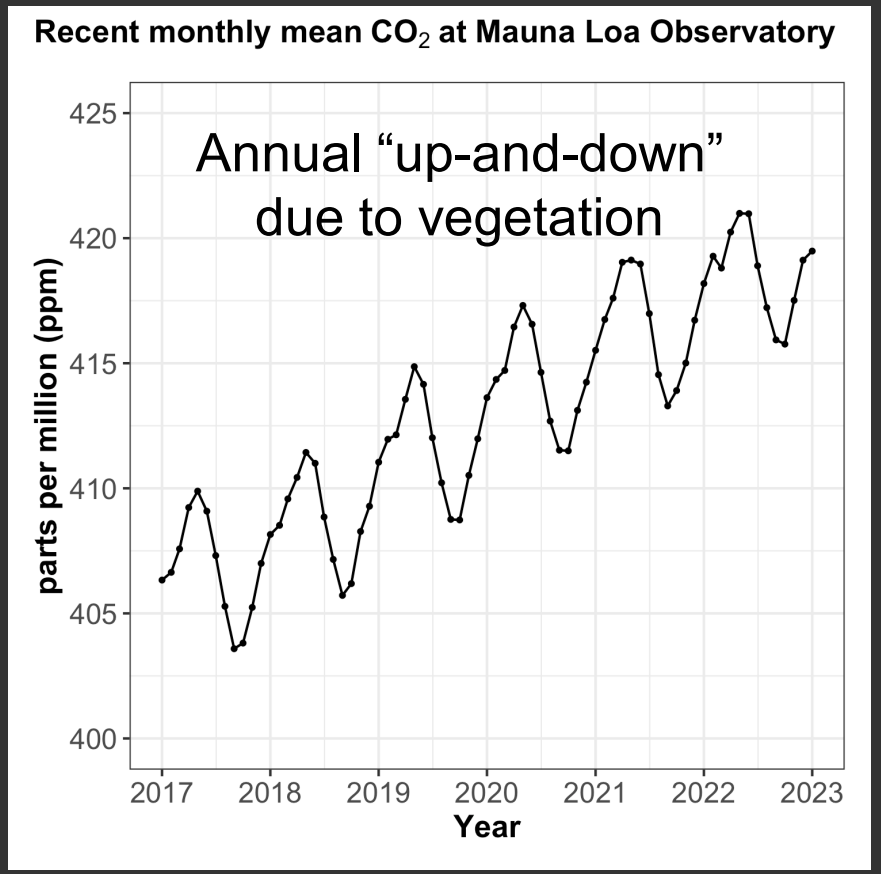
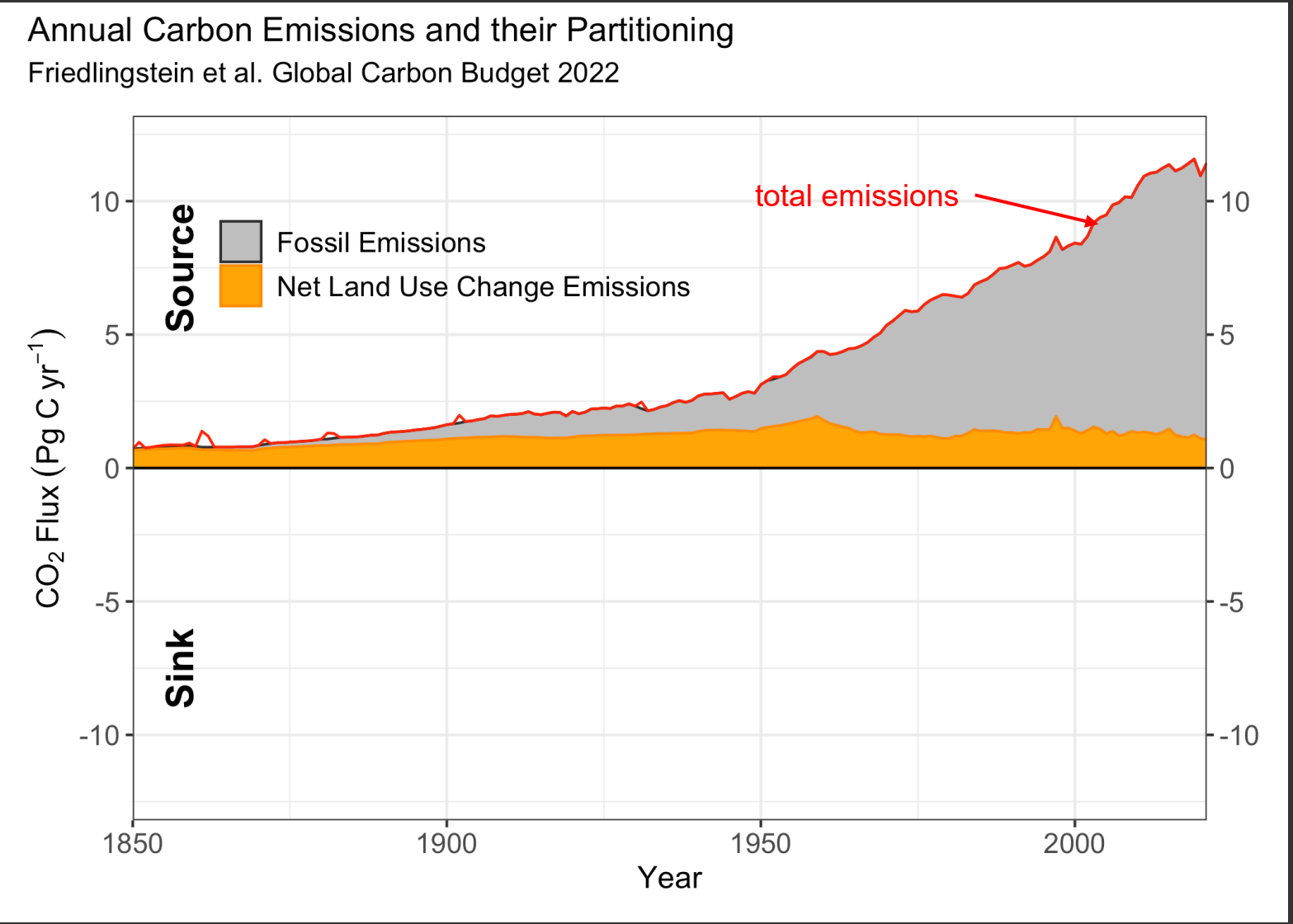
Vegetation impacts climate

MODIS NDVI





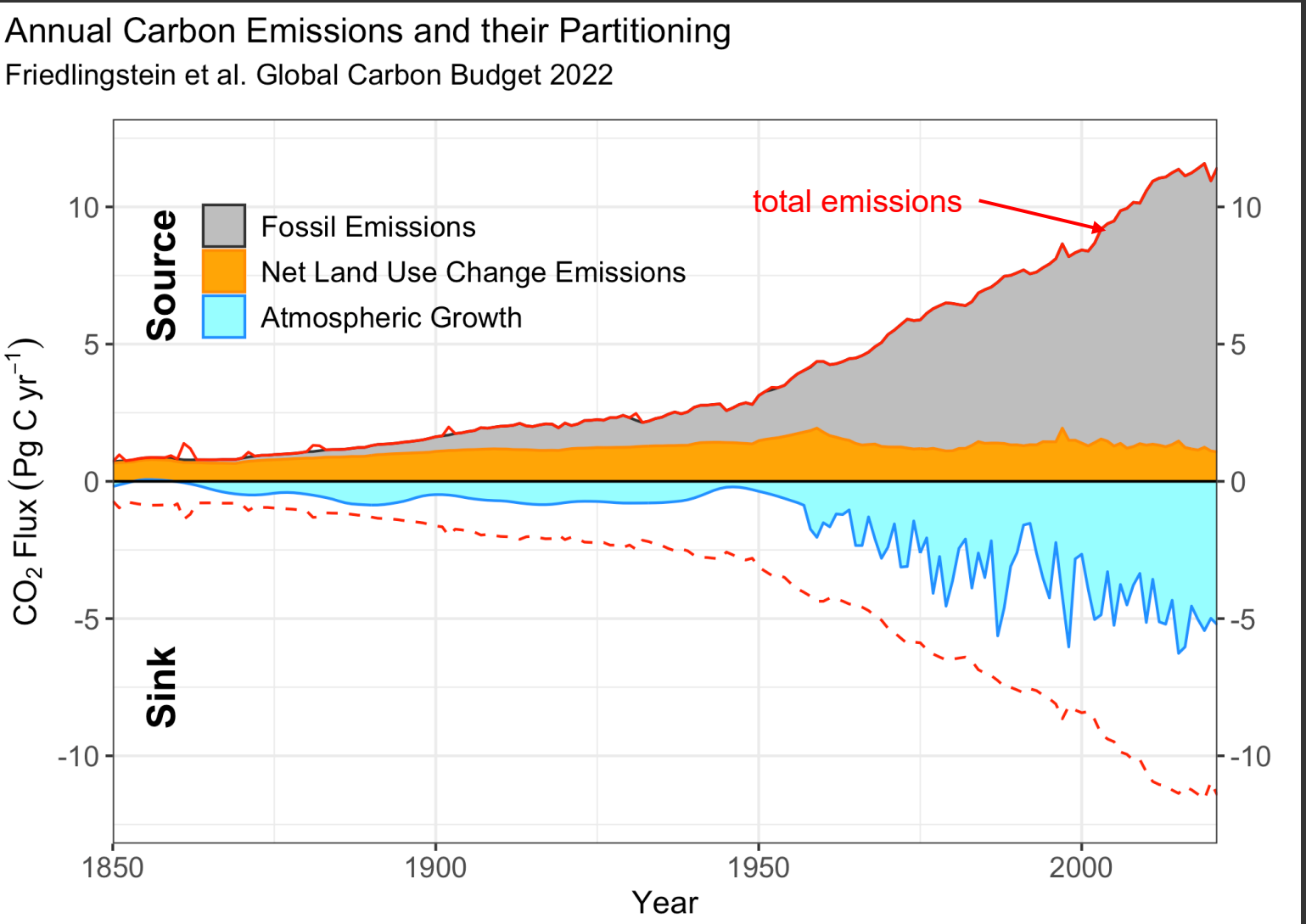
Annual C emissions



Energy statistics and cement production data

Land use and land use change data

Where are these emissions going?



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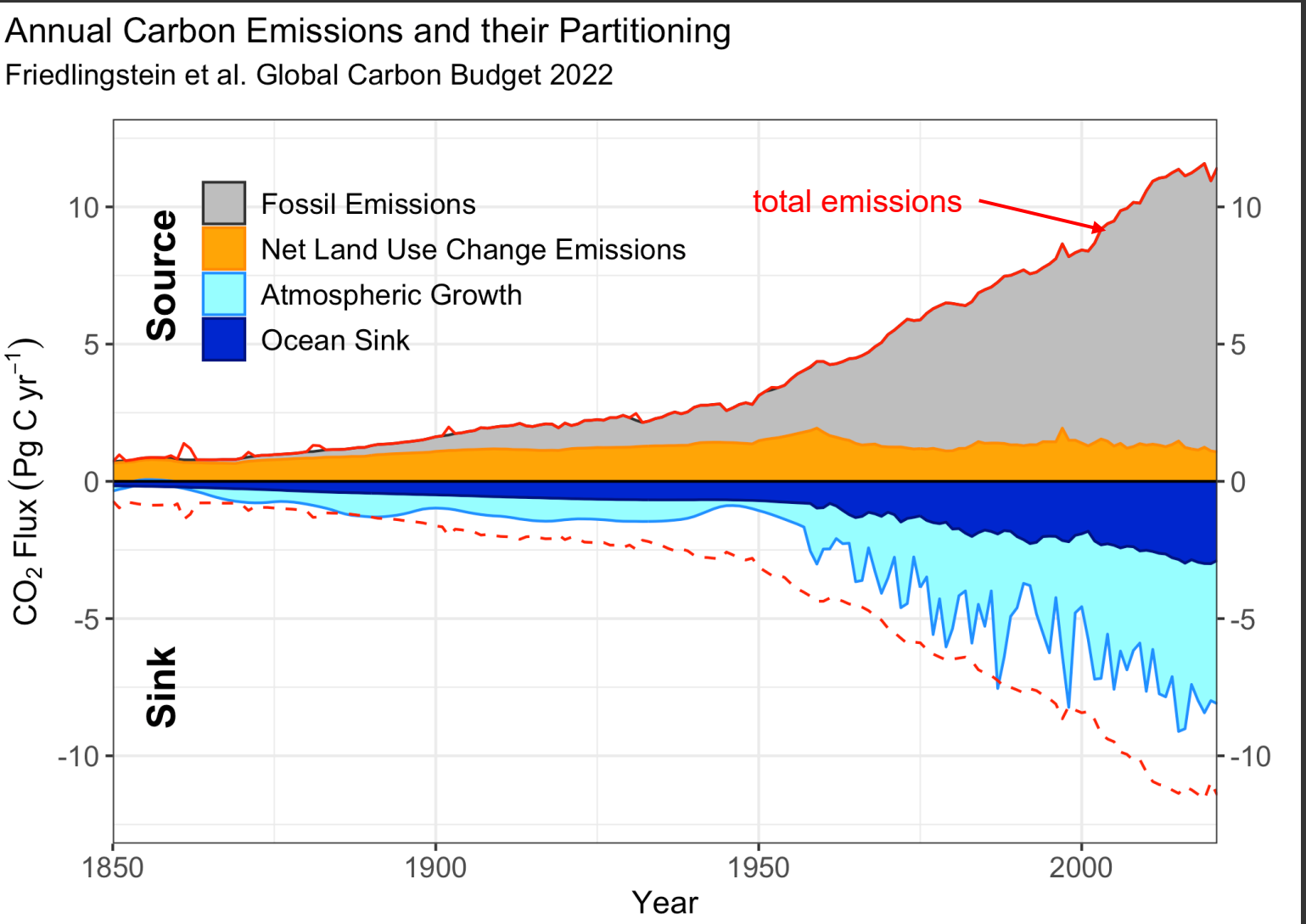

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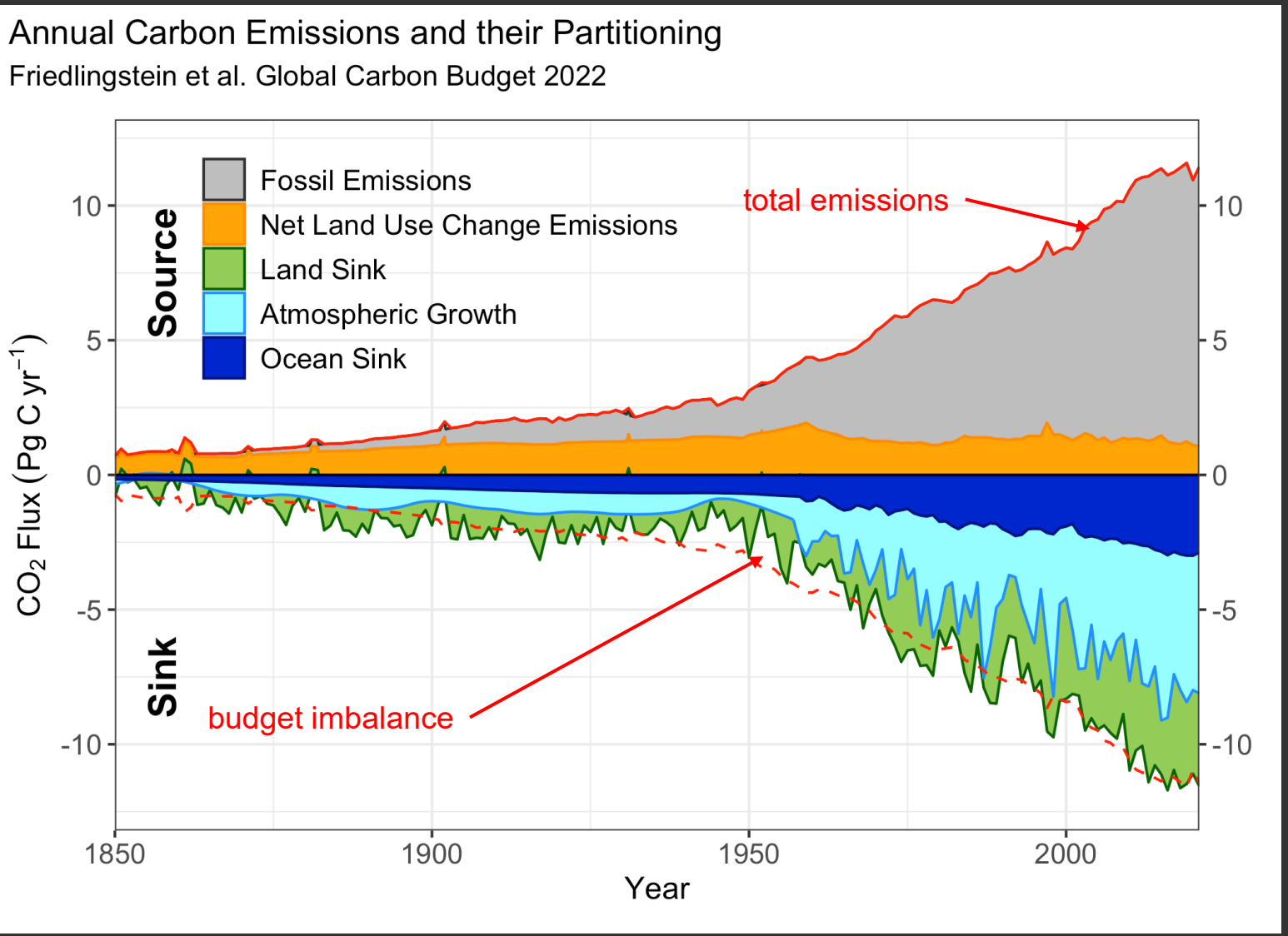

