Land Modeling II: Biogeochemistry

Will Wieder

CESM Tutorial

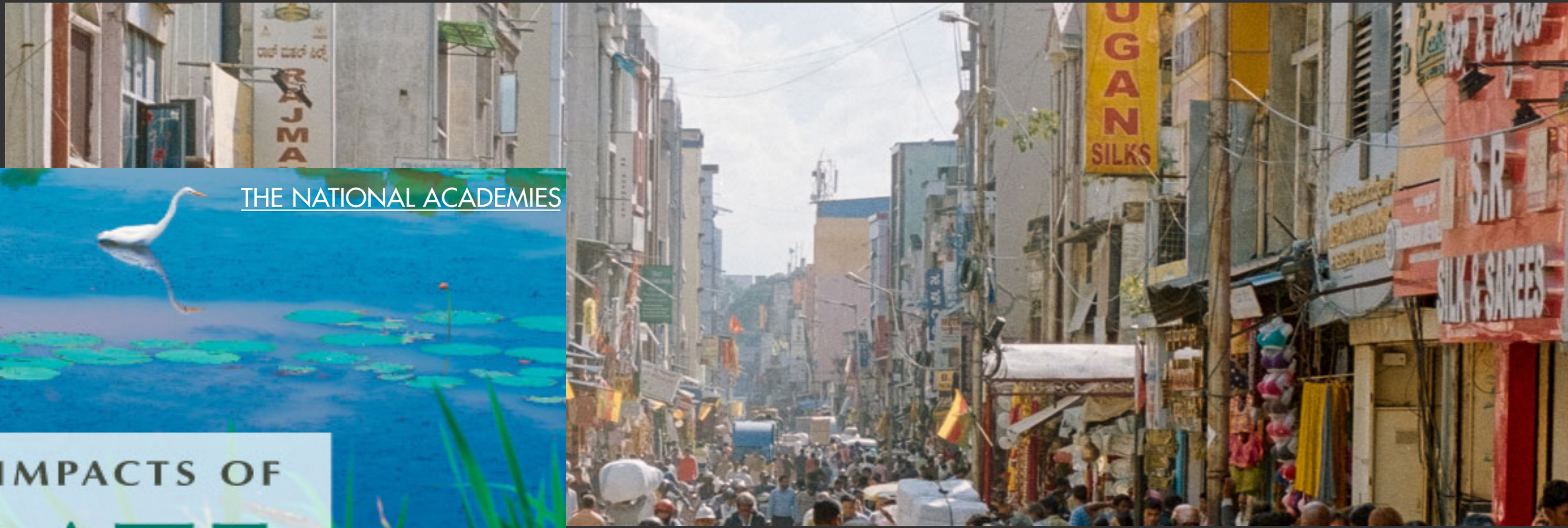
9 August 2022

NCAR

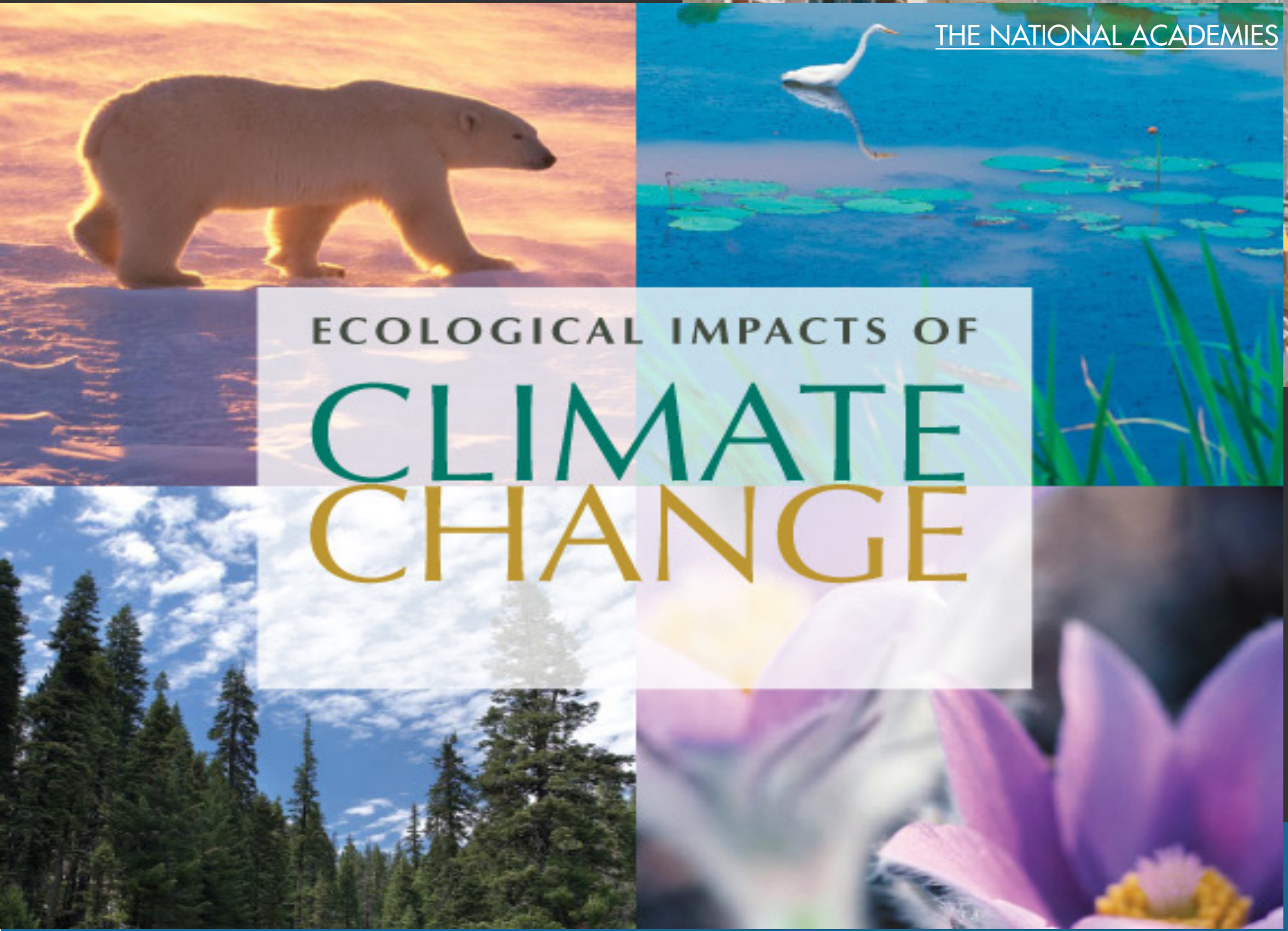
NSF

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

“Climate change made devastating early heat in India and Pakistan 30 times more likely”



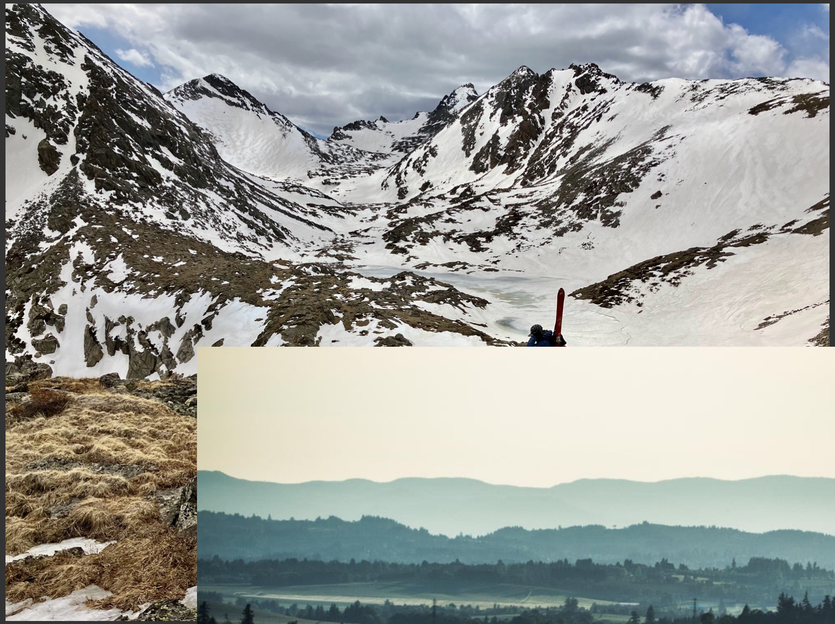
https://www.worldweatherattribution.org/



Ecological Impacts of Climate Change (2009):

www.nas.edu/climatechange.

Land biogeochemistry in CESM?



Why?

How?

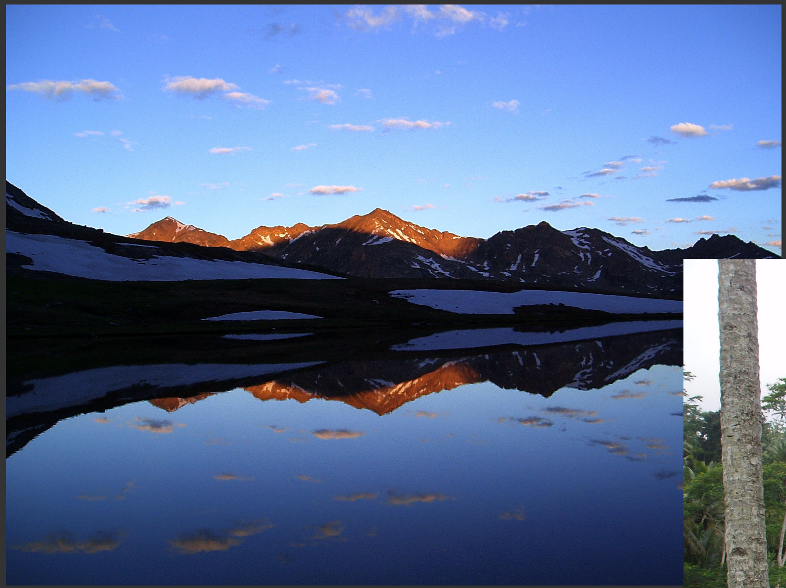
Uncertainties and
Future directions.

Land biogeochemistry in CESM?

Why?

