# Incorporating Observations of OCS and SIF into Carbon Cycle Models

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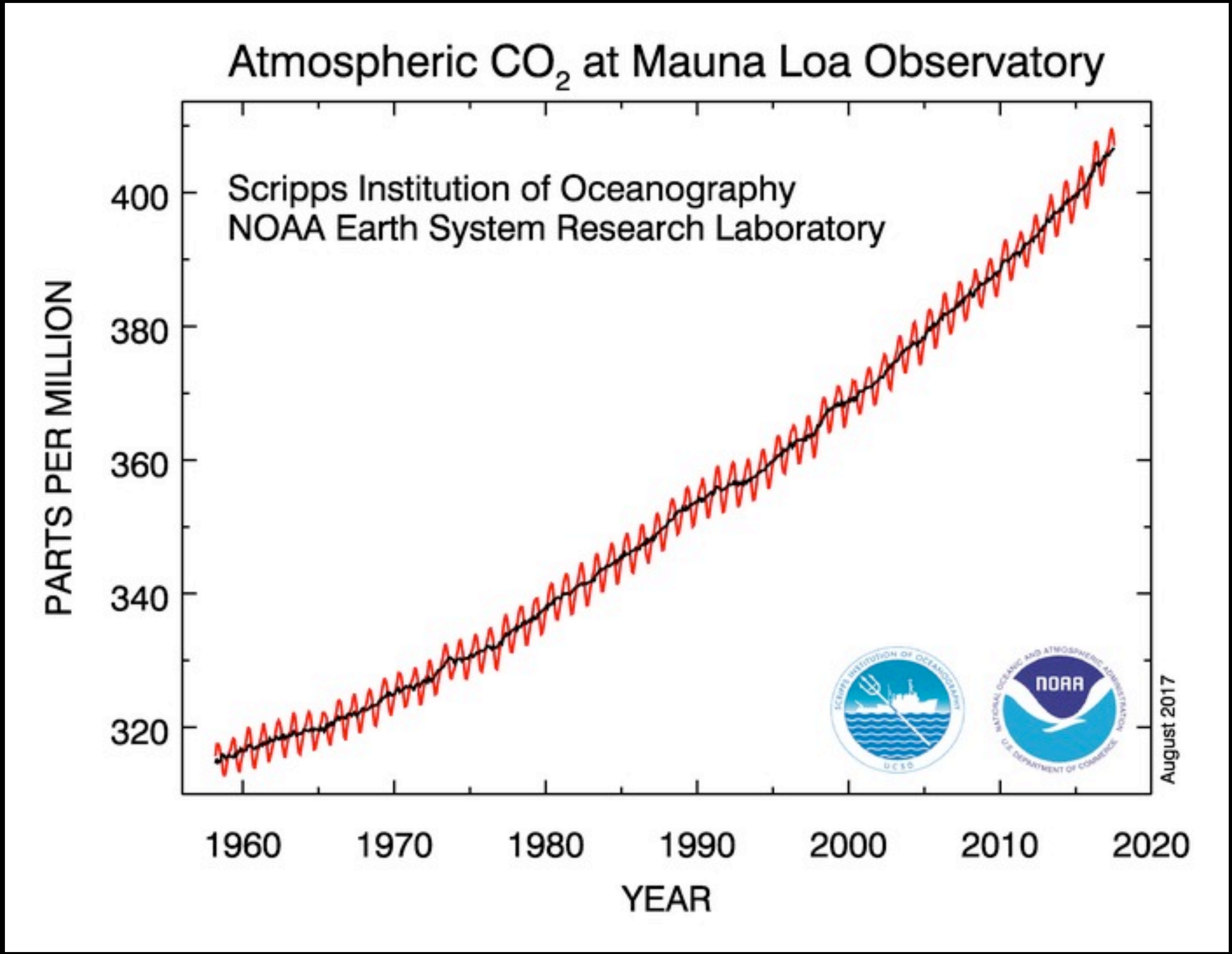
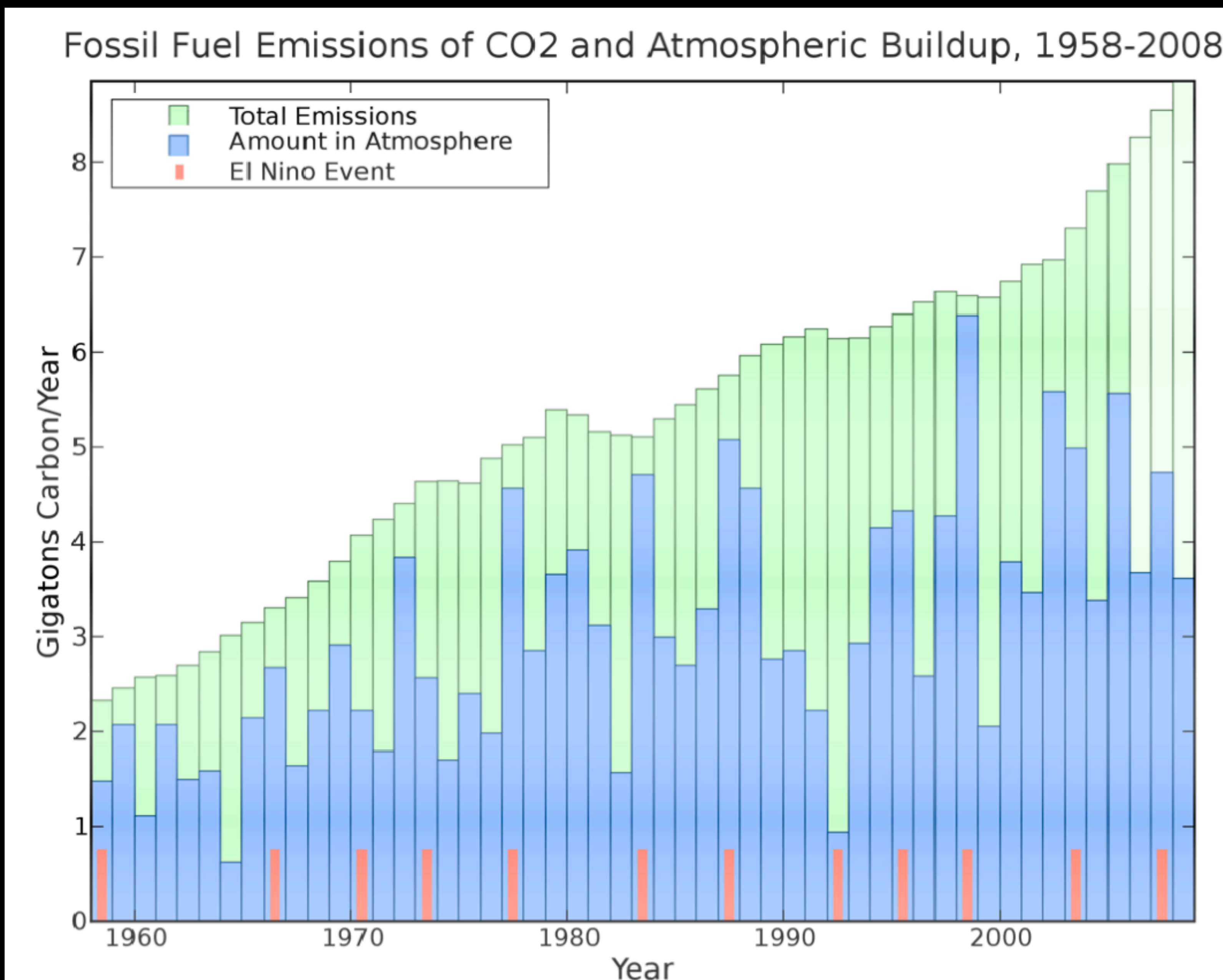
Colorado State University
and other institutions