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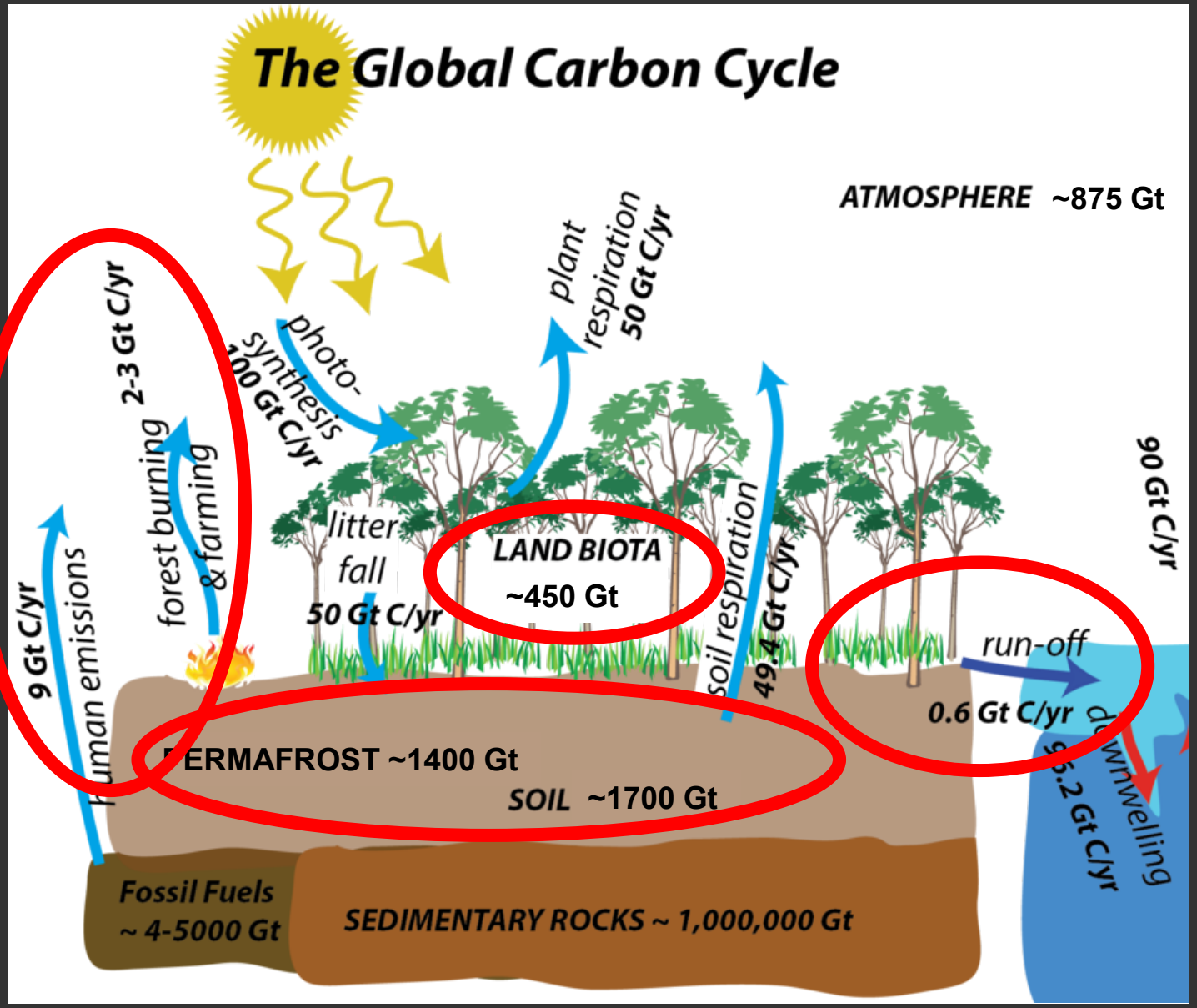
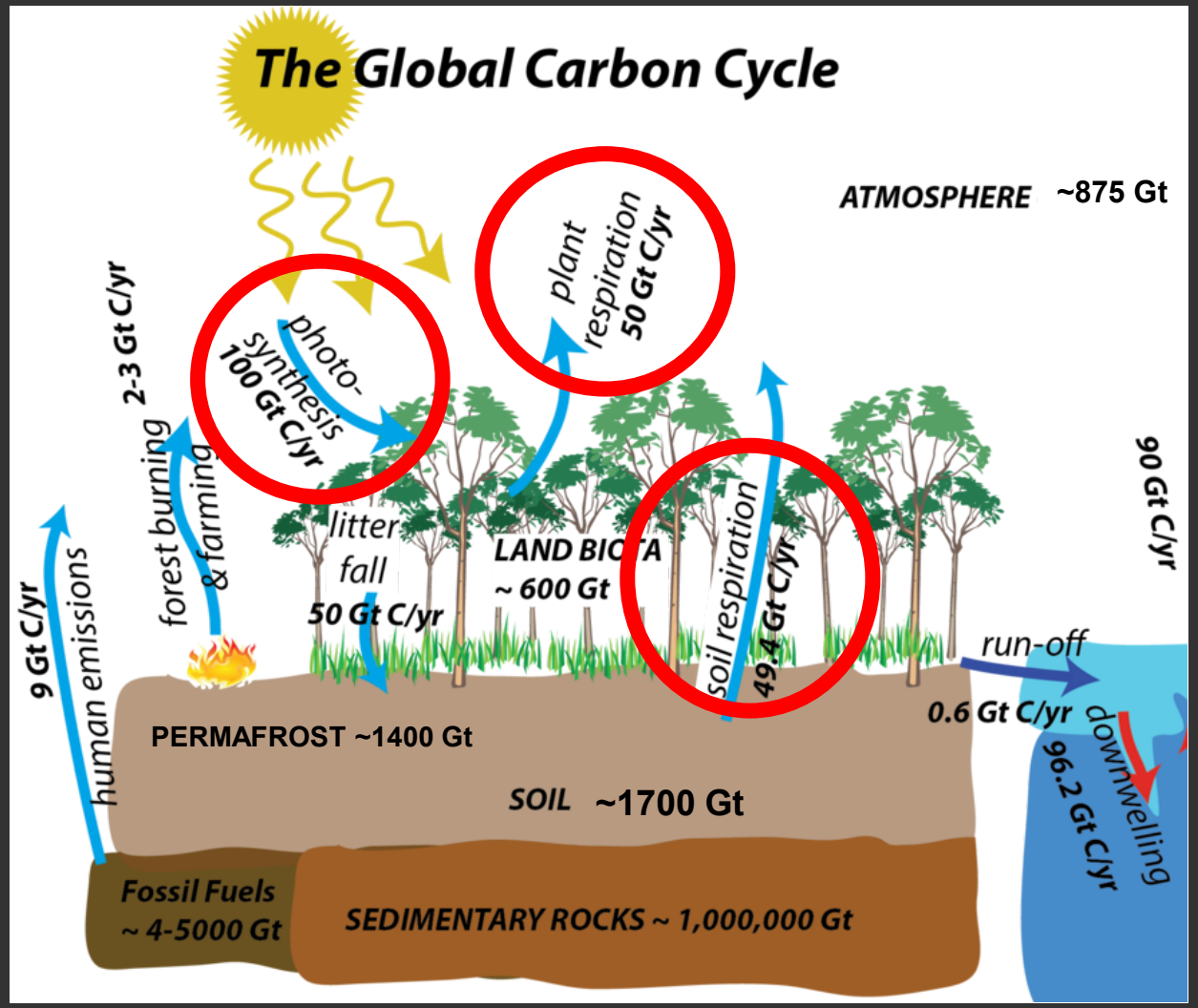
Land sink – global vegetation models



https://serc.carleton.edu/integrate/teaching_materials/earth_modeling/student_materials/unit9_article1.html

Huge pools
Large fluxes
Sink = small residual



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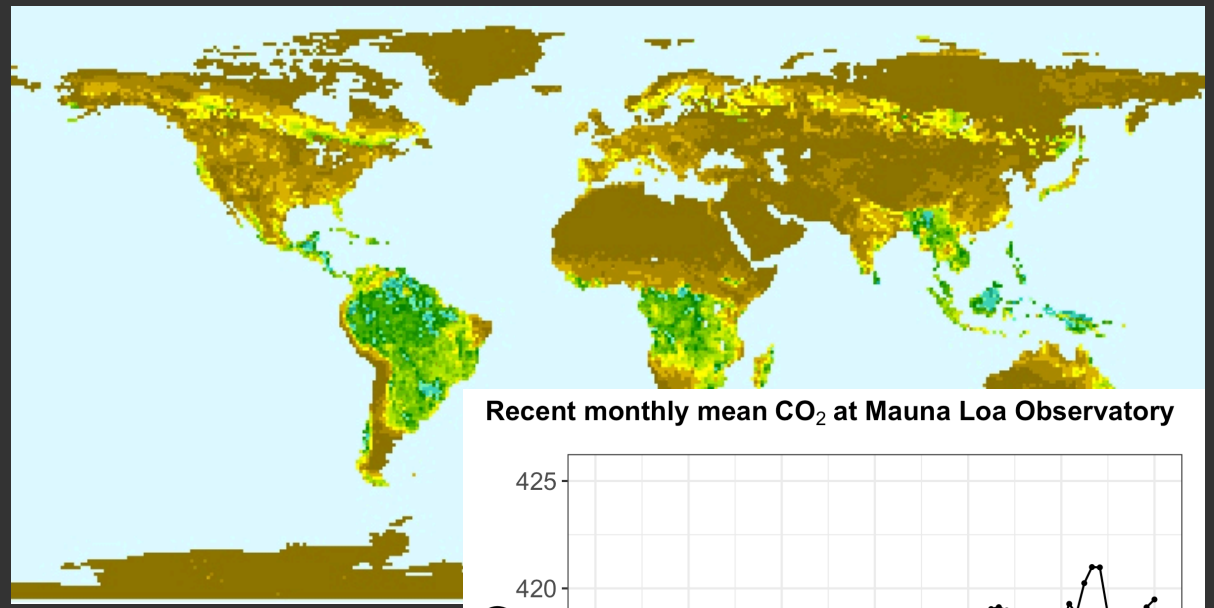
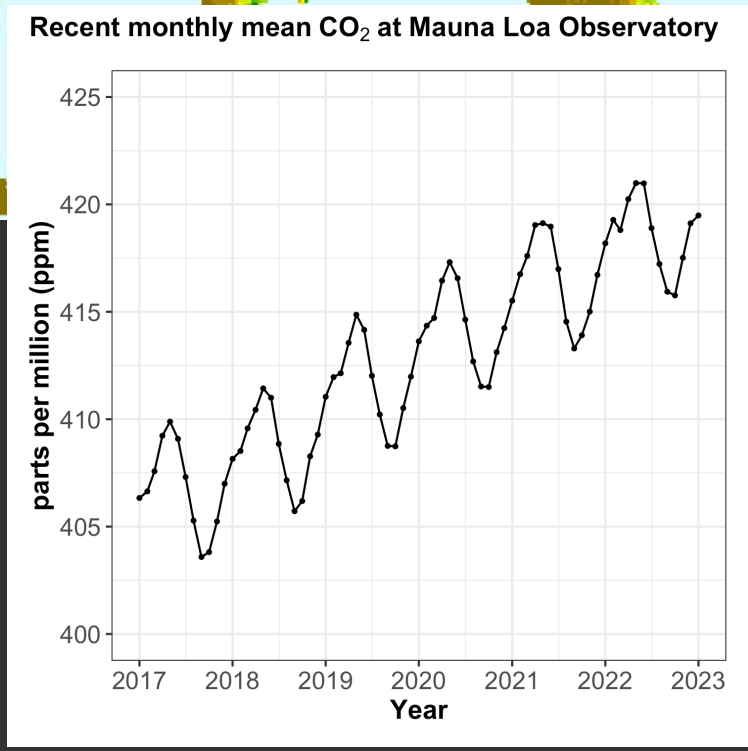
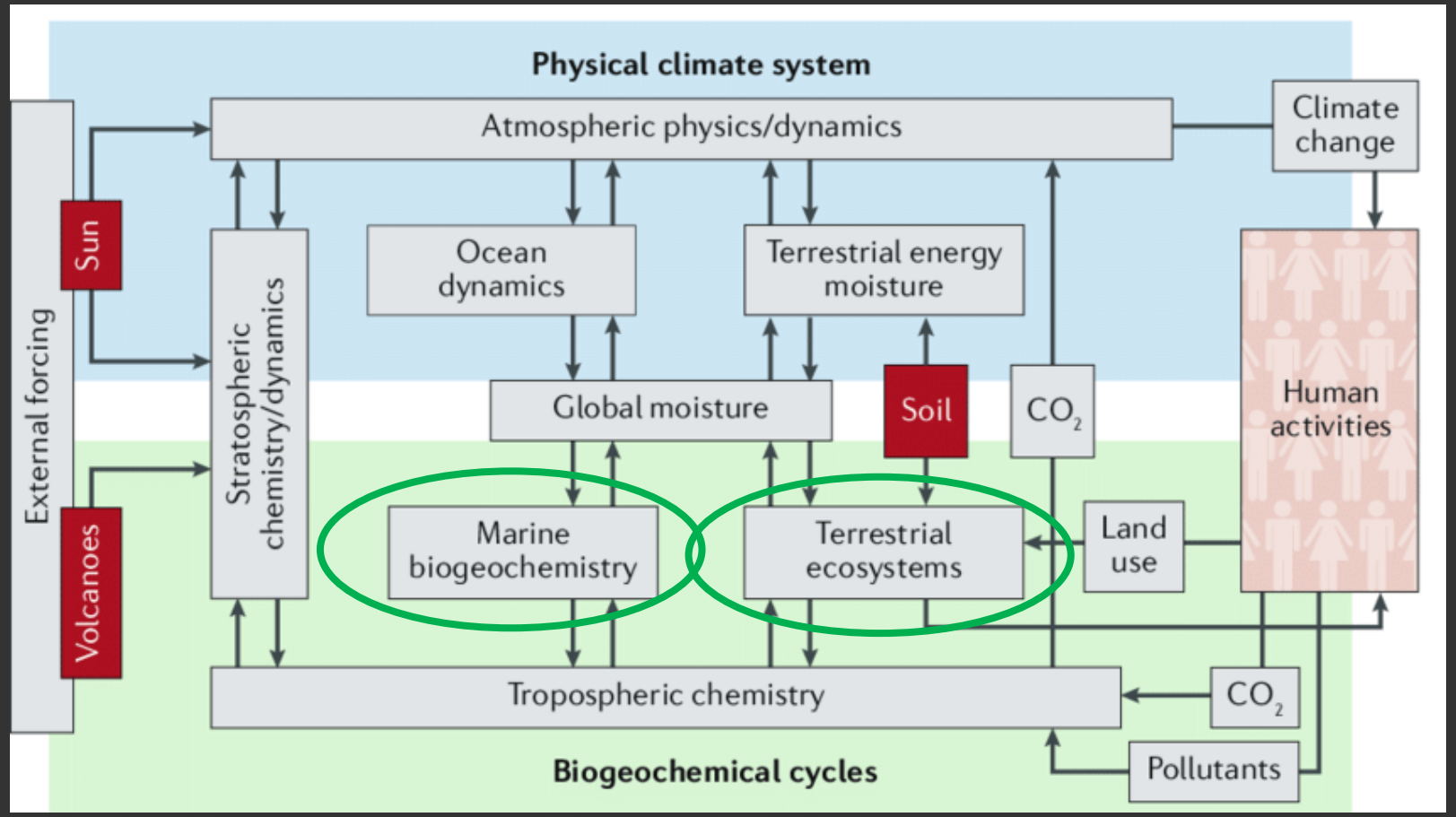




Land biogeochemistry in CESM

Why?

How?



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

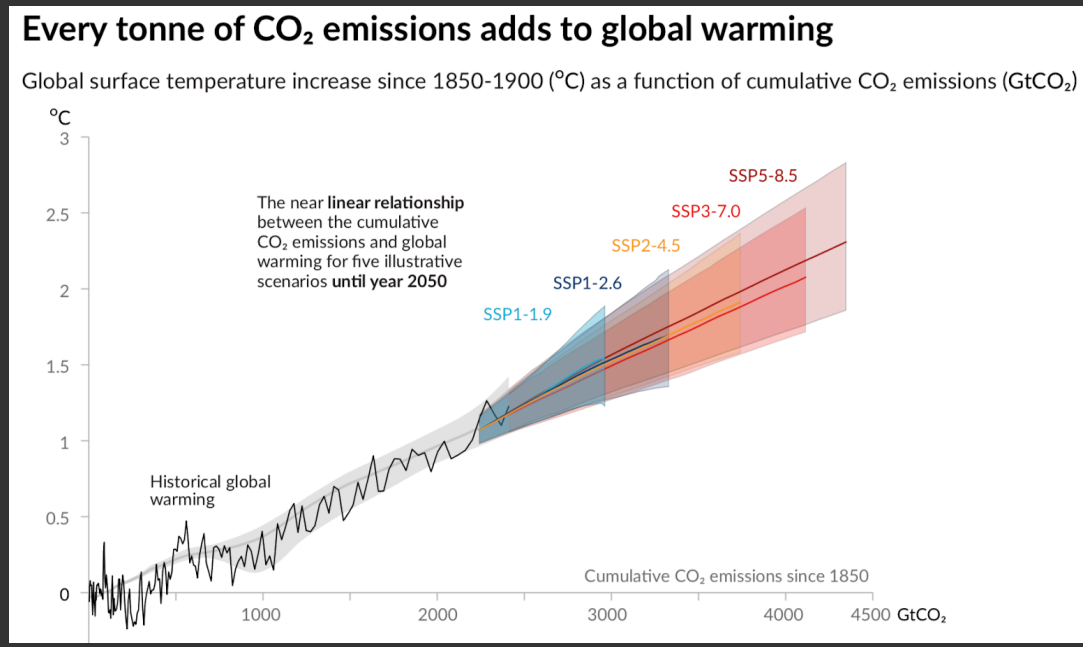
Full-Form Earth System Models: Coupled Carbon-Climate Interaction Experiment (the "Flying Leap")

by Inez Fung, Peter Rayner, and Pierre Friedlingstein; Edited by Dork Sahagian

IGBP Newsletter, May 2000. The flying leap proposal was to make atmospheric CO2 a prognostic variable in climate models

A. Swann, BGCWG

NCAR and CESM were key players in the development of the concept and creation of the first coupled carbon cycle models.



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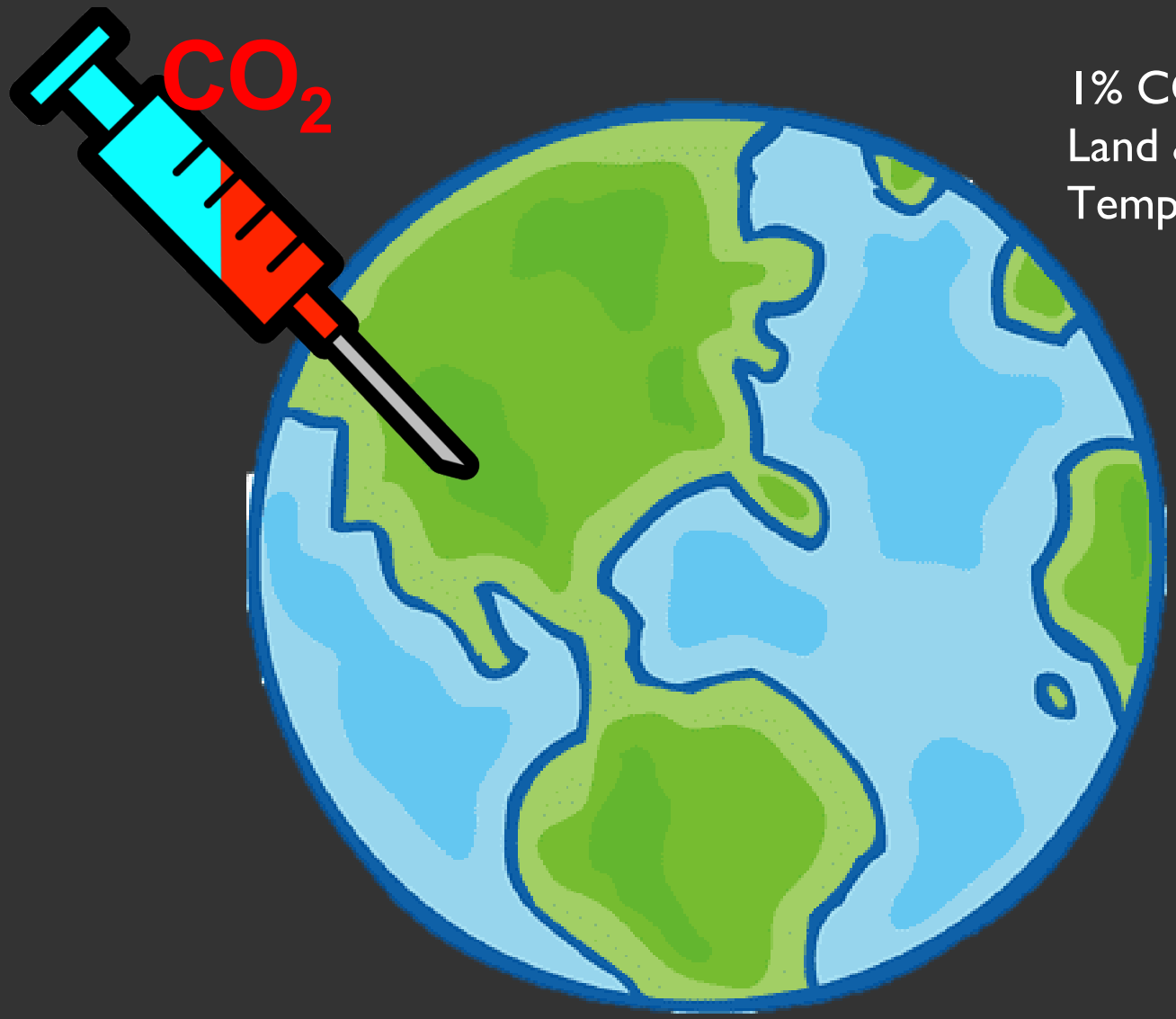
NCAR and CESM were key players in the development of the concept and creation of the first coupled carbon cycle models.
+ Coupled C-N biogeochemistry, CESM1
+ Explicit crop management, CESM2