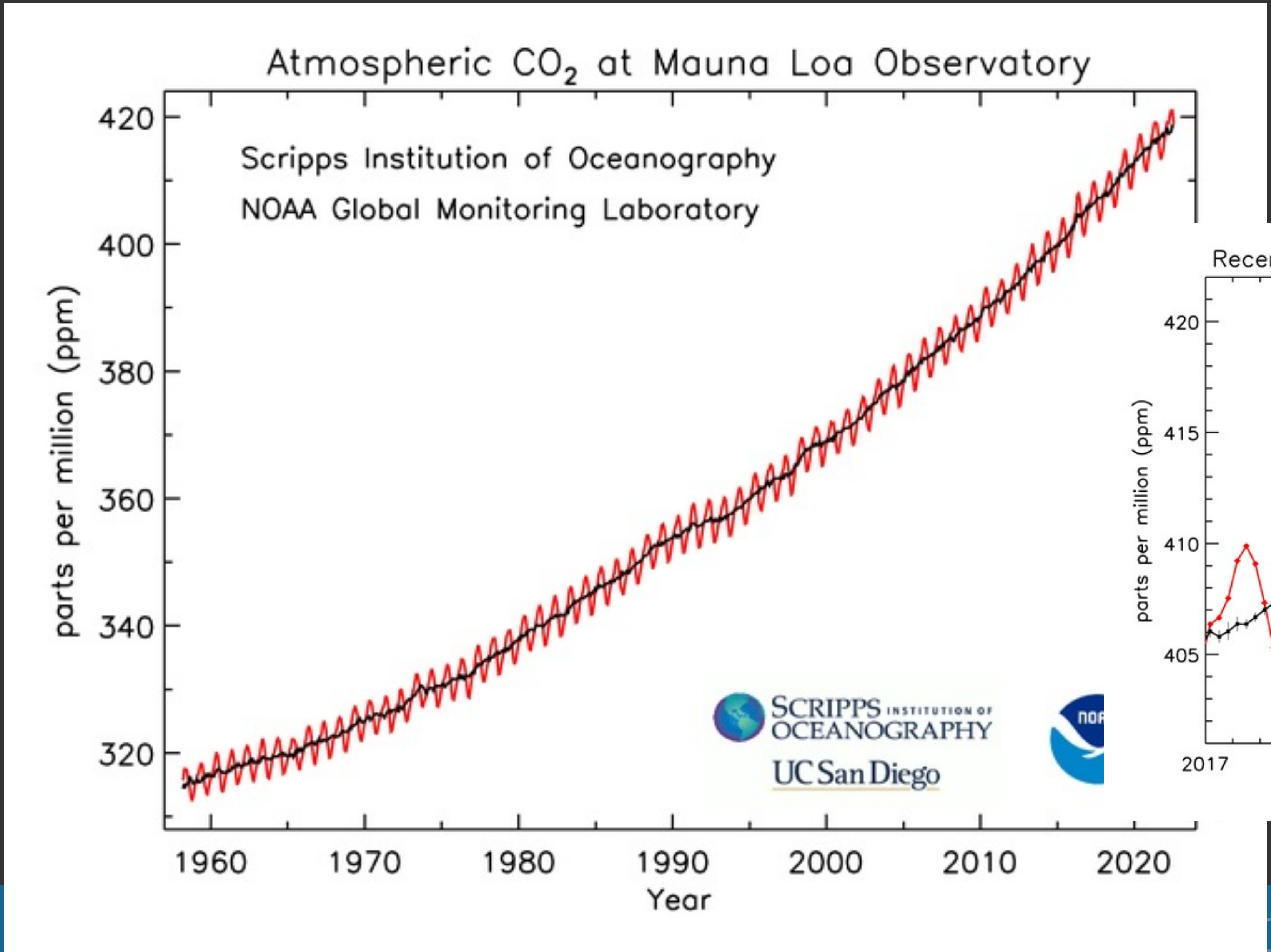
Ecosystems & Climate Change

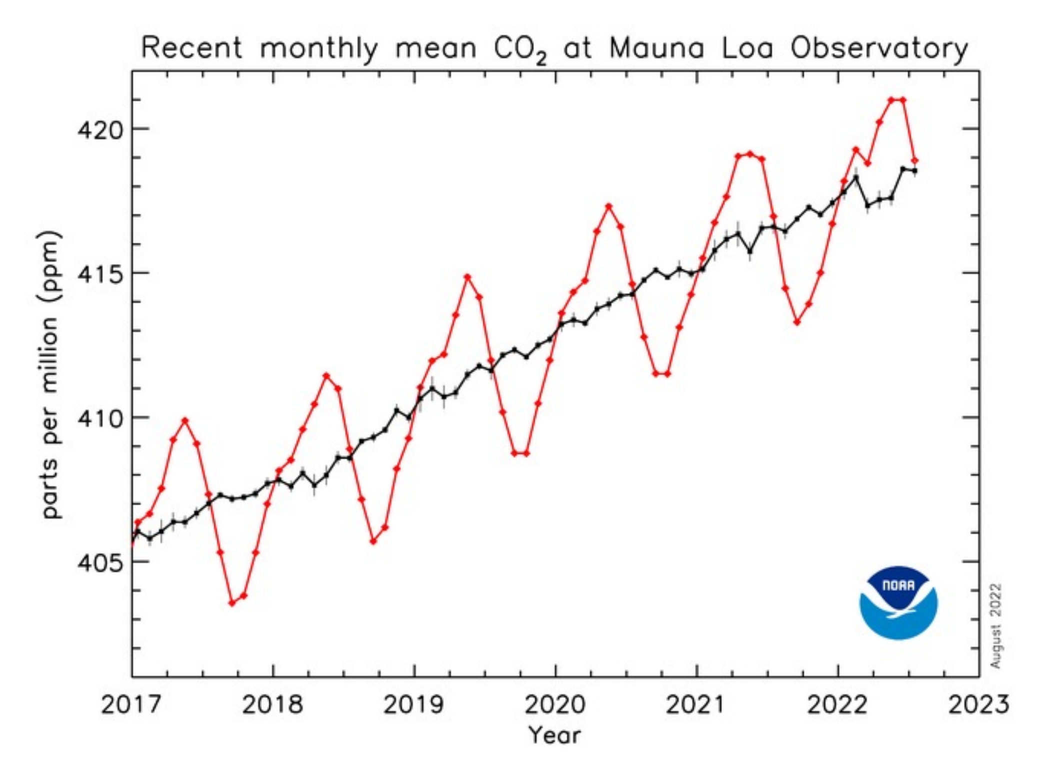
You can't eat the MJO



NCAR
UCAR | CES

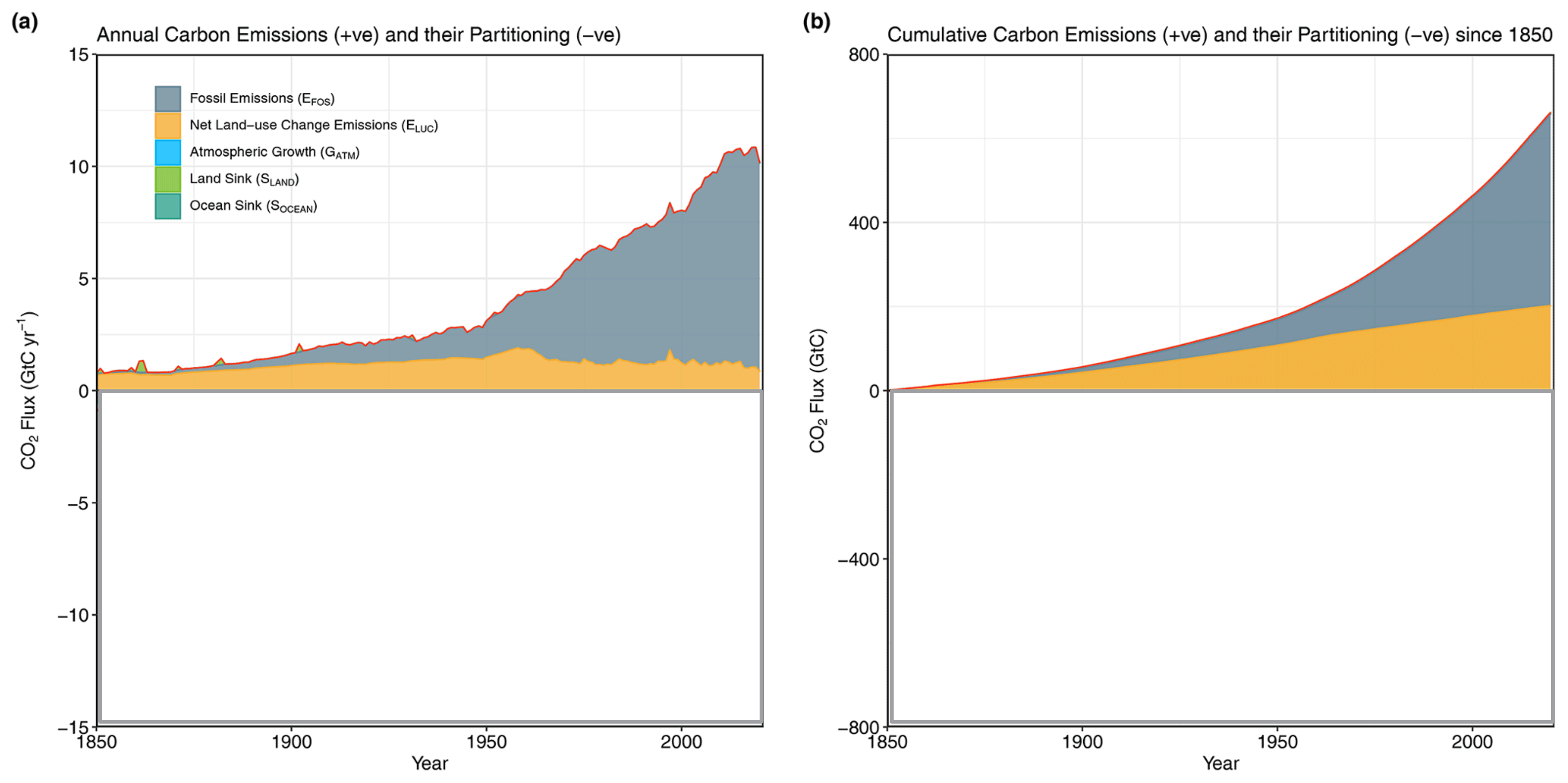
Biogeochemistry = Carbon cycle





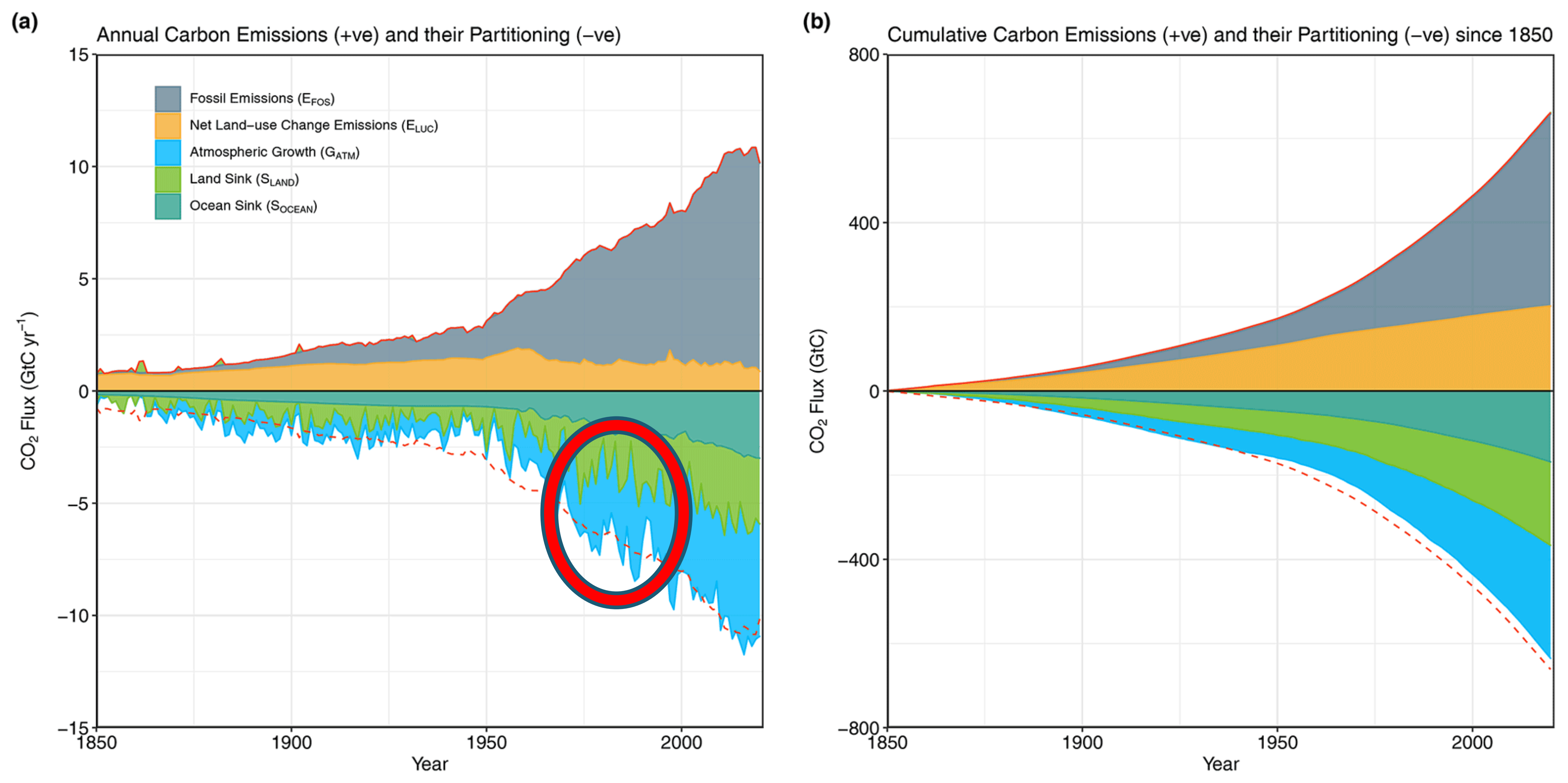
https://gml.noaa.gov/ccgg/trends/mlo.html

Ecosystem services at global scales



Friedlingstein et al. 2022 *Global Carbon Budget 2021*

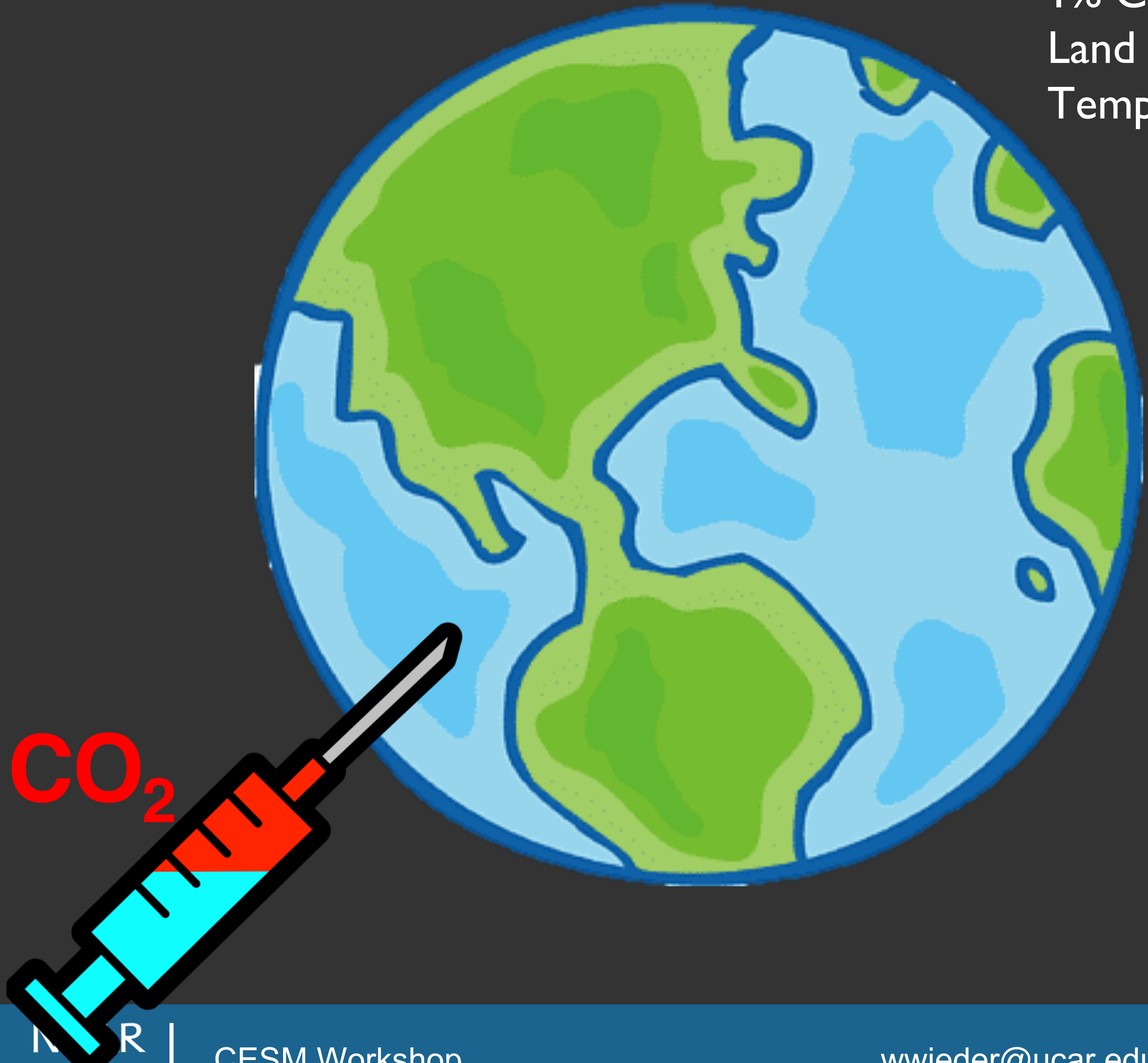
Ecosystem services at global scales



Friedlingstein et al. 2022 *Global Carbon Budget 2021*

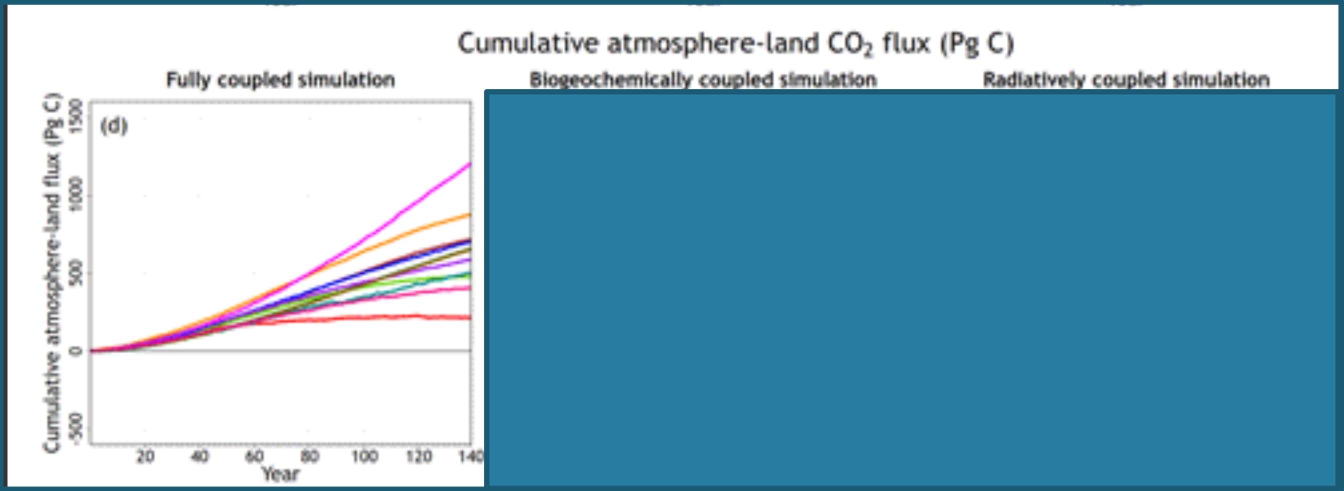
Idealized experiments
C4MIP

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



Arora et al. 2020

Idealized experiments



Arora et al. 2020

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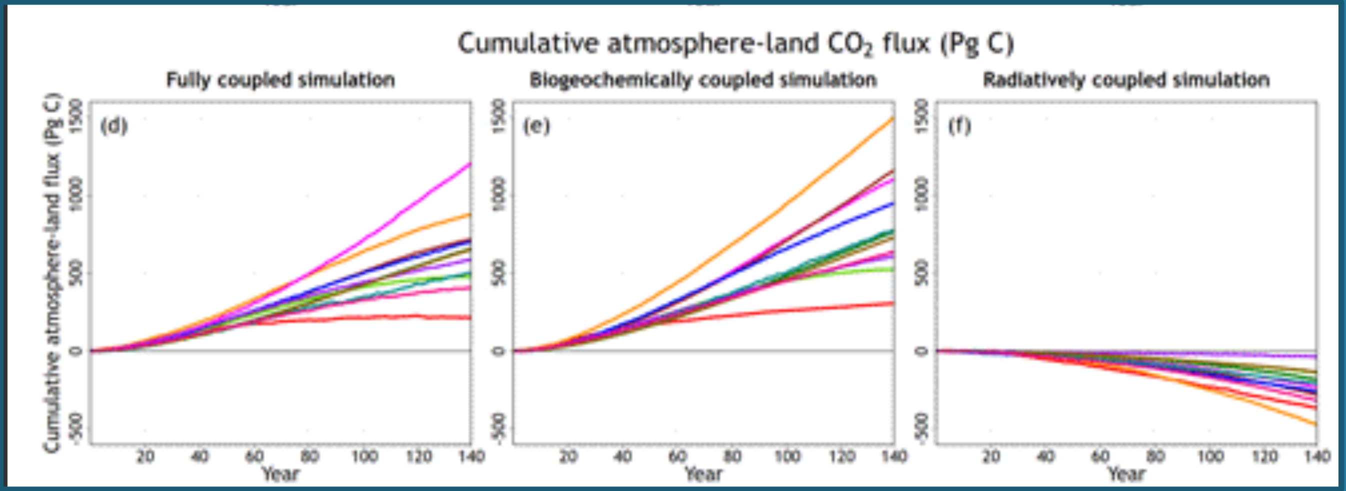