# Global $CO_2$ Levels



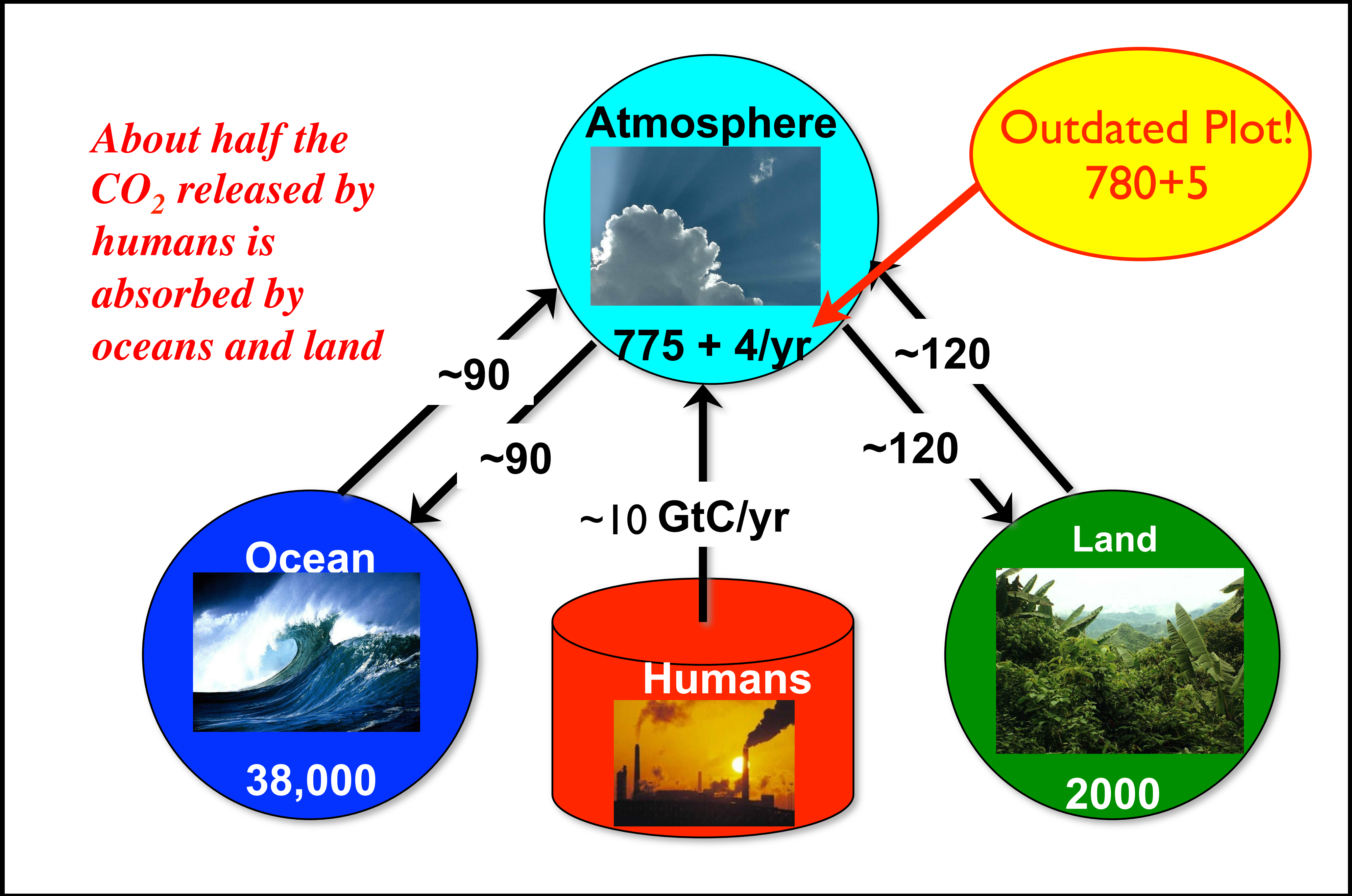
# CO2 Accumulation in the Atmosphere



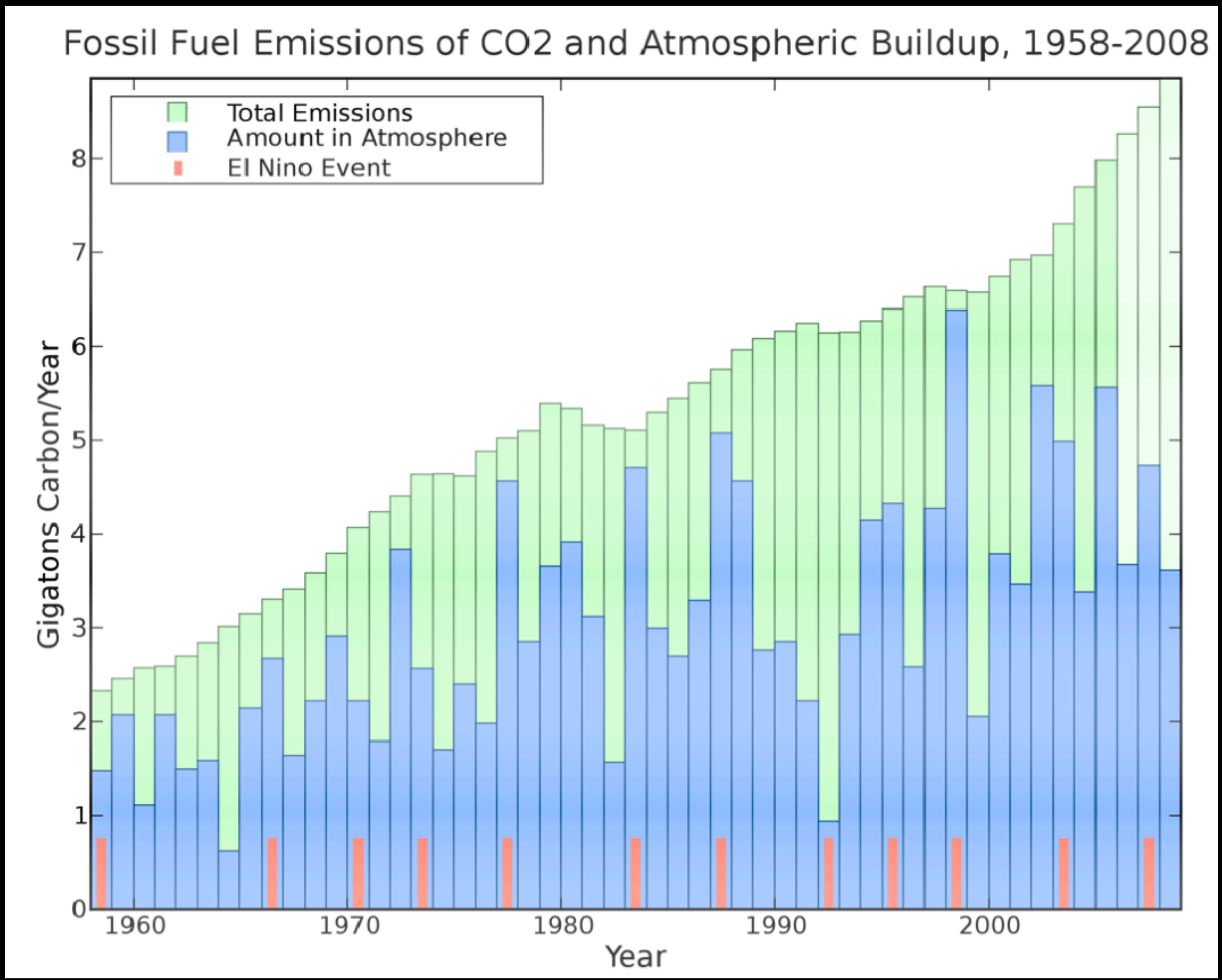

NASA/NOAA data

- About 1/2 of fossil-fuel $CO_2$ remains in the atmosphere!
- Extremely variable