Idealized experiments

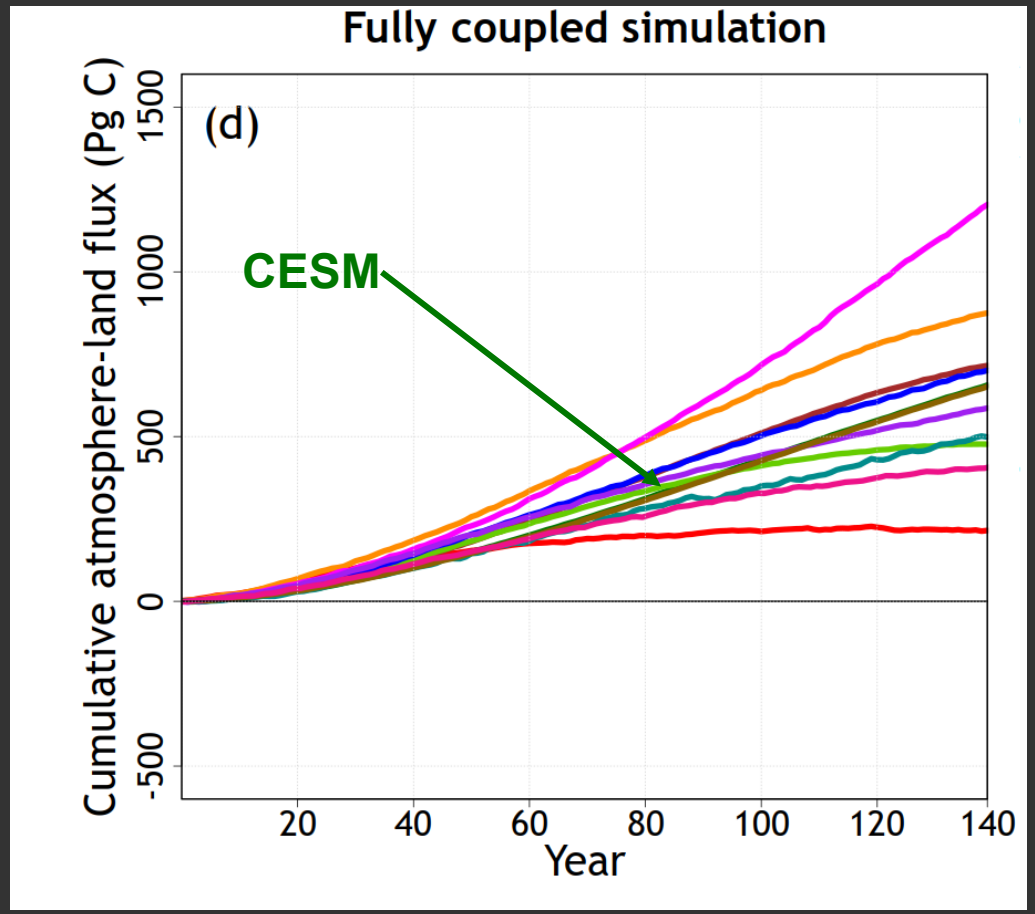


1% CO2 / year
Land & Ocean uptake
Temperature change
- Fully coupled
- Biogeochemically coupled
- Radiatively coupled

Arora et al. 2020

Idealized experiments

Cumulative land CO_2 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

Arora et al. 2020

Idealized experiments

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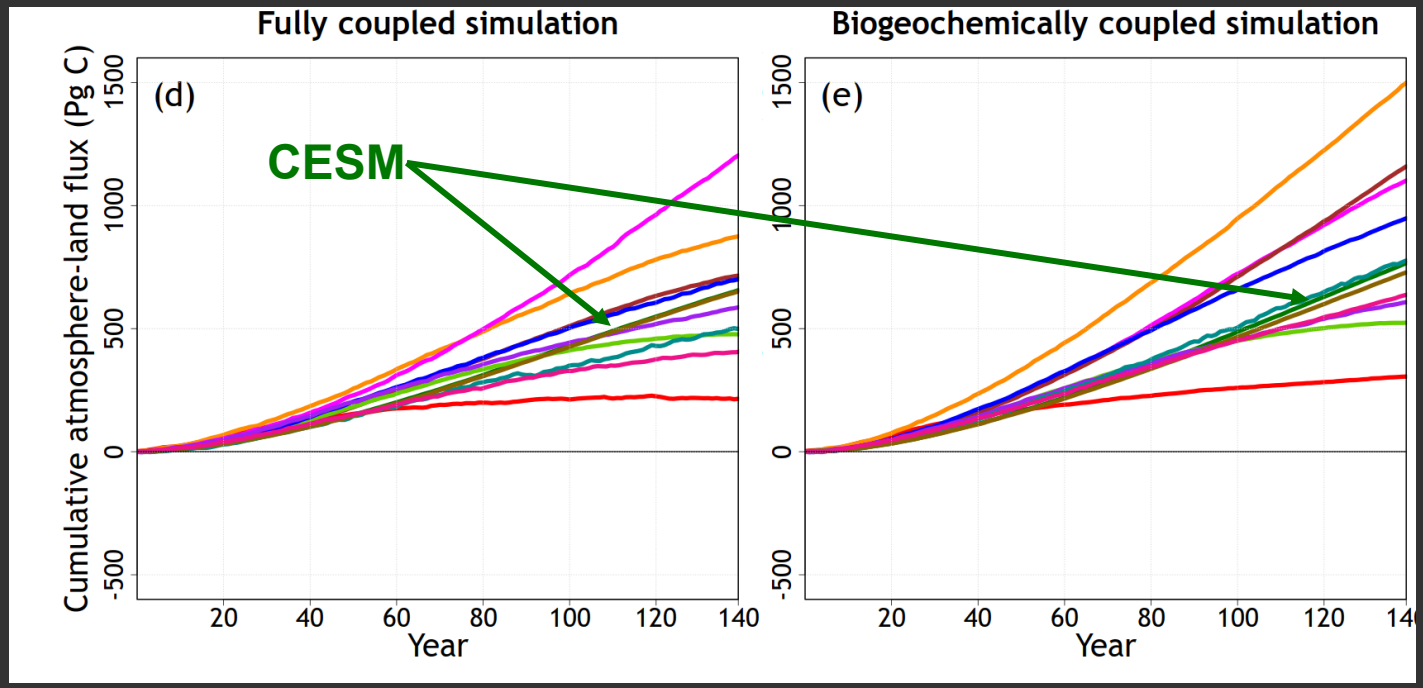

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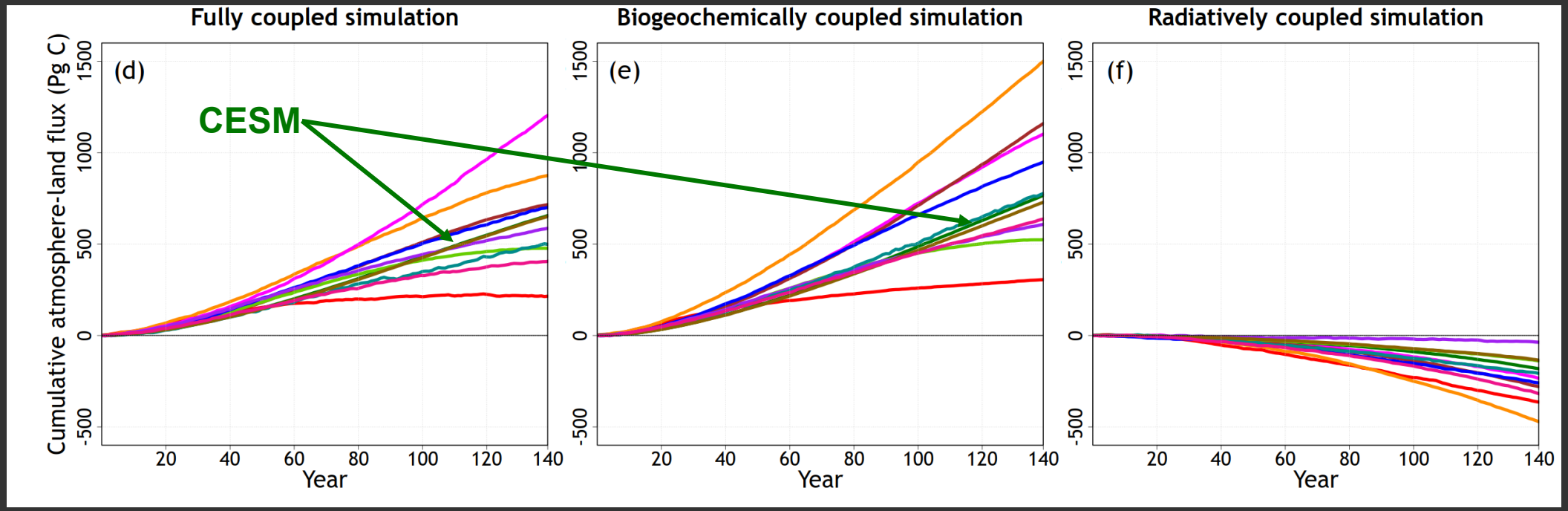
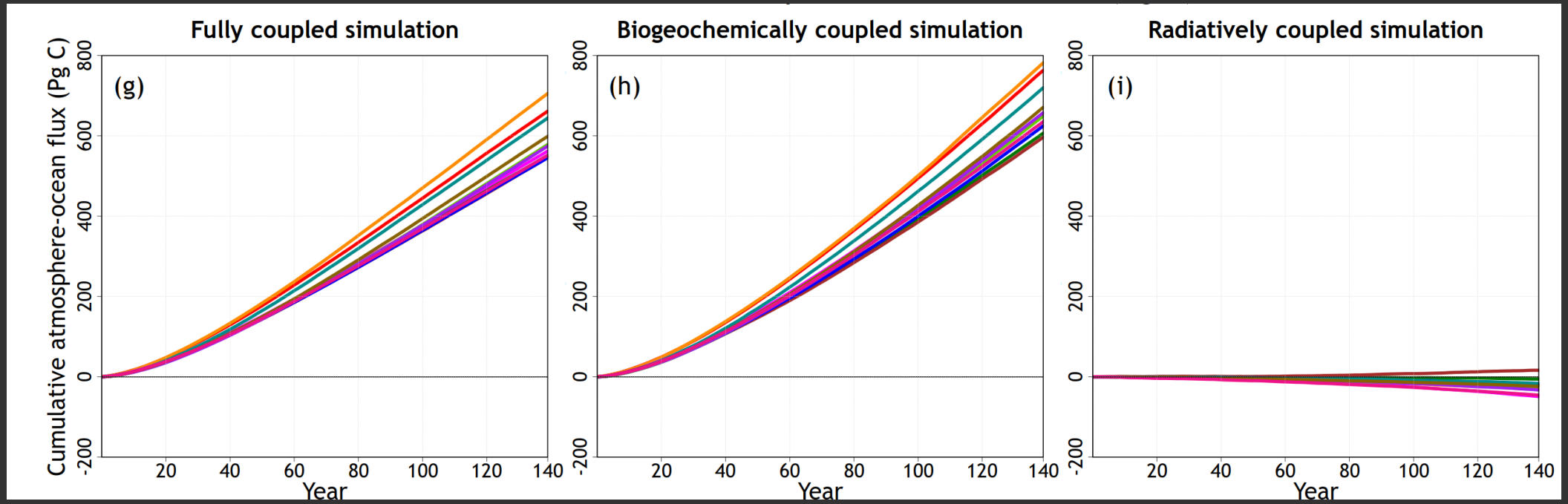


Arora et al. 2020

Idealized experiments

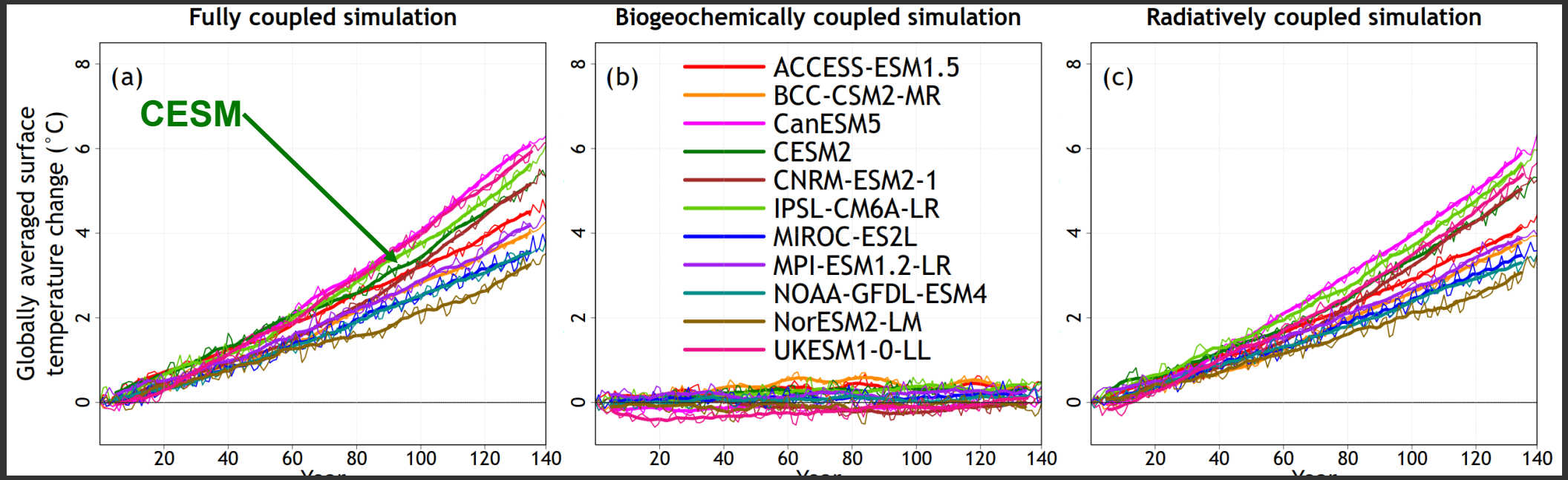
Cumulative ocean CO_2 sink



Arora et al. 2020

Idealized experiments

Global average surface temperature change (ºC)