Arora et al. 2020

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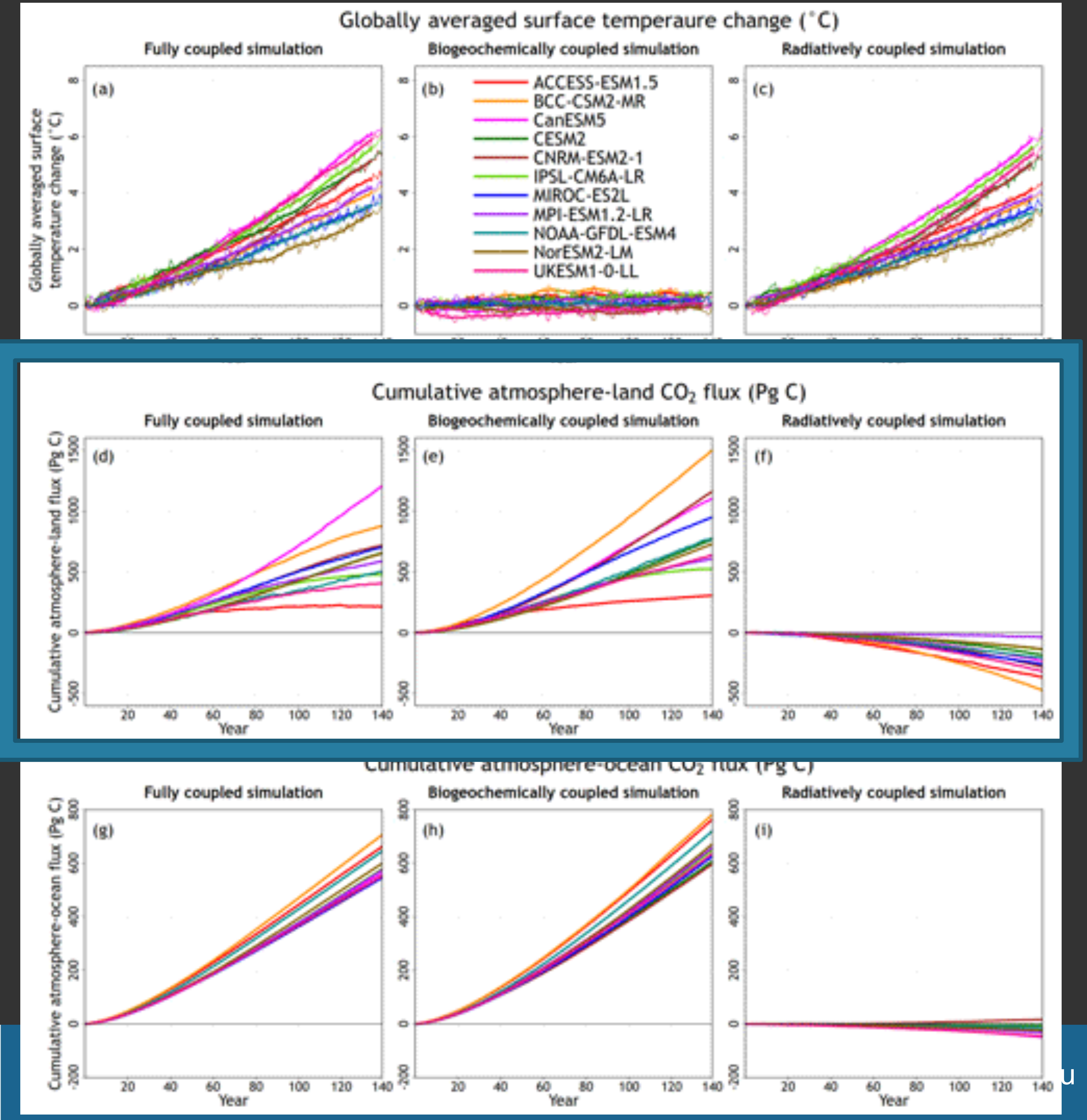
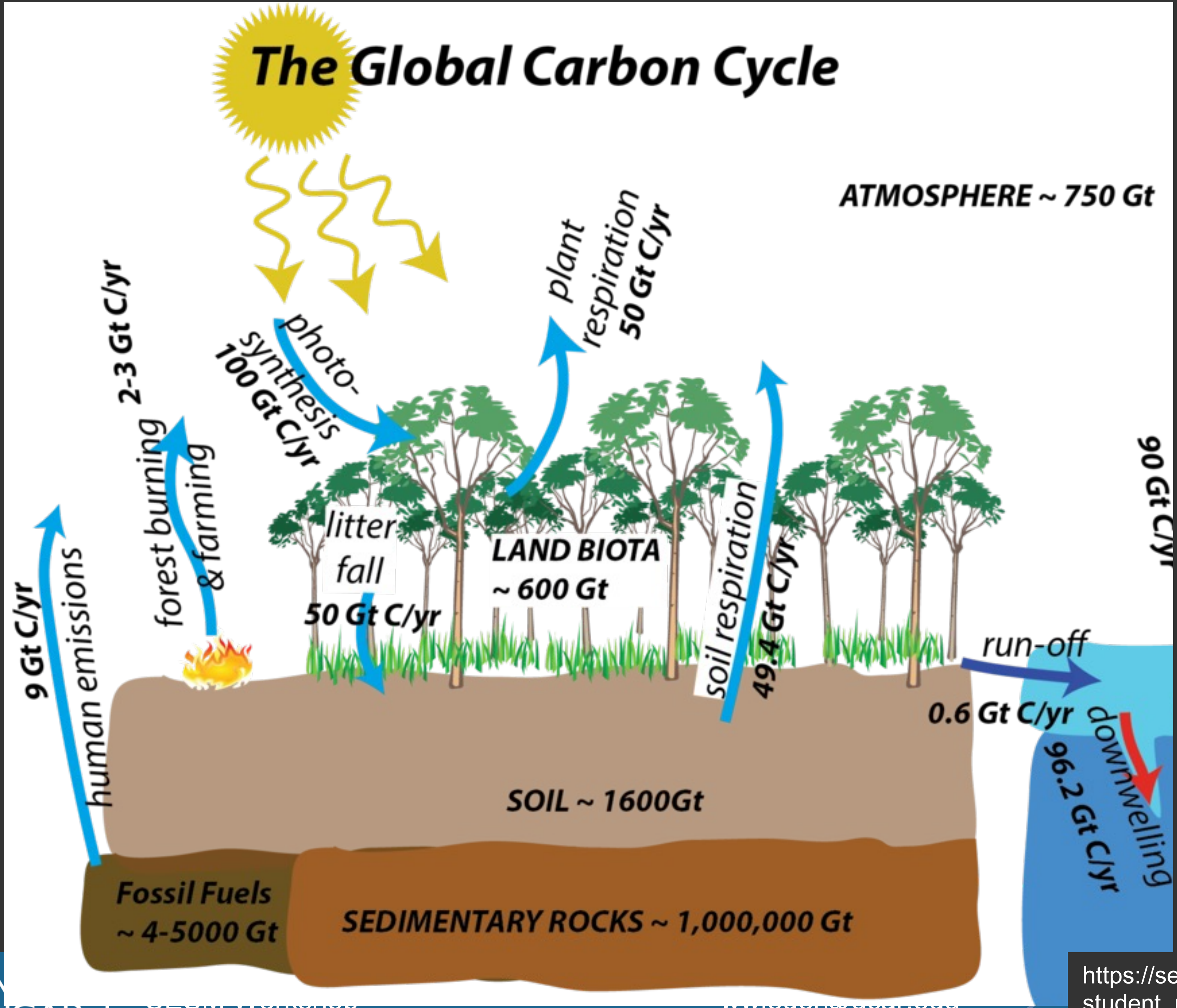


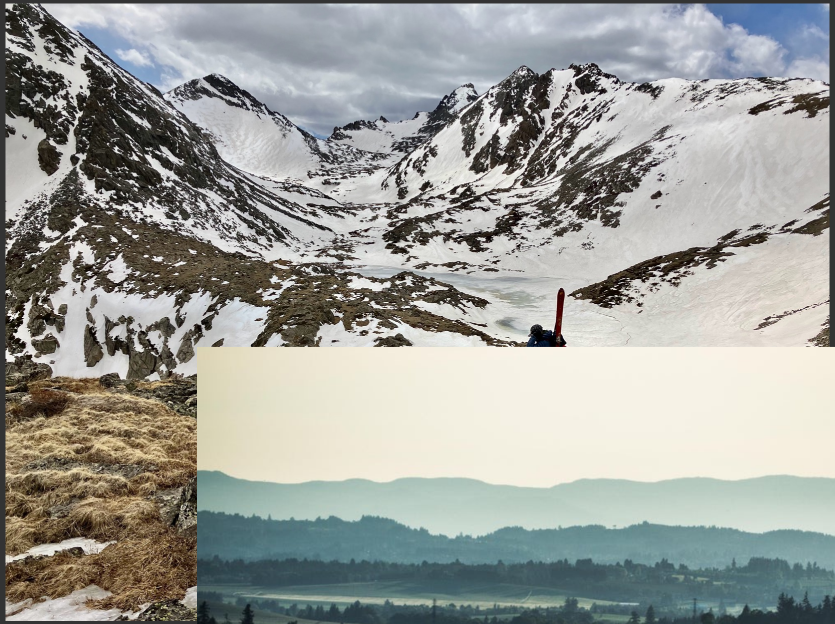
- Land BGC is hard
  - CO_2 fertilization
  - Warming response
- Ocean BGC is boring
- Resulting uncertainty matters for warming!

Arora et al. 2020



Huge pools
Large fluxes
Sink = small residual

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

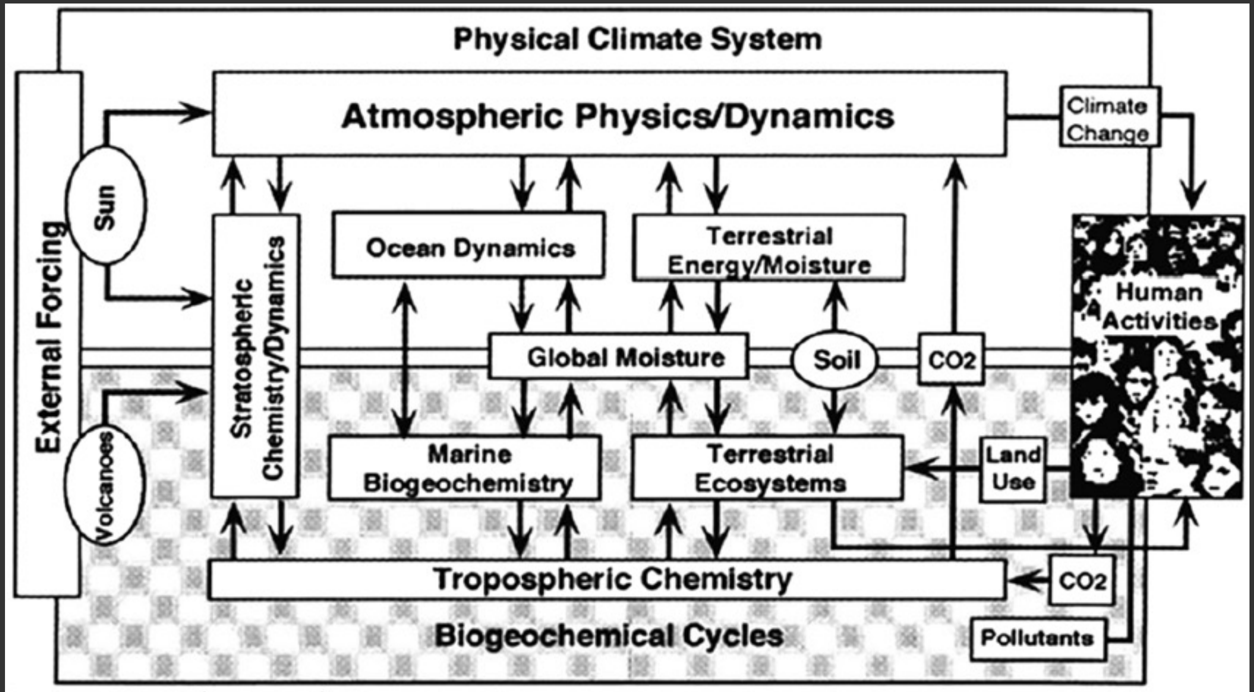


Land biogeochemistry in CESM?

Why?

How?

“Bretherton diagram” showing the concept of an Earth System Model



Source: NASA (1986, 19).

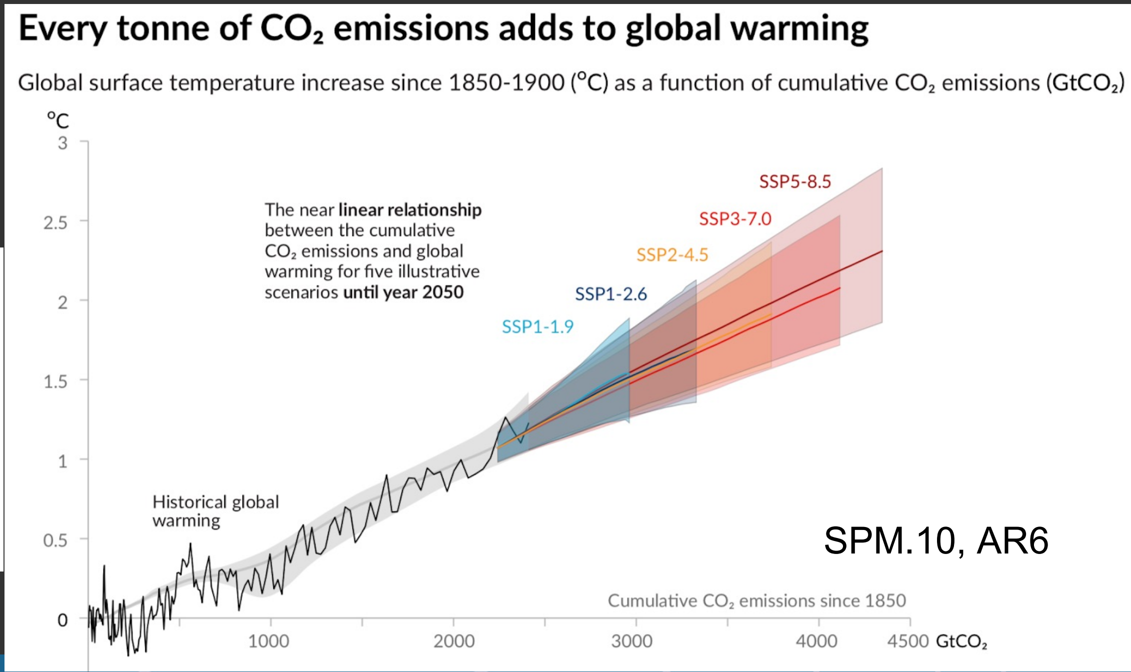
NCAR and CESM were key players in the development of the concept and creation of the first coupled carbon cycle models through the “Flying Leap” experiment (which led to C4MIP experiments).