# Global Carbon Cycle

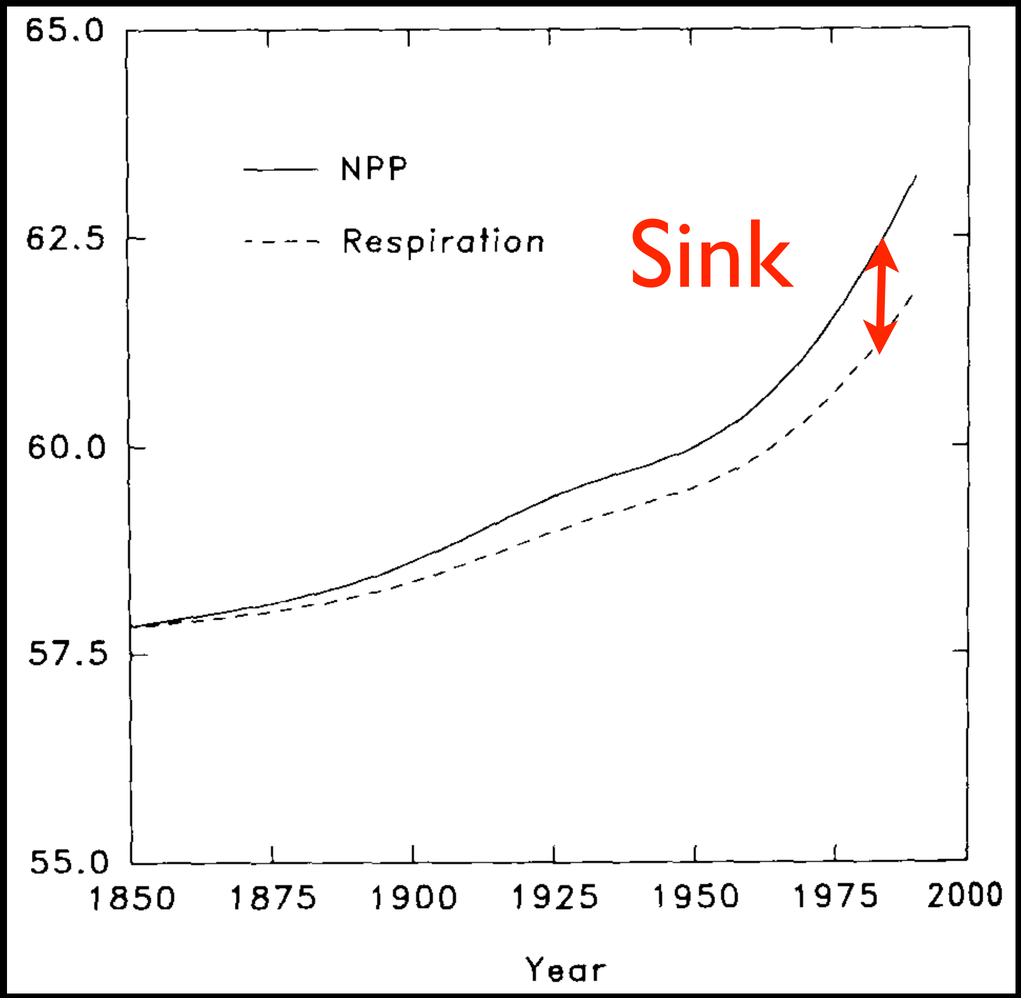


# Land and Ocean Sinks




- Most of the variability in the sink is due to land
- Where?
- What causes the inter-annual changes?
- What about the Future?

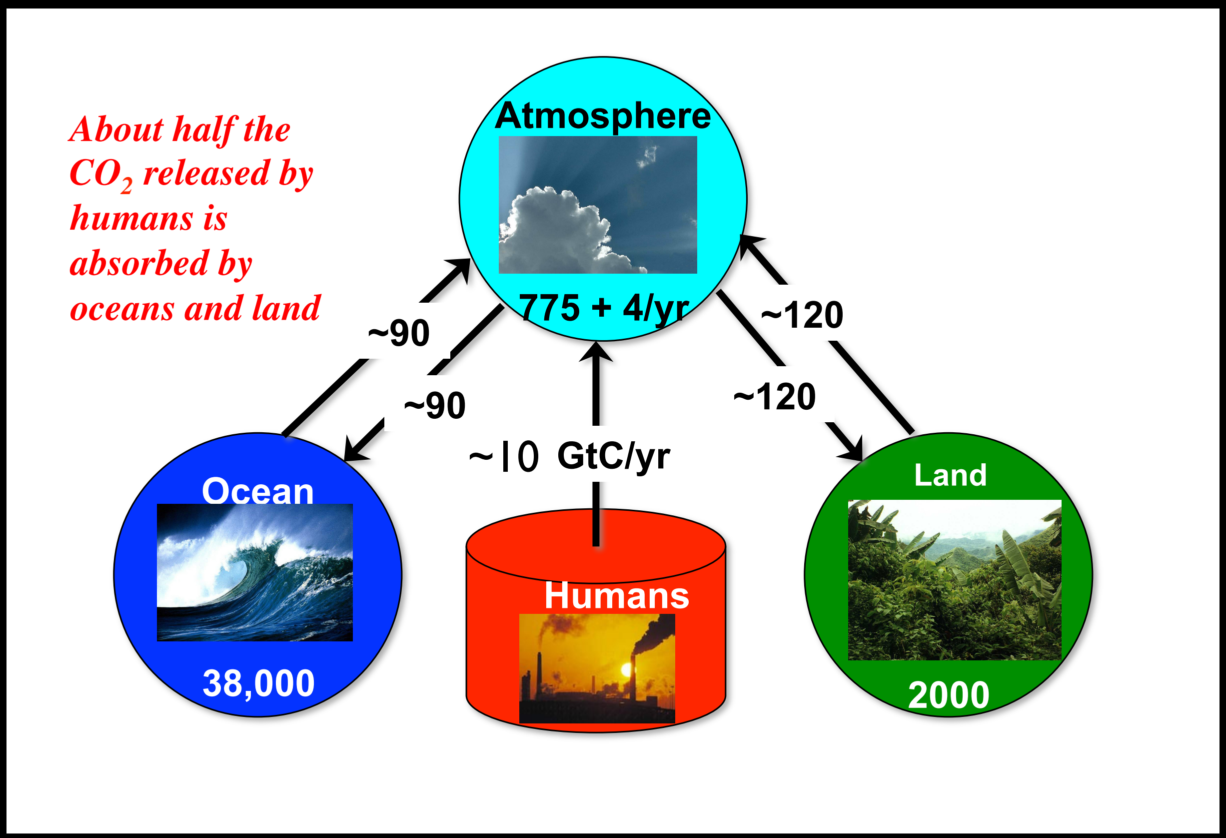
# Plants are Growing Faster than they are Dying




