GEO 827: Hyperspectral RS and Land Surface Model Benchmarking

November 10 & 12, 2015

Kyla Dahlin

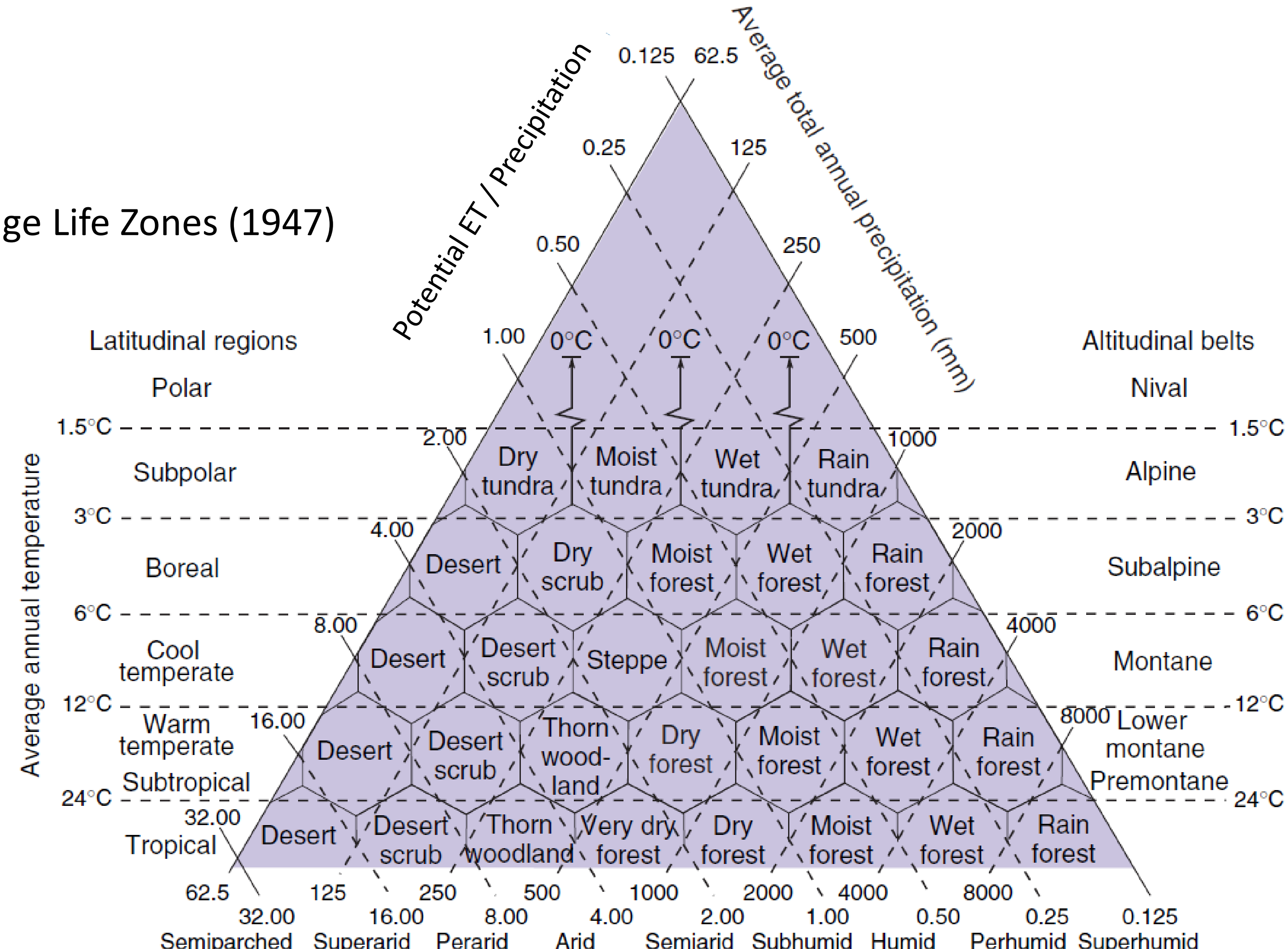
Assistant Professor, Geography Department

Outline for the next 2 days

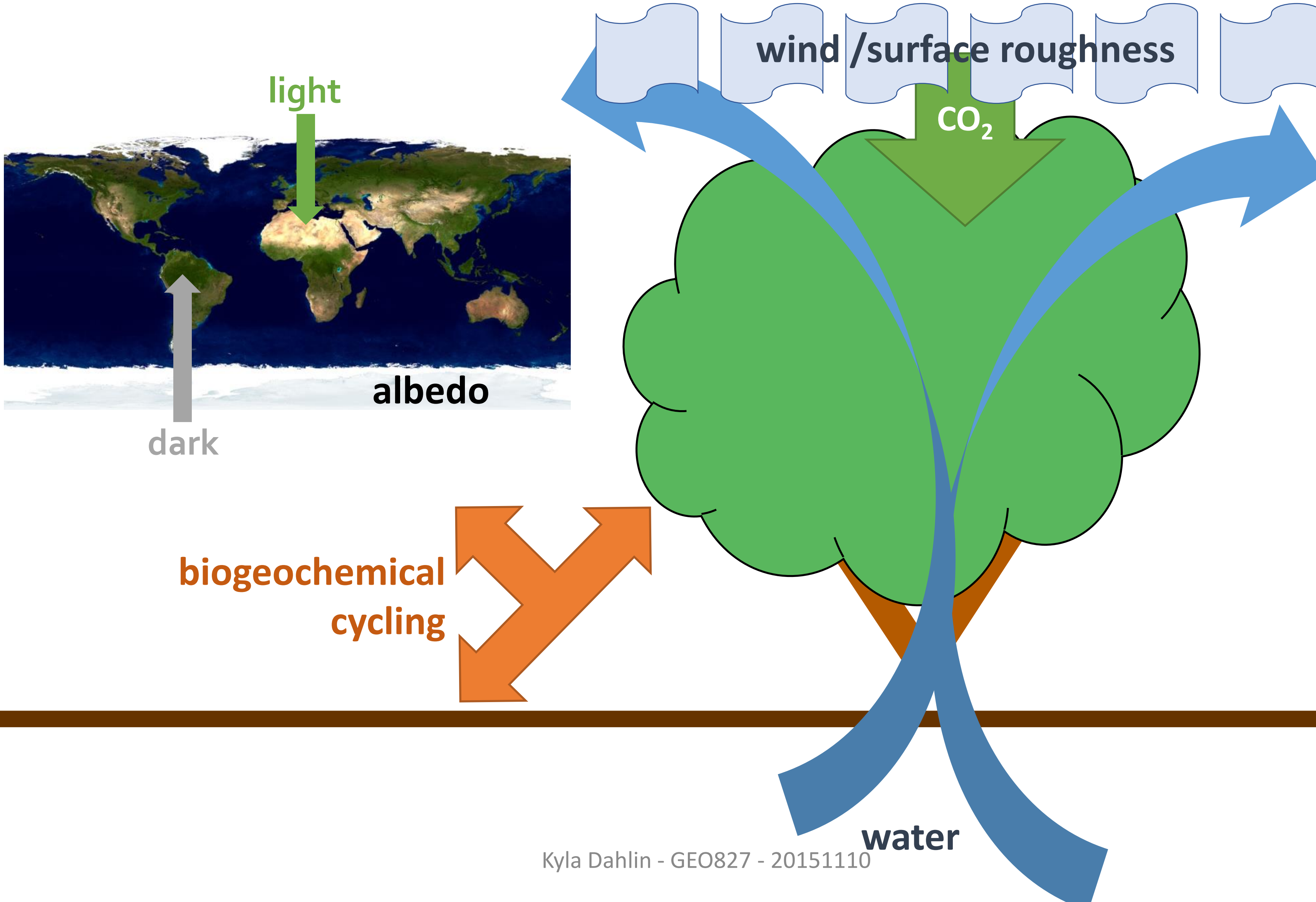
- Intro to Kyla
- Intro to Hyperspectral RS
- Project examples
- Lab – exploring imaging spectroscopy in ERDAS
- **Intro to Land Surface Models & Benchmarking**
- **Project example**
- **Lab – simple climate envelope modeling in R**

Climate and Plants

Holdridge Life Zones (1947)



Climate Change and Plants



History of Climate Change Research

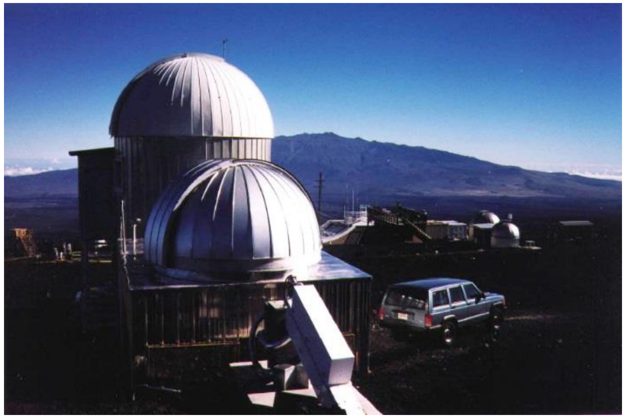
1824: Joseph Fourier figures out that the Earth's surface would be colder in the absence of an atmosphere ("Remarques generals sur les temperatures du globe terrestre et des espaces planetaires." *Annales de Chemie et de Physique* 27: 136-167)

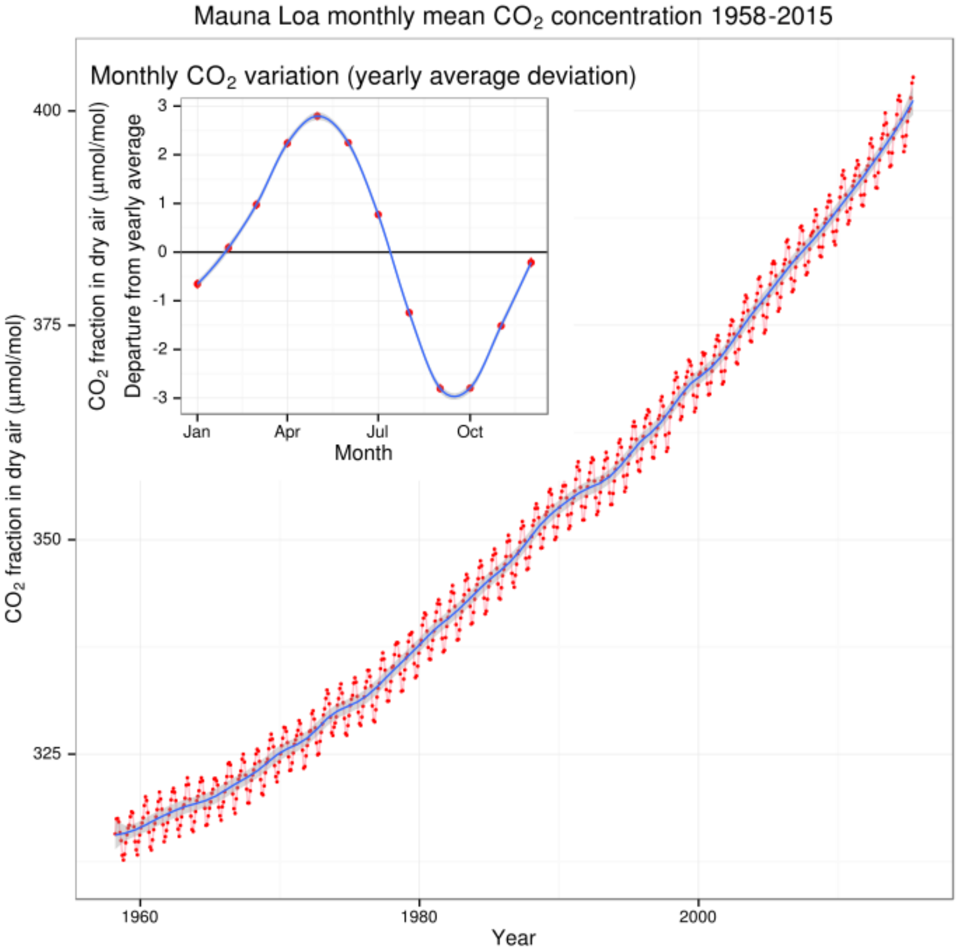
1861: John Tyndall discovers that water vapor, CO_2 & CH_4 trap heat, O_2 and N_2 do not. ("On the absorption and radiation of heat by gases and vapours…" *Philosophical Magazine* 4 & 22: 169-194, 273-285)

1896: Svante Arrhenius estimates that a doubling of atmospheric CO_2 will raise surface temperatures by 4^{o}C. ("On the influence of carbonic acid in the air upon the temperature of the ground." *Philosophical Magazine* 41: 237-276)

slide info from John Holdren AAAS Climate50

Mauna Loa Observatory





Current concentration = **398.29 ppm** (co2now.org)

Tans & Keeling NOAA

What are Climate Models?

- Gridded mathematical representations of the Earth System
- ~40 around the world
- HUGELY computationally expensive – run on supercomputers
- In the US there are 2 global climate models:
  - National Center for Atmospheric Research’s Community Earth System Model (CESM)
  - National Oceanic and Atmospheric Administration’s Geophysical Fluid Dynamics Lab’s ESM

What are Climate Models?

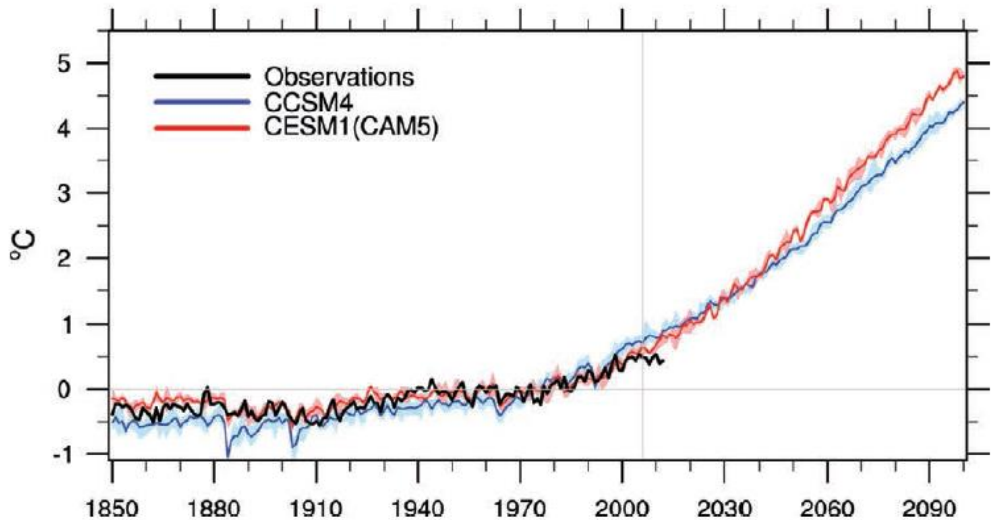
What are Climate Models?

- Operate with varying degrees of complexity in terms of
  - Spatial scale
  - Temporal scale (?)
  - Parts of the Earth system included
  - Processes included

What do people do with ESMs?