Arora et al. 2020

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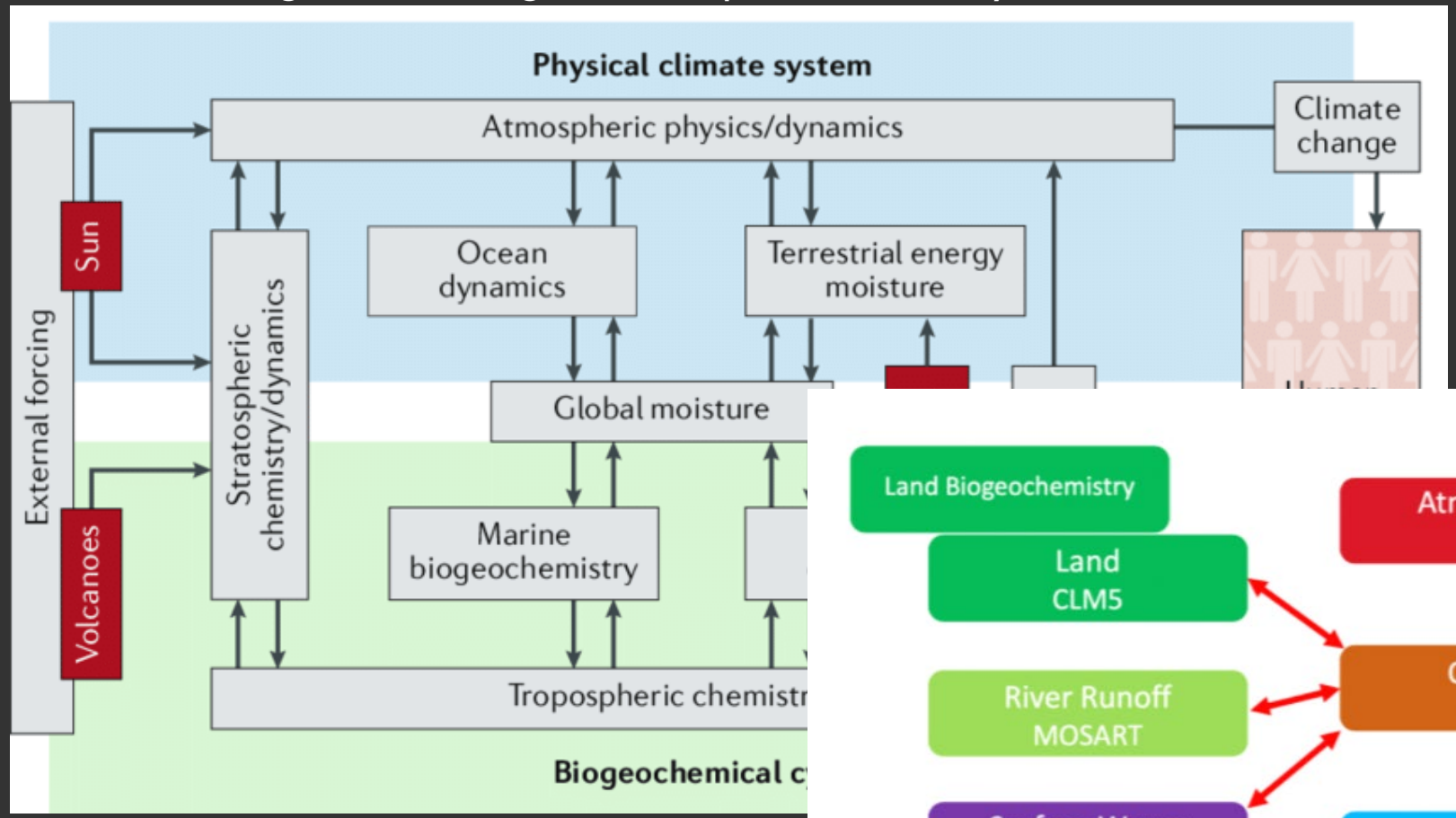
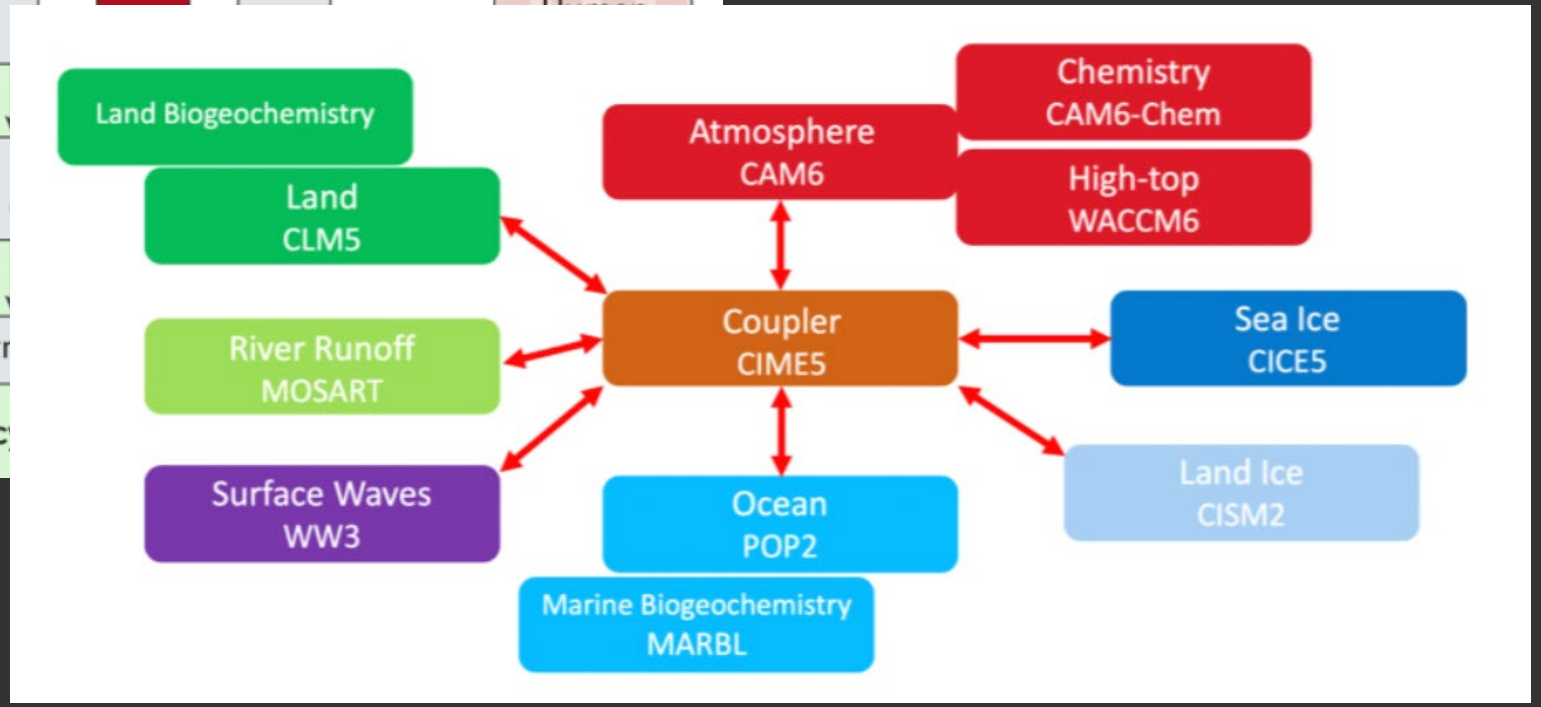
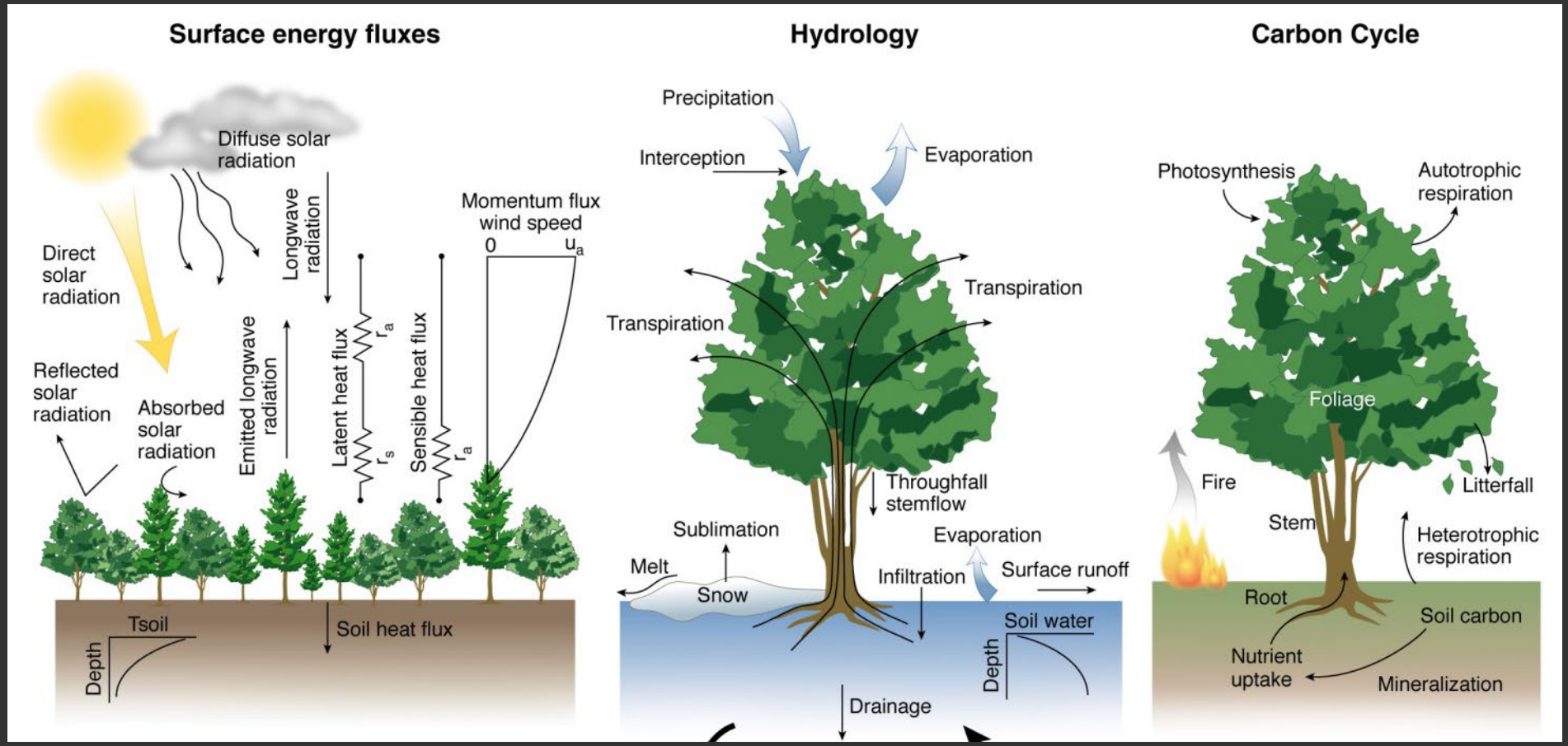
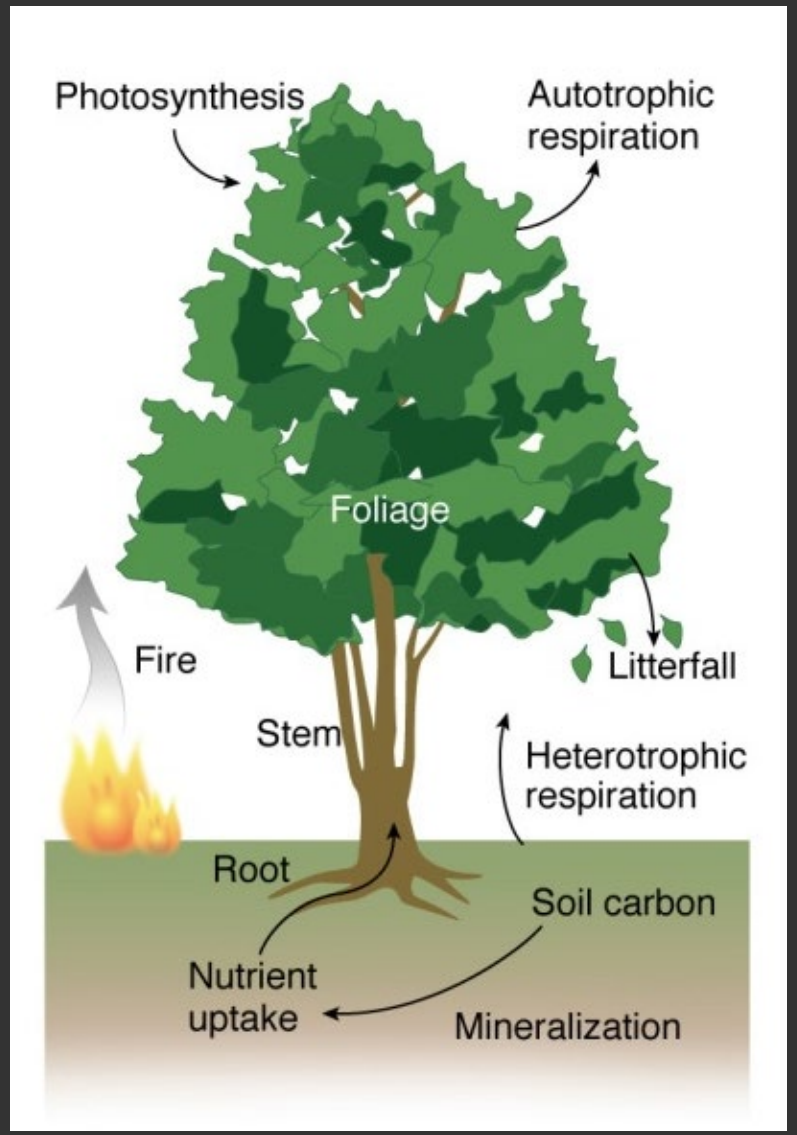




Community LAND MODEL DEVELOPM



Bonan 2008, Science



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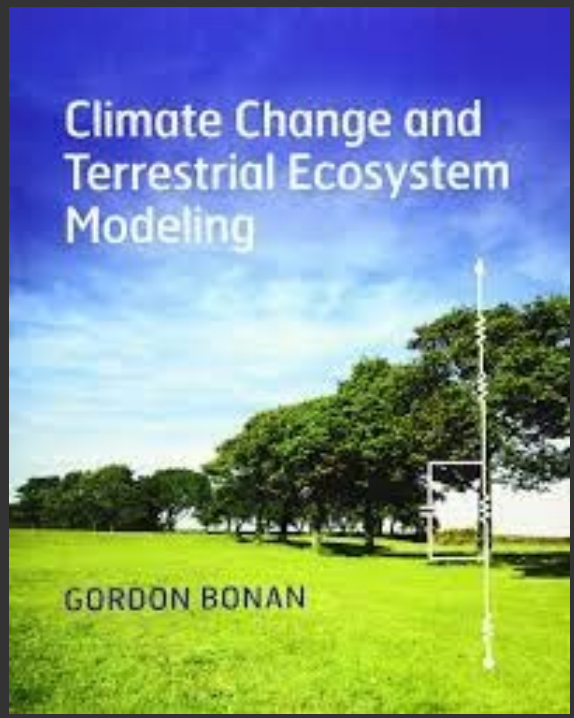
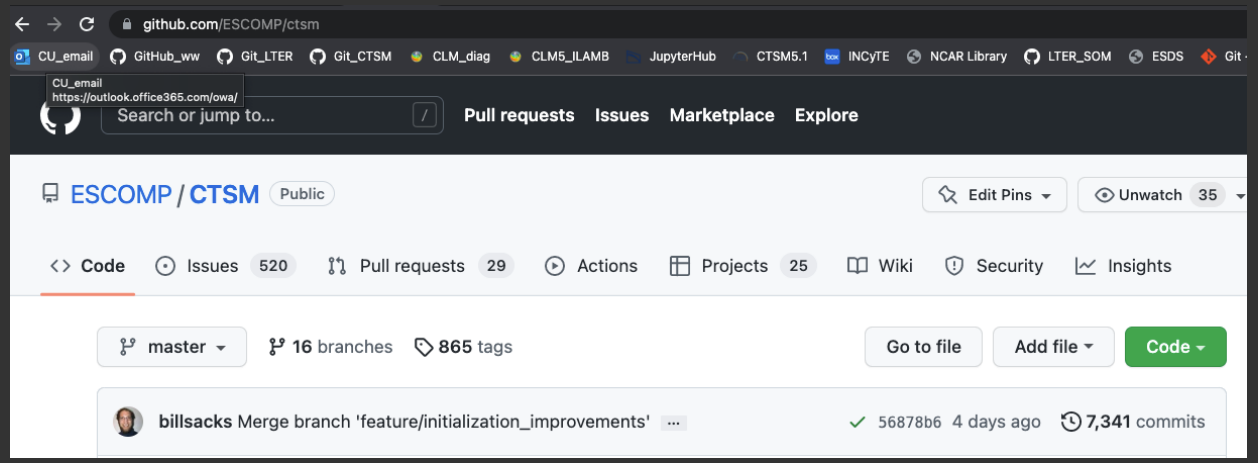
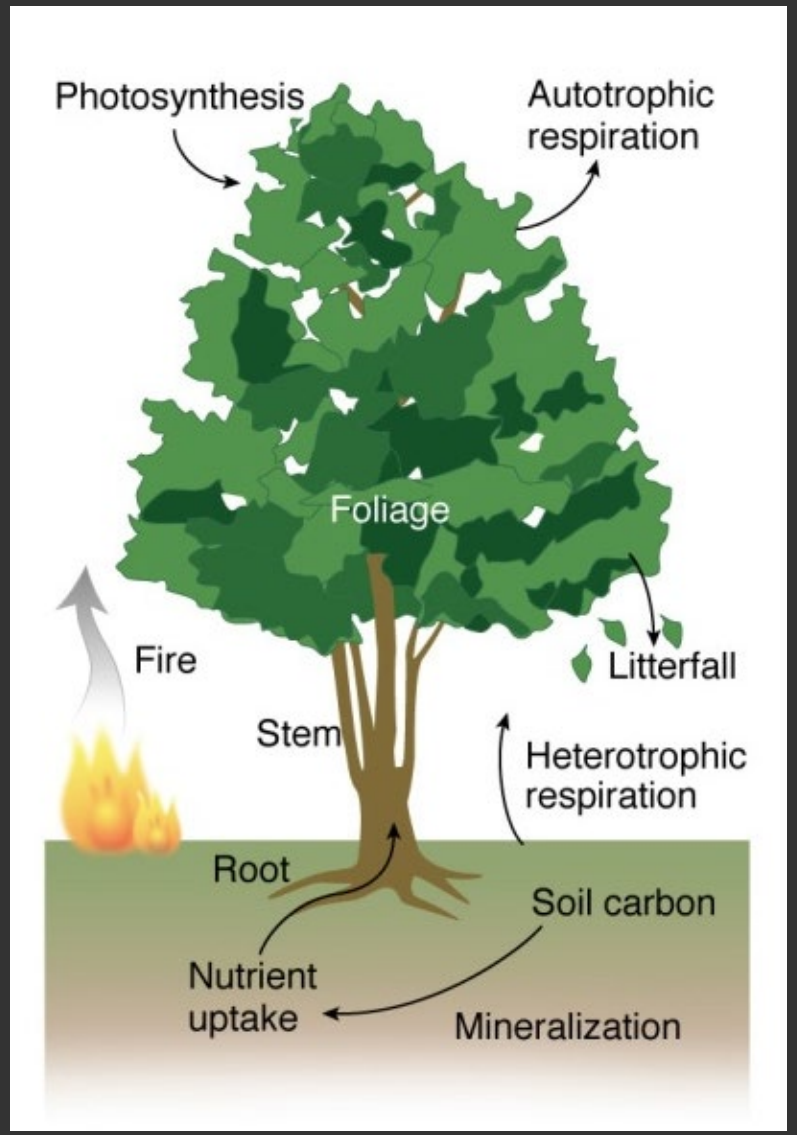




https://github.com/ESCOMP/ctsm



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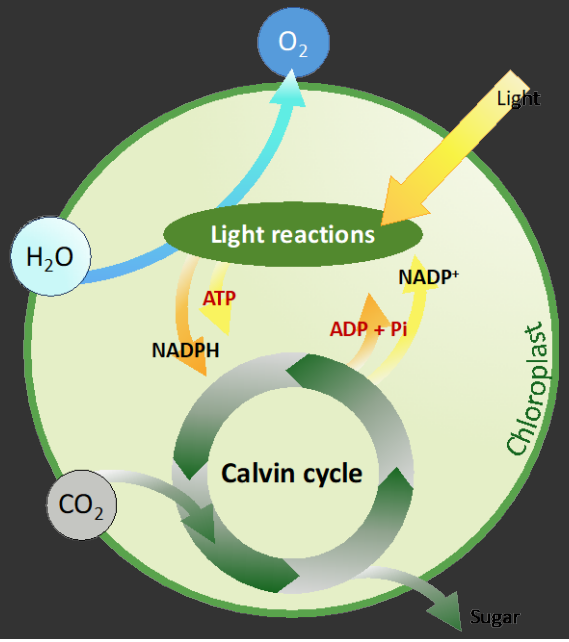
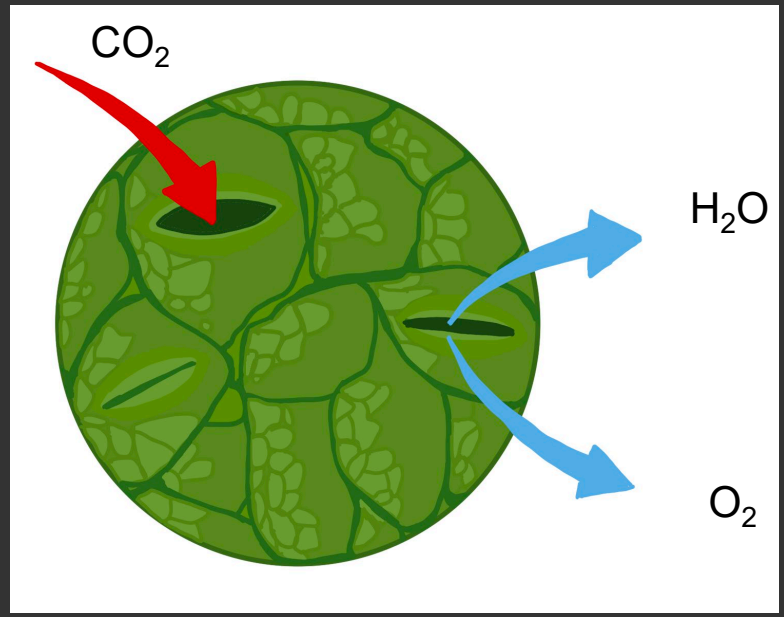
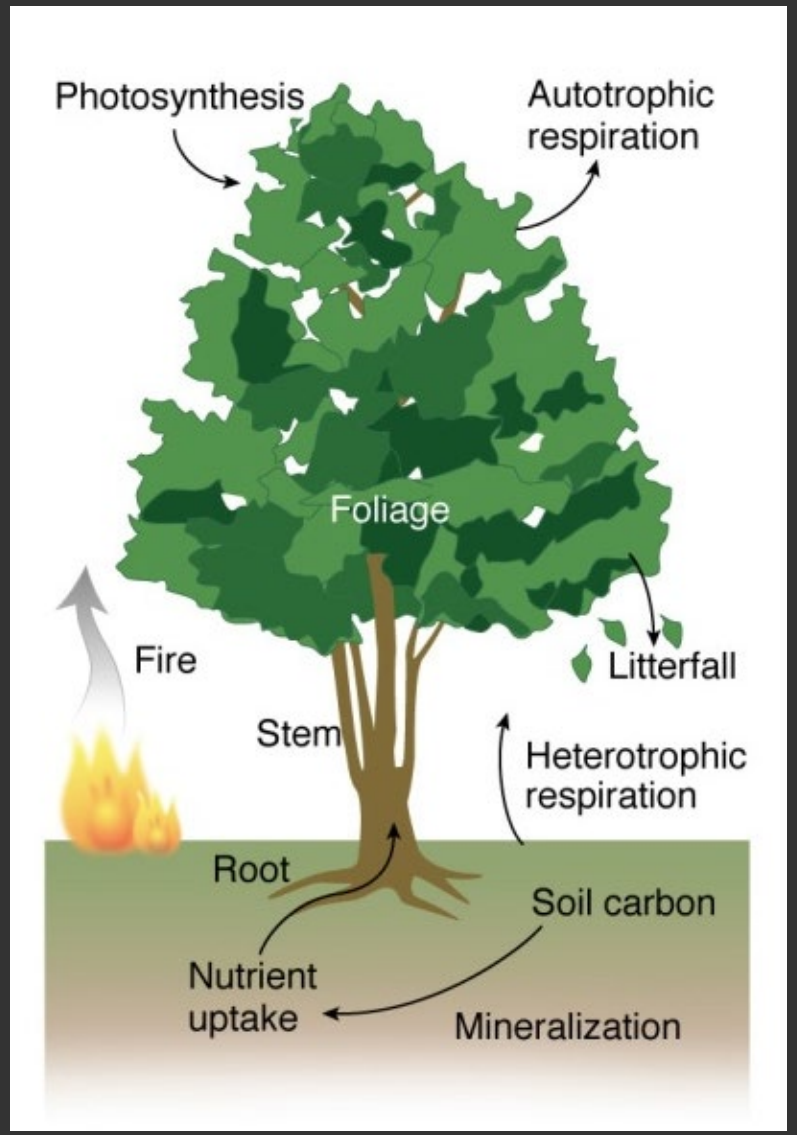
Leaves