- \+ Coupled C-N biogeochemistry, CESM1
- \+ Explicit crop management, CESM2

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

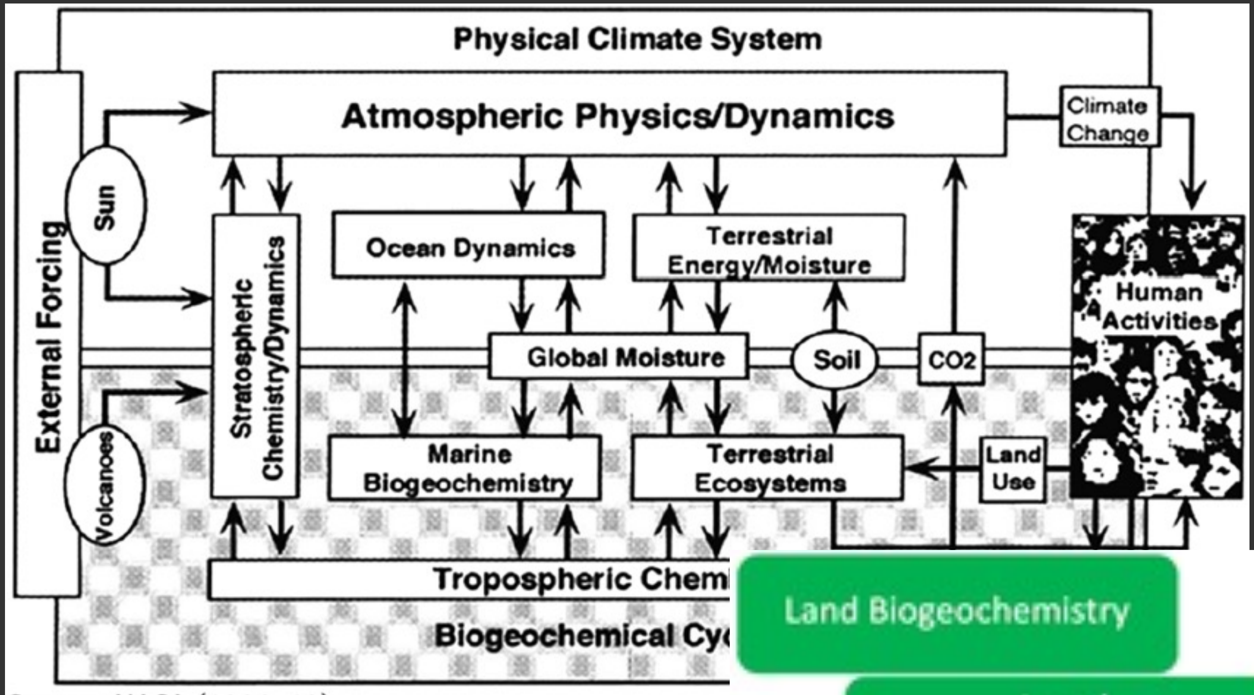
by Inez Fung, Peter Rayner, and Pierre Friedlingstein; Edited by Dork Sahagian

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



SPM.10, AR6

“Bretherton diagram” showing the concept of an Earth System Model



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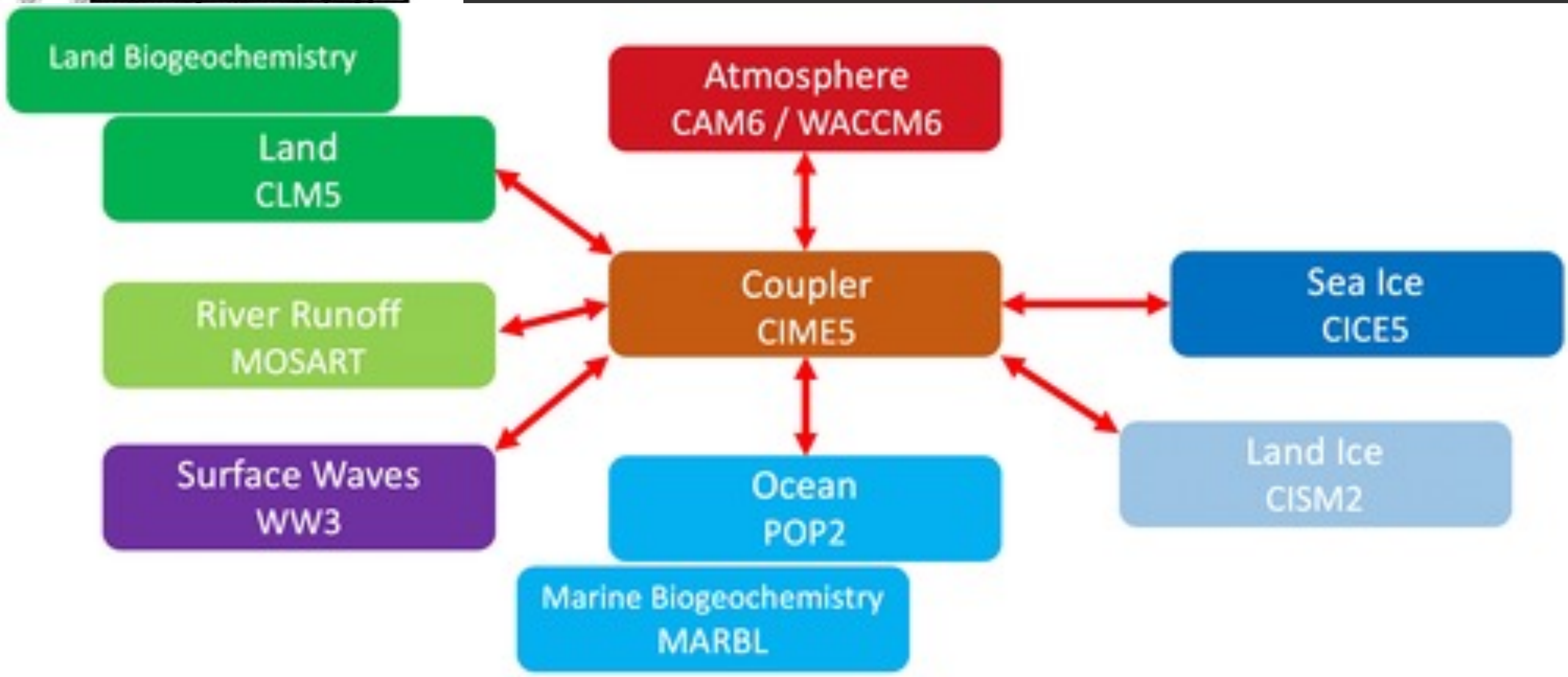


Community LAND MODEL DEVELOPMENT





















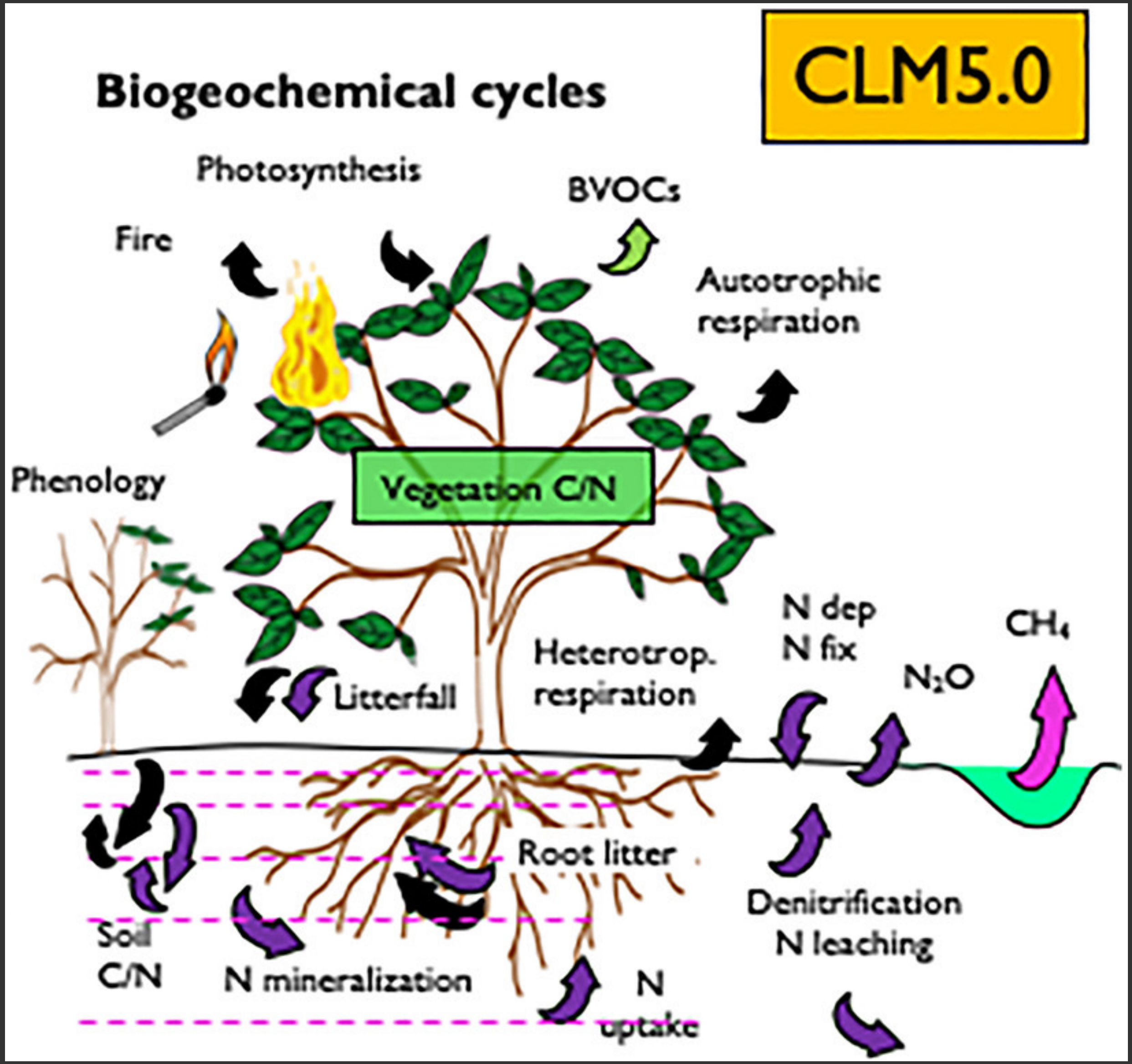


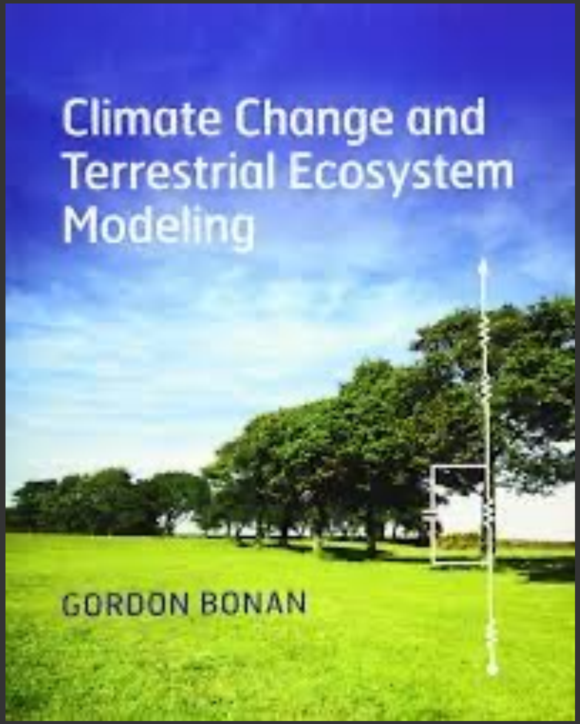


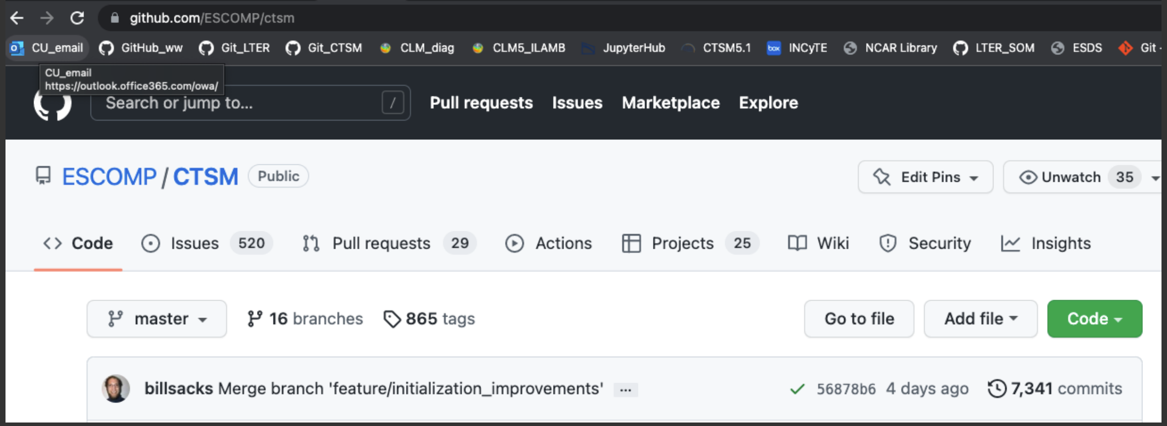




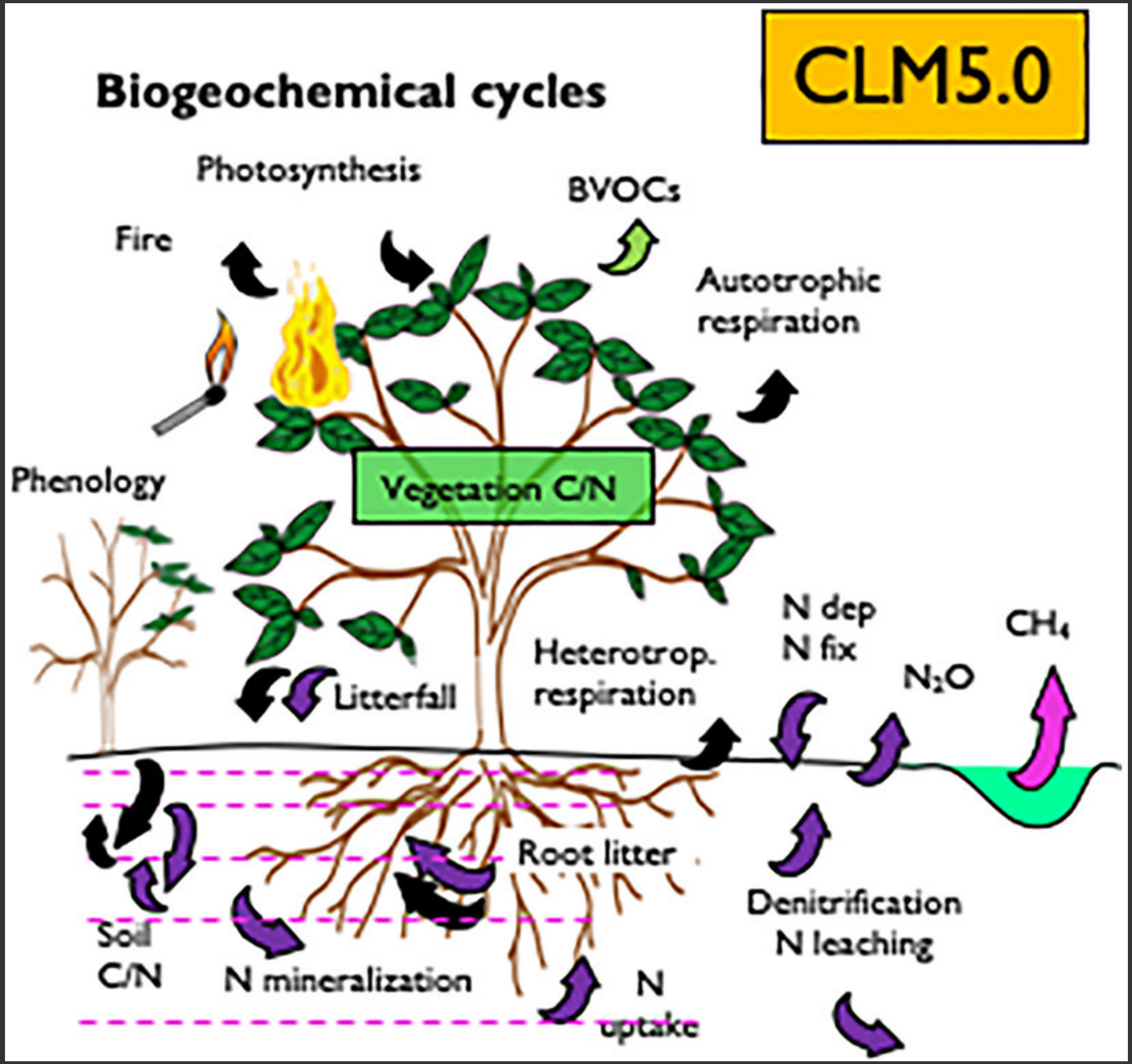








Lawrence et al 2019, JAMES
https://github.com/ESCOMP/ctsm



Leaves

- Farquhar Photosynthesis
- Medlyn Stomatal Conductance

Canopy

- Two stream approximation, sunlit / shaded

Allocation

- Respiration, leaves, wood, roots

Phenology

- mortality and turnover
- (e.g., evergreen, drought or stress deciduous)