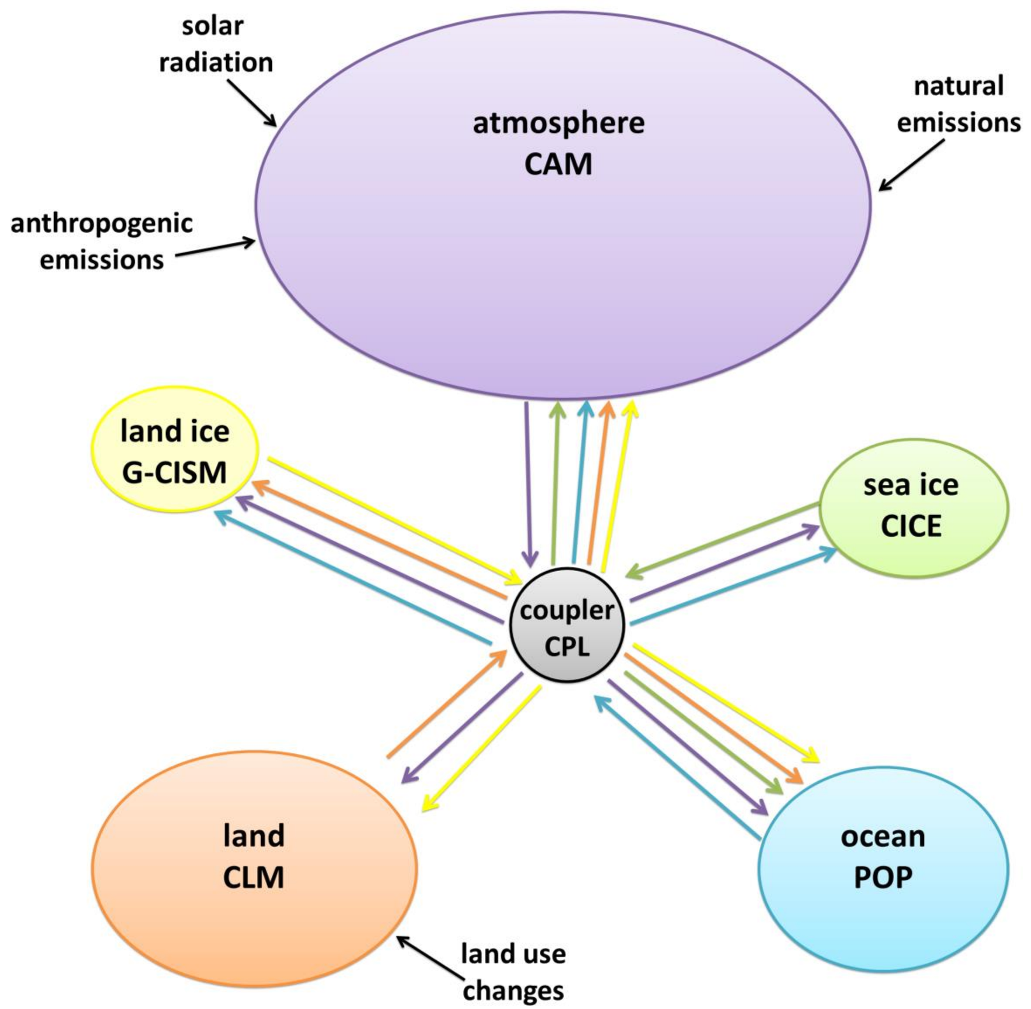
- Try to understand how the atmosphere works
- Try to understand how the oceans work
- Try to understand ocean-atmosphere interactions
- Try to understand how the land surface interacts with the atmosphere
- Try to understand land-ocean-atmosphere interactions
- Predict what the future planet will look like

NCAR's CESM



Hurrell et al 2013 (D2L)

NCAR's CESM



Alexander & Easterbrook 2011

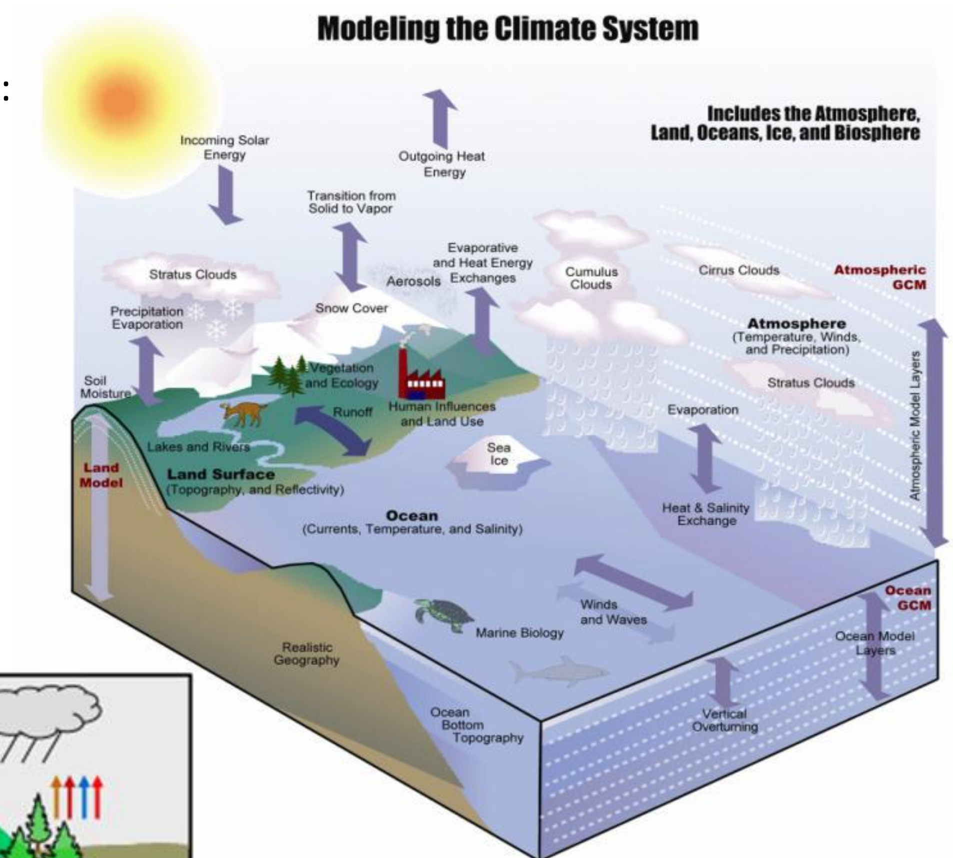
NCAR's Community Land Model (CLM)

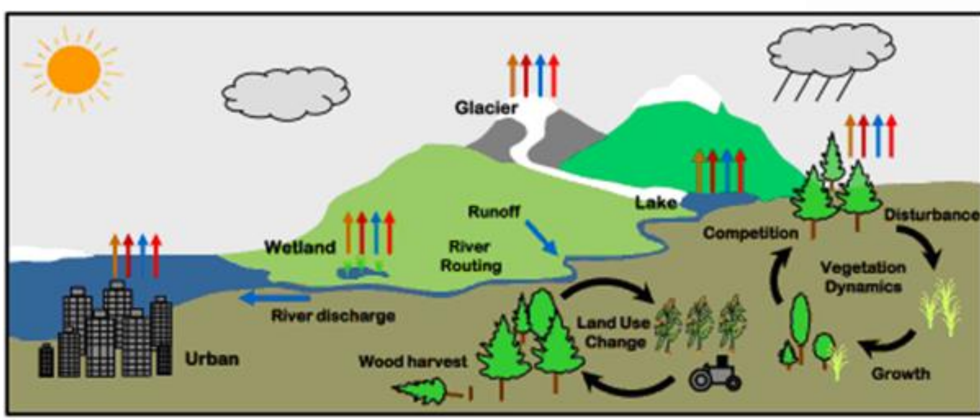
The land is a critical interface through which:

1. Climate and climate change impacts humans and ecosystems

and

2. Humans and ecosystems can force global environmental and climate change





slide from Dr. Peter Lawrence, NCAR

Land Surface in the Climate System

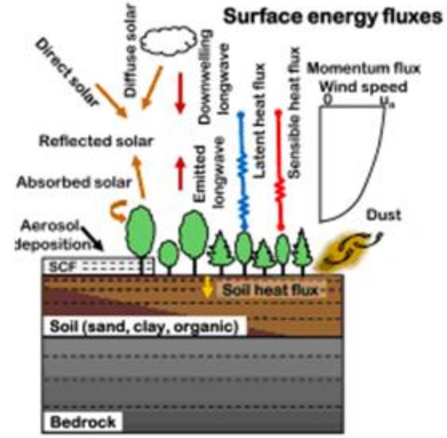
1. Surface Energy Fluxes:
- Solar Energy Fluxes (Albedo – Vegetation, Snow, Soils)
- Long Wave Energy Fluxes (Surface Temp & Emissivity)
- Latent Heat Fluxes (Transpiration, Evaporation)
- Sensible Heat Fluxes (Surface Temp & Roughness)

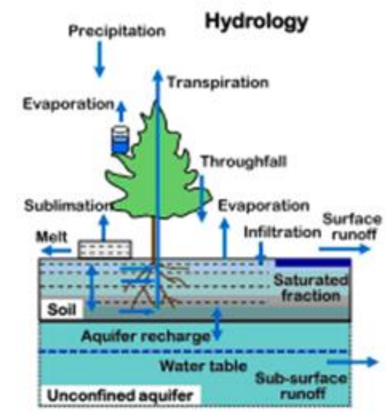
2. Surface Hydrology:
- Rain and Snow (Vegetation, Snow Pack, Runoff)
- Transpiration, Evaporation, Snow melt, Sublimation
- Soil Hydrology 10 Soil Layers in CLM (Richards Eqns)
- Deep Aquifer recharge and drainage (Top Model)

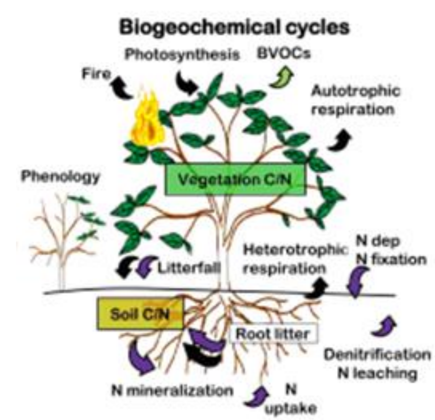
3. Biogeochemistry (Carbon and Nitrogen Cycles):
- Plant Photosynthesis and Respiration

$$6\ CO_2 + 6\ H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

- Carbohydrates are allocated to Leaves, Roots, Wood
- Leaves, roots and wood become litter, debris, soil C
- Organic decomposition and fire remove carbon
- Nitrogen is cycled impacting growth and decay

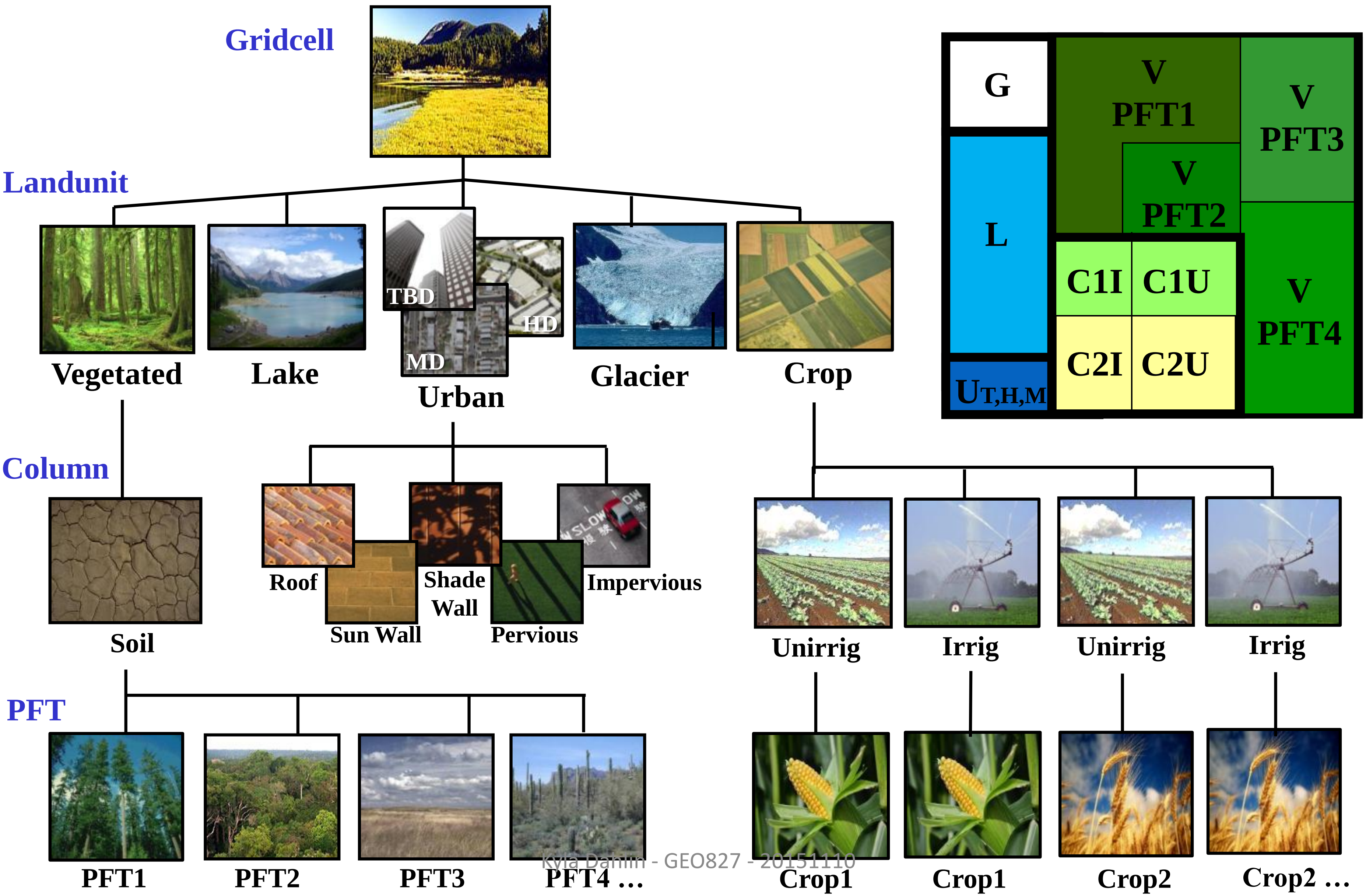






slide from Dr. Peter Lawrence, NCAR

Community Land Model (CLM 4.5) subgrid tiling structure



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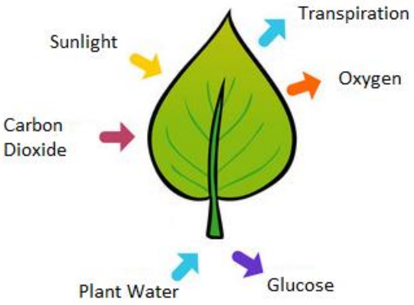
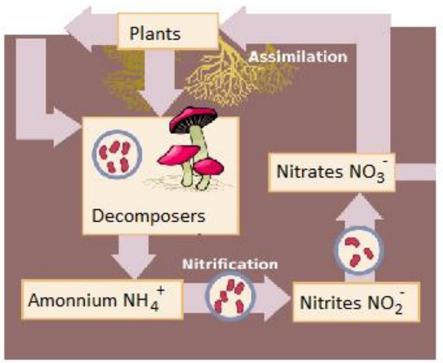
CLM Vegetation Modeling Leaf to Landscape Processes

1. CLM Photosynthesis, Respiration and Transpiration
Traits, Sunlight, CO_2, Temperature, Water and Nitrogen



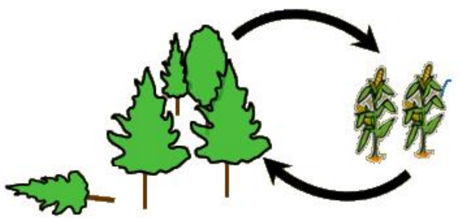
2. Carbon Allocation for Leaf, Stem and Root growth from
Photosynthesis, Nitrogen availability and Phenology