Farquhar Photosynthesis

Medlyn Stomatal Conductance







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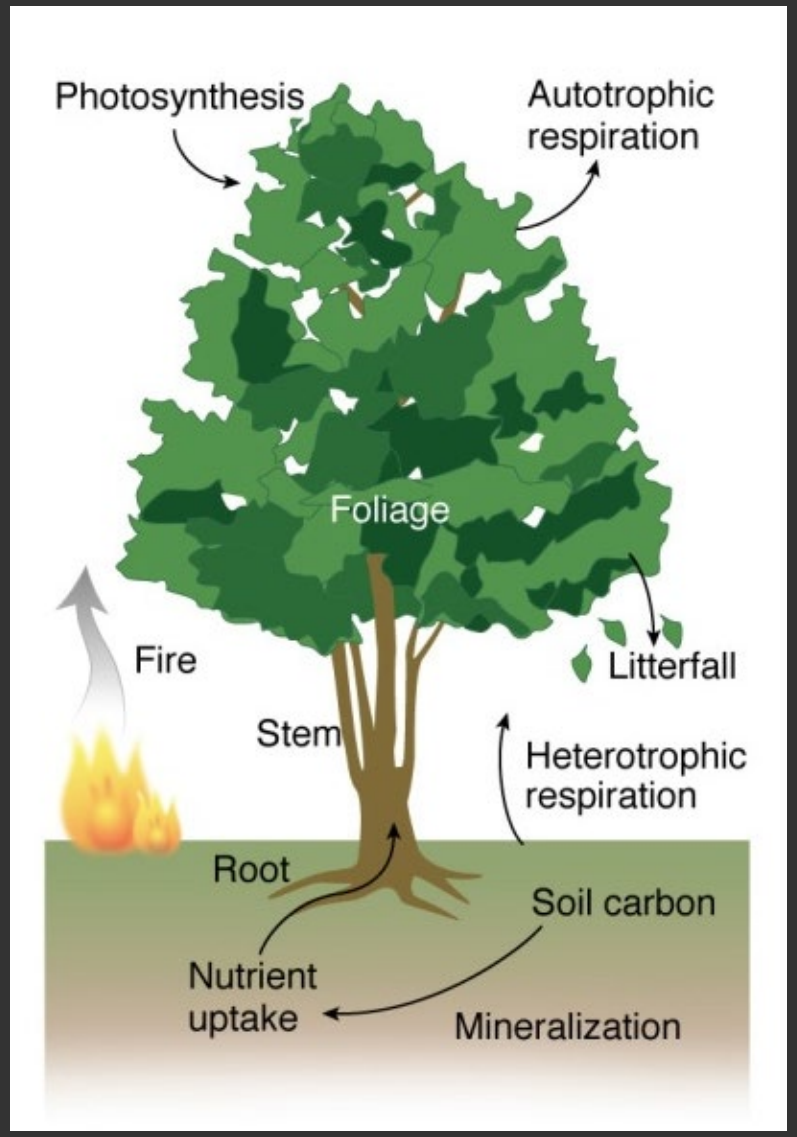
Leaves
- Farquhar Photosynthesis
- Medlyn Stomatal Conductance

Canopy
- Two stream approximation, sunlit / shaded

GPP - Gross Primary Productivity



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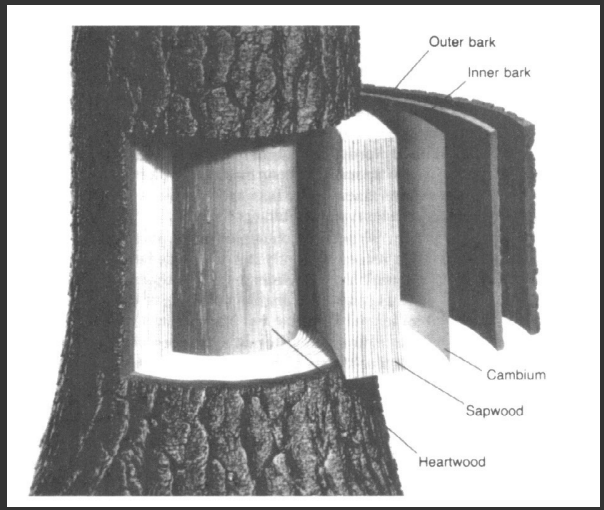
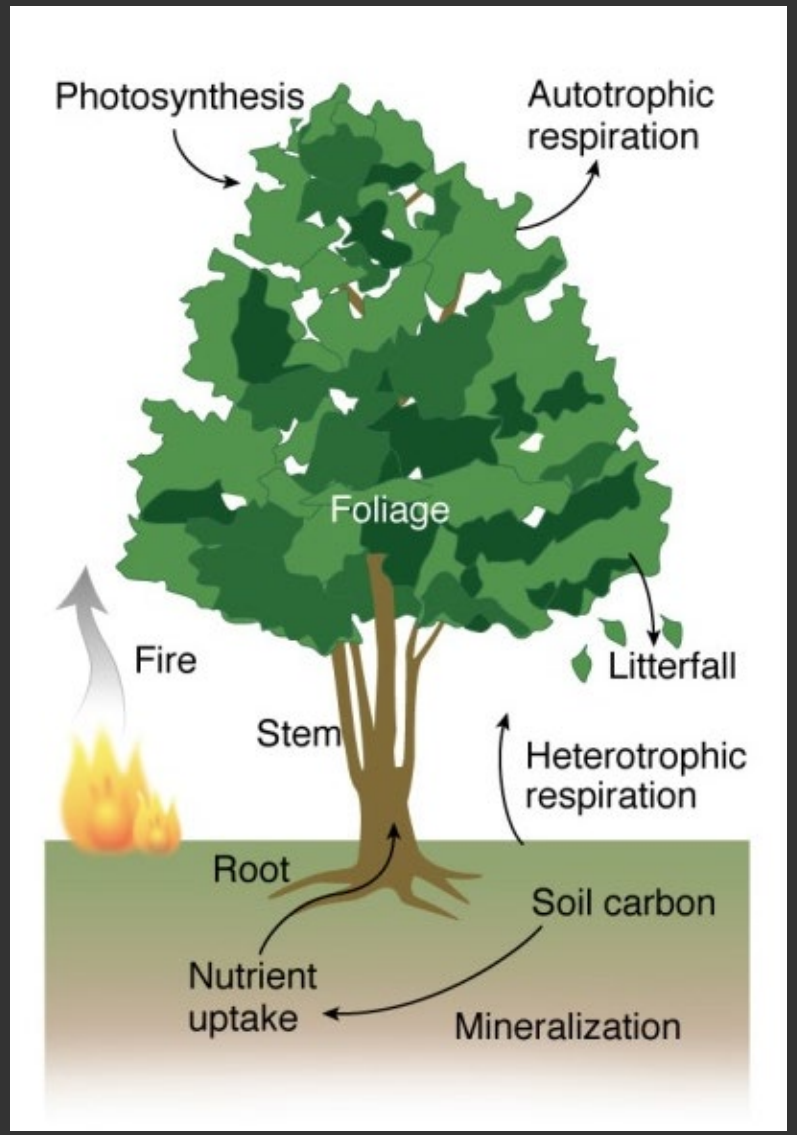
Canopy
- Two stream approximation, sunlit / shaded

Allocation
- Respiration, leaves, wood, roots

AR – Autotrophic Respiration
NPP – Net primary production = GPP - AR





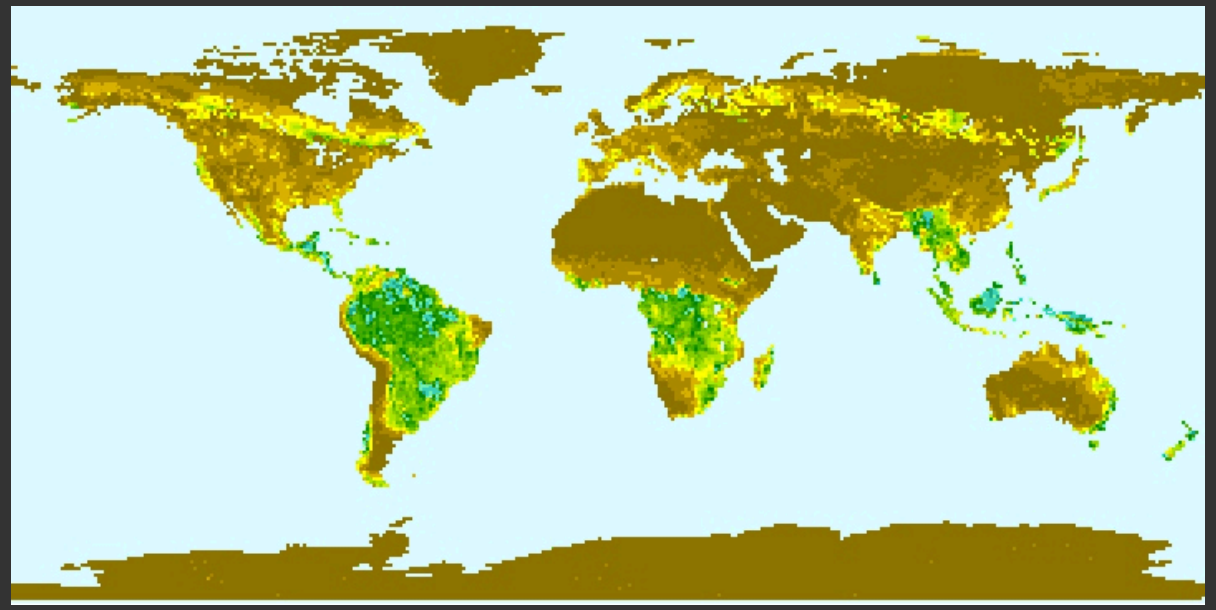
Bonan 2008, Science

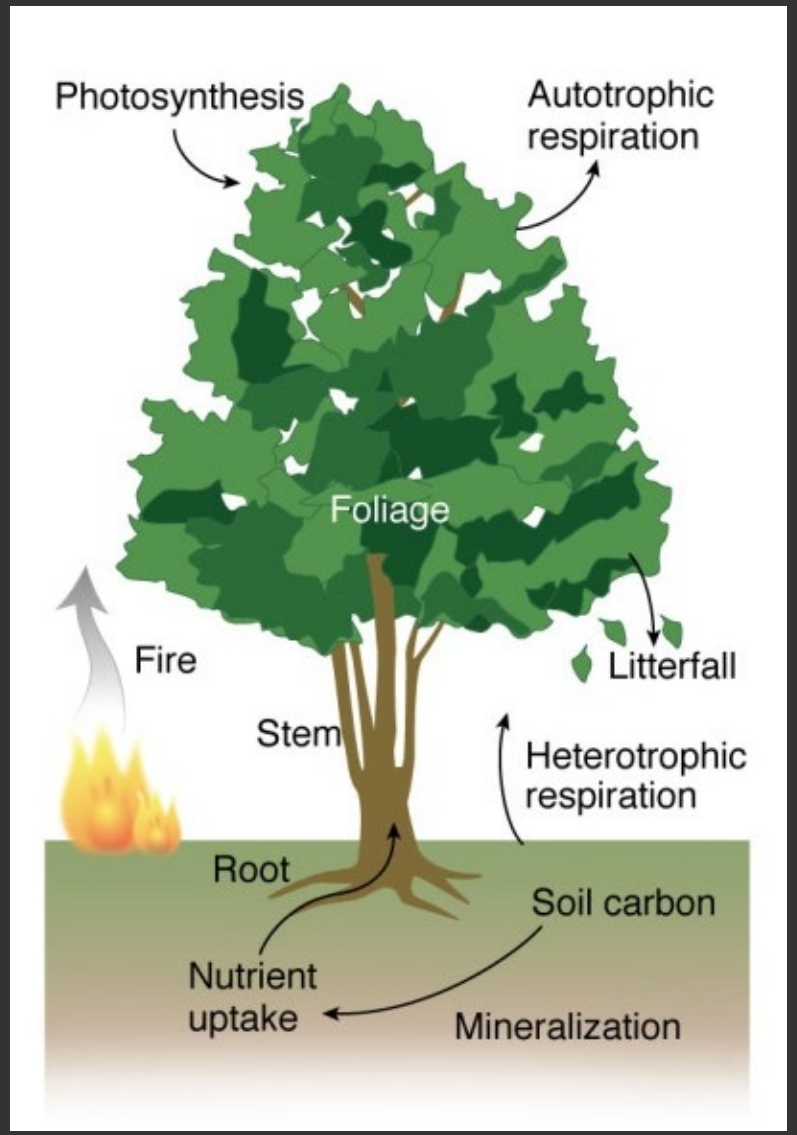
Phenology

mortality and turnover

(e.g., evergreen, drought or stress deciduous)

ELAI – Leaf Area Index





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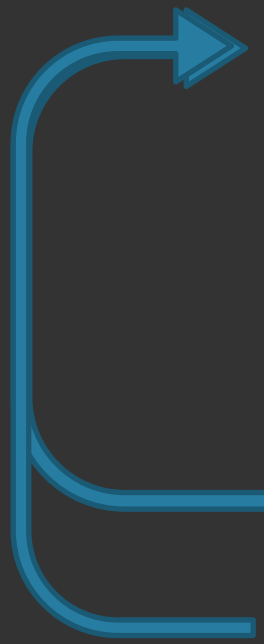
Decomposition

HR – Heterotrophic respiration



GPP - Gross Primary Productivity

AR – Autotrophic respiration

NPP – Net primary productivity = GPP - AR

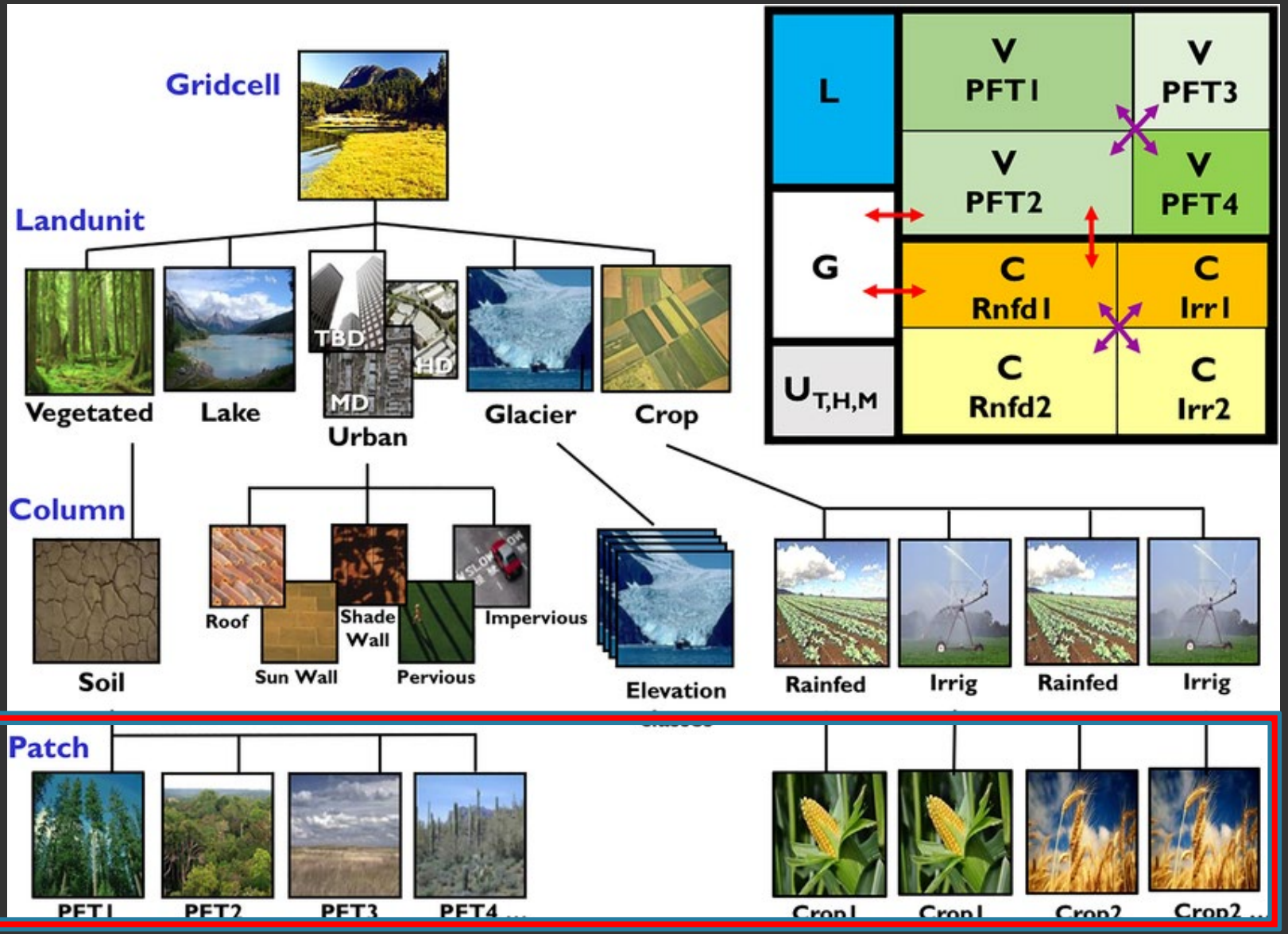
ELAI – Leaf Area Index

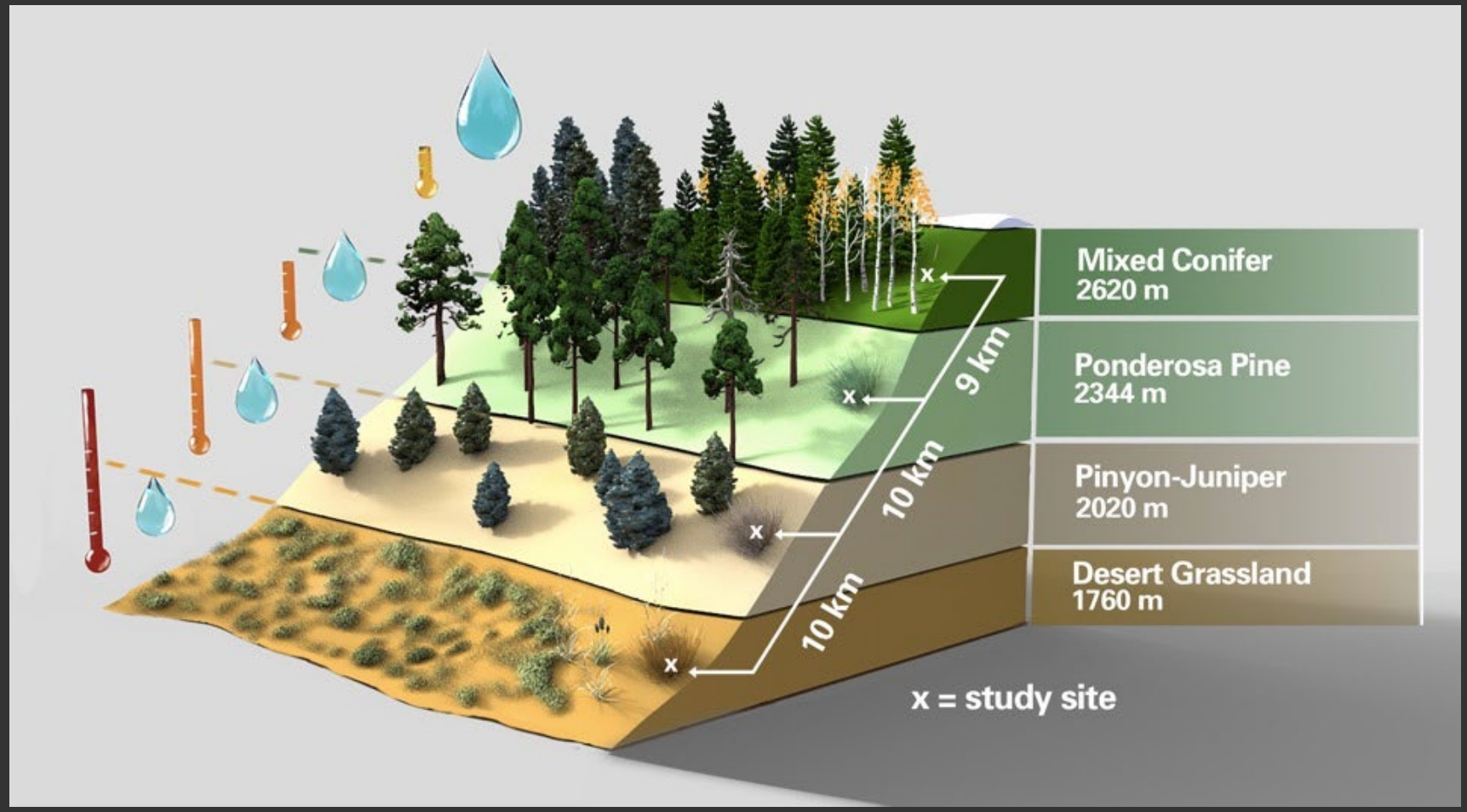
HR – Heterotrophic Respiration

NEP – Net Ecosystem Production = GPP – AR – HR

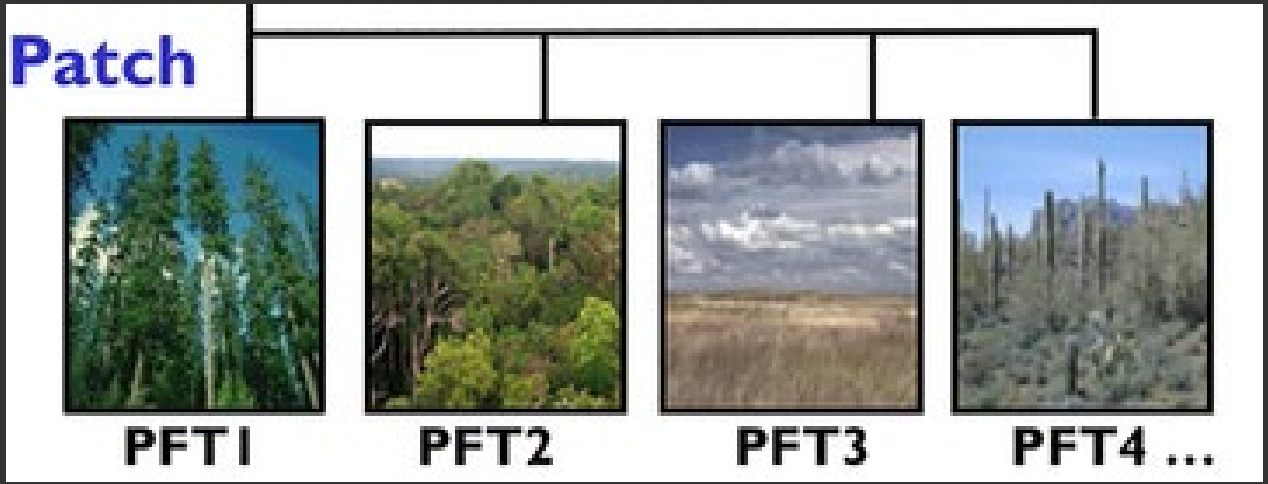
NEE – Net Ecosystem Exchange = NEP – Fire