Decomposition

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

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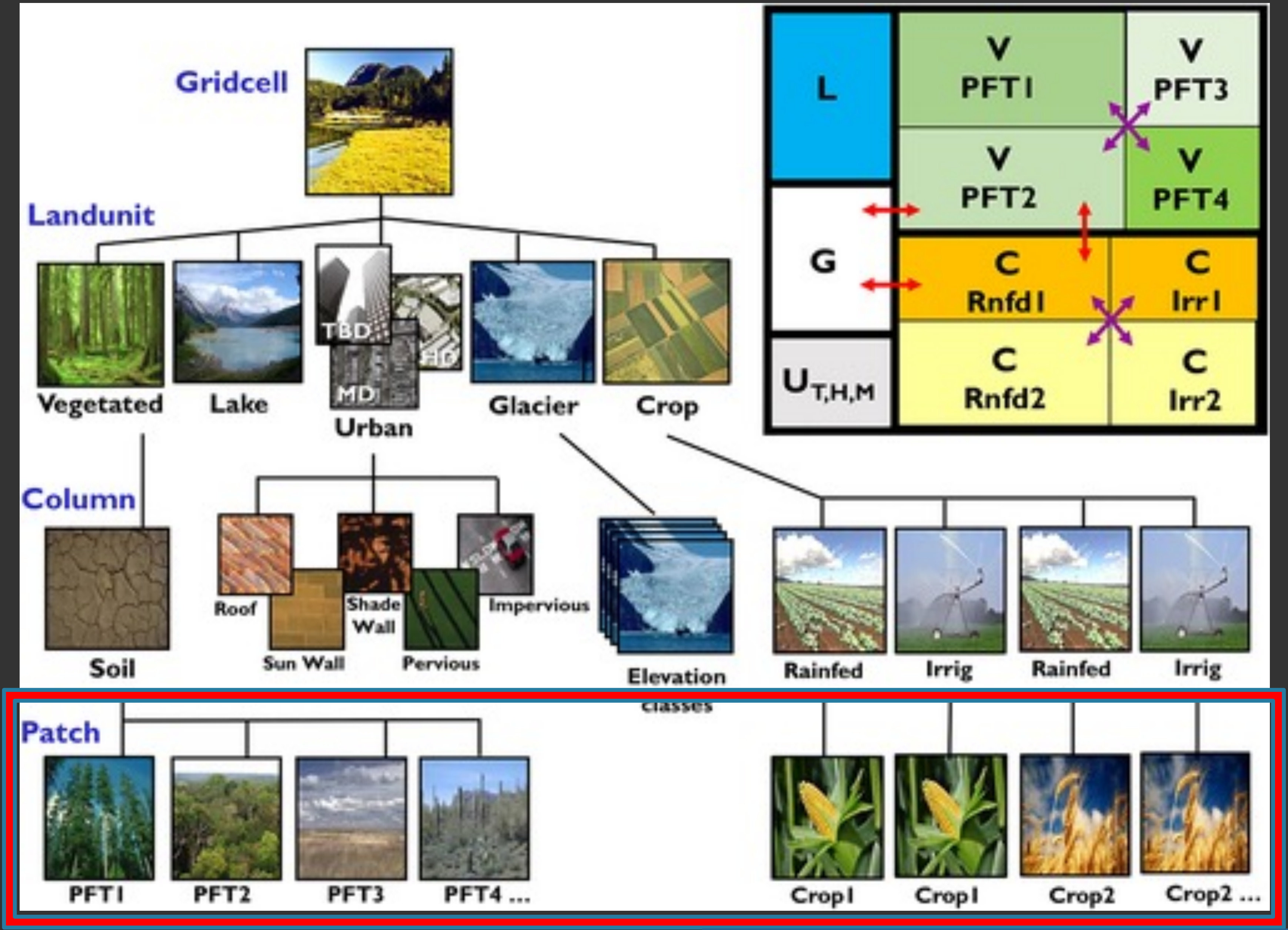

Lawrence et al 2019, JAMES
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Agriculture in CLM5

Agriculture in CLM5

Corn*

Wheat

Sugarcane

Soy*

Cotton

Rice

* Temperate and tropical varieties

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., Photosynthesis is co-limited by: light, energy, export of sugars

2. **Empirical relationships: From as large a sample of the real world as possible**

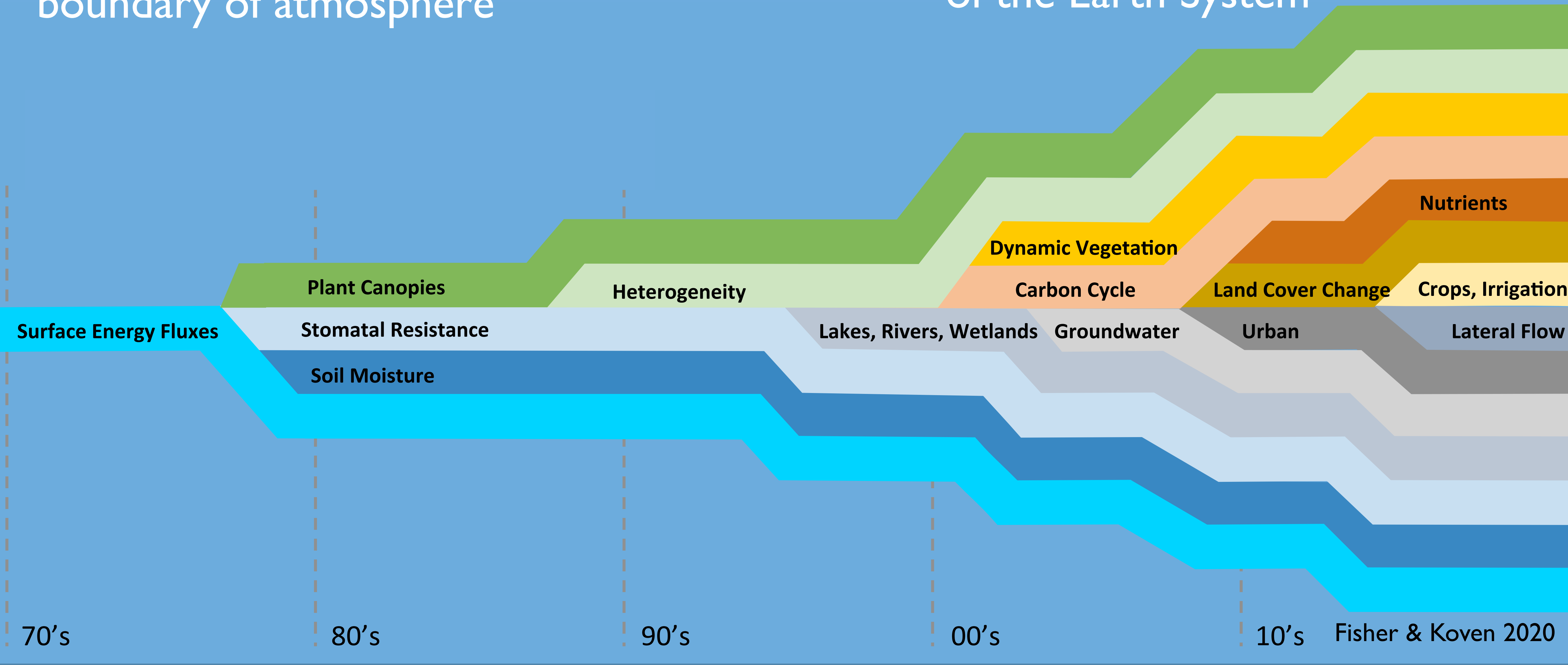
   e.g., TRY Database (Leaf N and dark respiration)

3. **Optimality theory: plants are rational actors, on average**

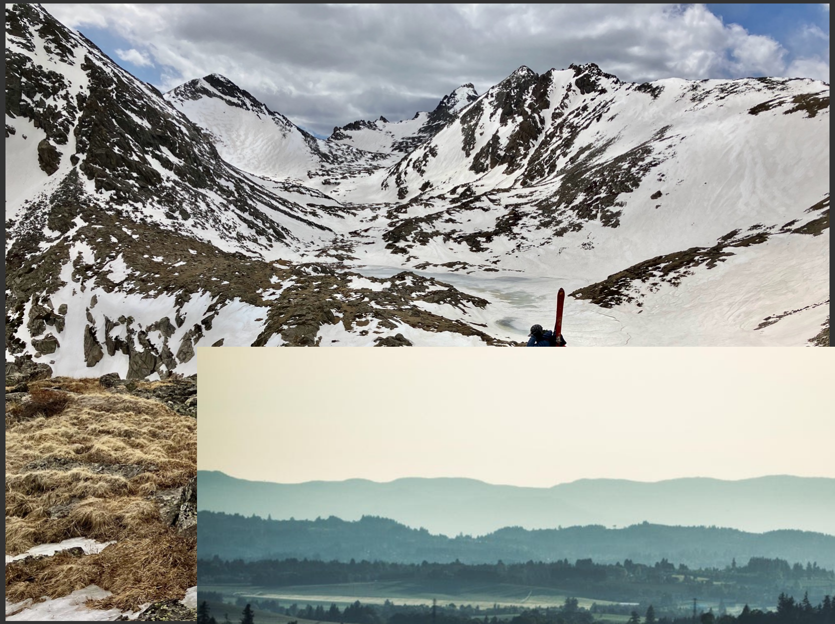
   e.g., FUN and LUNA modules

the Evolution of land modeling

Land as lower boundary of atmosphere → Land as an integral component of the Earth System



Land biogeochemistry in CESM?

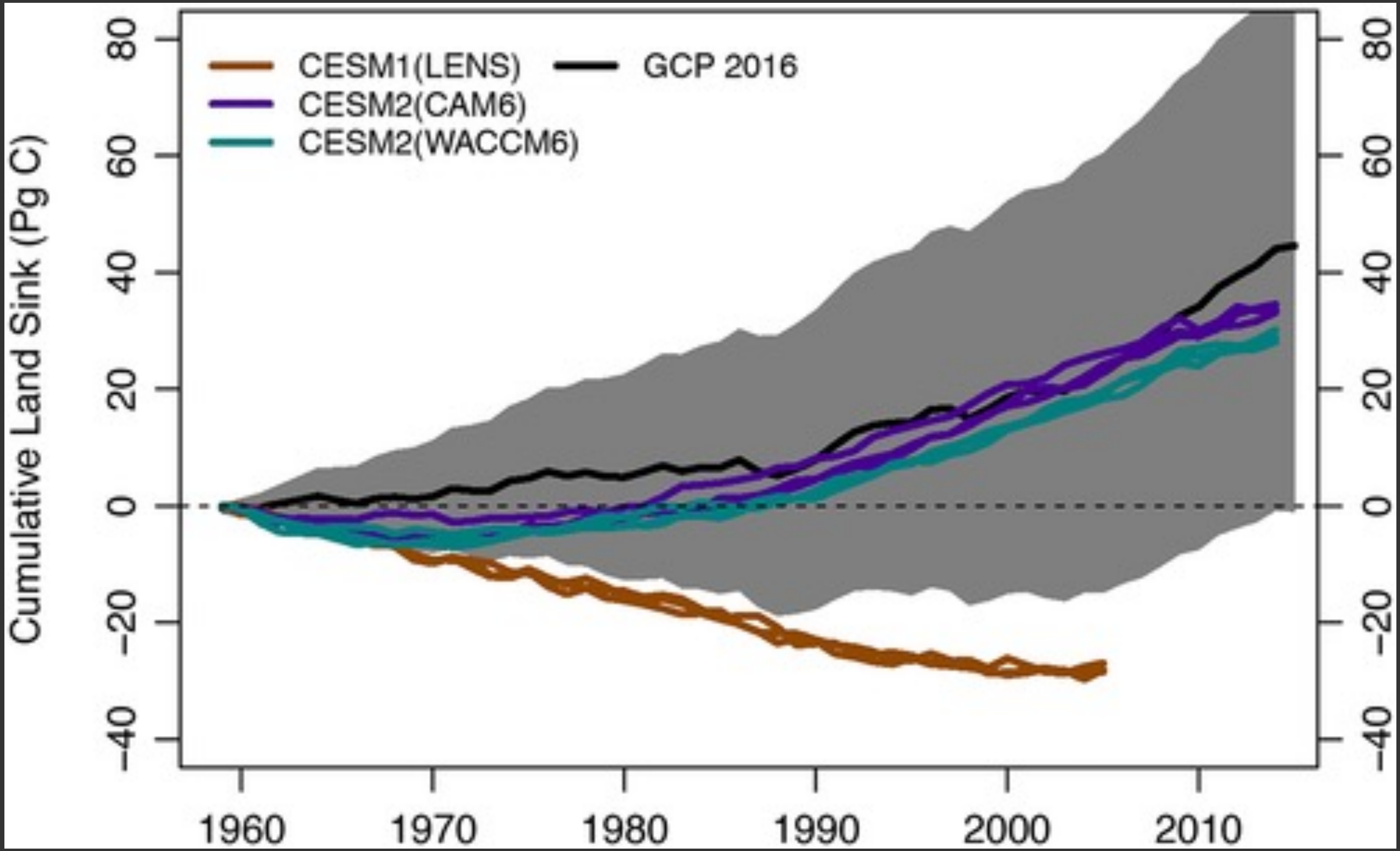


Why?