Friedlingstein et al., 1995

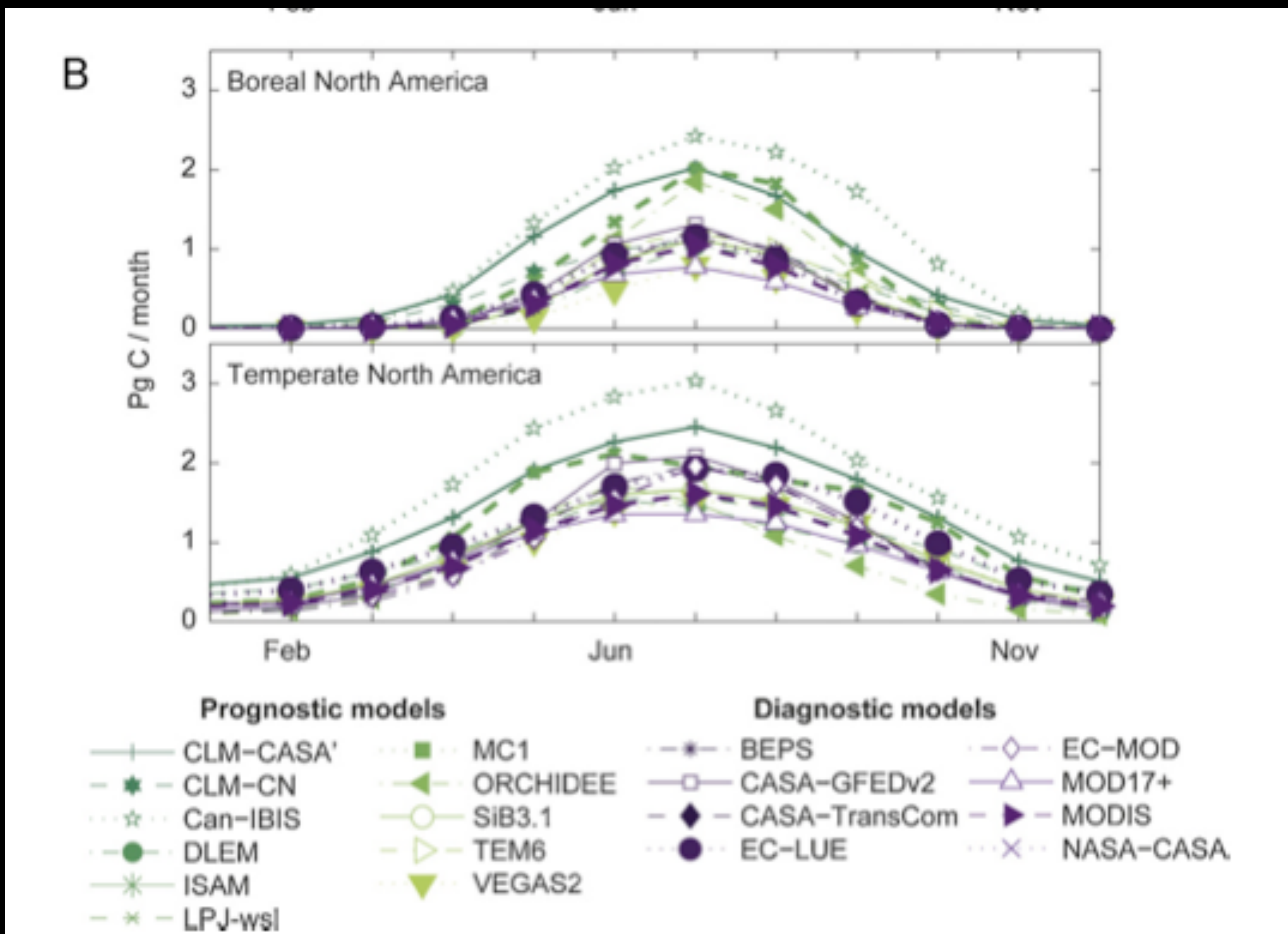
- $CO_2$ fertilization
- Nitrogen fertilization
- Woody encroachment
- Season Lengthening
- Fire suppression
- Again, the Future?

# Quantification




- We are searching for a very small difference between large gross fluxes
- In models, this sink must be *emergent* from model physics
  - Inversions
  - *A Priori* models