3. Soil Hydrology, Soil and Litter Carbon and Nitrogen Cycles,
and Heterotrophic Respiration



4. Land Cover Change, Wood Harvest, Mortality and Fire

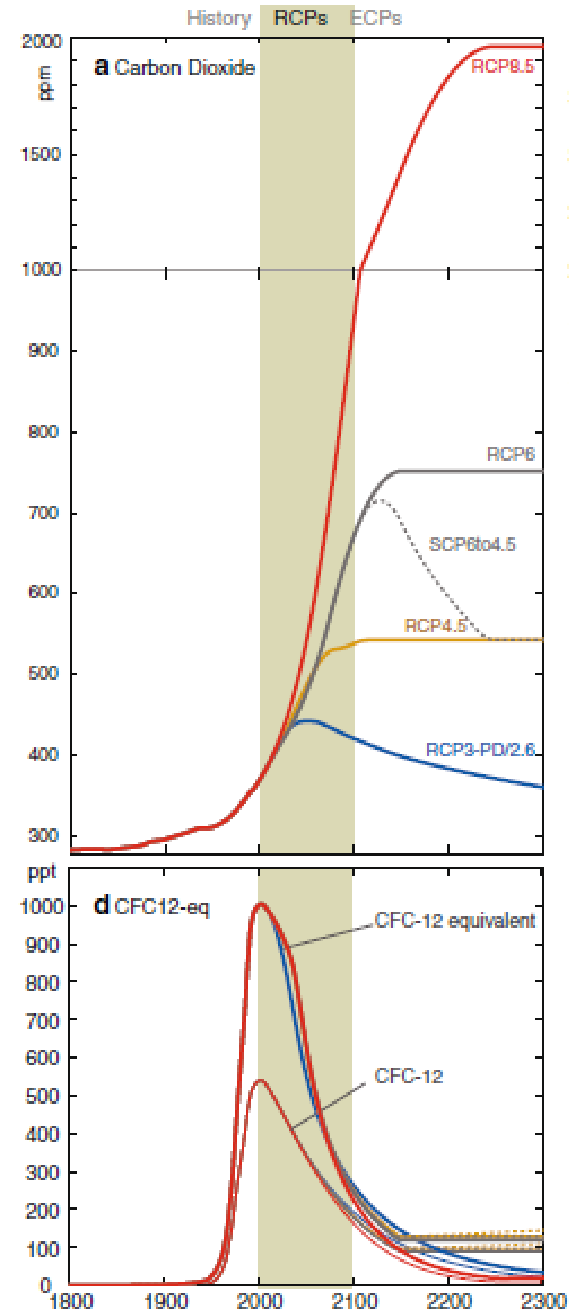
5. Crop modeling with Planting, Fertilizer, Irrigation,
Grain fill and Harvest



slide from Dr. Peter Lawrence, NCAR

What about the future?

- Representative Concentration Pathways (RCPs) = possible future conditions. (Meinshausen et al 2011 on D2L)
- Lots of decisions go in to these projections!
- We care about 2:
  - RCP8.5 = worst case (also "business as usual")
  - RCP4.5 = medium case (hopefully we get some stuff figured out soon!)



What is Benchmarking?

Global Change Biology

Global Change Biology (2009) **15**, 2462–2484, doi: 10.1111/j.1365-2486.2009.01912.x

Systematic assessment of terrestrial biogeochemistry in coupled climate–carbon models

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307 McCone, Mail Code 4767, University of California, Berkeley, CA 94720, USA

Abstract

With representation of the global carbon cycle becoming increasin
models, it is important to develop ways to quantitatively evalua
against *in situ* and remote sensing observations. Here we prese

onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2009.01912.x/pdf

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www.biogeosciences.net/10/3313/2013/
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Biogeosciences
Open Access

A comprehensive benchmarking system for evaluating global vegetation models

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Revised: 5 March 2013 – Accepted: 7 March 2013 – Published: 17 May 2013

Abstract. We present a benchmark system for global vegetation models. This system provides a quantitative evaluation of multiple simulated vegetation properties, including primary production; seasonal net ecosystem production; vegetation cover; composition and height; fire regime; and runoff. The benchmarks are derived from remotely sensed gridded datasets and site-based observations. The datasets al- demonstrably more accurately. Benchmarking also identified several weaknesses common to both DGVMs. The benchmarking system provides a quantitative approach for evaluating how adequately processes are represented in a model, identifying errors and biases, tracking improvements in performance through model development, and discriminating among models. Adoption of such a system would do much

biogeosciences.net/10/3313/2013/bg-10-3313-2013.pdf

Also see: biogeosciences.net/9/3857/2012/bg-9-3857-2012.pdf

What is Benchmarking?

2470 J. T. RANDERSON *et al.*

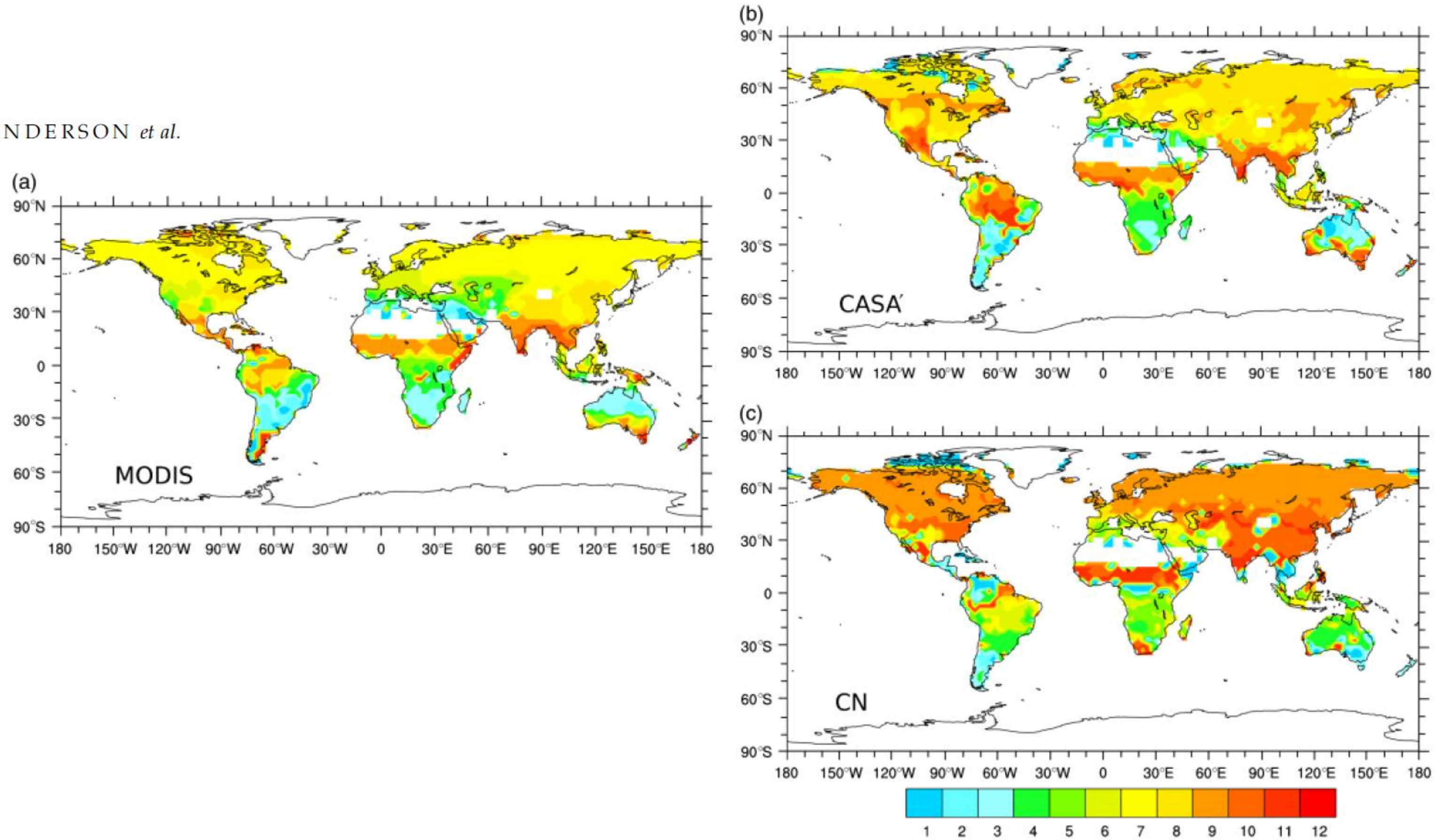
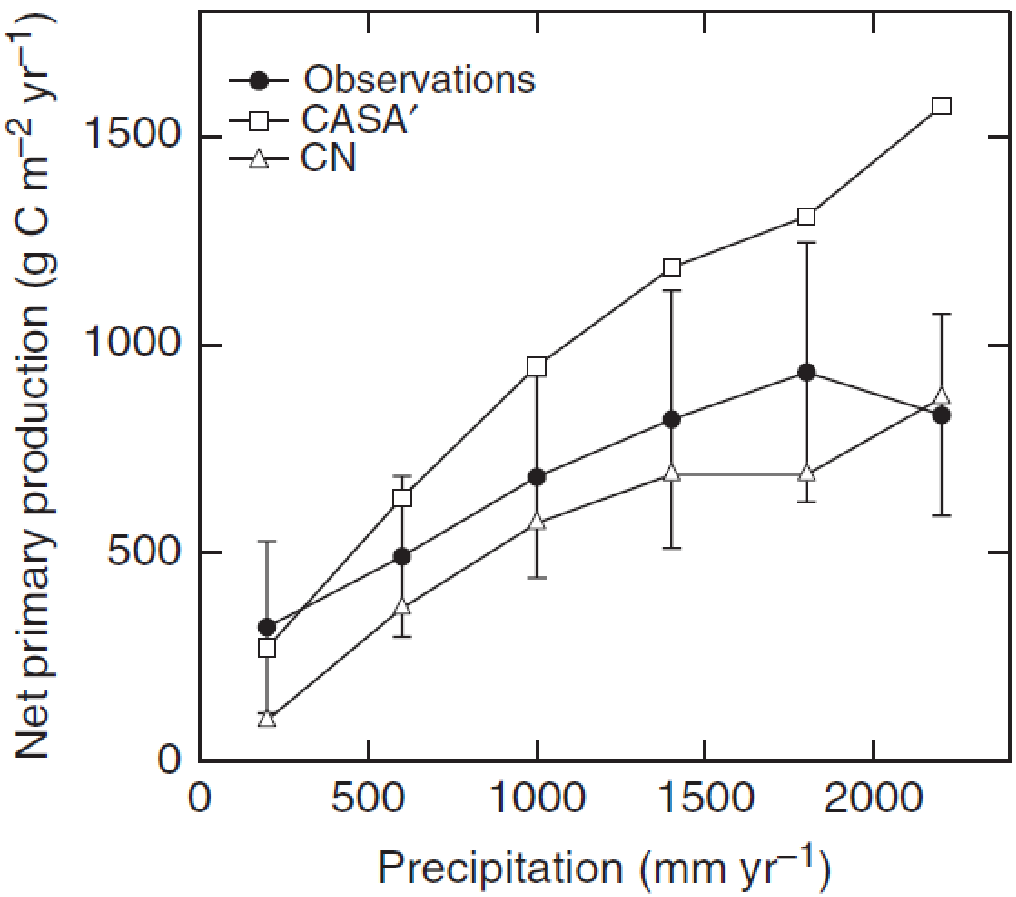


Fig. 1 Month of maximum leaf area index from (a) MODIS, (b) CASA′, and (c) CN. The observations are from the MOD15A2 collection 4 LAI product from MODIS (Myneni *et al.*, 2002) with additional adjustments to interpolate across periods of cloud contamination as described by Zhao *et al.* (2005). CASA, Carnegie-Ames-Stanford Approach; CN, carbon–nitrogen; LAI, leaf area index; MODIS, MODerate Resolution Imaging Spectroradiometer.

onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2009.01912.x/pdf

What is Benchmarking?



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What is Benchmarking?

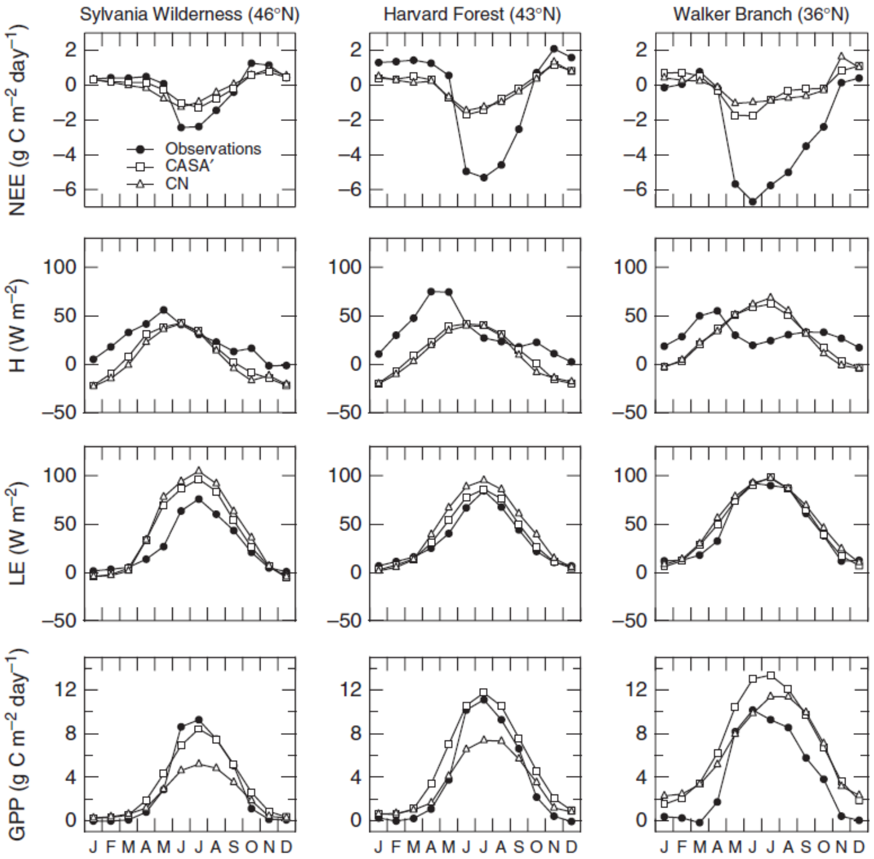

Fig. 4 Comparison of model estimates with eddy covariance measurements from Sylvania Wilderness (Desai *et al*., 2005), Harvard Forest (Barford *et al*., 2001), and Walker Branch (Wilson & Baldocchi, 2001) sites from the Ameriflux network. Level 4 gap-filled measurements from all available years were used to construct monthly means. Model information was extracted from experiment 1.4 for the same periods.

onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2009.01912.x/pdf

What is Benchmarking?

Lots of decisions to make…

- What variable(s)?
- What time scale?
- Spatial? (map? Zonal means?)
- Point?
- One number or multiple?

What is Benchmarking?

www.ilamb.org

ILAMB
THE INTERNATIONAL LAND MODEL BENCHMARKING PROJECT

HOME | BENCHMARKS | RESULTS & DIAGNOSTICS | MEETINGS | PUBLICATIONS | ABOUT

Meeting in January 2011

The last ILAMB Meeting was held in Irvine, California, USA, on 24–26 January 2011. Sponsored by the U.S. Department of Energy, NASA, and IGBP-AIMES, More...

Summary of UK Meeting

Summaries from the first ILAMB Meeting, held in Exeter, UK, are available here. The 22–24 June 2009, meeting was sponsored by QUEST and GLASS.