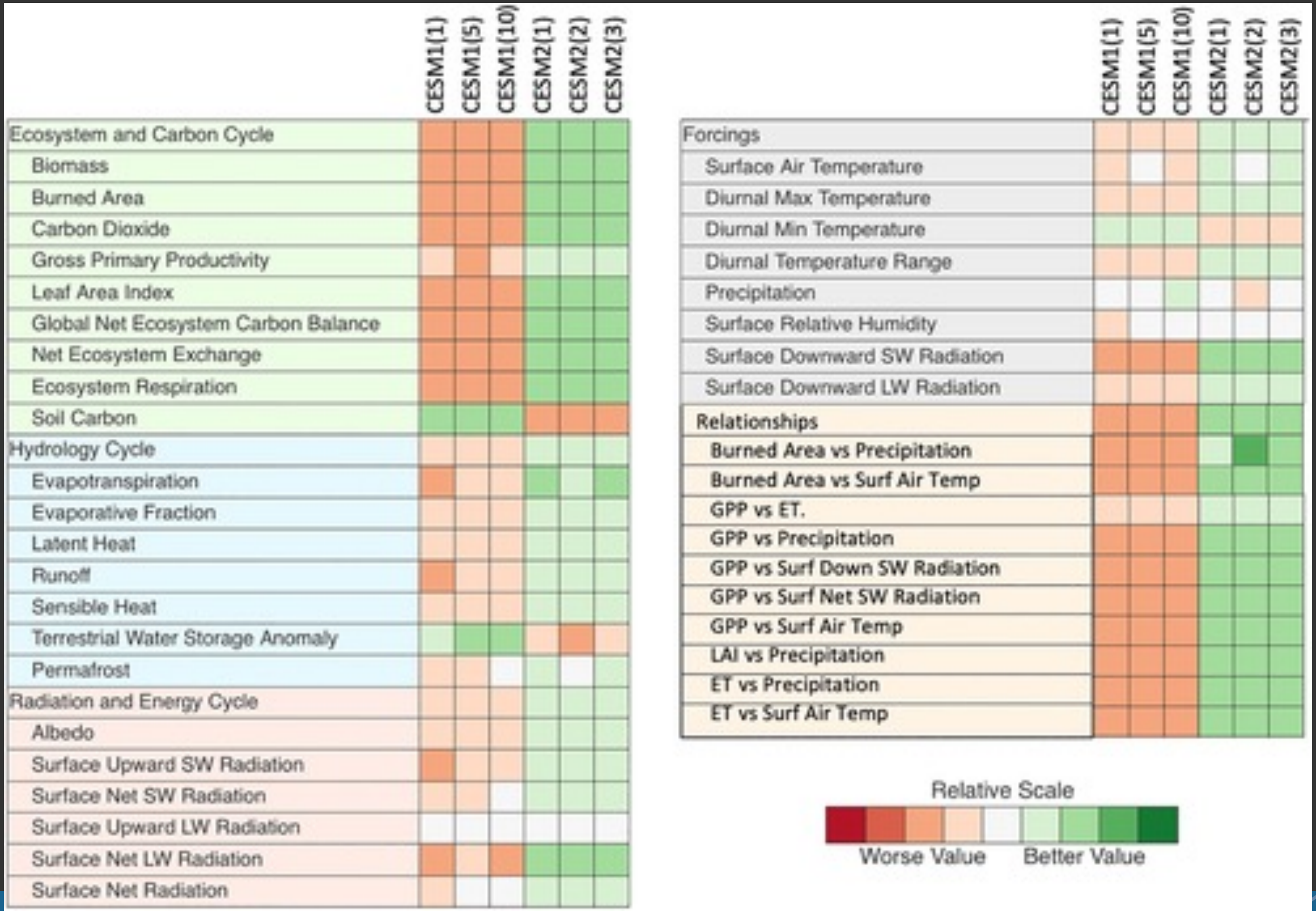
How?

Uncertainties and Future directions.

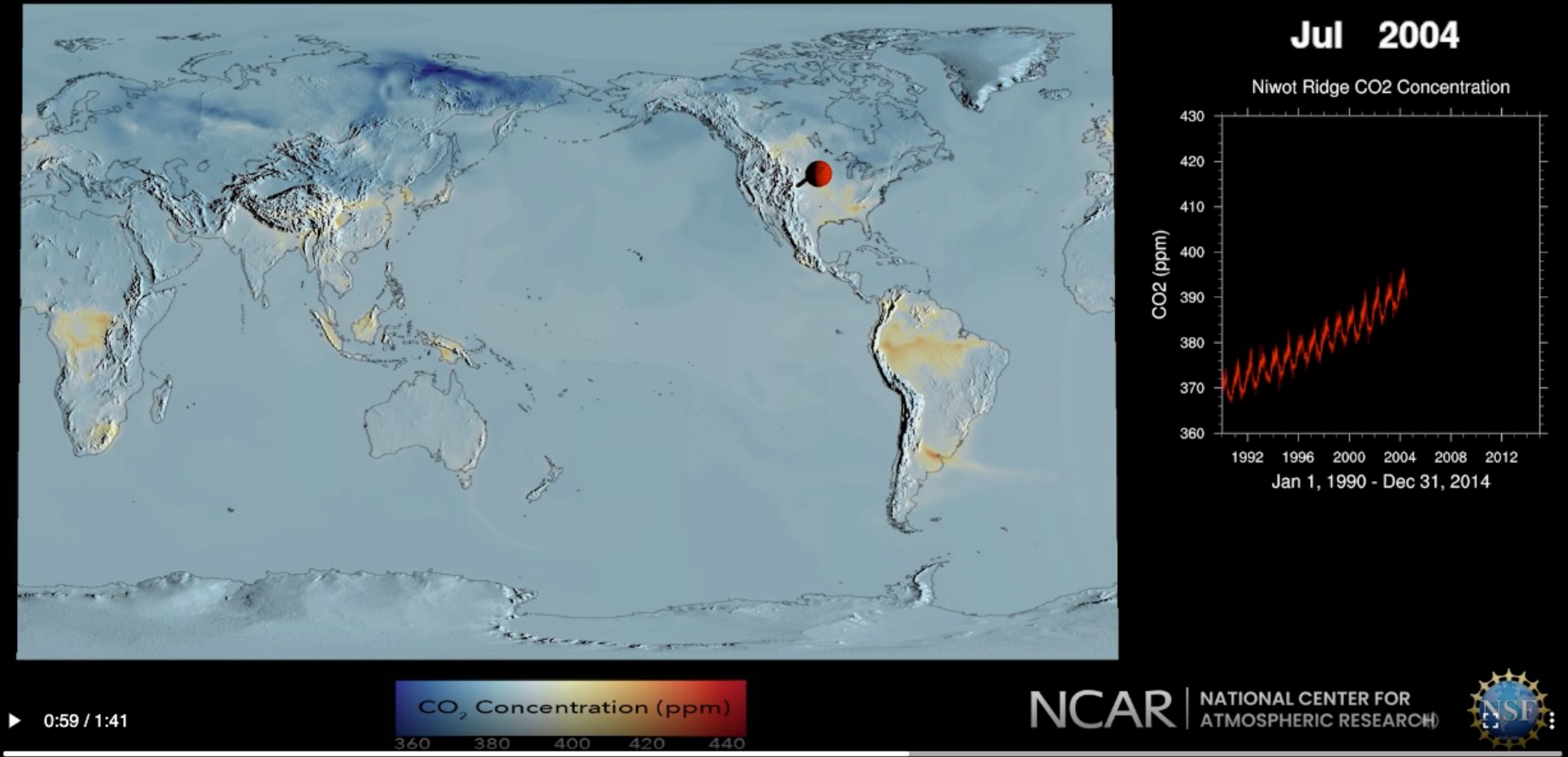
Represent land C sink!



Objectively ‘better’ carbon cycle



Atmospheric CO2 Simulated by CESM2



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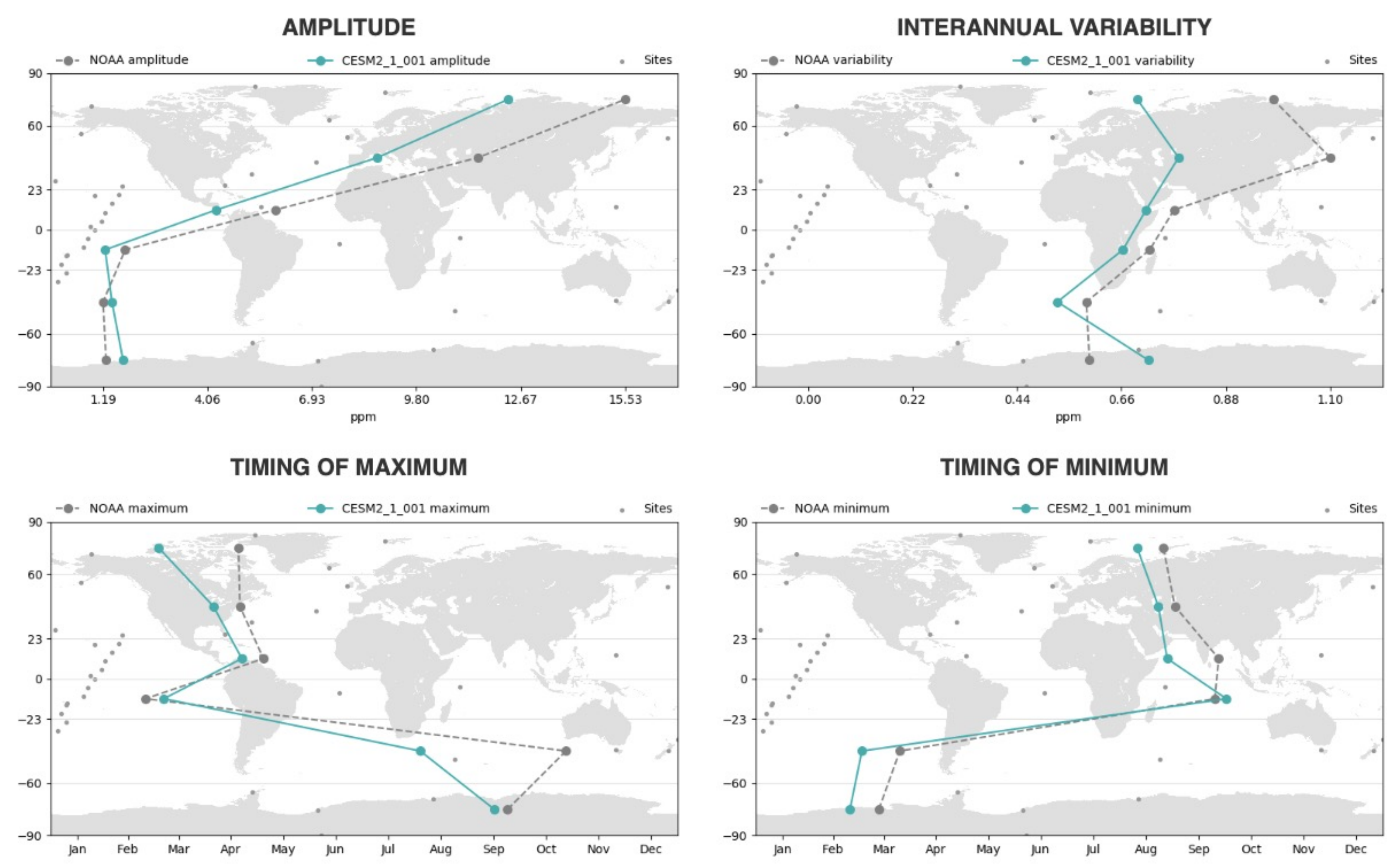

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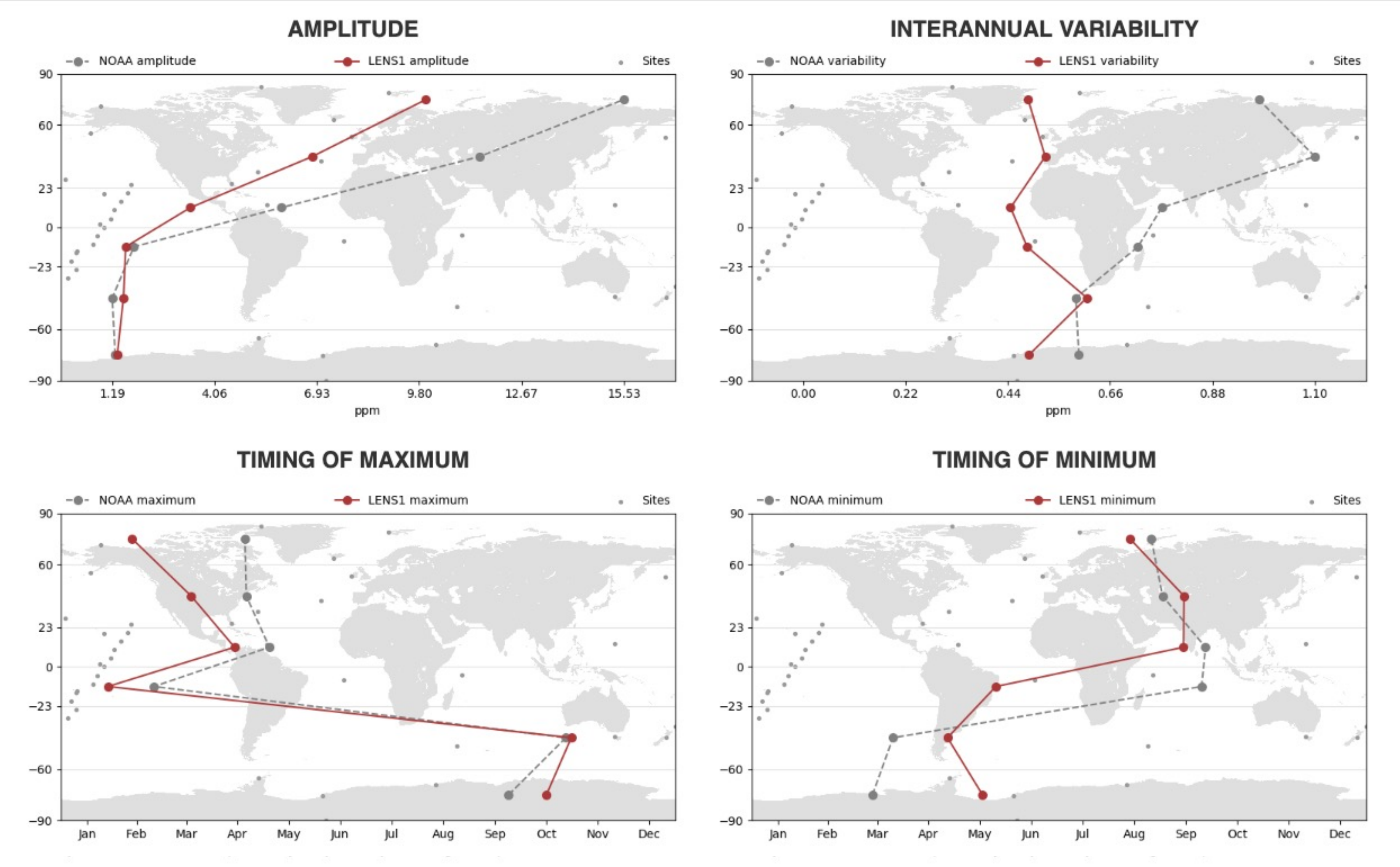
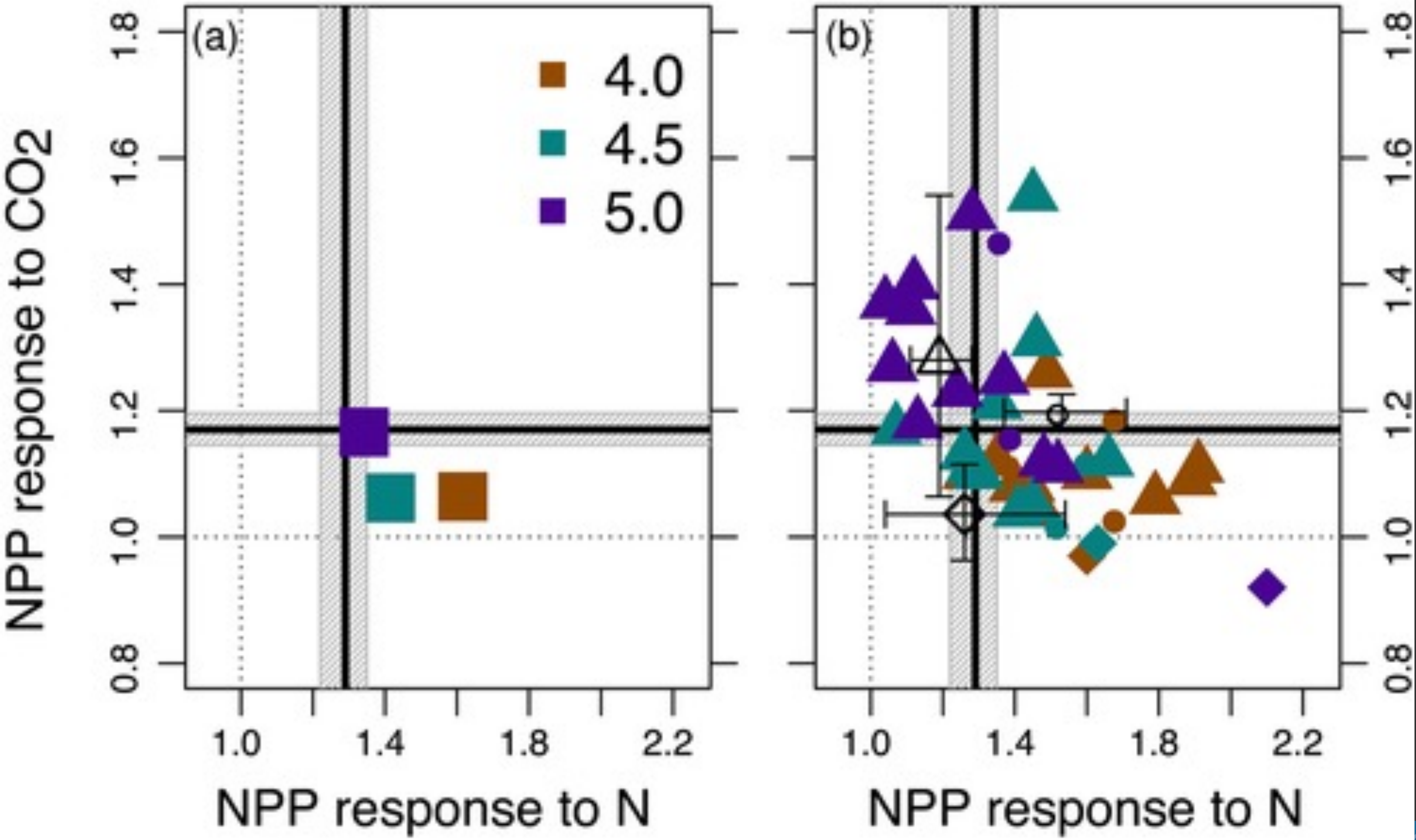