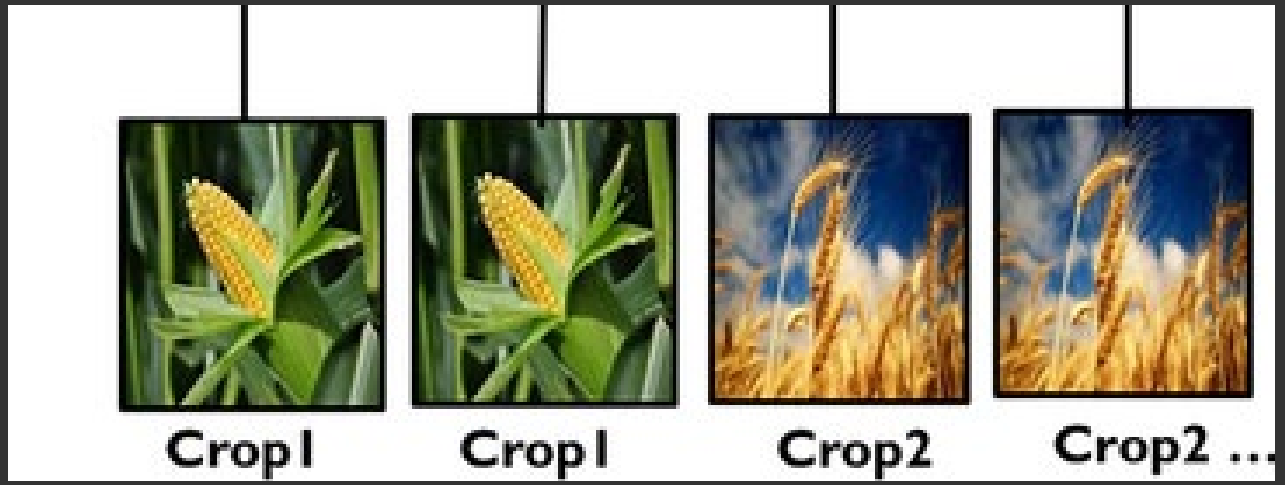
NBP = NEE - Land Use - Harvest

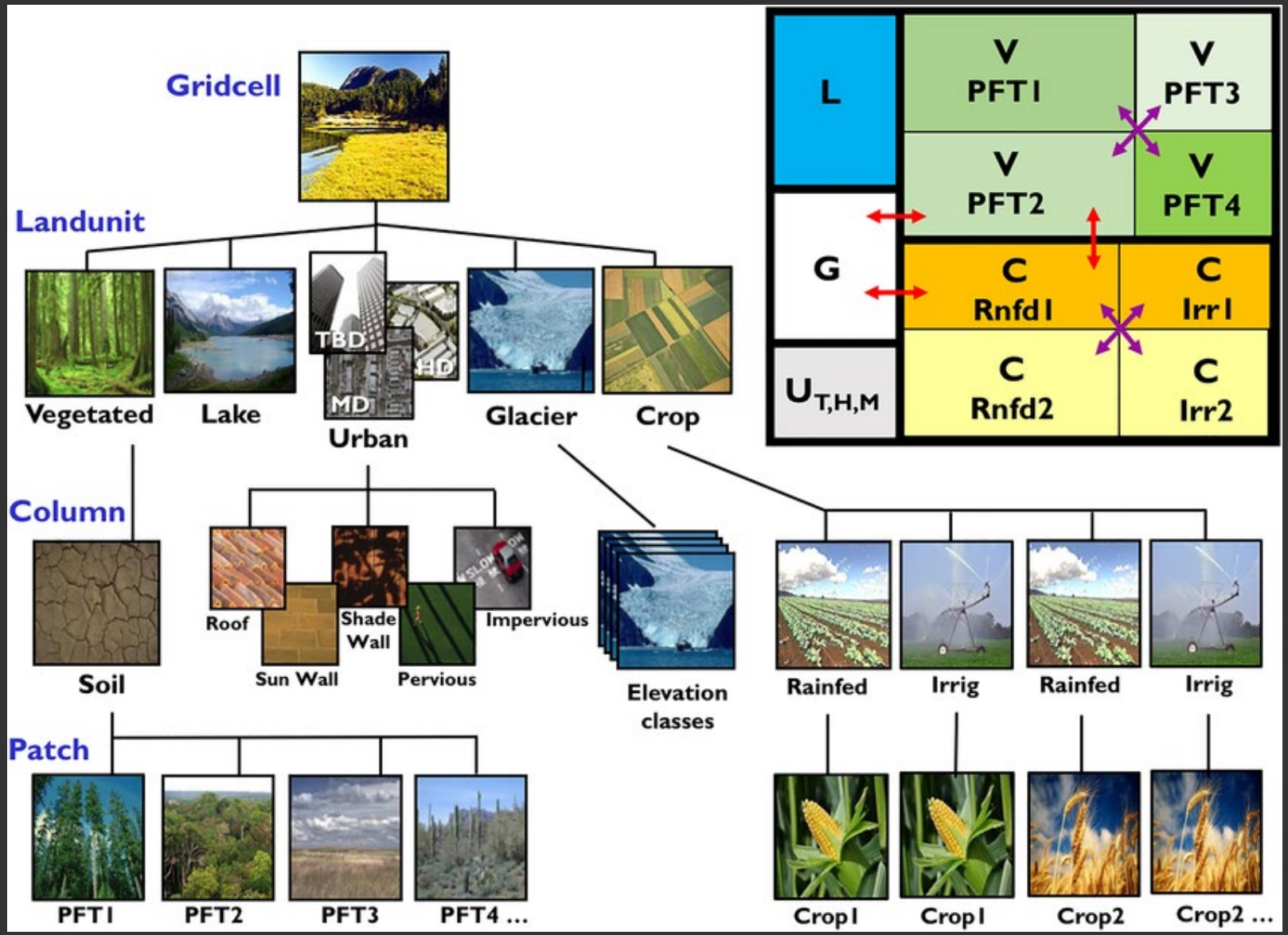

Gridcell
Landunit
Vegetated
Lake
TBD
HD
MD
Urban
Glacier
Crop
L
G
$U_{T,H,M}$
V PFT1
V PFT3
V PFT2
V PFT4
C Rnfd1
C Irr1
C Rnfd2
C Irr2
Column
Soil
Roof
Shade Wall
Impervious
Sun Wall
Pervious
Elevation
Rainfed
Irrig
Rainfed
Irrig
Patch
PFT1
PFT2
PFT3
PFT4
Crop1
Crop1
Crop2
Crop2



Morrissey et al. (2019) *Nature Ecology and Evolution*


Patch
PFT1
PFT2
PFT3
PFT4 ...


Crop1
Crop1
Crop2
Crop2 ...


Gridcell
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classes
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Irrig
Patch
PFT1
PFT2
PFT3
PFT4 ...
Crop1
Crop1
Crop2
Crop2 ...
L
V
PFT1
V
PFT3
V
PFT2
V
PFT4
G
C
Rnfd1
C
Irr1
U T,H,M
C
Rnfd2
C
Irr2

Agriculture in CLM5

Corn*

Wheat

Sugarcane

Soy*

Cotton

Rice

Agriculture in CLM5

Fertilize

Irrigate

Transient fertilizer and irrigation (1850-2100)

1850 fertilizer assumed to be from manure only

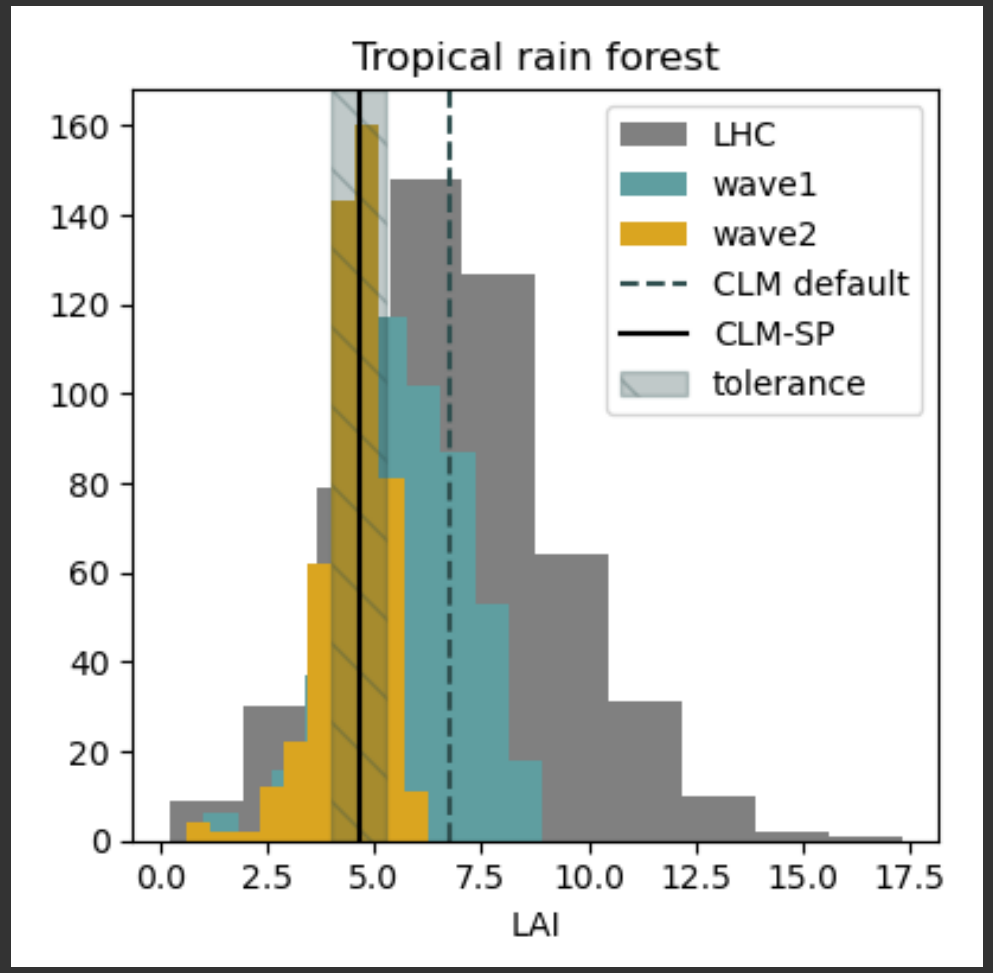
Where do parameterizations come from?

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

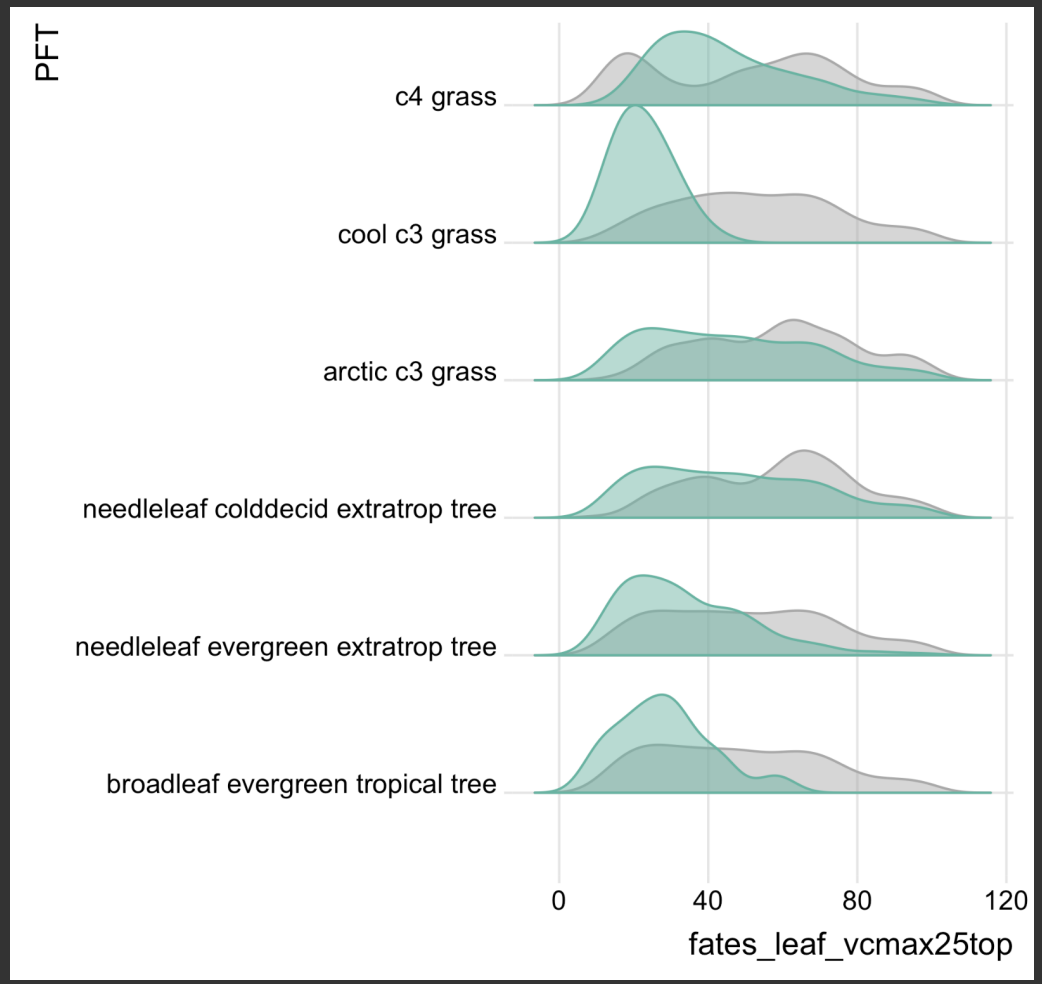
2. **Empirical relationships: From as large a sample of the real world as possible**
   e.g., TRY Database (Leaf N and dark respiration)

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

Parameter calibration – a tough problem!



Hawkins, et al. in prep



Foster, et al. in prep

Land biogeochemistry in CESM?

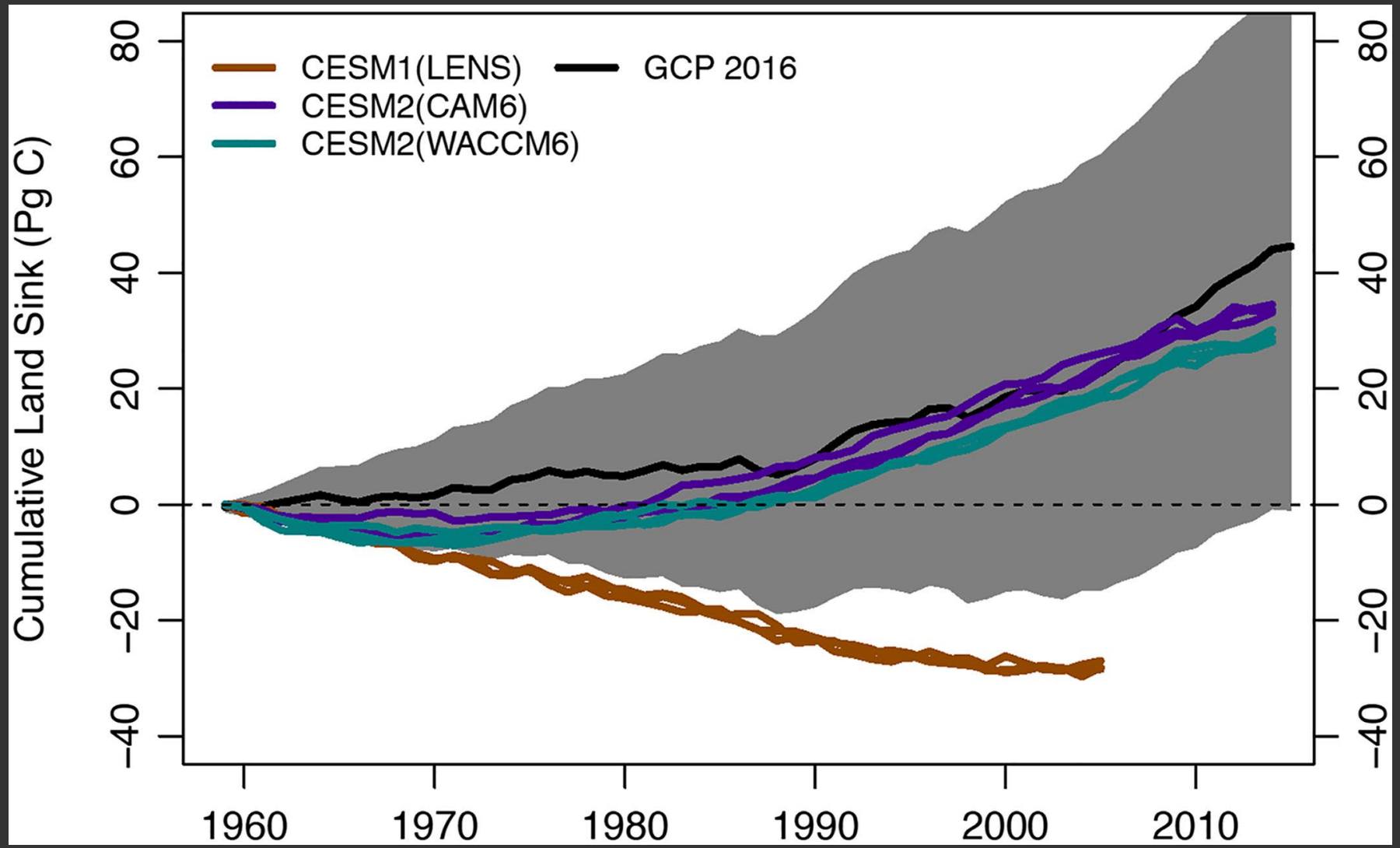
Why?