Welcome to ILAMB!

The International Land Model Benchmarking (ILAMB) project is a model-data intercomparison and integration project designed to improve the performance of land models and, in parallel, improve the design of new measurement campaigns to reduce uncertainties associated with key land surface processes. Building upon past model evaluation studies, described below, the goals of ILAMB are to:

1. develop internationally accepted benchmarks for land model performance,
2. promote the use of these benchmarks by the international community for model intercomparison,
3. strengthen linkages between experimental, remote sensing, and climate modeling communities in the design of new model tests and new measurement programs, and
4. support the design and development of a new, open source, benchmarking software system for use by the international community.

Improving the representation of the carbon cycle and land surface processes in climate models requires extensive comparison of model results with observations. This process is difficult and time intensive. Past data-model intercomparisons have strengthened the representation of key processes in land models, but often this information has not been easily accessible for use by other modeling teams or in future intercomparisons. Specifically, there is a large cost in developing the infrastructure to make meaningful model-data comparisons, even when the data are freely and easily available. Further, the development of sophisticated model diagnostics programs—that can fully exploit the richness of large Earth System data sets like satellite or Fluxnet measurements—are outside the scope of any single modeling center. Thus, an important direction for the field is the development of a community-based model evaluation system that is open source and modular, allowing for contributions by many different modeling and measurement teams.

Multiple past intercomparison efforts provide a foundation a new international benchmarking activity. C^4MIP provided the community with an elegant conceptual framework for diagnosing the causes of model-to-model

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Environmental drivers of drought deciduous phenology in the Community Land Model

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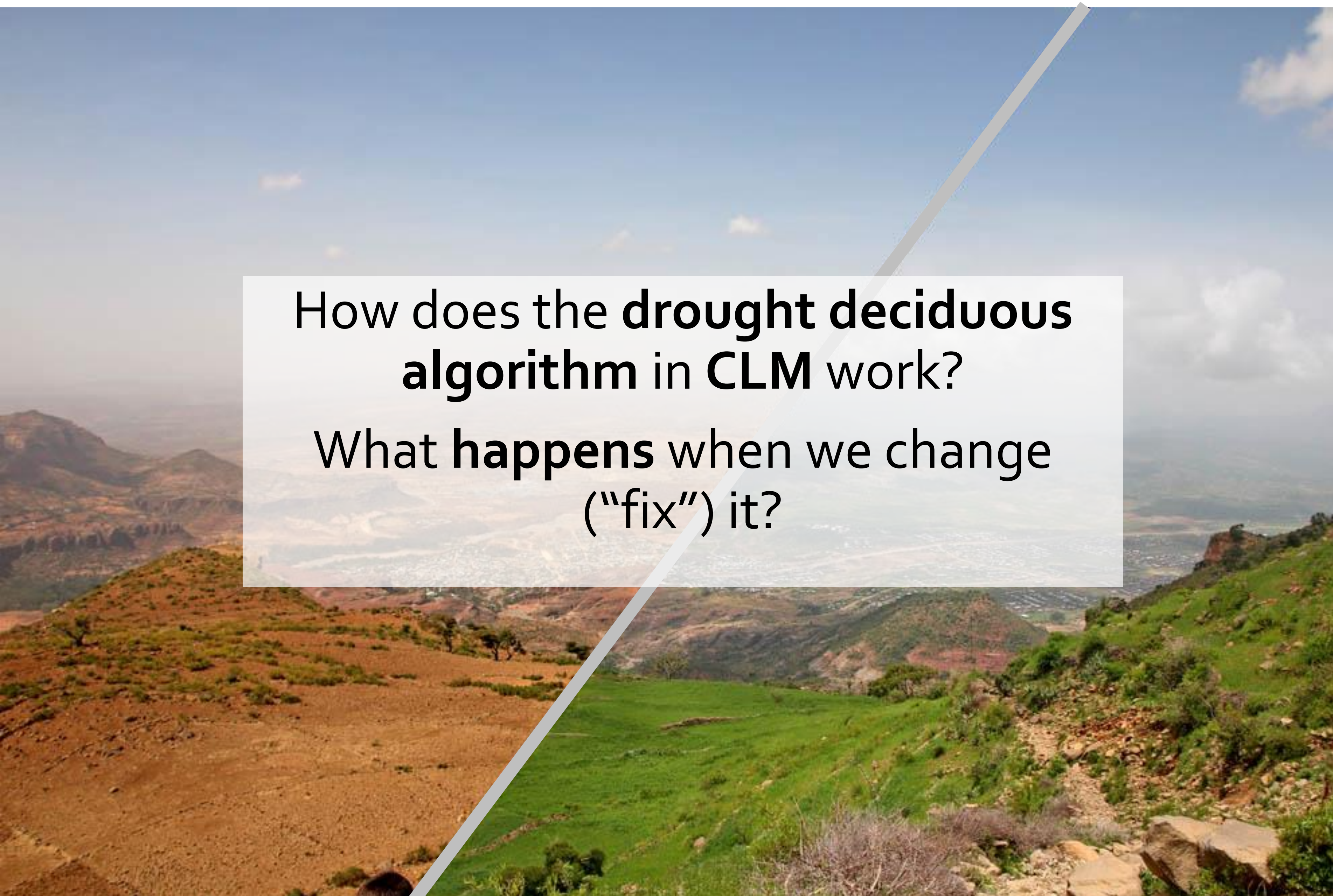
Abstract. Seasonal changes in plant leaf area have a substantial impact on global climate. The presence of leaves and the time when they appear affect surface roughness and albedo, and the gas exchange occurring between leaves and the atmosphere affects carbon dioxide concentrations and the global water system. Thus, correct predictions of plant phenological processes are important for understanding the present and future states of the Earth system. Here we compare plant phenology as estimated in the Community Land Model (CLM)

cal shifts due to climate change have already been identified (e.g., Parmesan and Yohe, 2003). Phenology can refer to a large number of patterns and behaviors in plants and animals that shift with the seasons. Here, however, because we are focused on land surface model simulations, we use phenology specifically to refer to intra-annual variations in leaf area index (LAI). Leaf area can vary significantly within a year and is, therefore, a critical control on land–atmosphere feedbacks (Lawrence et al., 2012).

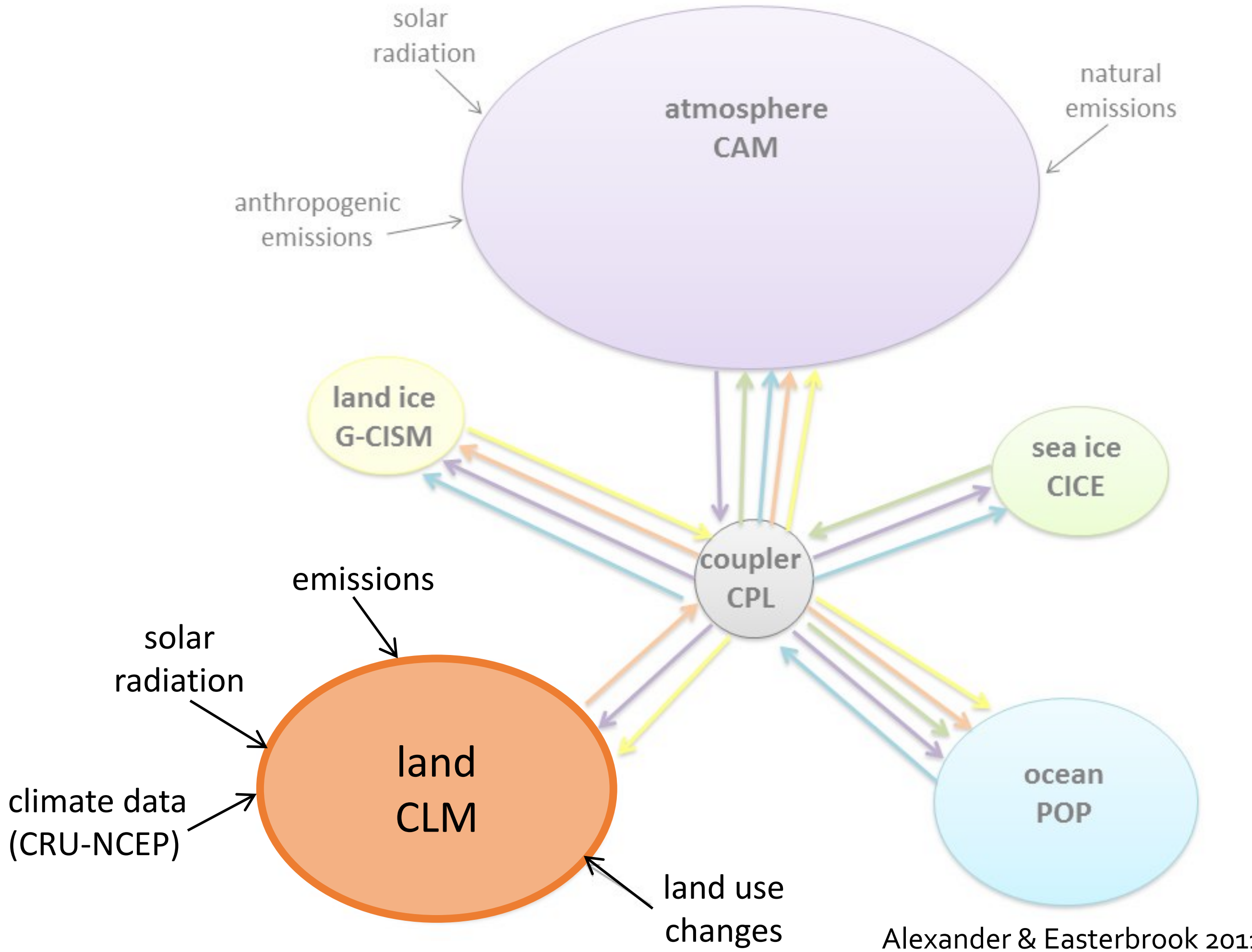


How does the **drought deciduous algorithm** in **CLM** work?

What **happens** when we change ("fix") it?

image credit: Forrest Copeland
talesfromthebigcountry.wordpress.com

Extremely Short Introduction to the Community Land Model (CLM) and the Community Earth System Model (CESM)

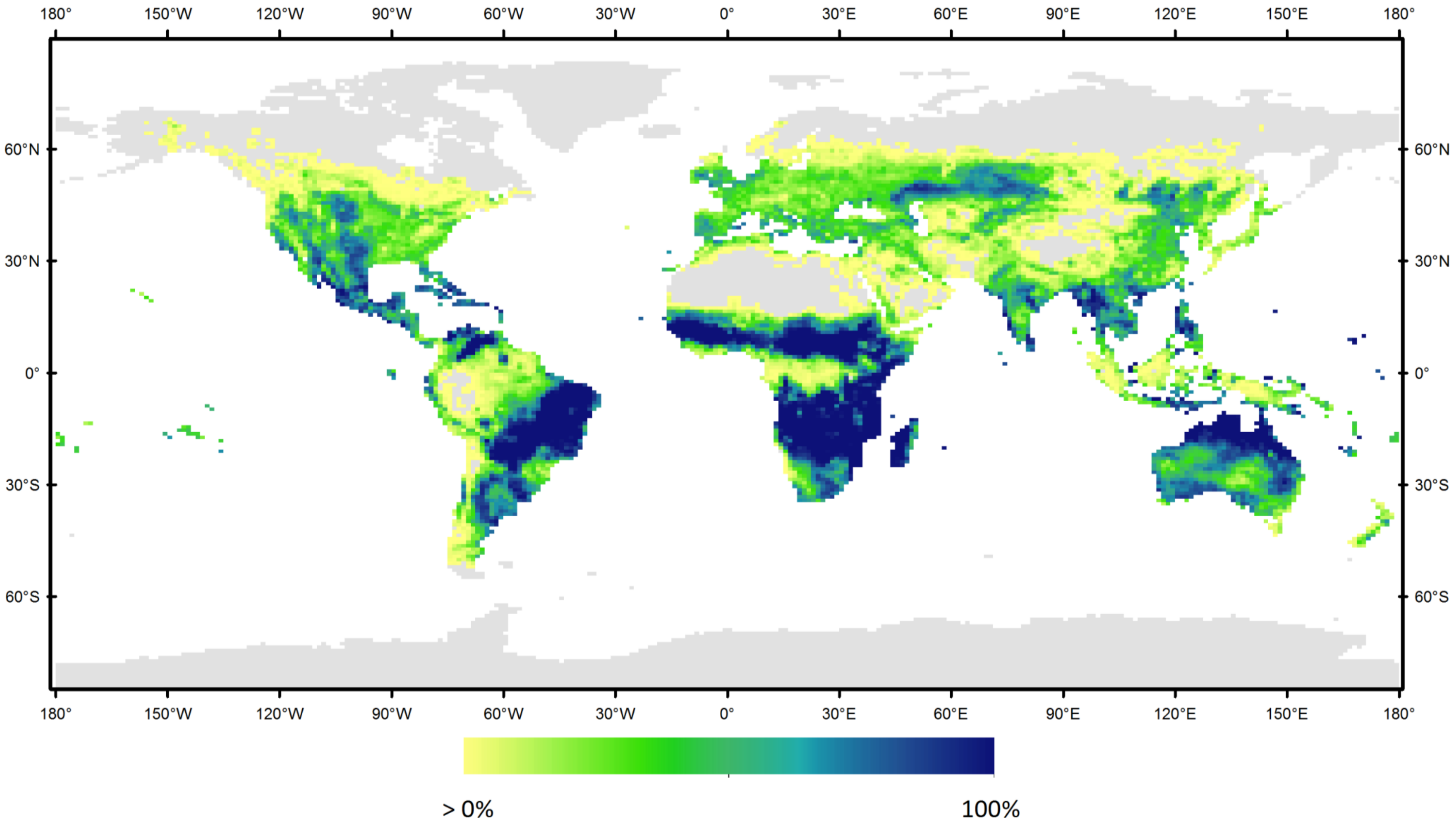


Alexander & Easterbrook 2011 (modified)

Phenology in CLM

- **15** non-crop **plant functional types**
- **3** phenology algorithms
  - evergreen
  - cold deciduous
  - **stress (= drought) deciduous**

Where is CLM Stress Deciduous?

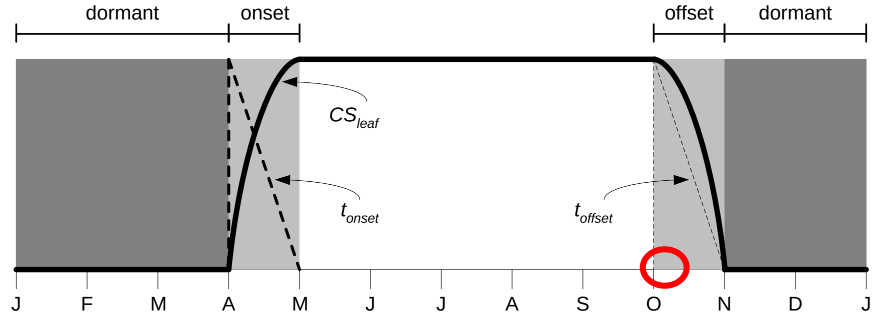


Questions

- How well does the stress deciduous phenology algorithm work in CLM? **[Leaf Area Index]**
  (compared to AVHRR-derived LAI3g for 1982-2010; Zhu et al 2013)
- Did we make it work better? (with relatively simple changes)
- What are the ecological consequences of this change?