Objectively 'better' carbon cycle
For less wrong reasons



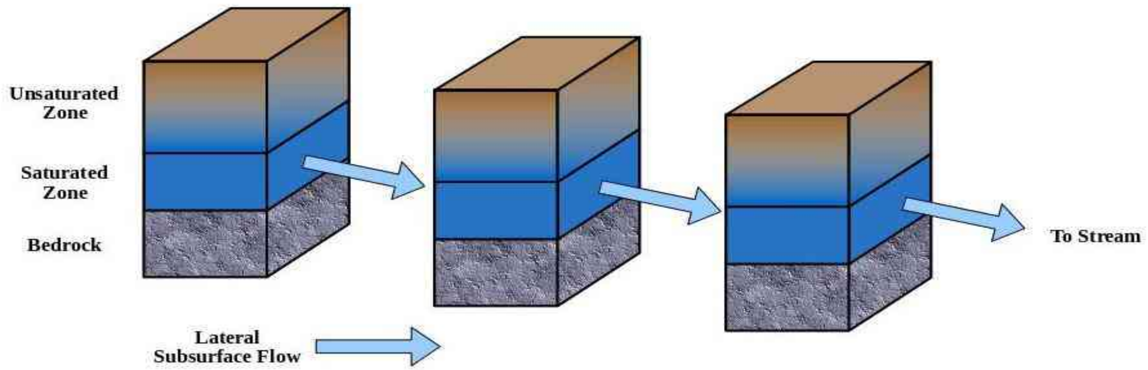
Wieder et al 2019 GBC

LMWG priorities for CESM3+

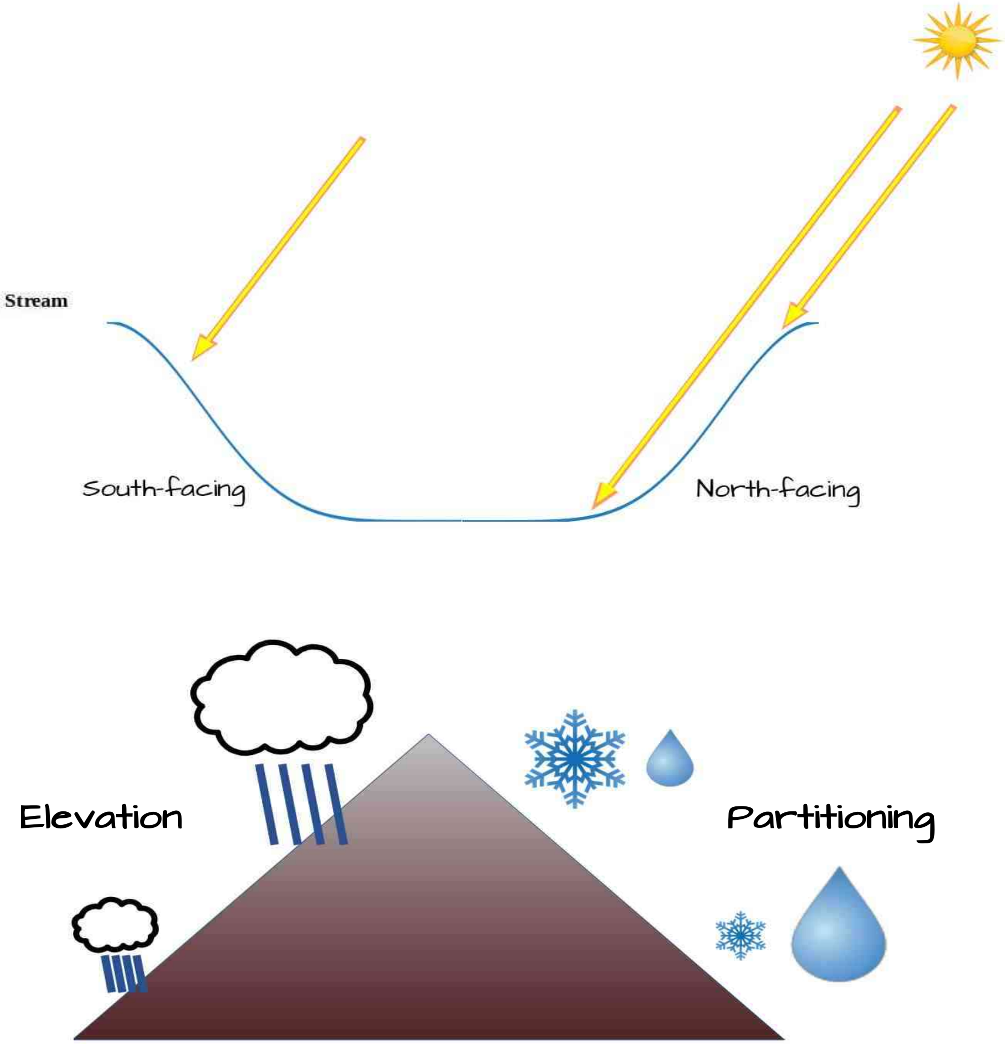
How do ecosystem function and vulnerabilities transform under climate change?

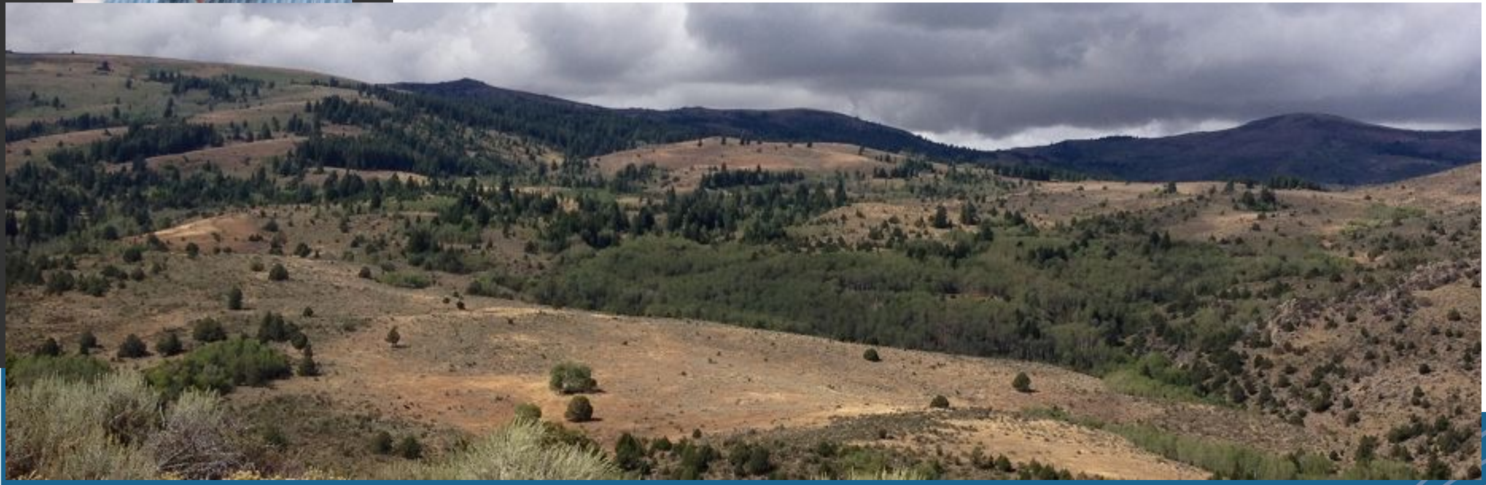
CTSM Representative Hillslope

Explicit Lateral Flow Within Gridcell



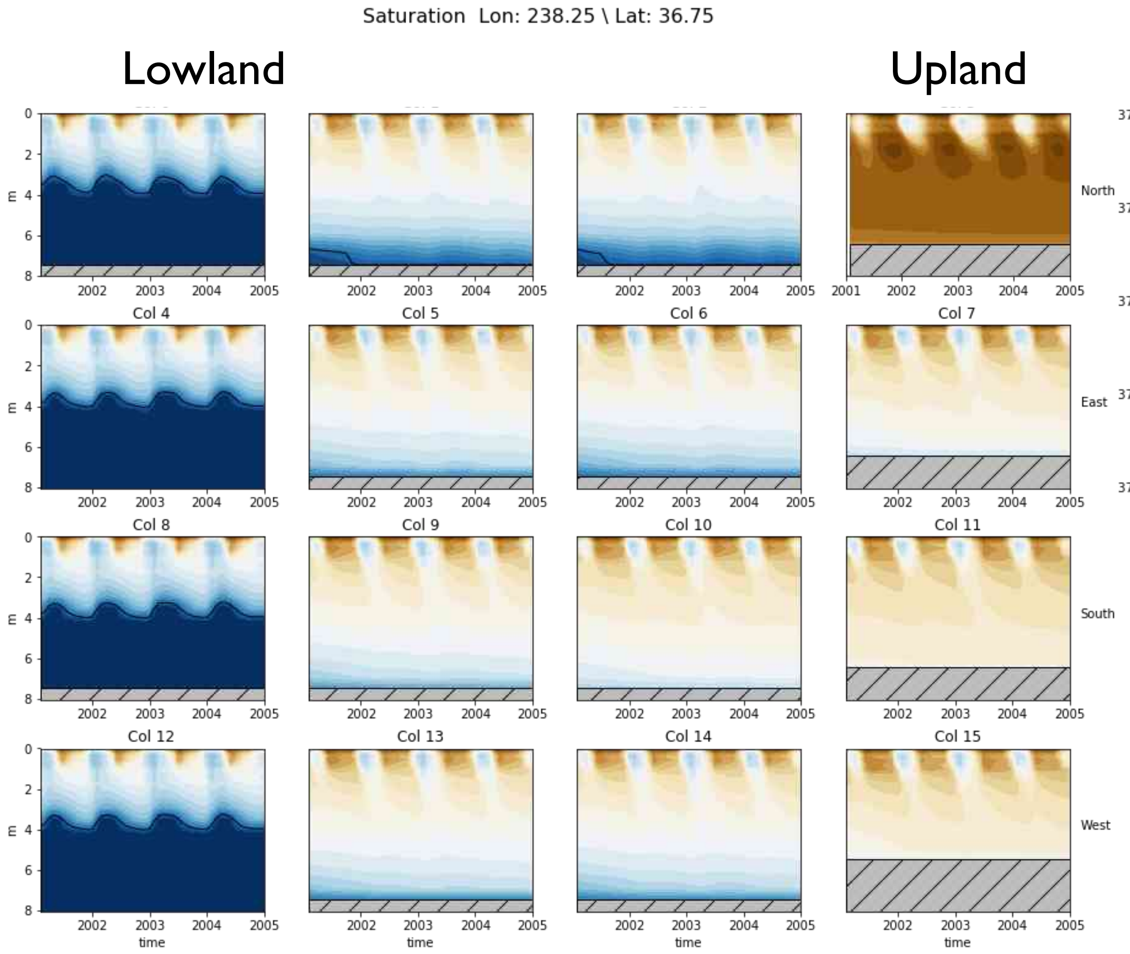
Downscaled Meteorology



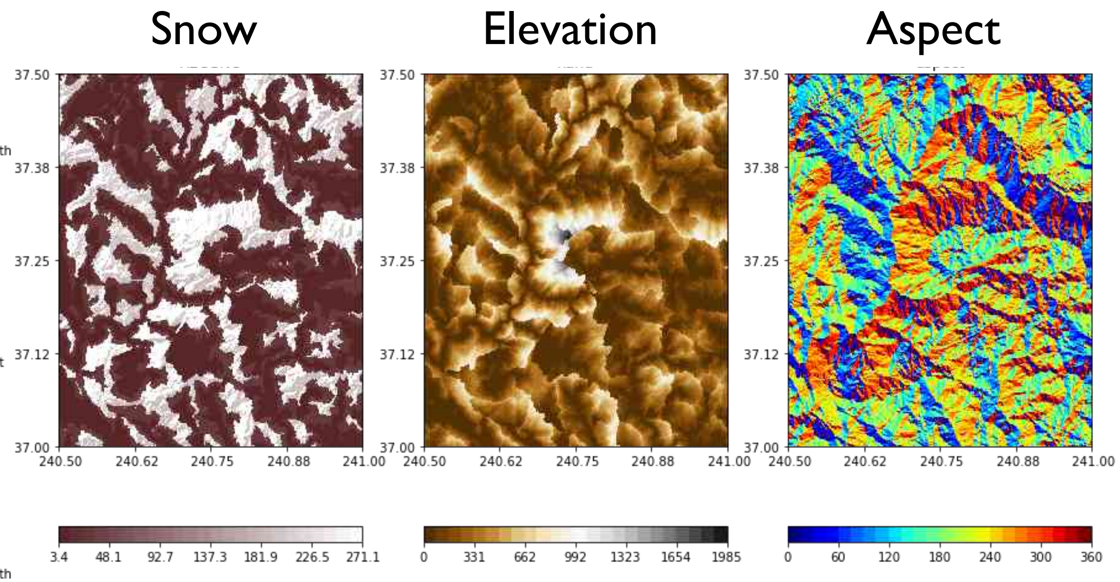


CTSM Representative Hillslope

Soil Moisture Heterogeneity



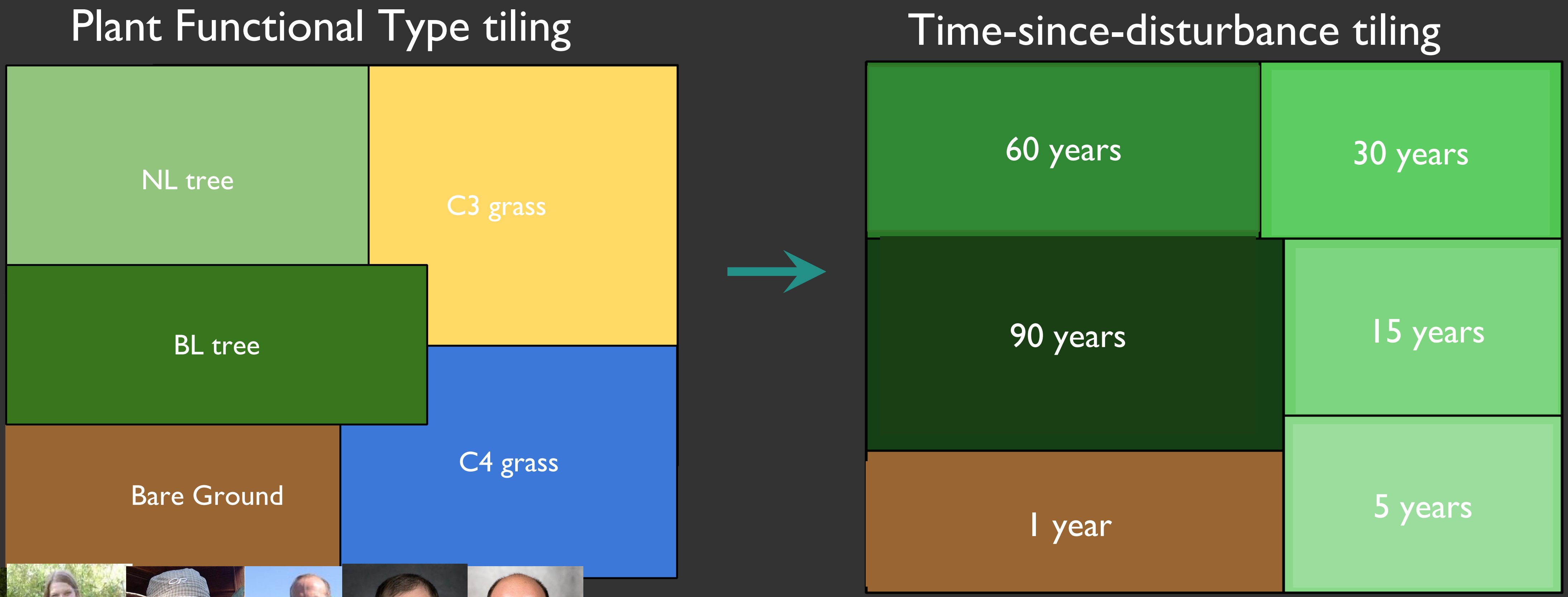
High Resolution Mapping of CTSM Hillslope Output