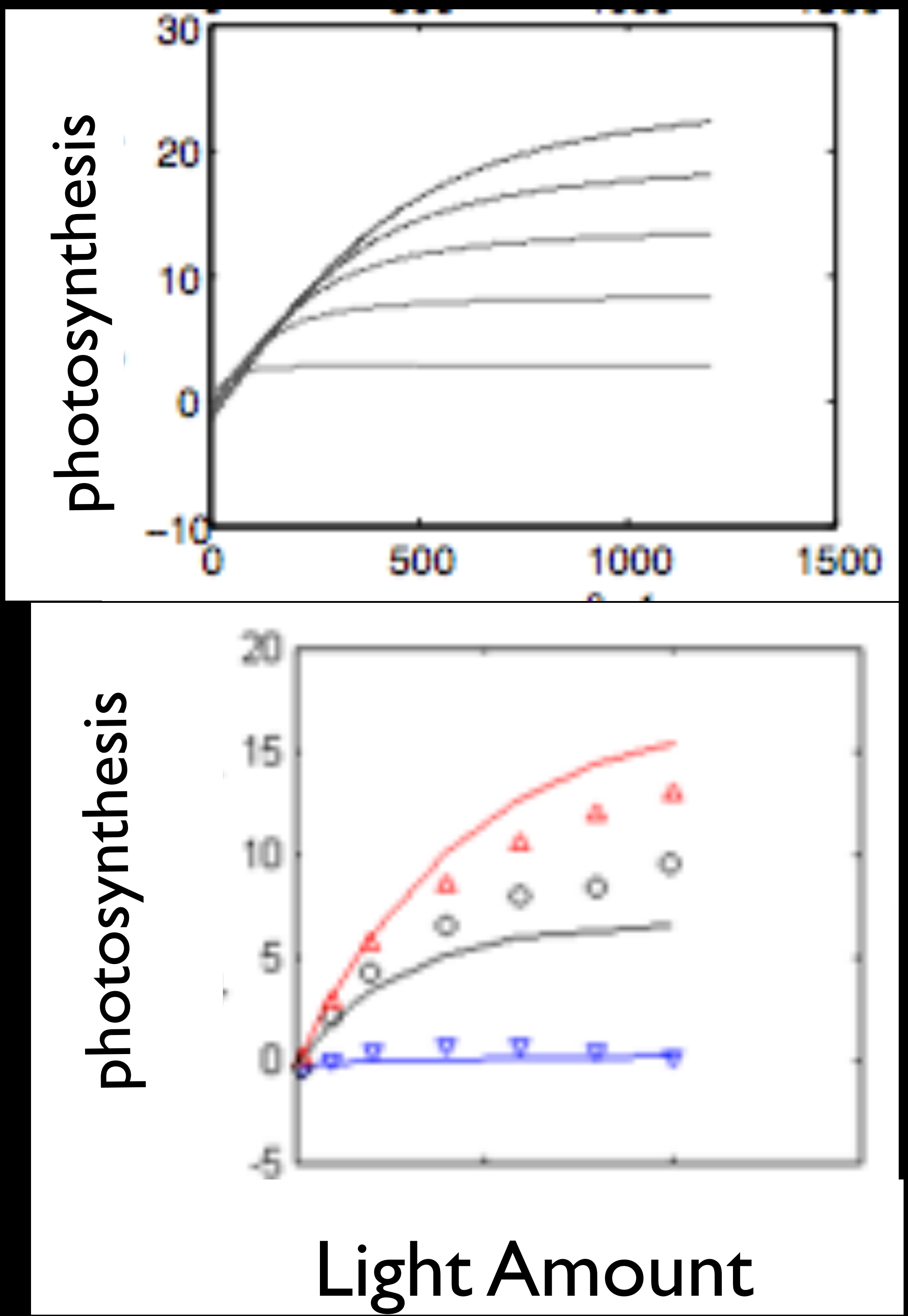
# Models of Photosynthesis



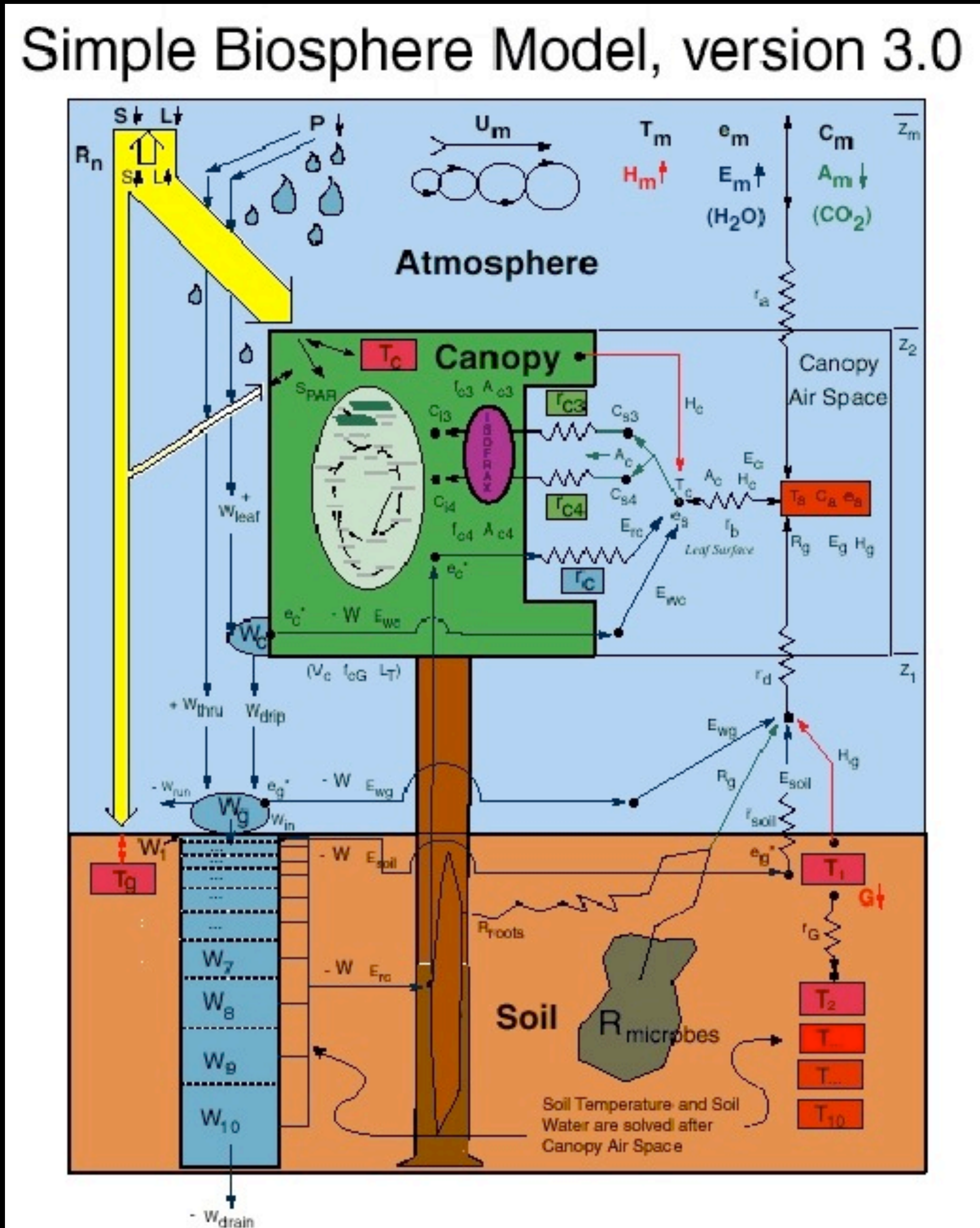

- Do our models agree with respect to global/ continental scale photosynthesis?
- Um, no.

Huntzinger et al., 2012

# Types of Models




- "Light Response"
- Simple, statistical models
- Few Parameters
- Multiple mechanisms combined into single eqns