How does stress/drought decidousness work in CLM?
(in warm, long-day regions*)

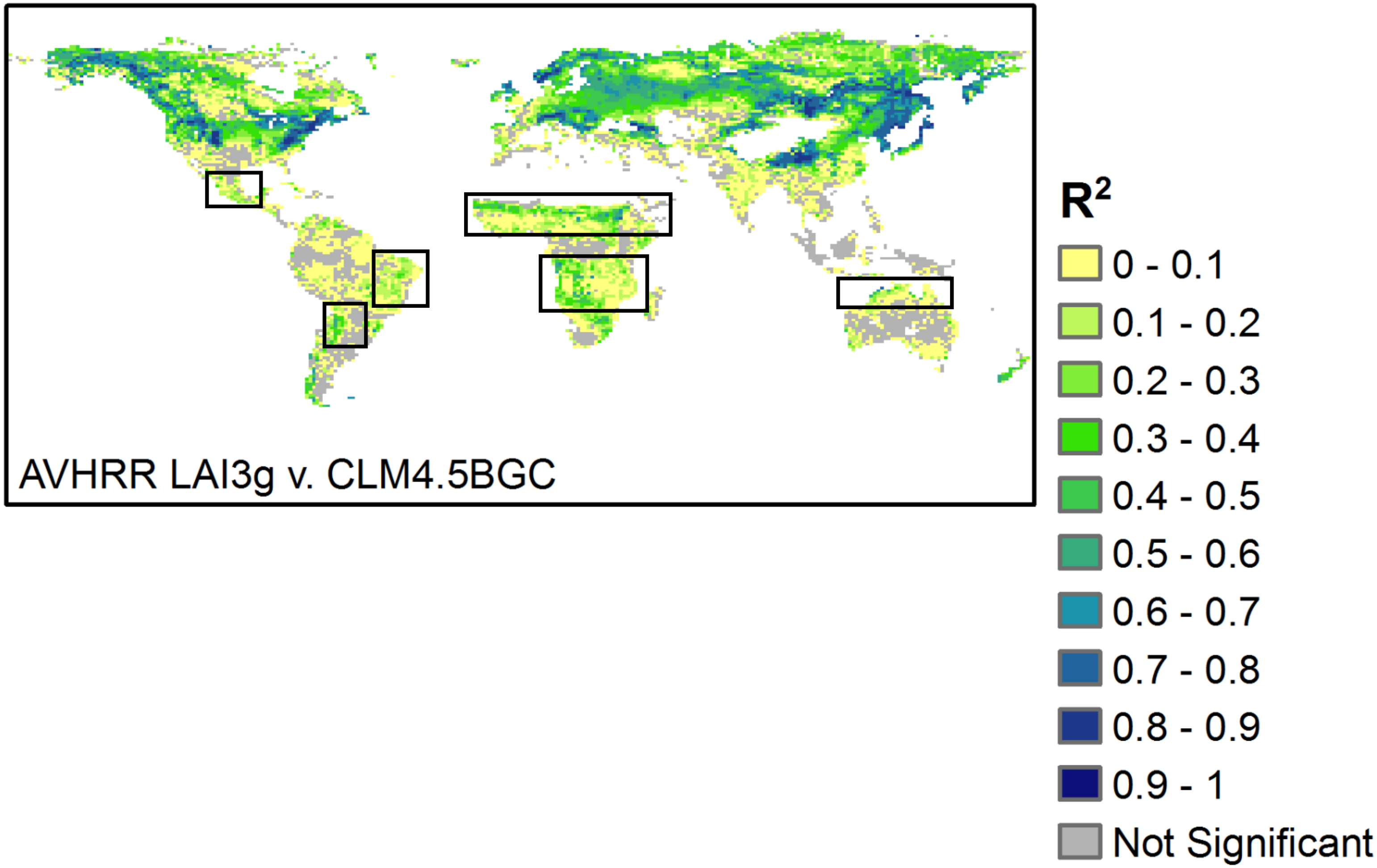
CLM4.5 Tech Note
from White et al 1997



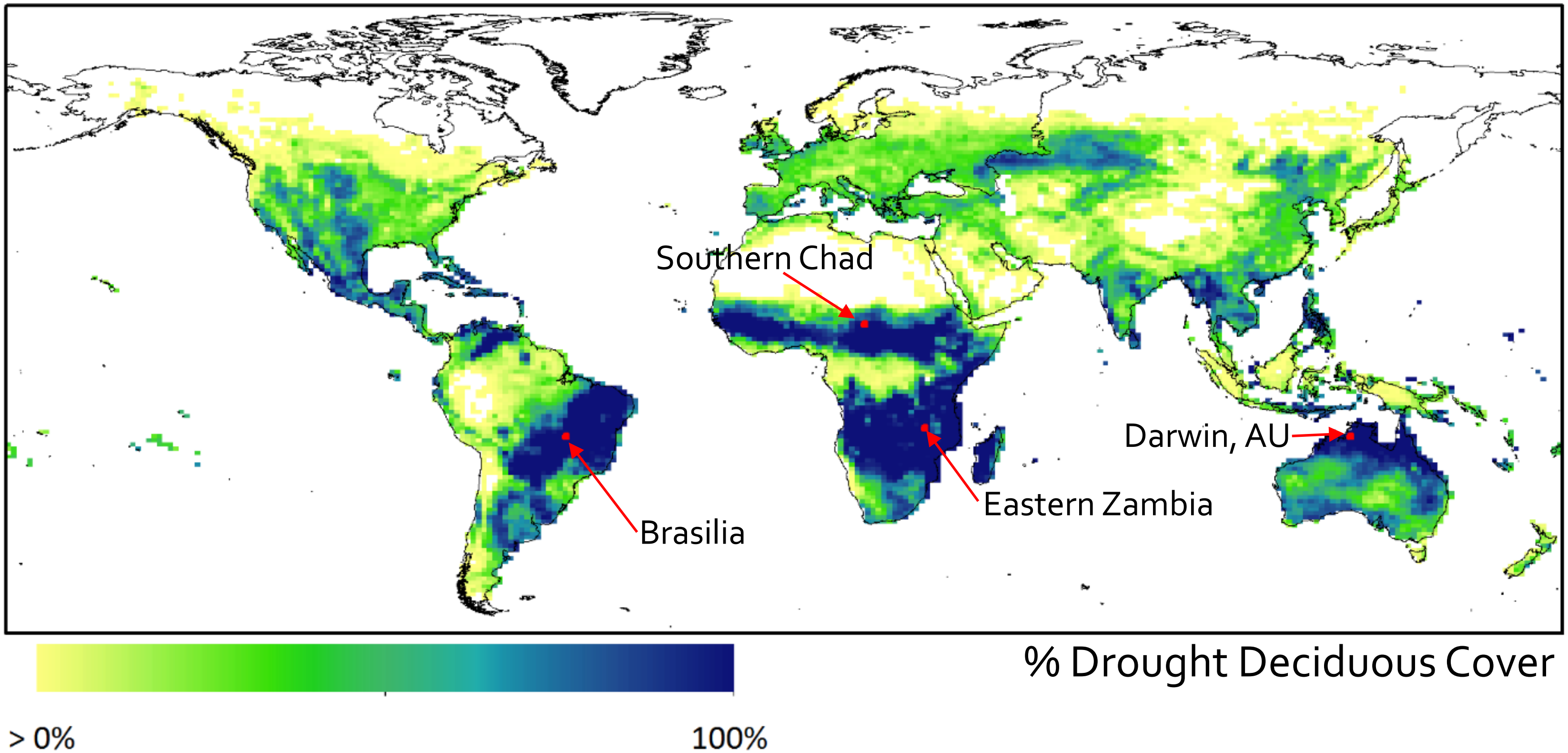
CLM4.5 Tech Note

- Start growing leaves if…
  - 3rd soil layer is wet (soil water potential > -2 MPa) for 15 days
- Onset period fixed at 30 days
- Start dropping leaves if…
  - Onset period is complete
  - 3rd soil layer is dry (soil water potential < -2 MPa) for 15 days
- Leaf drop period fixed at 15 days

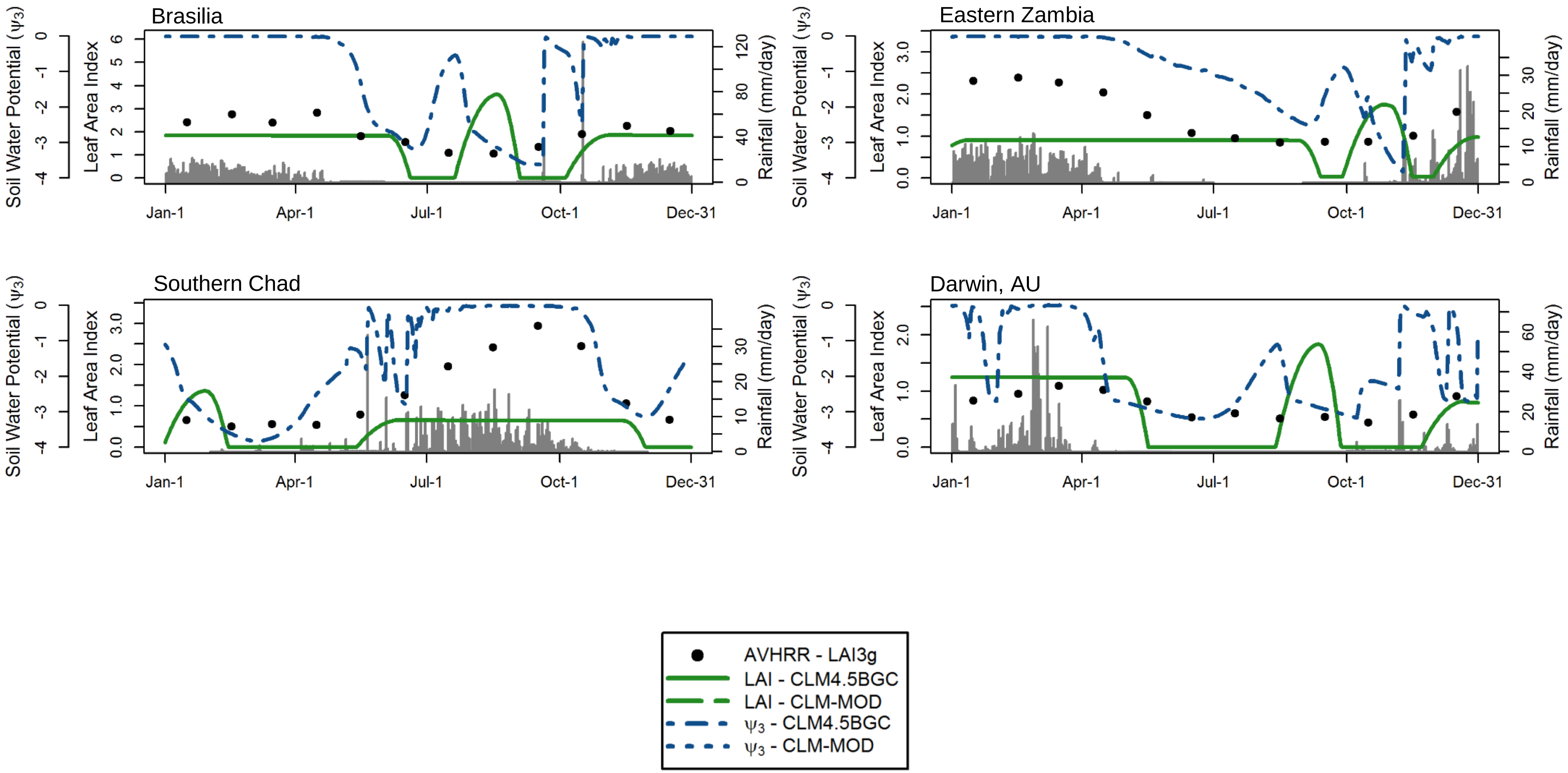
Correlations



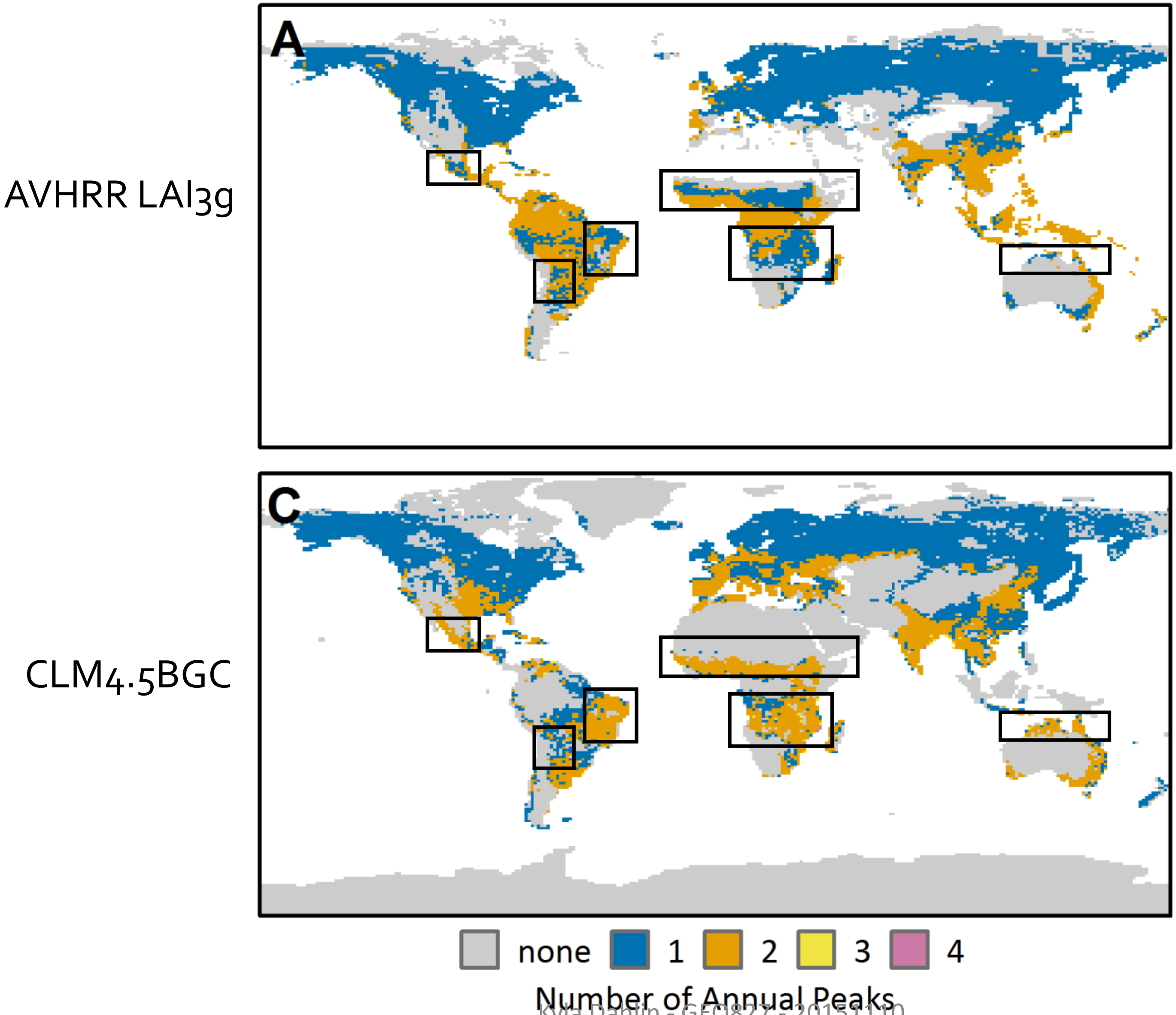
What about at single points?



What's going on?