How?

Uncertainties and future directions

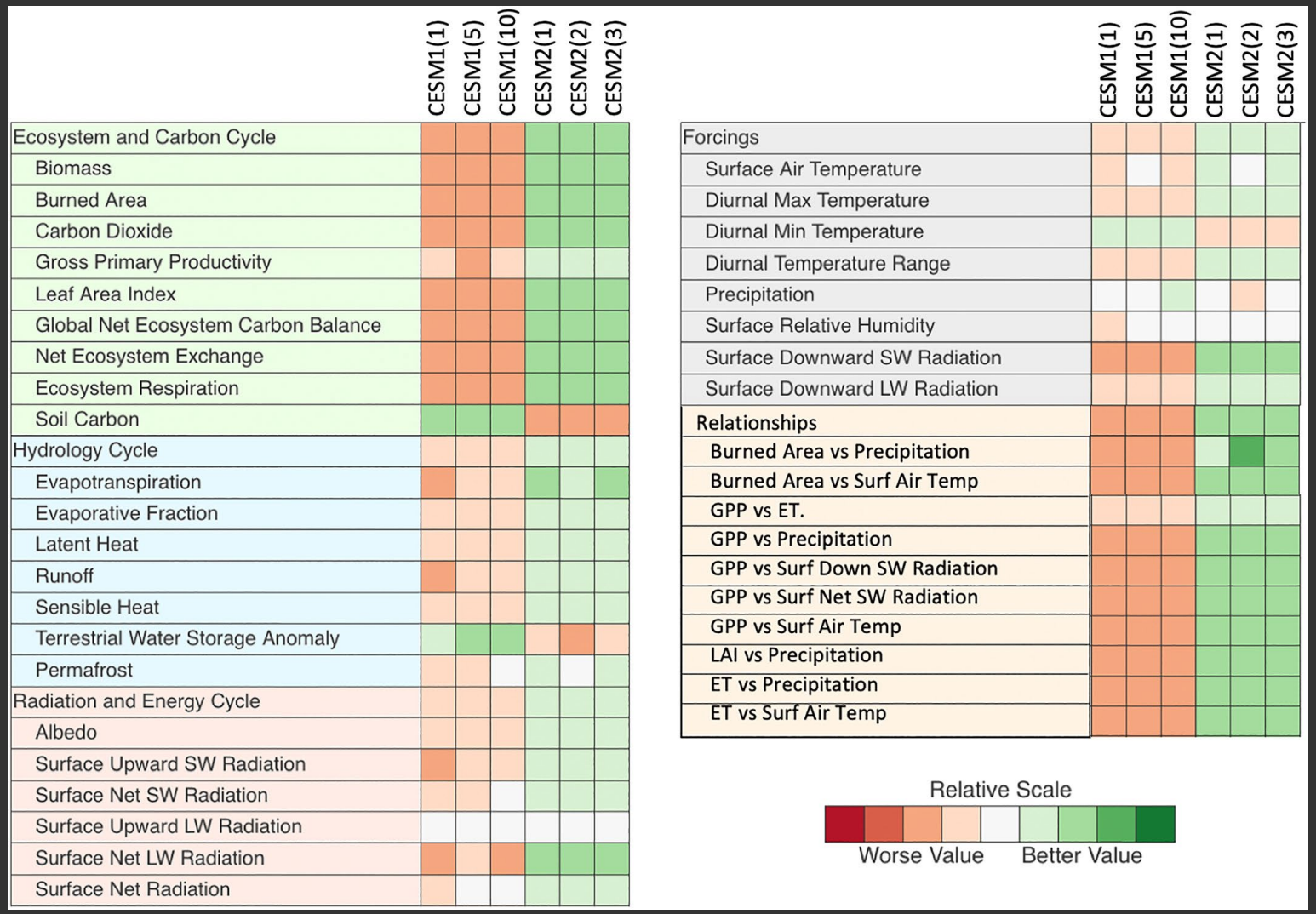
Represent land C sink!

Danabasoglu et al 2020 JAMES



Objectively 'better' carbon cycle

Danabasoglu et al 2020 JAMES

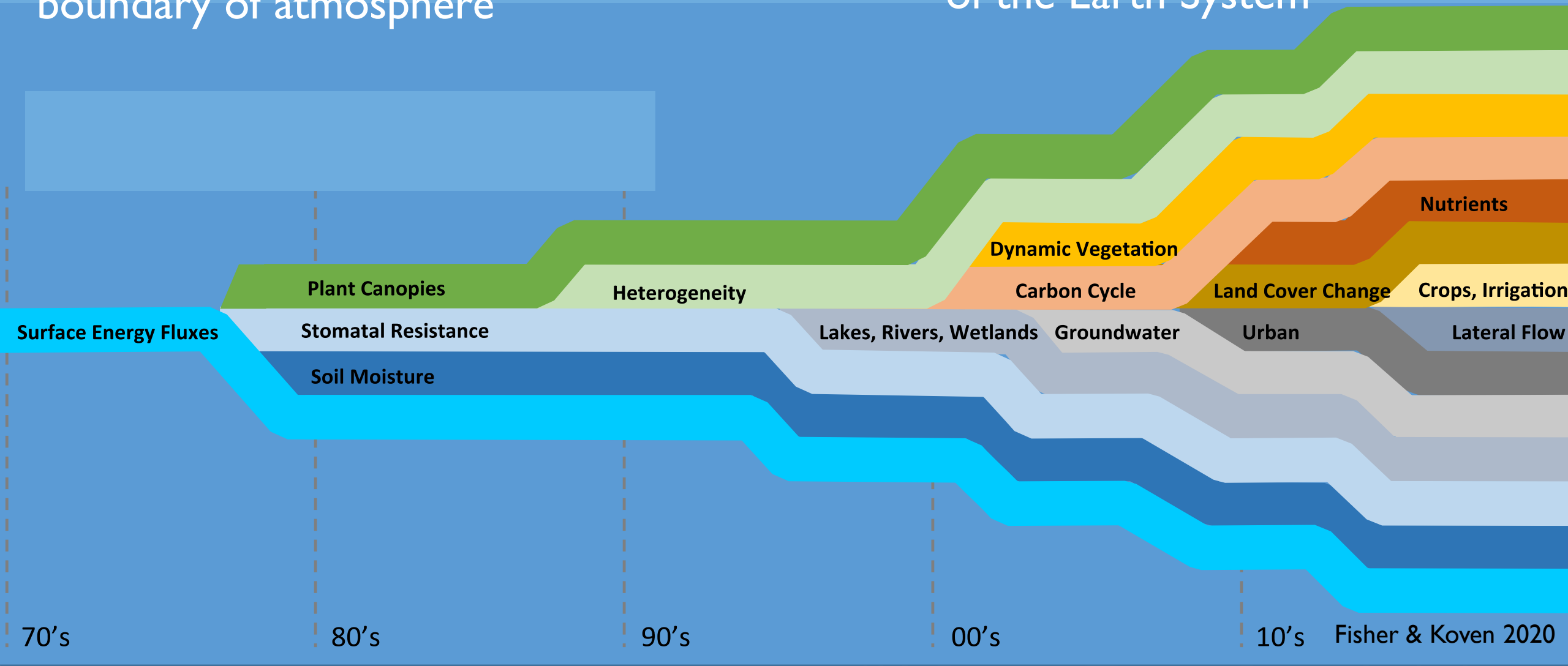


ILAMB – International Land Model Benchmarking package

the Evolution of land modeling

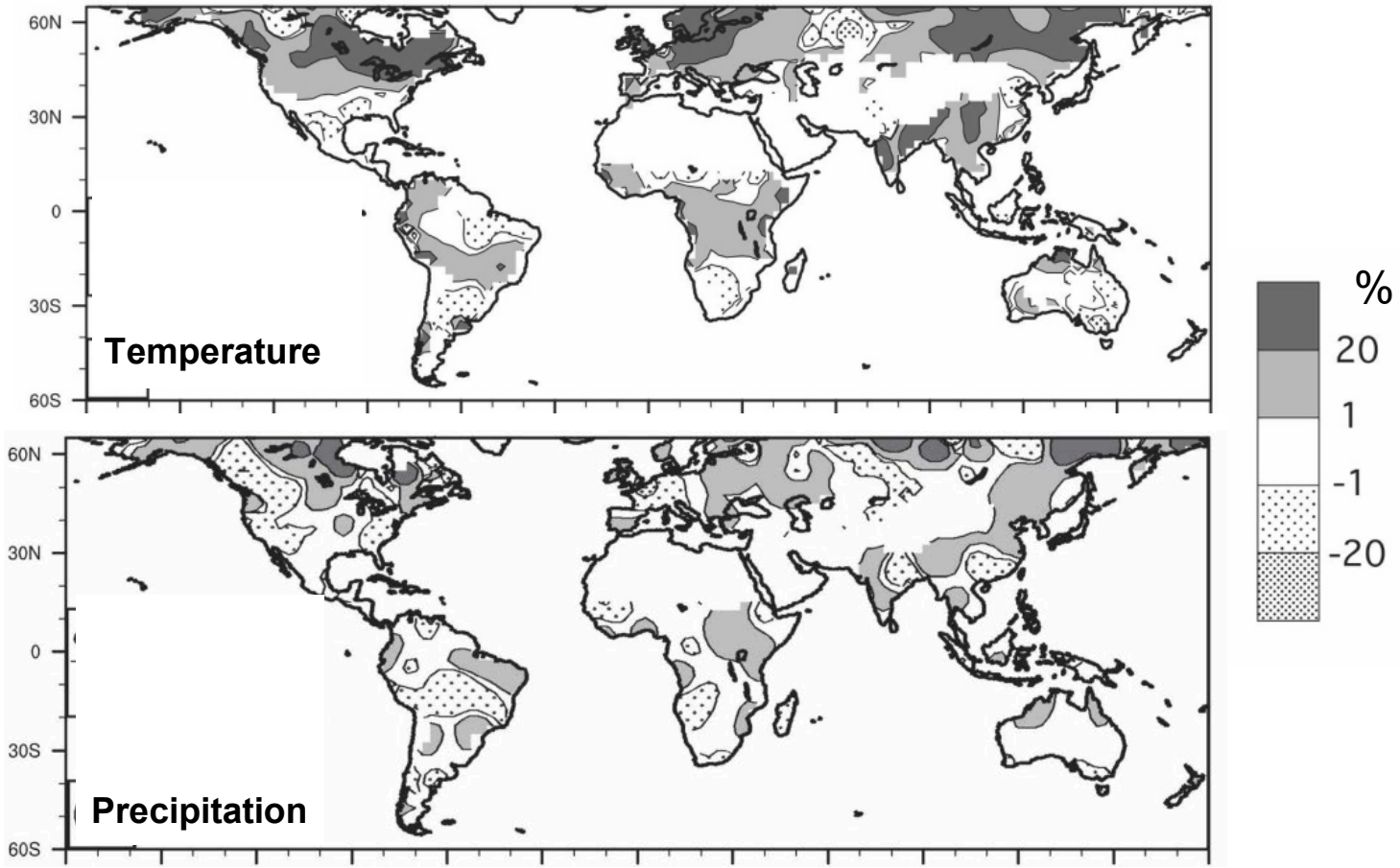
Land as lower boundary of atmosphere

Land as an integral component of the Earth System



LMWG priorities for CESM3+

Functionally Assembled Terrestrial Ecosystem Simulator (FATES)



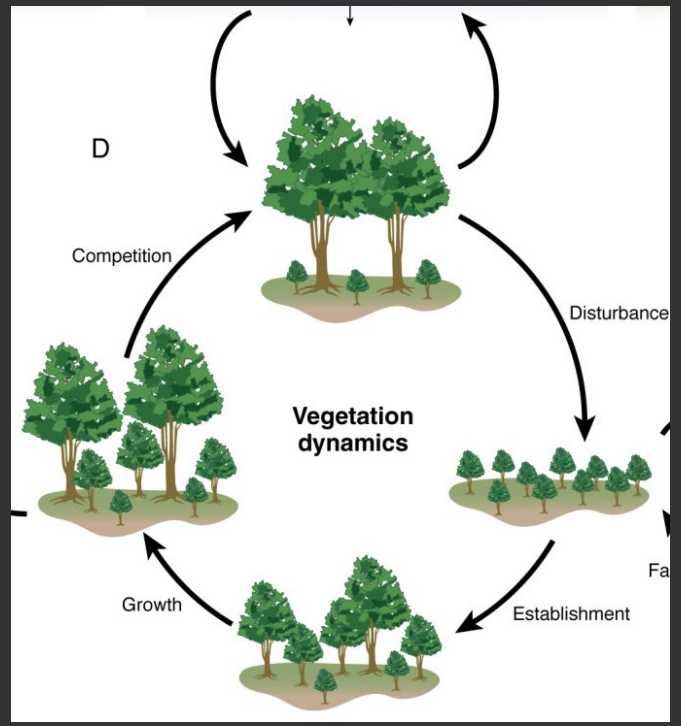
Forest height, structure, age, competition all feed back to climate!

Liu et al. 2006 *Journal of Climate*

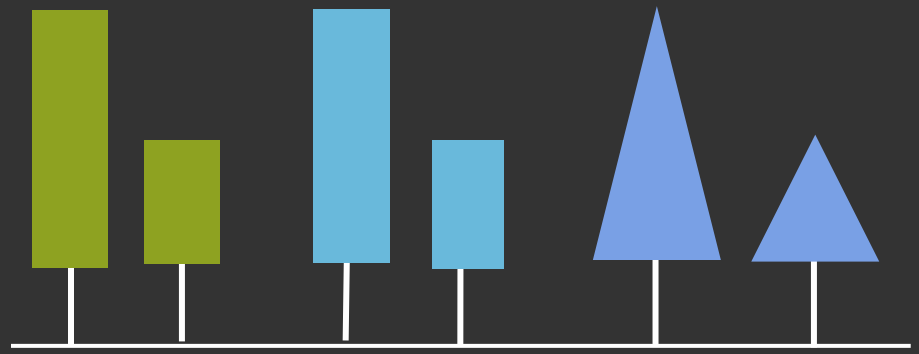
Functionally Assembled Terrestrial Ecosystem Simulator (FATES)

Forests are a mosaic of patches

Forest dynamics are the average responses of many such gaps/patches

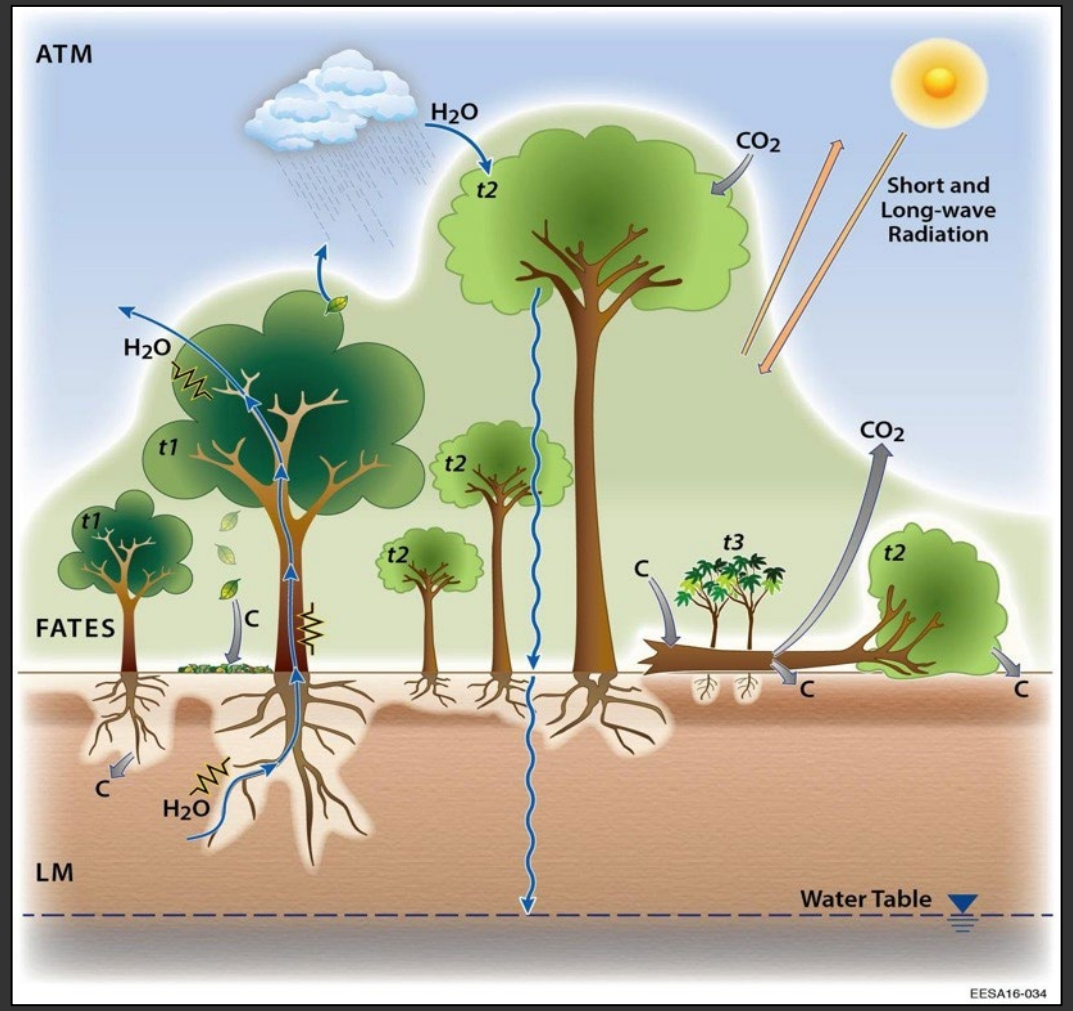


Functionally Assembled Terrestrial Ecosystem Simulator (FATES)