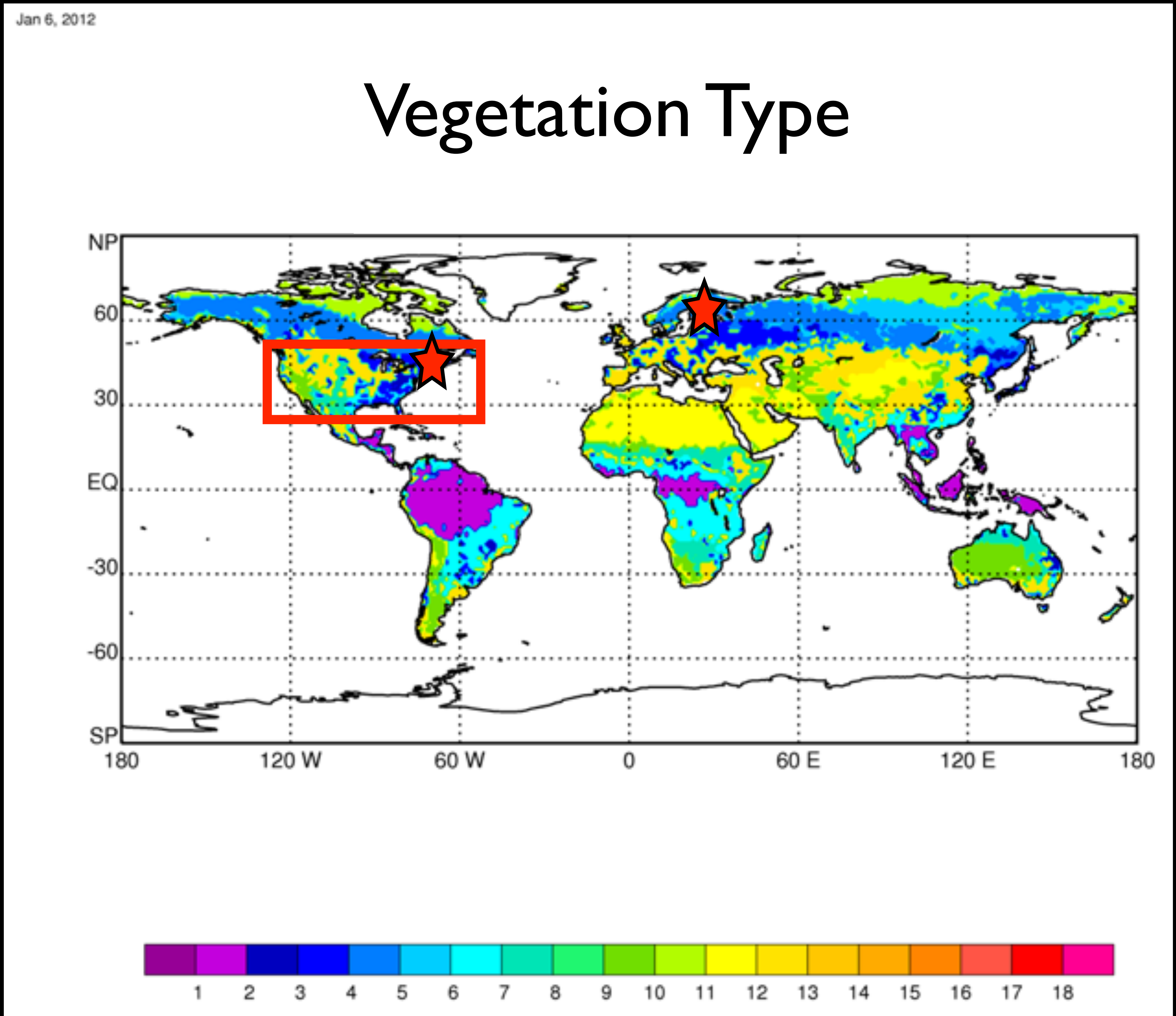



# Types of Models

- "Enzyme Kinetic"
- More complex
- Explicit representation of physical processes
- Many parameters

# “All Models Are Wrong, Some Models Are Useful”

- How can we use SIF and OCS observations to constrain our models?




- OCS Studies
  - First model (Berry)
  - Harvard Forest MA, USA (Commane)
  - Hyytiala, Finland (Kooijmans)
  - North America (Iowa) (Chen)

# The OCS Model: Berry et al., 2013

BERRY ET AL.: CARBONYL SULFIDE AS A GLOBAL CARBON CYCLE TRACER

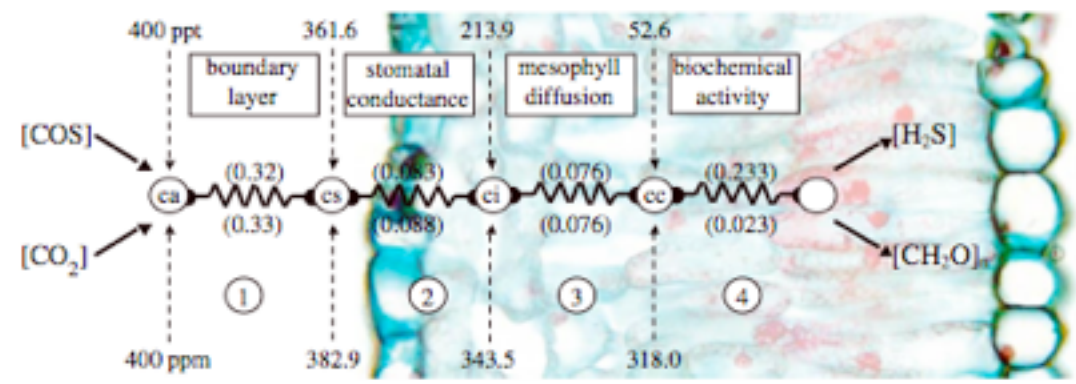



**Figure 2.** Resistance analog model of $CO_2$ and COS uptake. Numbers in parentheses are conductance values ($mol\,m^{-2}\,s^{-1}$) corresponding to the numbered key: (1) Boundary layer conductance, $g_b$. (2) Stomatal conductance, $g_s$. (3) Mesophyll conductance, $g_i$. (4) Biochemical rate constant used approximate photosynthetic $CO_2$ uptake by Rubisco or the reaction of COS with carbonic anhydrase as a linear function of $c_c$. In this case, COS uptake is 12.6 $pmol\,m^{-2}\,s^{-1}$ and that of $CO_2$ is 5.6 $\mu mol\,m^{-2}\,s^{-1}$.