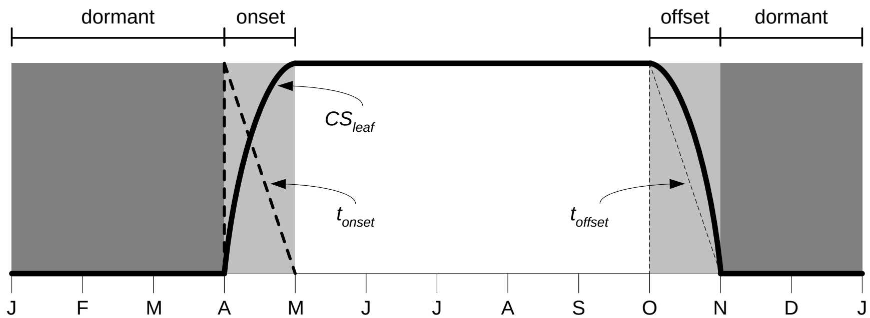


Counting Peaks



How does stress decidousness currently work in CLM?
(in warm, long-day regions)

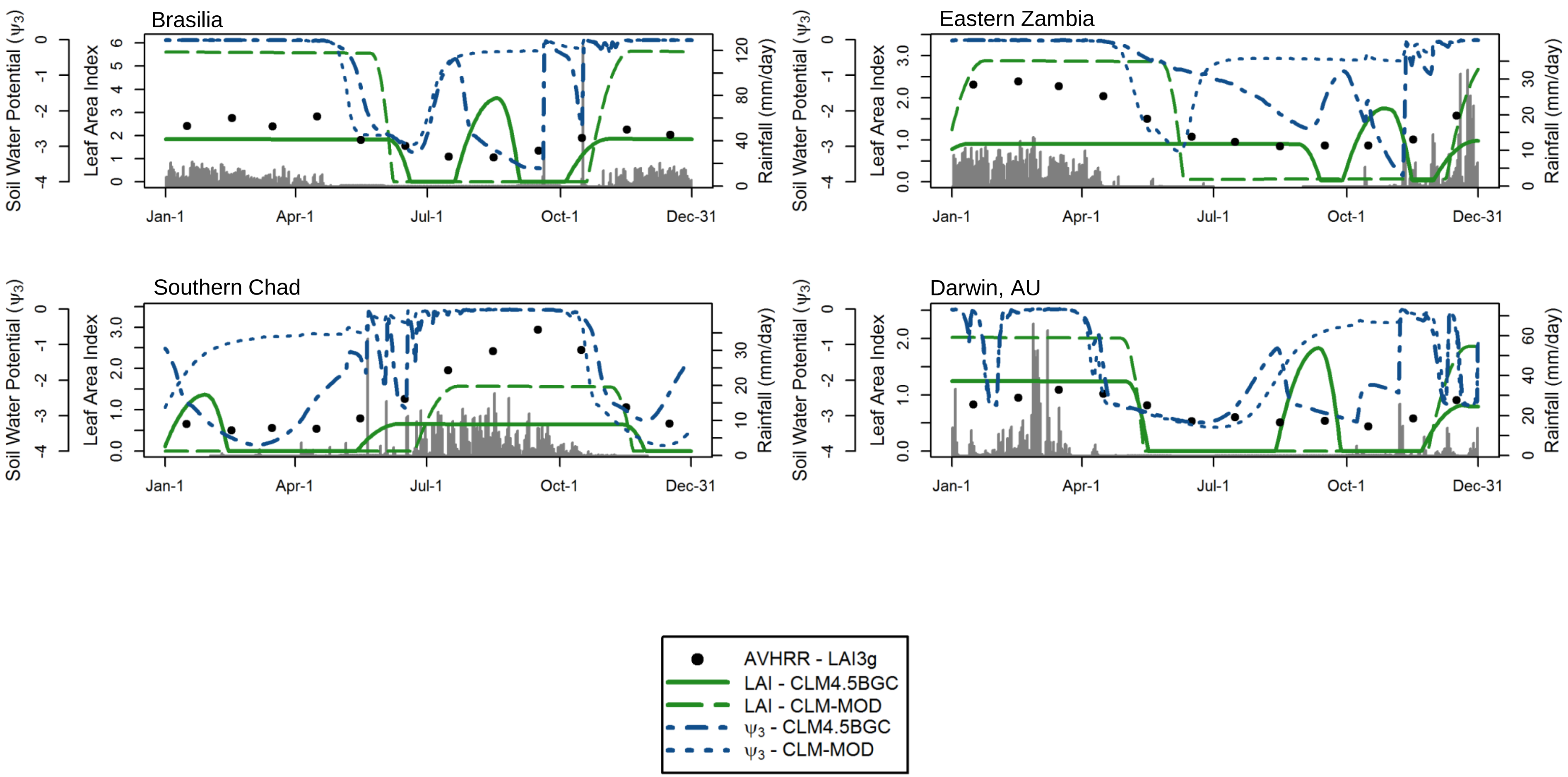
CLM4.5 Tech Note
from White et al 1997



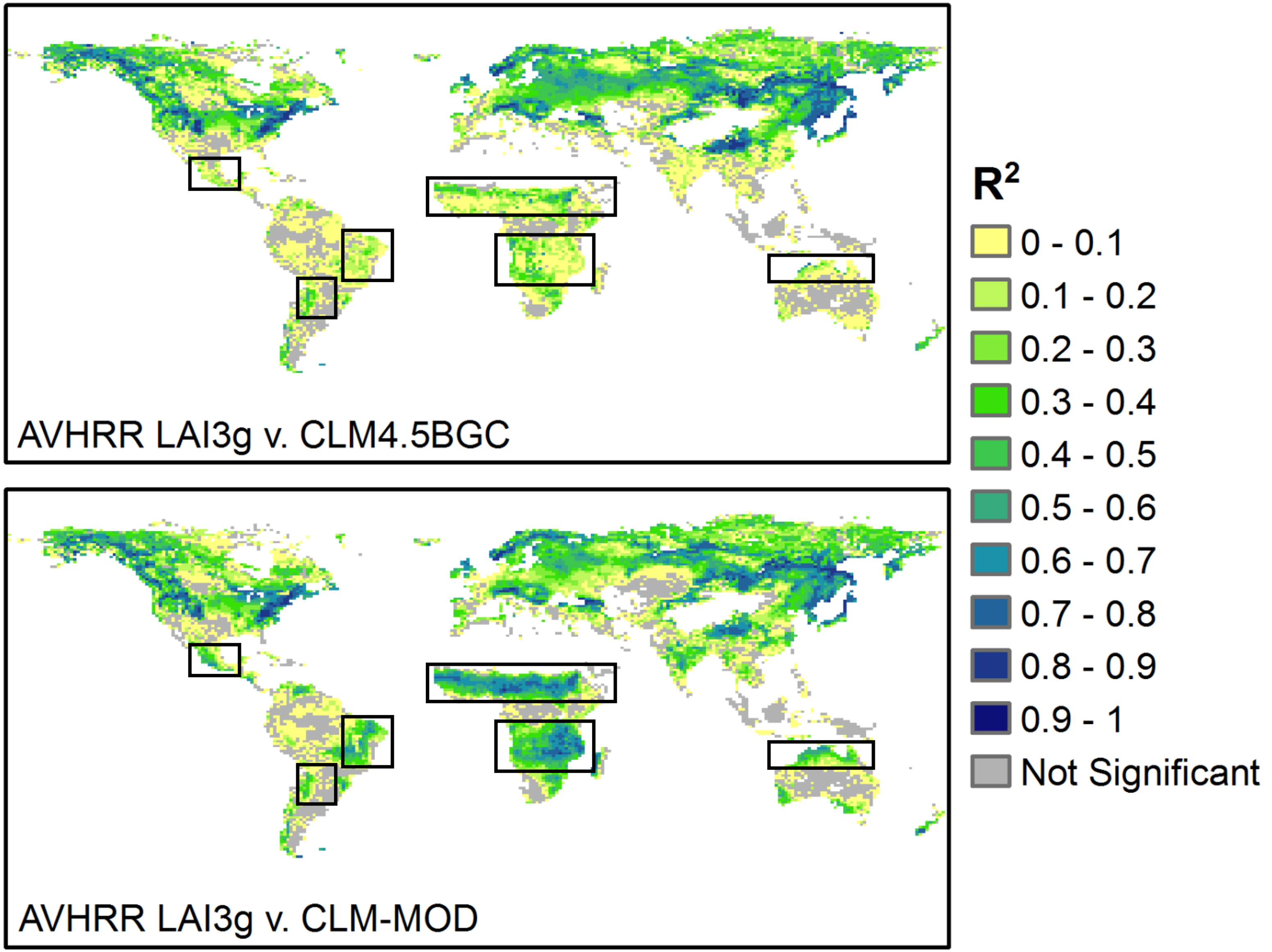
CLM4.5 Tech Note

- Start growing leaves if…
  - 3rd soil layer is wet (soil water potential > -2 MPa) for 15 days
  - **<u>It RAINS!</u> (20 mm in the past 10 days)**
- Onset period fixed at 30 days
- Start dropping leaves if…
  - Onset period is complete
  - 3rd soil layer is dry (soil water potential < -2 MPa) for 15 days
- Leaf drop period fixed at 15 days

What’s going on?

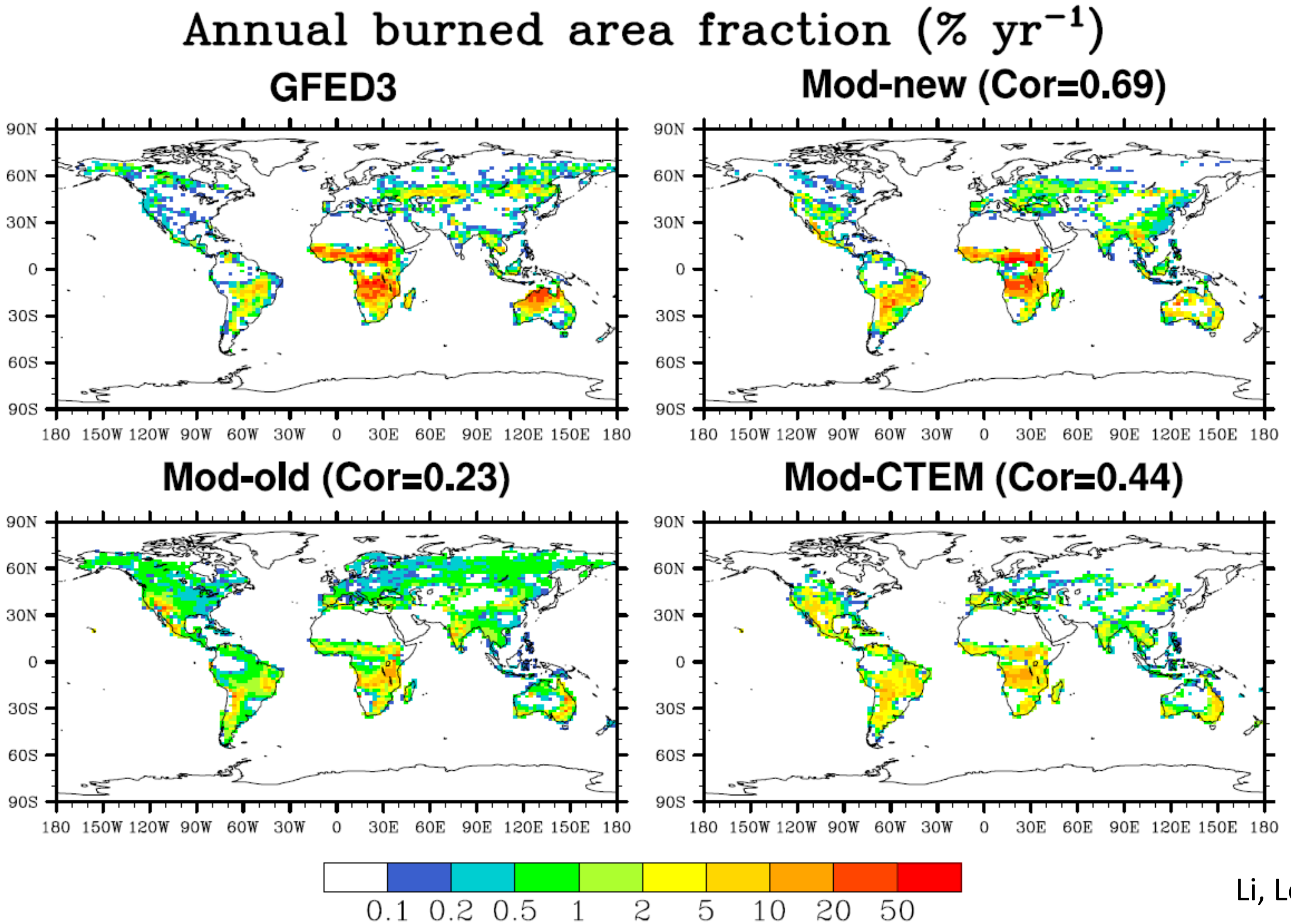


Correlations



What about fire?

What about fire?

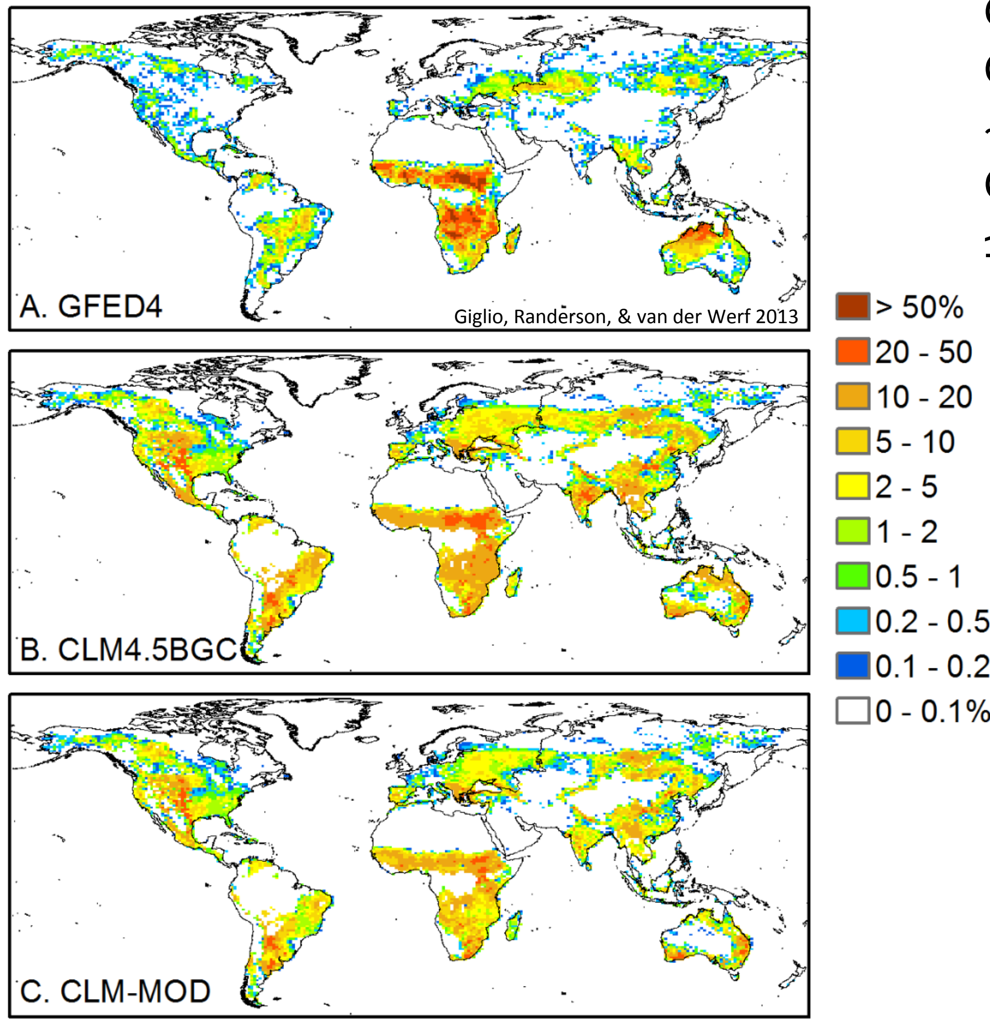


GFED3
CLM4CN
~2° resolution*
Qian forcing
1997-2004

Li, Levis & Ward 2013

New

Annual burned area fraction (% yr^{-1})