CTSM & FATES

Functionally Assembled Terrestrial Ecosystem Simulator (FATES)

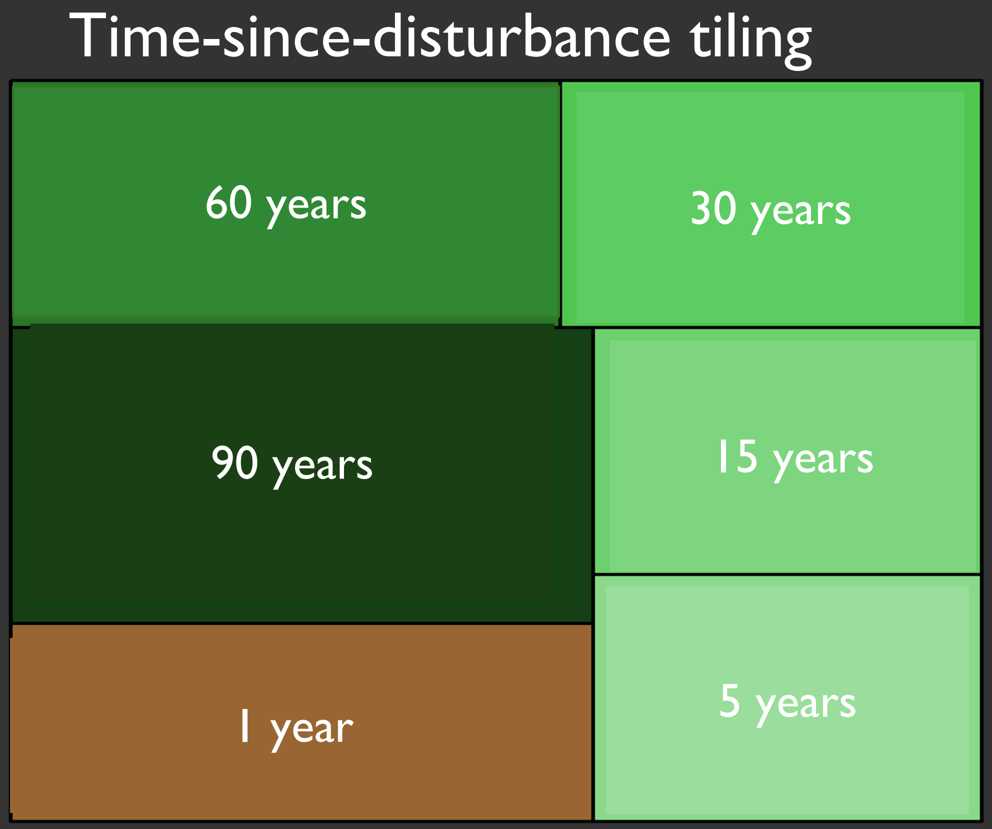
Vegetation structure in FATES

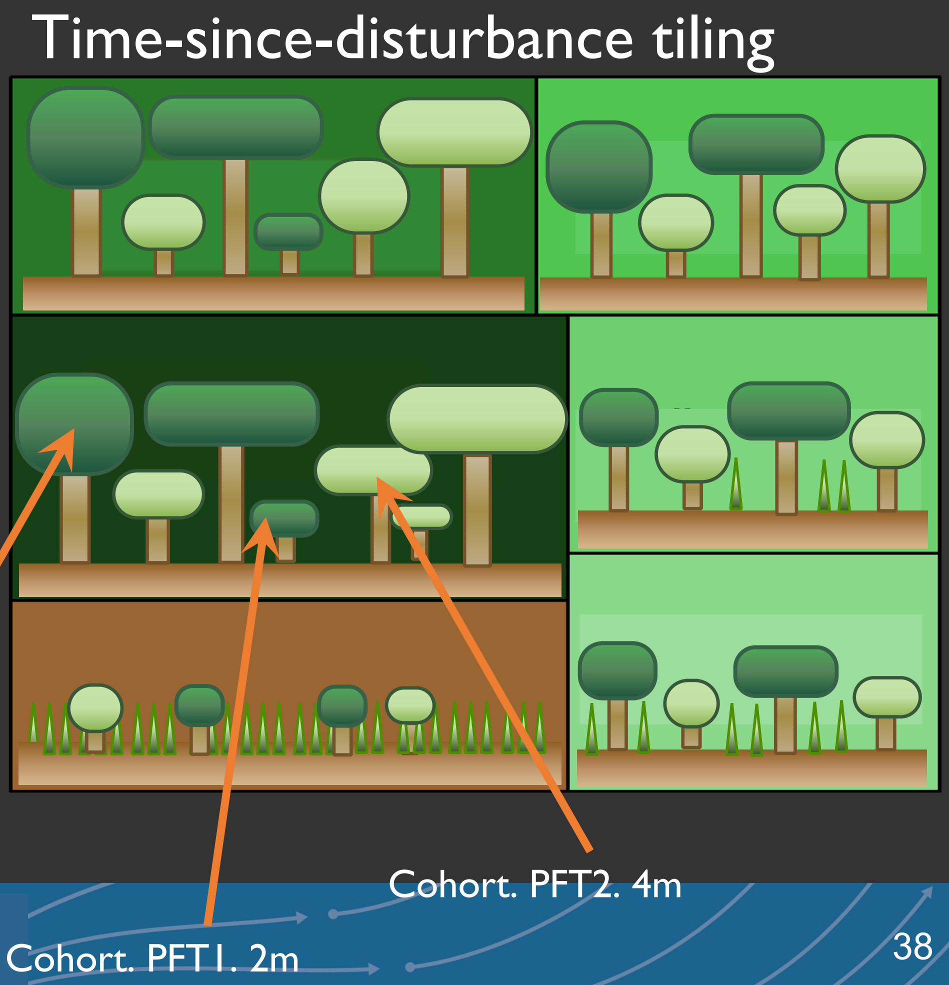


+ many more

CTSM & FATES

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

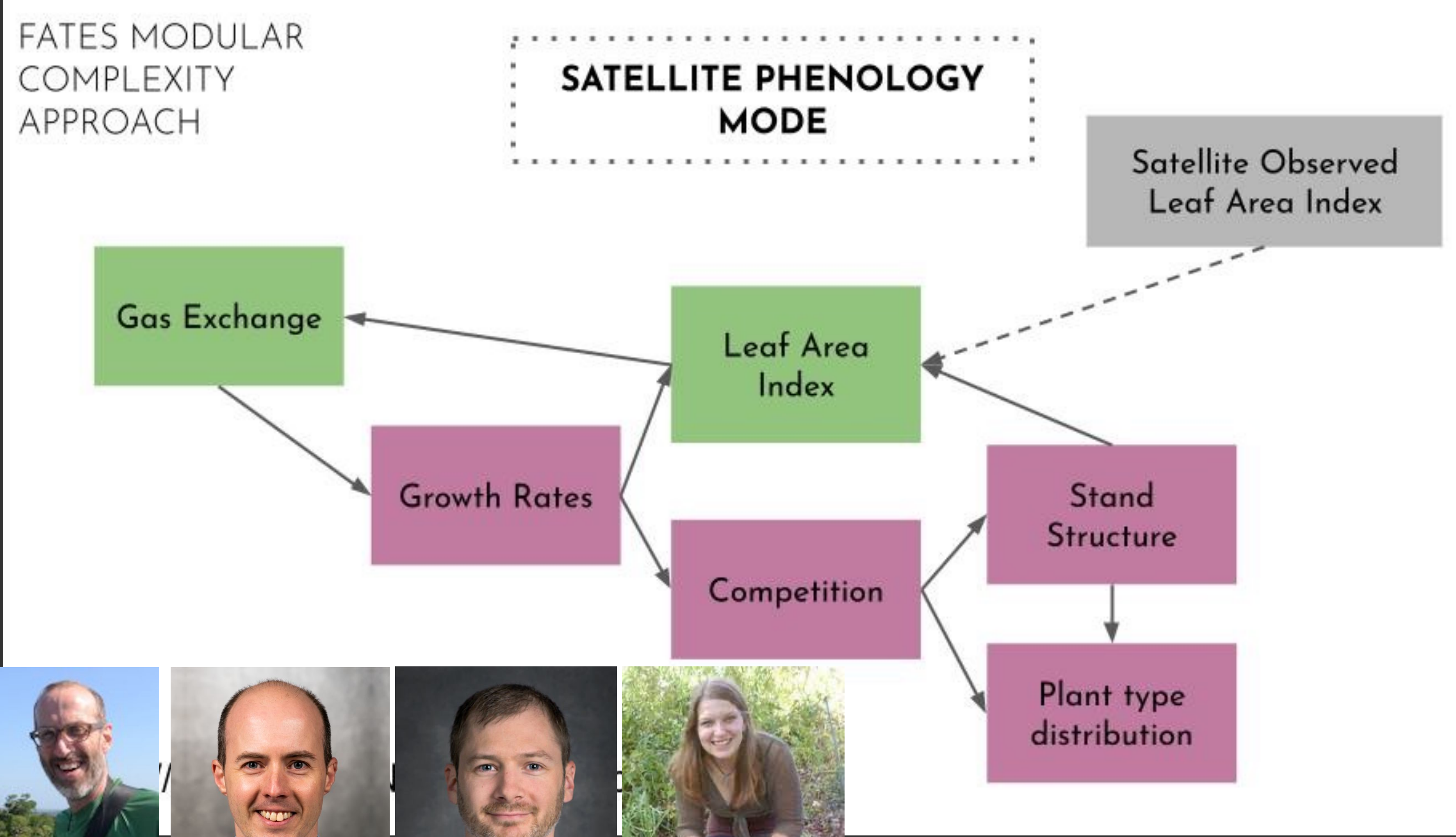




CTSM & FATES

More complexity
- Fire
- Nutrients
- Crown damage
- Hydraulic Stress
- Land Management

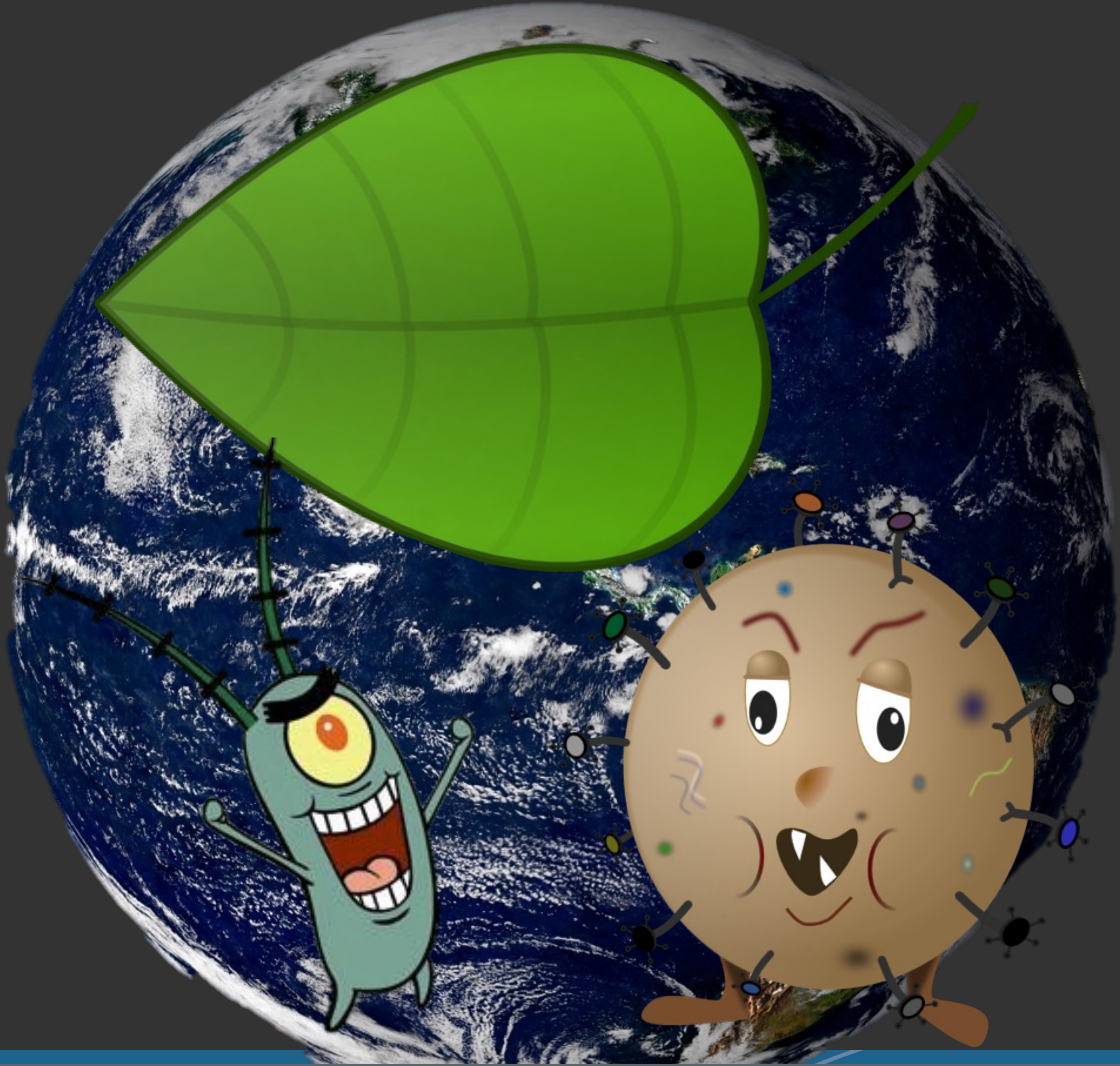
Reduced Complexity Modes
- Satellite Phenology
- No competition
- Fixed Biogeography
- Prescribed physiology



+ many more

CTSM & MIMICS

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).