- Equations in SiB3
- OCS Analogous to $CO_2$

# The OCS Model: Berry et al., 2013

**Table 1.** A Compilation of the Global Sources and Sinks Used for PCTM Simulations of Atmospheric COS[a]

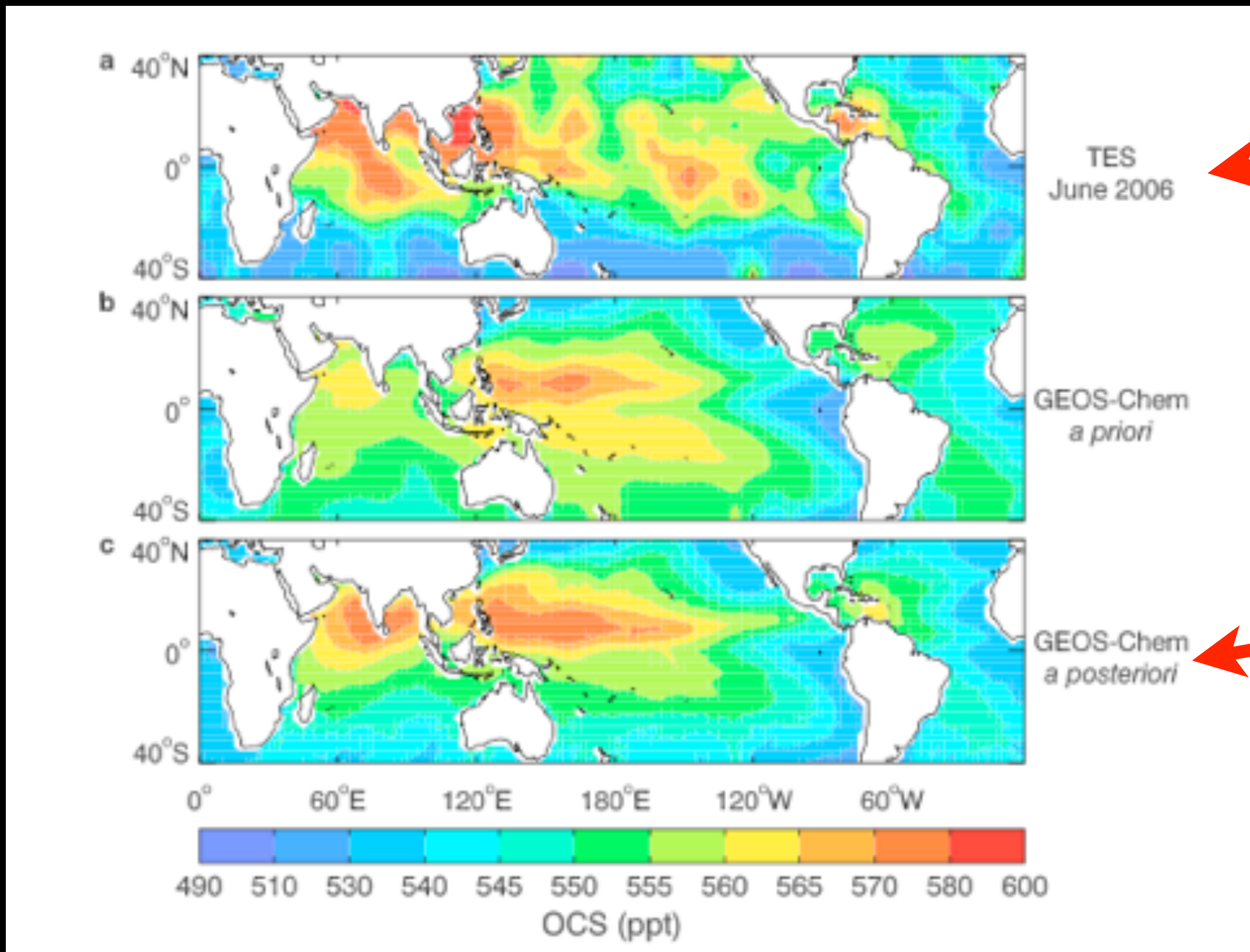
| Sources | *Kettle et al.*, 2002 | This Study |
|---|---|---|
| Direct COS Flux From Oceans | 39 | 39 |
| Indirect COS Flux as DMS From Oceans | 81 | 81 |
| Indirect COS Flux as $CS_2$ From Oceans | 156 | 156 |
| Direct Anthropogenic Flux | 64 | 64 |
| Indirect Anthropogenic Flux From $CS_2$ | 116 | 116 |
| Indirect Anthropogenic Flux From DMS | 0.5 | 0.5 |
| Biomass Burning | 11 | **136** |
| Additional (Photochemical) Ocean Flux | | **600** |
| *Sinks* | | |
| Destruction by OH Radical | −94 | **−101** |
| Uptake by Canopy | −238 | **−738** |
| Uptake by Soil | −130 | **−355** |
| Net Total | −5 | −2.5 |

[a]Units are $1.0 \times 10^9$ g of sulfur. Fluxes changed in this study are highlighted with bold type.

The first simulations said there must be a much larger OCS source in the tropical oceans to balance plant and soil uptake