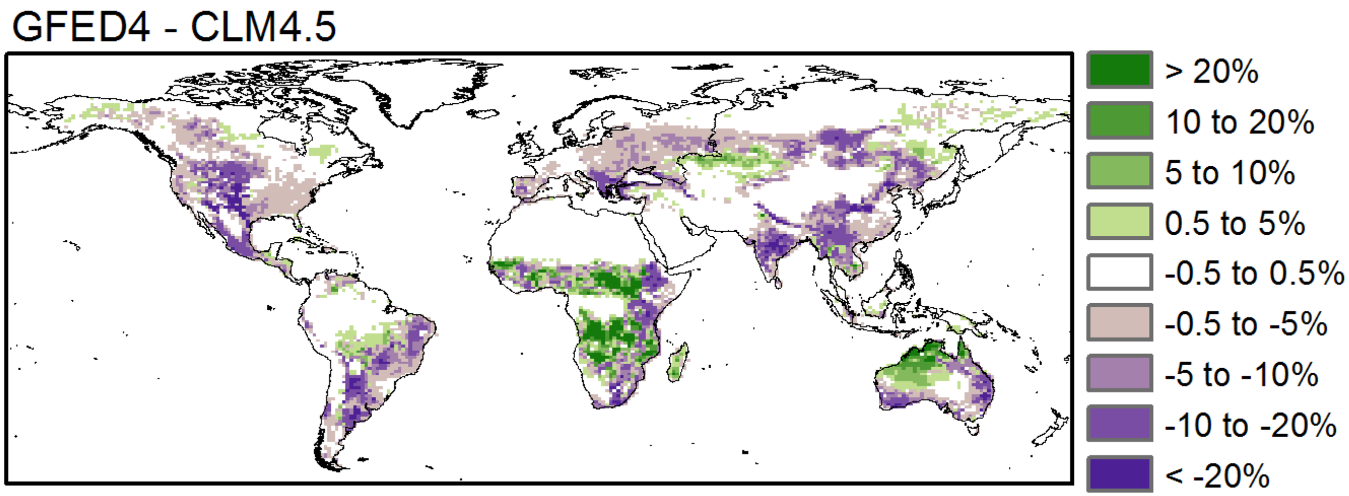


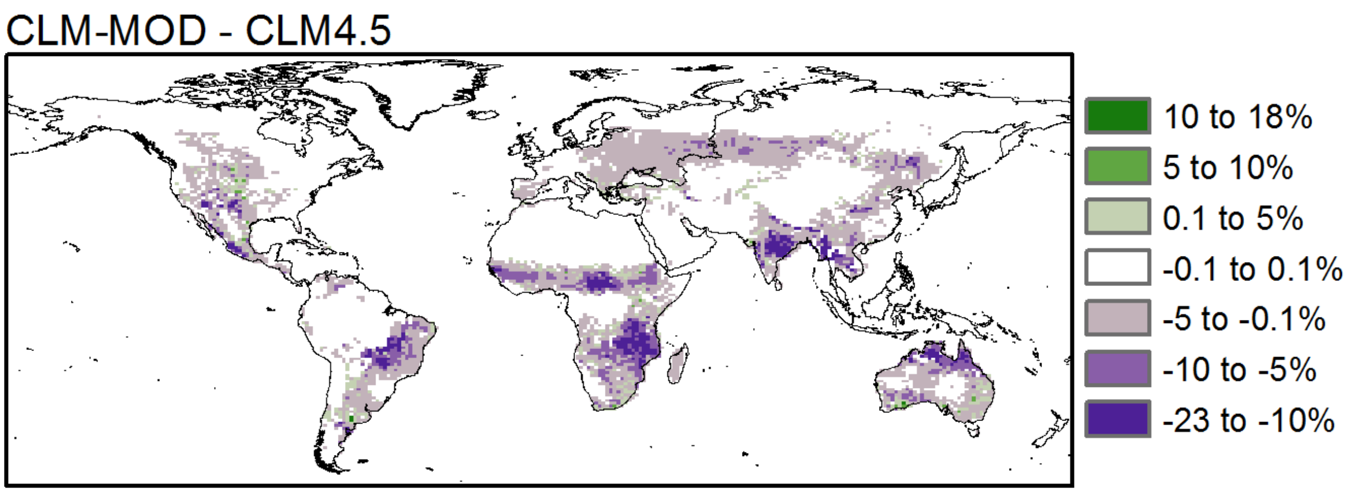
GFED4
CLM4.5BGC
~1° resolution
CRU-NCEP forcing
1996-2010

R = 0.44
(drought deciduous only R = 0.35)

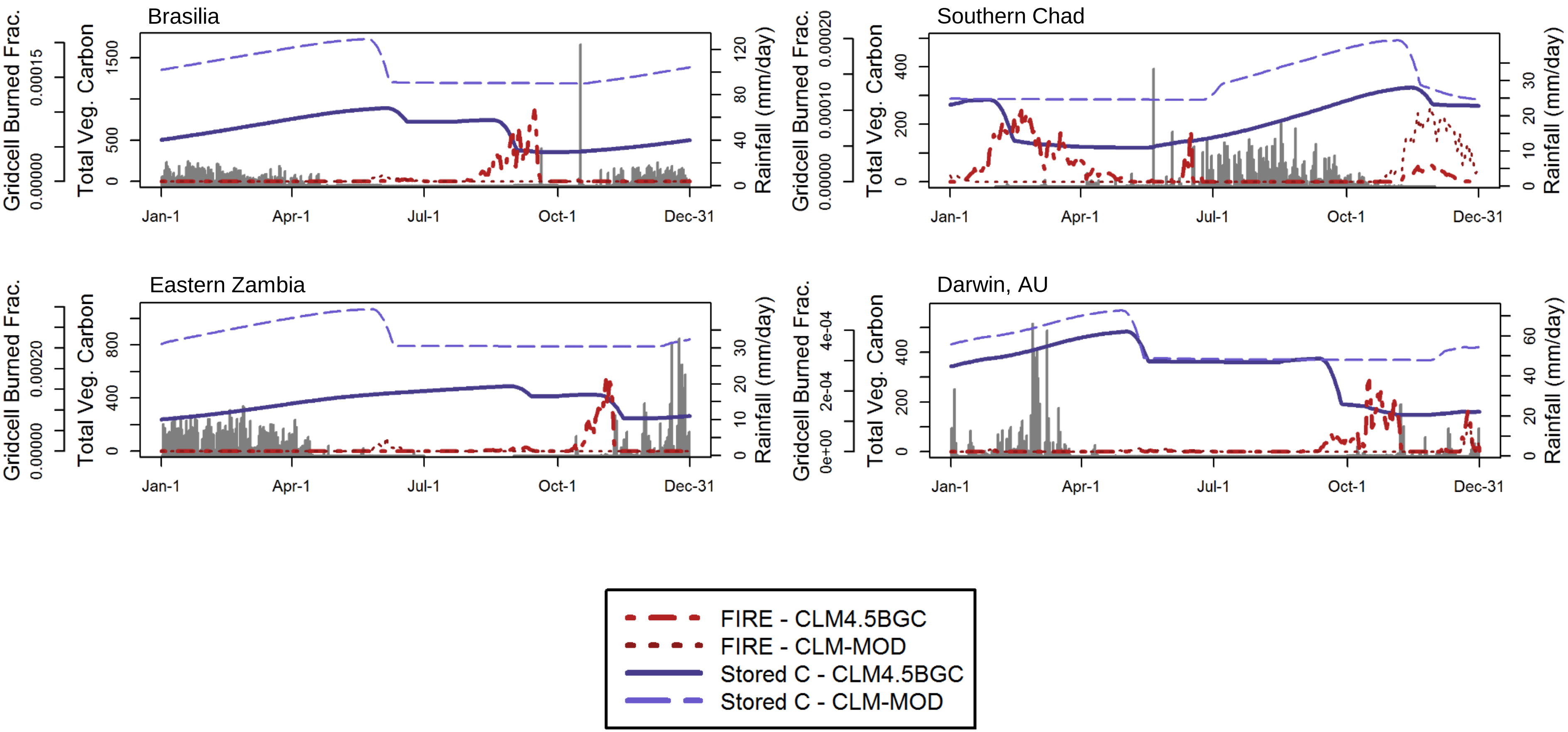
R = 0.33
(drought deciduous only R = 0.23)

Difference Maps





1 year of Fire & Veg Carbon



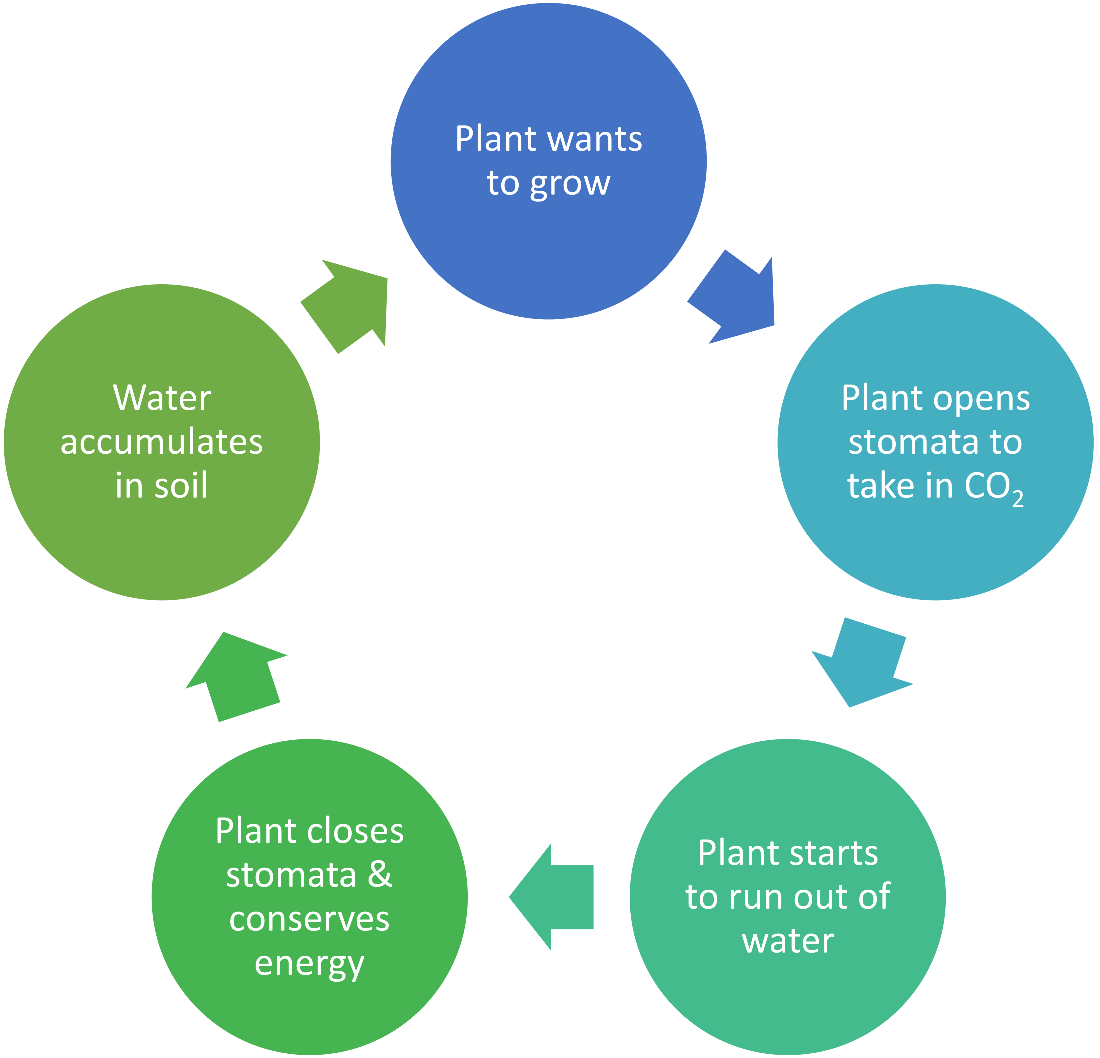
Conclusions

- Delaying budburst until some **rain has fallen gives better agreement with the satellite-derived LAI data**, both for magnitude and seasonal cycle in savanna regions.
- But this change degrades our ability to predict **fire patterns**. But not by much.
- More implications? Soil C, climate feedbacks, etc.

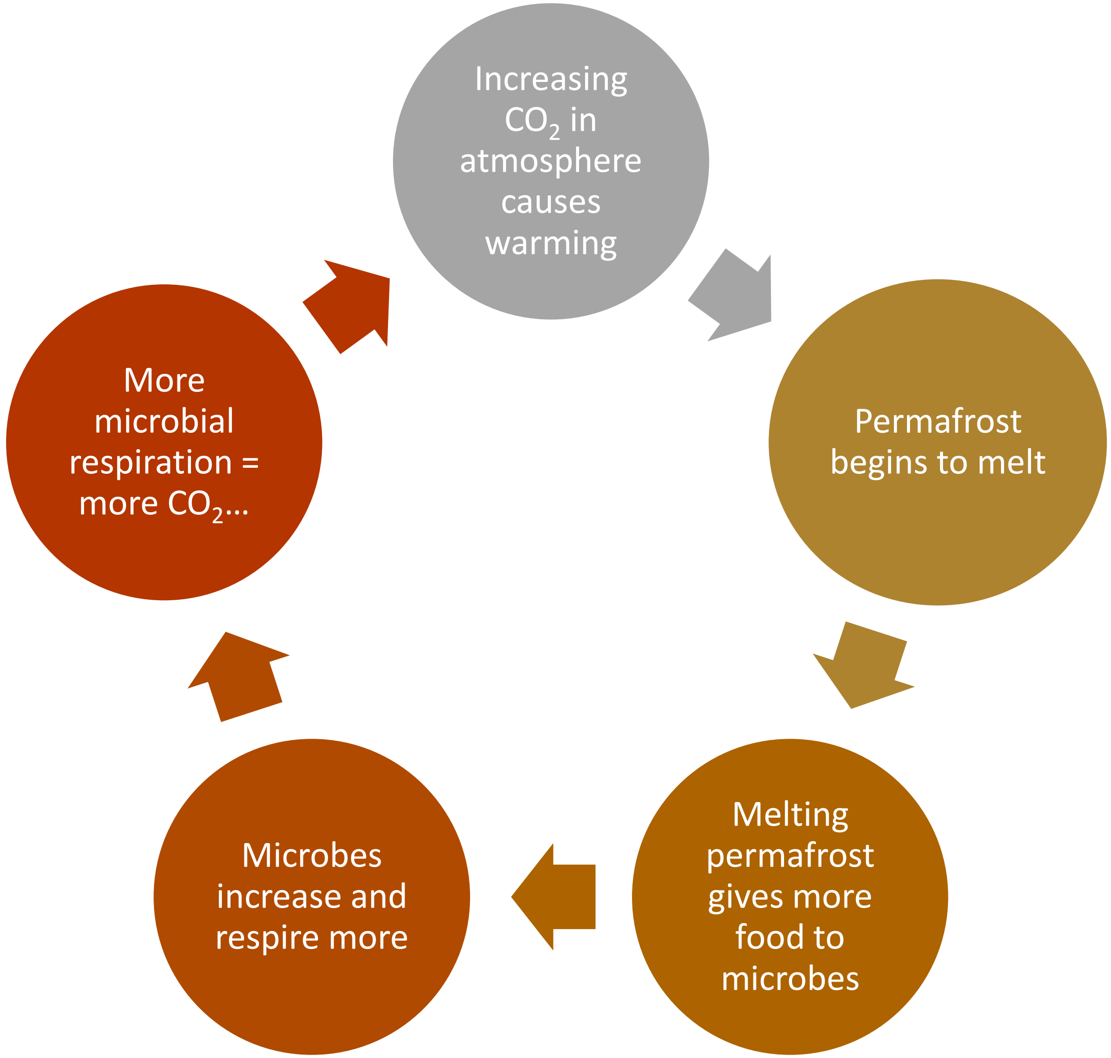
So… Species Distribution Modeling?