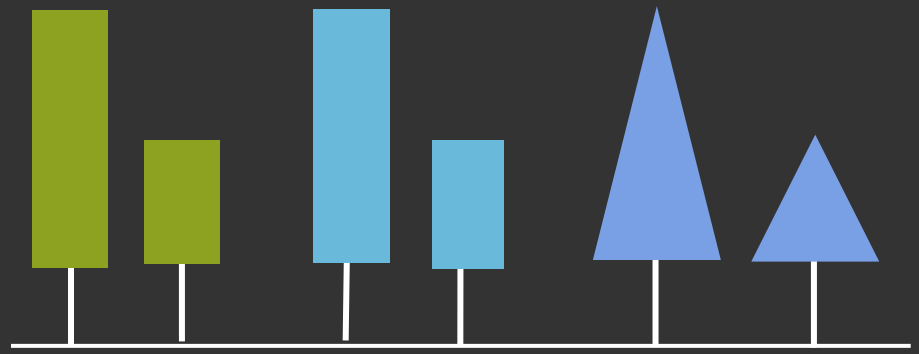


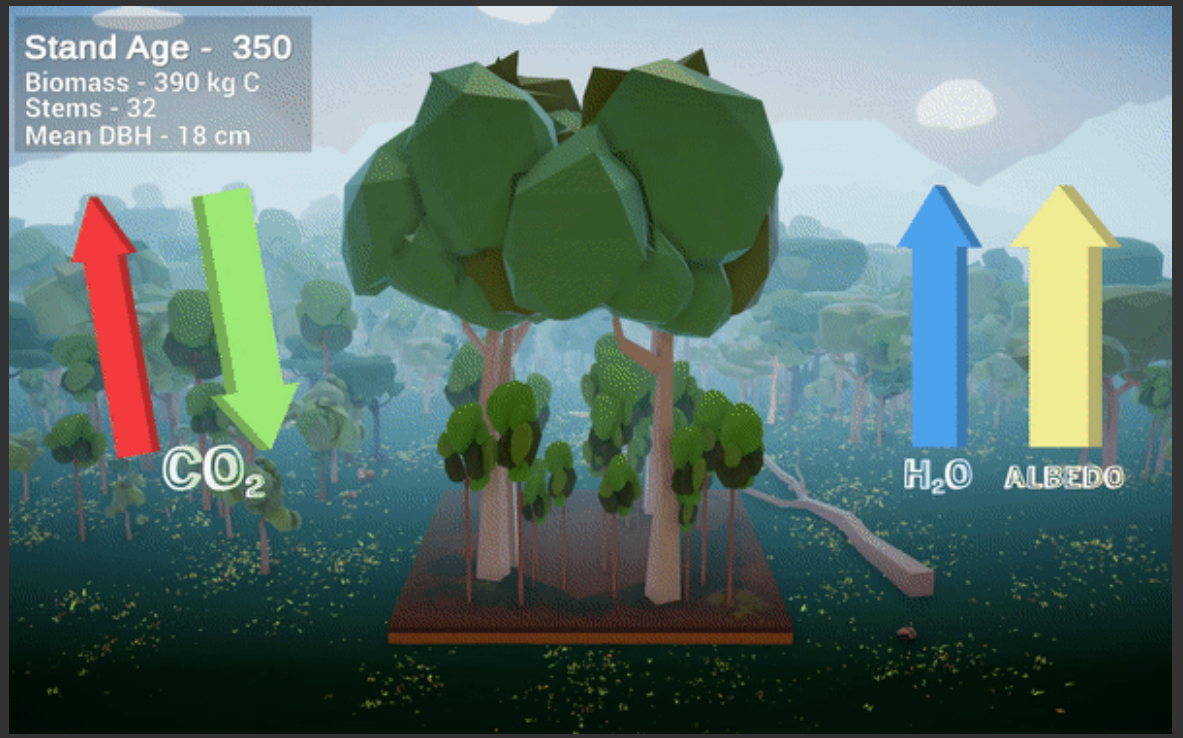
cohort-specific model

30-minute photosynthesis and fluxes



Functionally Assembled Terrestrial Ecosystem Simulator (FATES)





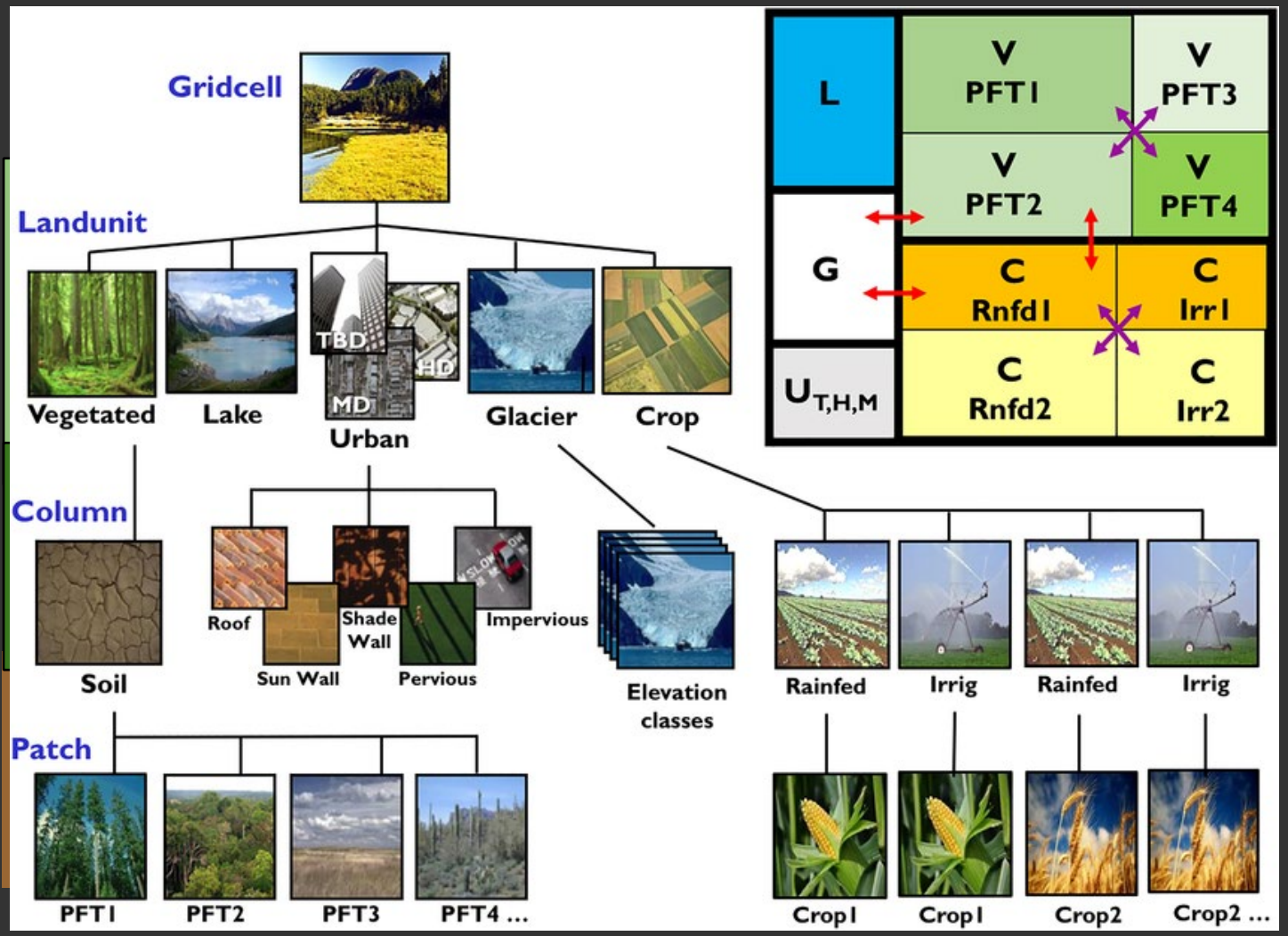
cohort-specific model

30-minute photosynthesis and fluxes

daily growth and allocation

dynamic vegetation!

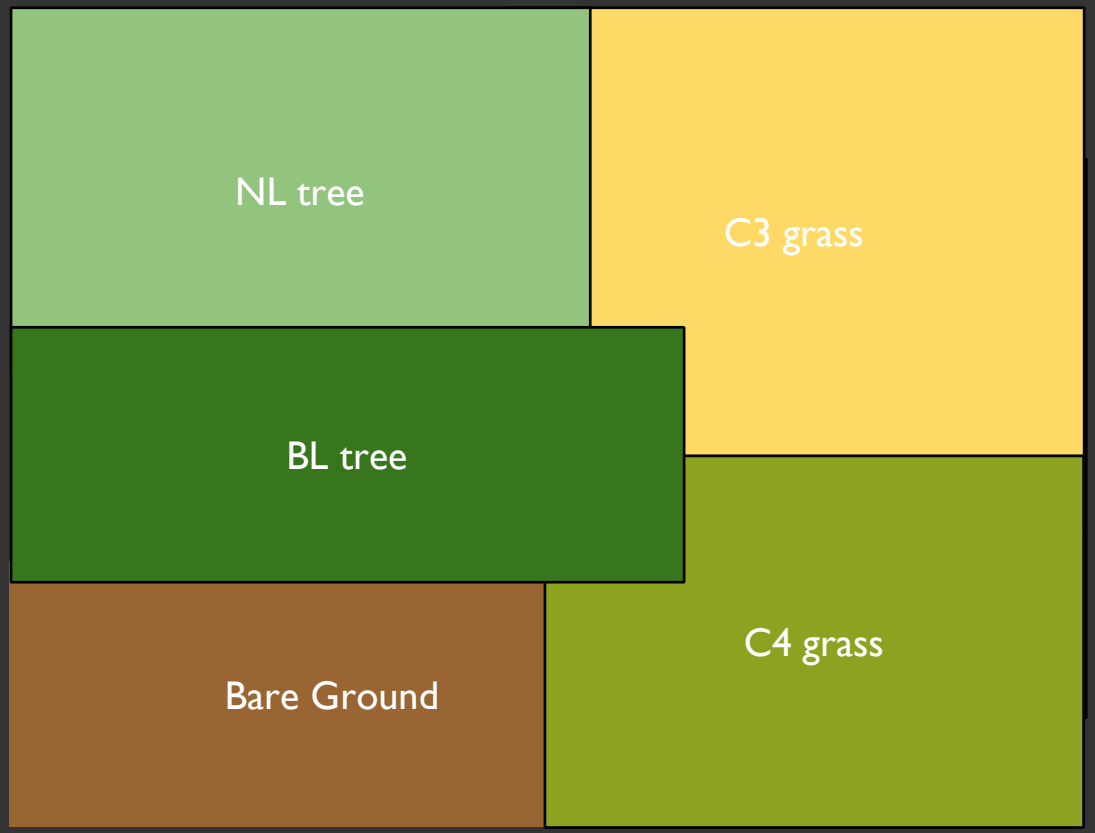
Functionally Assembled Terrestrial Ecosystem Simulator (FATES)



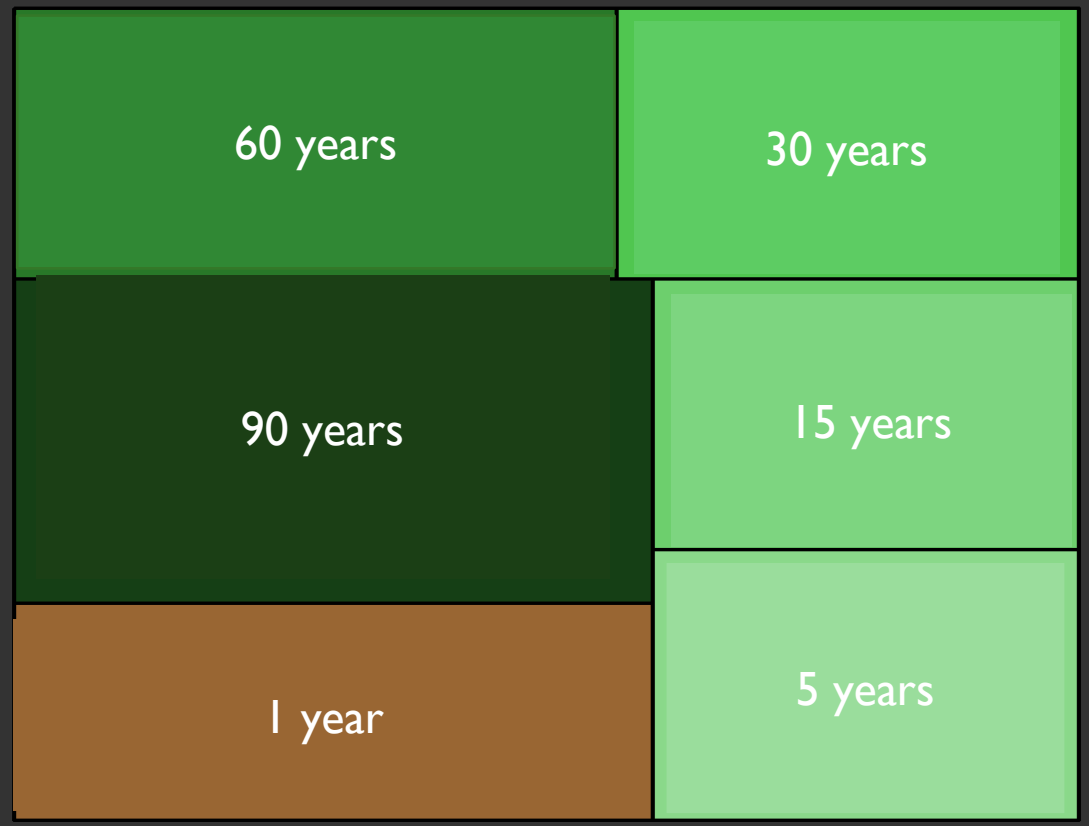
+ many more

Functionally Assembled Terrestrial Ecosystem Simulator (FATES)

Plant Functional Type tiling (base CLM)



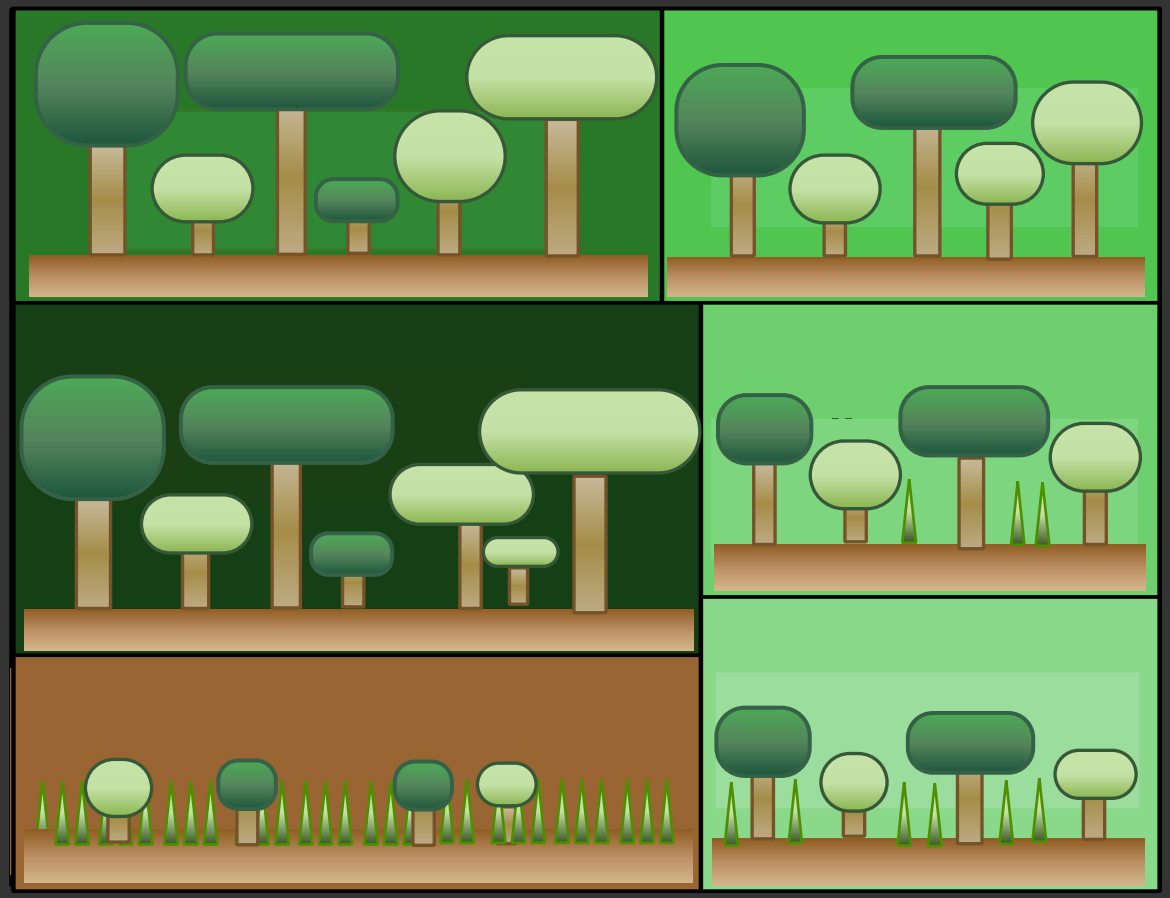
Time-since-disturbance tiling (FATES)



+ many more

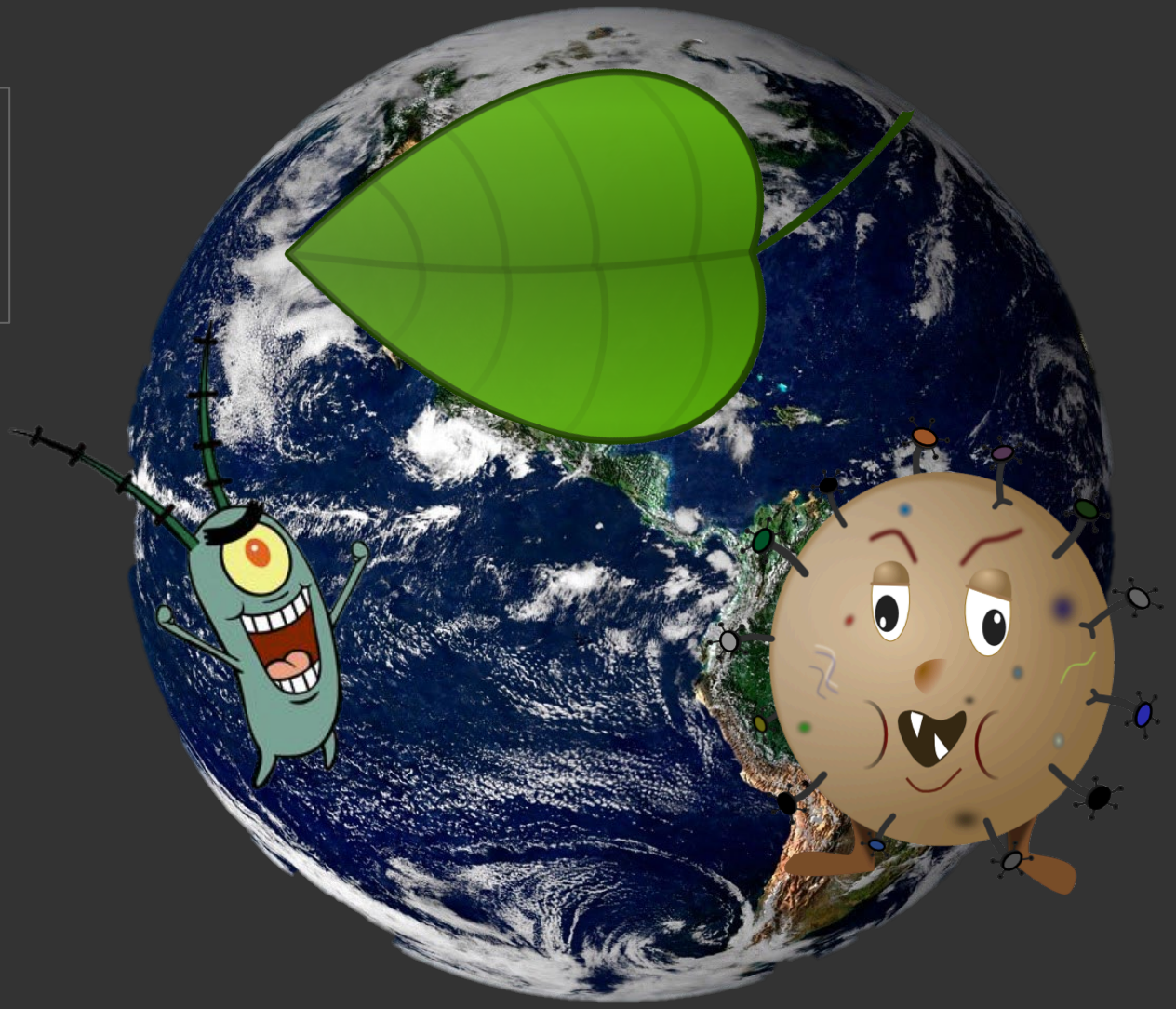
Functionally Assembled Terrestrial Ecosystem Simulator (FATES)

Each time-since-disturbance tile contains cohorts of plants, defined by PFT and size.



Functional traits and the global C cycle

We consider biology above ground and at sea, what about in the world beneath our feet?



How do ecosystem function and vulnerabilities transform under climate change?

- **Community Terrestrial Systems Model**: Land model used for climate change and weather predictions that can be run at single points (~ 1 ha) to global scale.
- **Hillslope Hydrology**: Considers effects of aspect, elevation, and hydrologic connectivity on water availability (feature within CTSM).
- **FATES:** Represents vegetation demographics, traits, and recovery from disturbance (feature within CTSM).
- **MIMICS**: Soil biogeochemistry model (explicitly represent microbial activity and physiological diversity).