- Where are species now?
- Where are they going?
- What does that mean for the other organisms that rely on them?
- Will it impact the climate?
- Will it impact people?

Negative Feedback (good!)



Positive Feedback (not good!)



Types of SDMs
(see Elith & Leathwick 2009)

- Climate Envelope Modeling (just climate)
- Habitat modeling (abiotic factors)
- Niche modeling (abiotic + biotic)

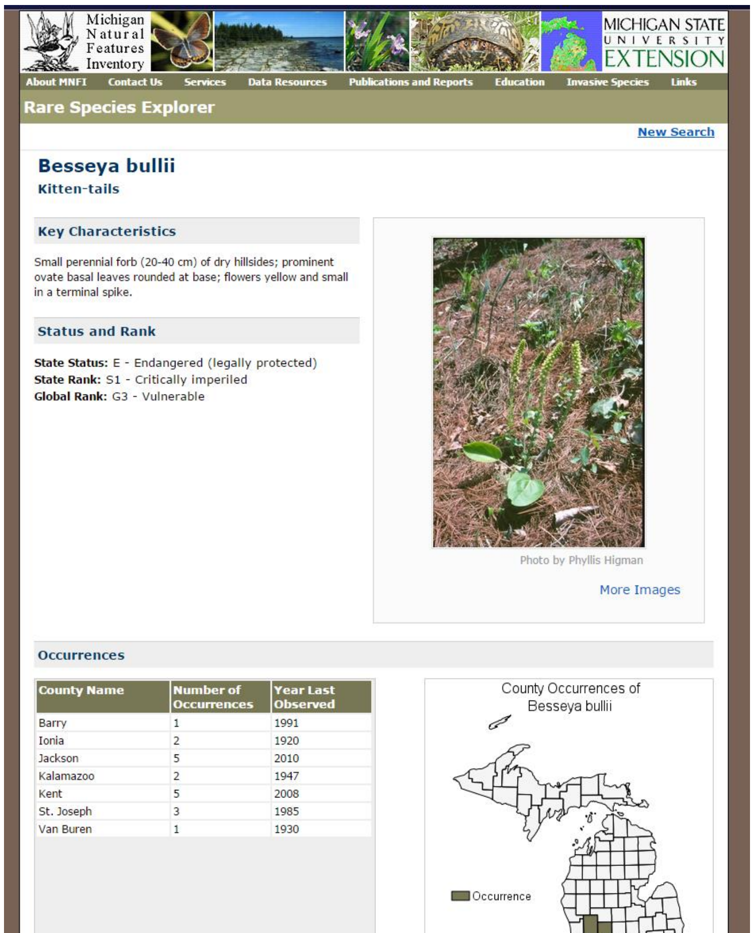
- ‘Gap’ models (every tree)
- MaxEnt (fancy statisics)
- Ecosystem Demographics (more fancy statistics)

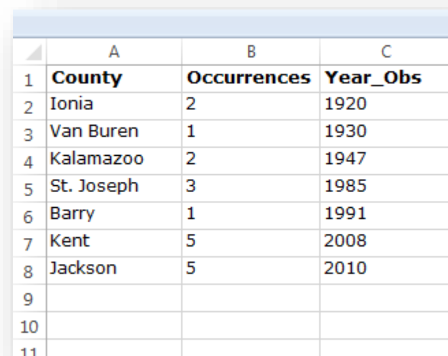
So… what are we doing for the lab?

- Climate Envelope Modeling!
- Issues and Caveats…
- Where is everything?
  - Dropbox

Step 1: Pick a Rare Plant in MI

Example: Kitten tails (*Besseya bullii*)

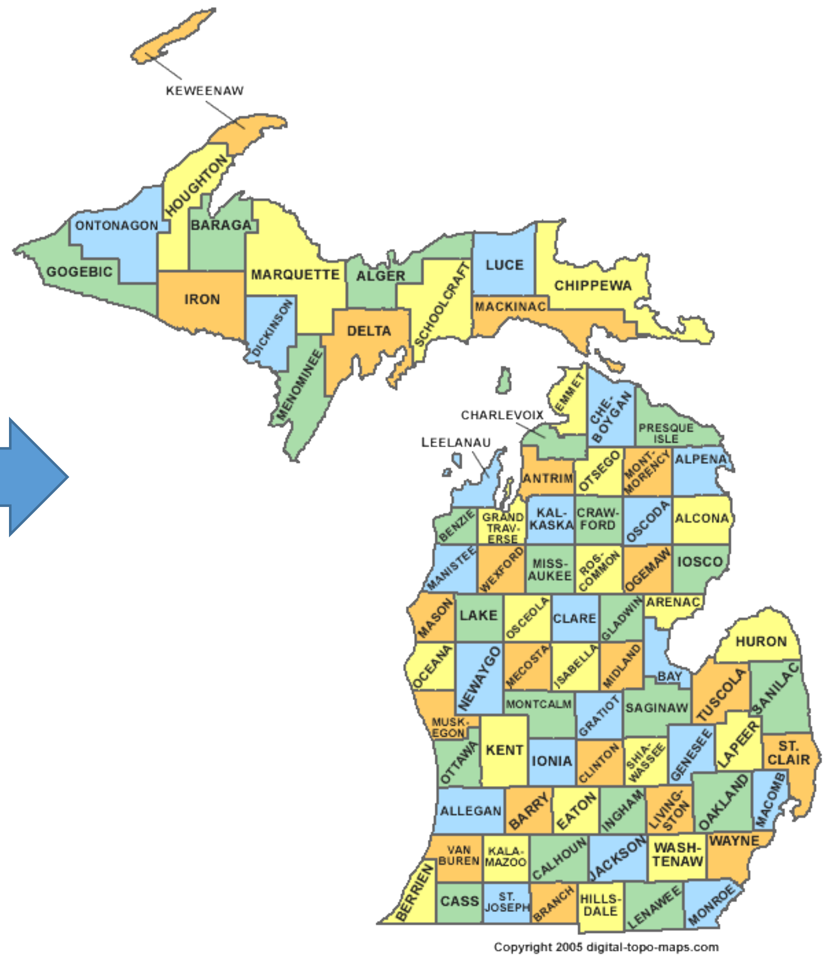




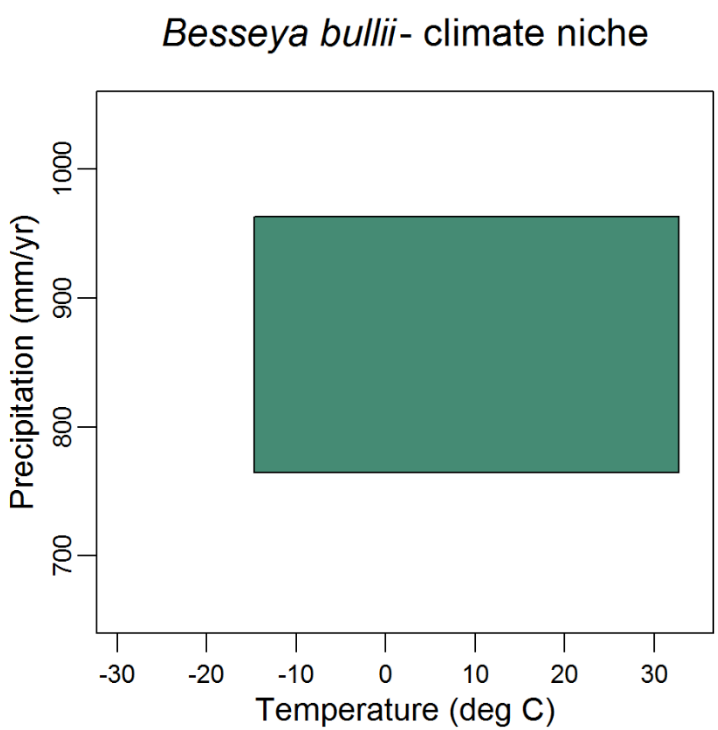
	A	B	C
1	County	Occurrences	Year_Obs
2	Ionia	2	1920
3	Van Buren	1	1930
4	Kalamazoo	2	1947
5	St. Joseph	3	1985
6	Barry	1	1991
7	Kent	5	2008
8	Jackson	5	2010
9			
10			
11			

Step 2: Map its locations

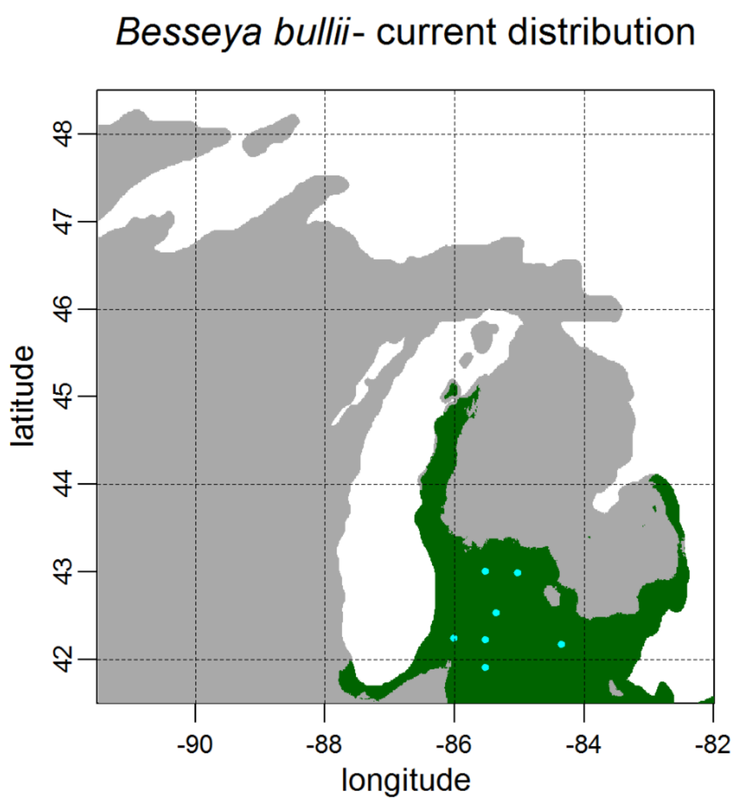
	A	B	C
1	**County**	**Occurrences**	**Year_Obs**
2	Ionia	2	1920
3	Van Buren	1	1930
4	Kalamazoo	2	1947
5	St. Joseph	3	1985
6	Barry	1	1991
7	Kent	5	2008
8	Jackson	5	2010
9			
10			
11			



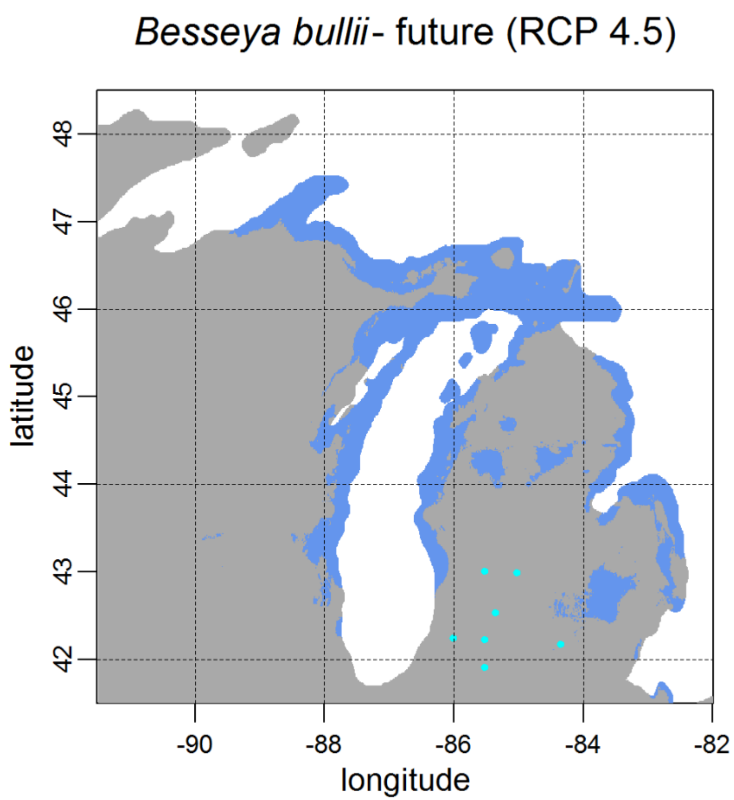
Step 3: Calculate its climatic niche



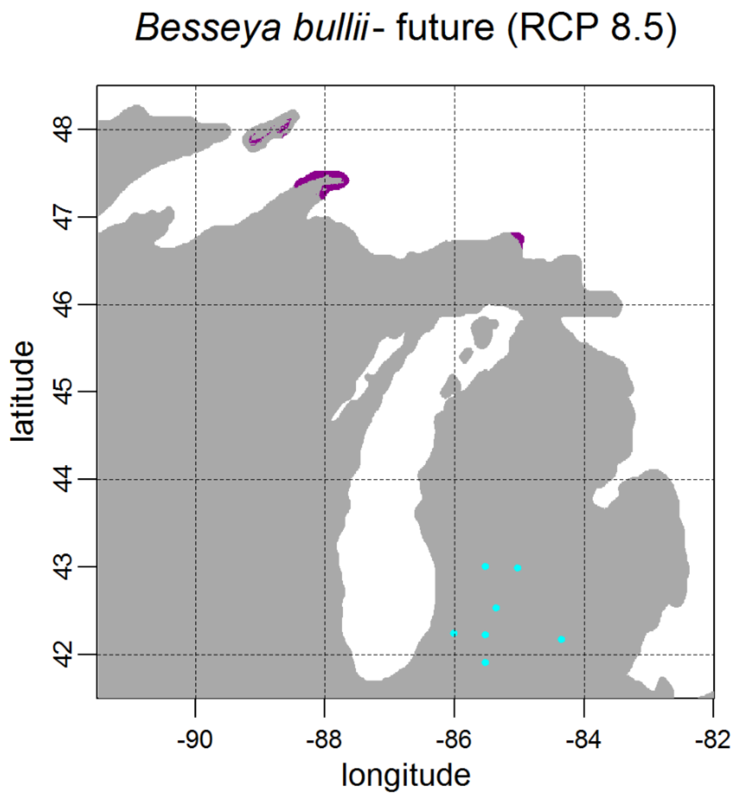
Step 4: Estimate its current climatic range



Step 5: Estimate its future climatic range under RCP4.5



Step 6: Estimate its future climatic range under RCP8.5



Thanks!

Questions?

[shameless plug for GEO837]

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