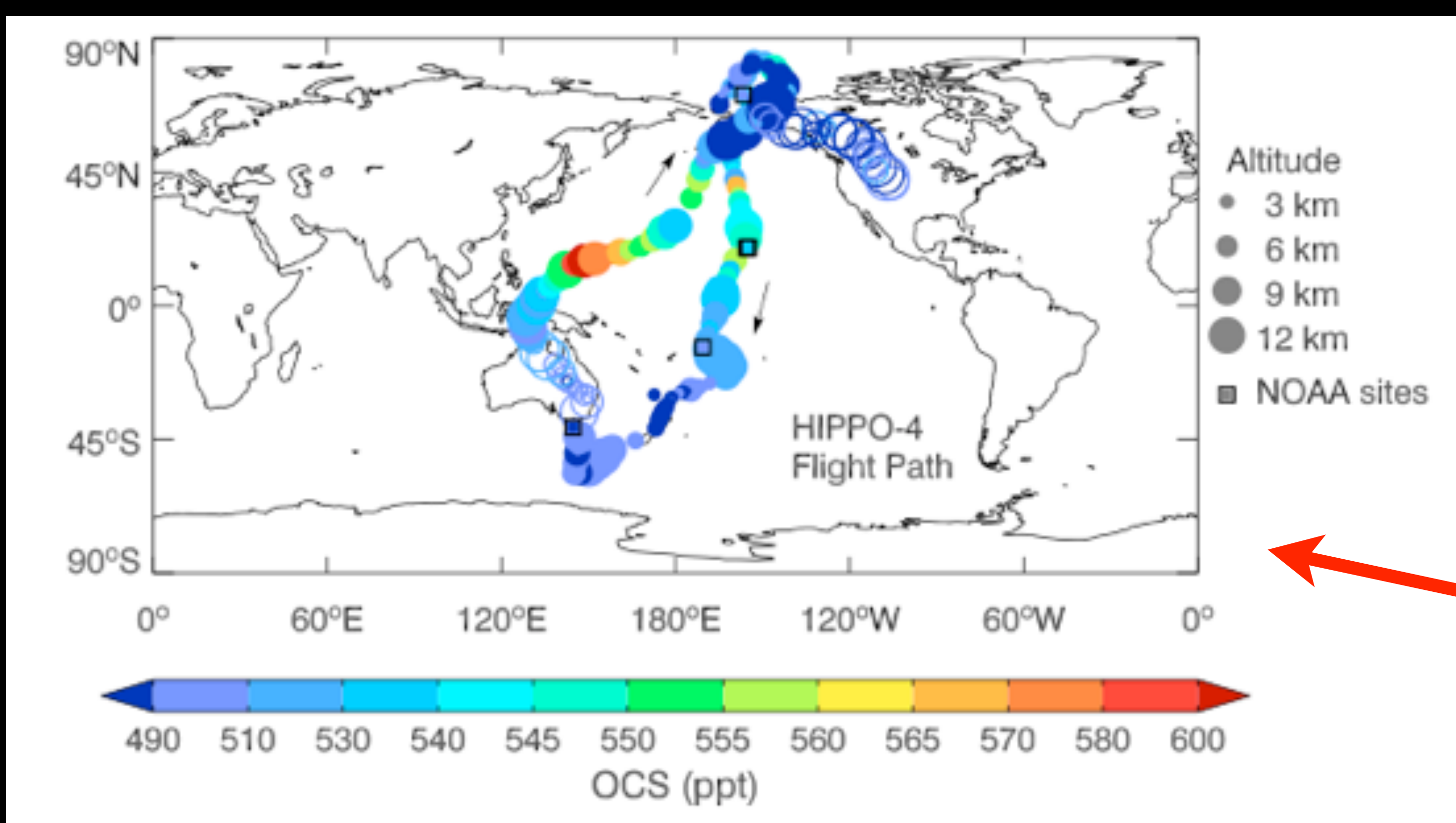
Kuai et al., 2014

# Ocean OCS flux




Satellite

Inversion model

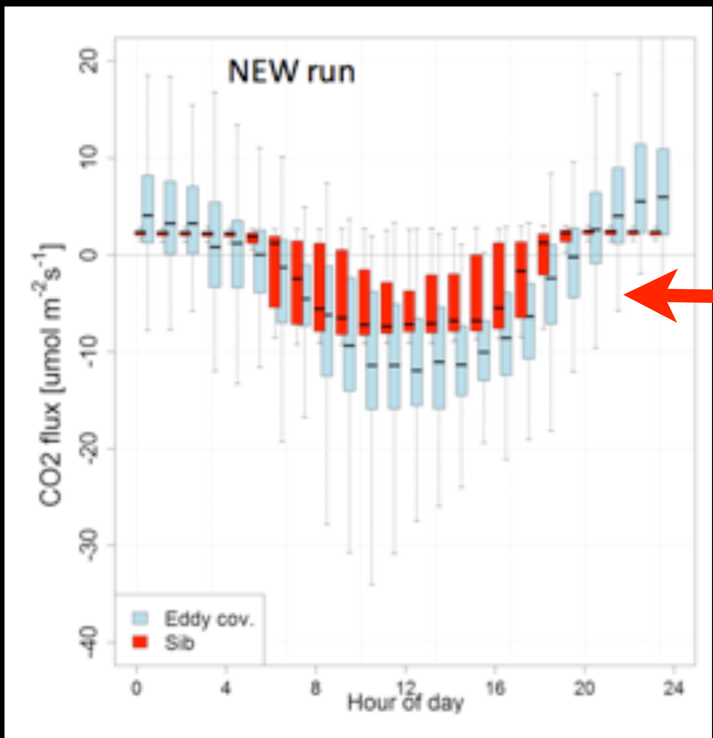



The ocean source is right where Joe said it would be!

Aircraft Observations

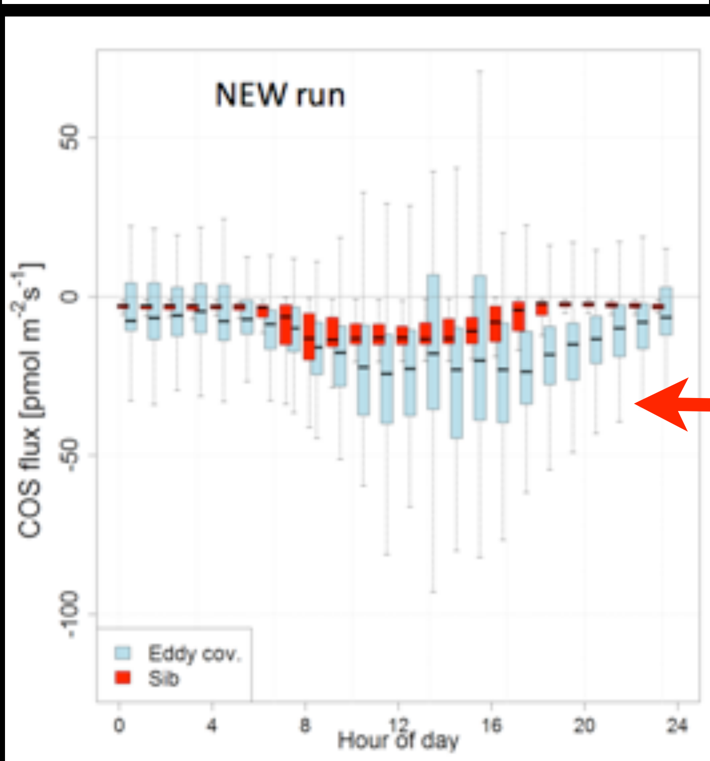
# Site-Level Studies-Hyytiala, Finland

## Pine Forest

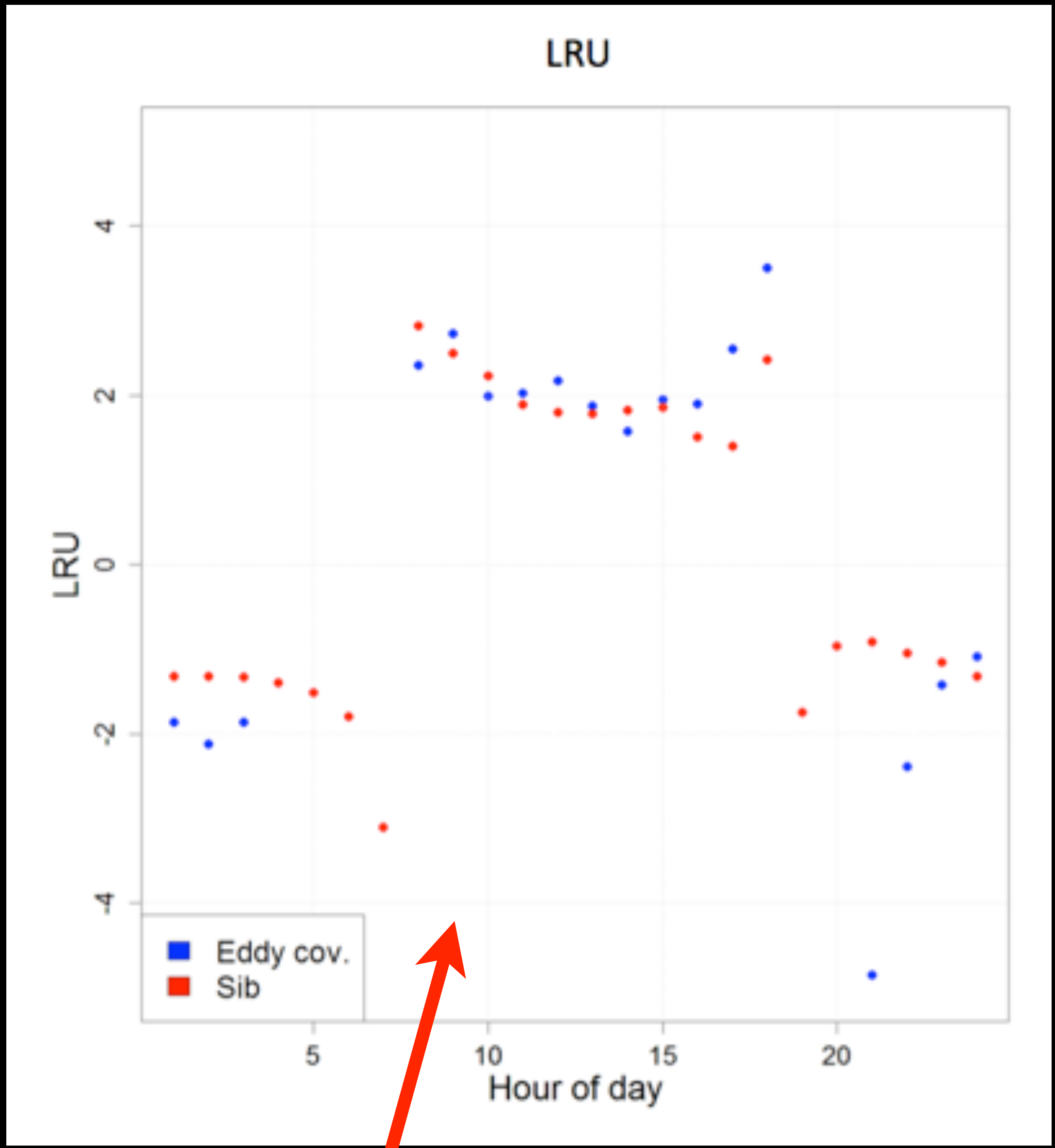



Model $CO_2$ flux too small!

**Fluxes: $CO_2$ and OCS moving past a sensor**




Model OCS flux too small!

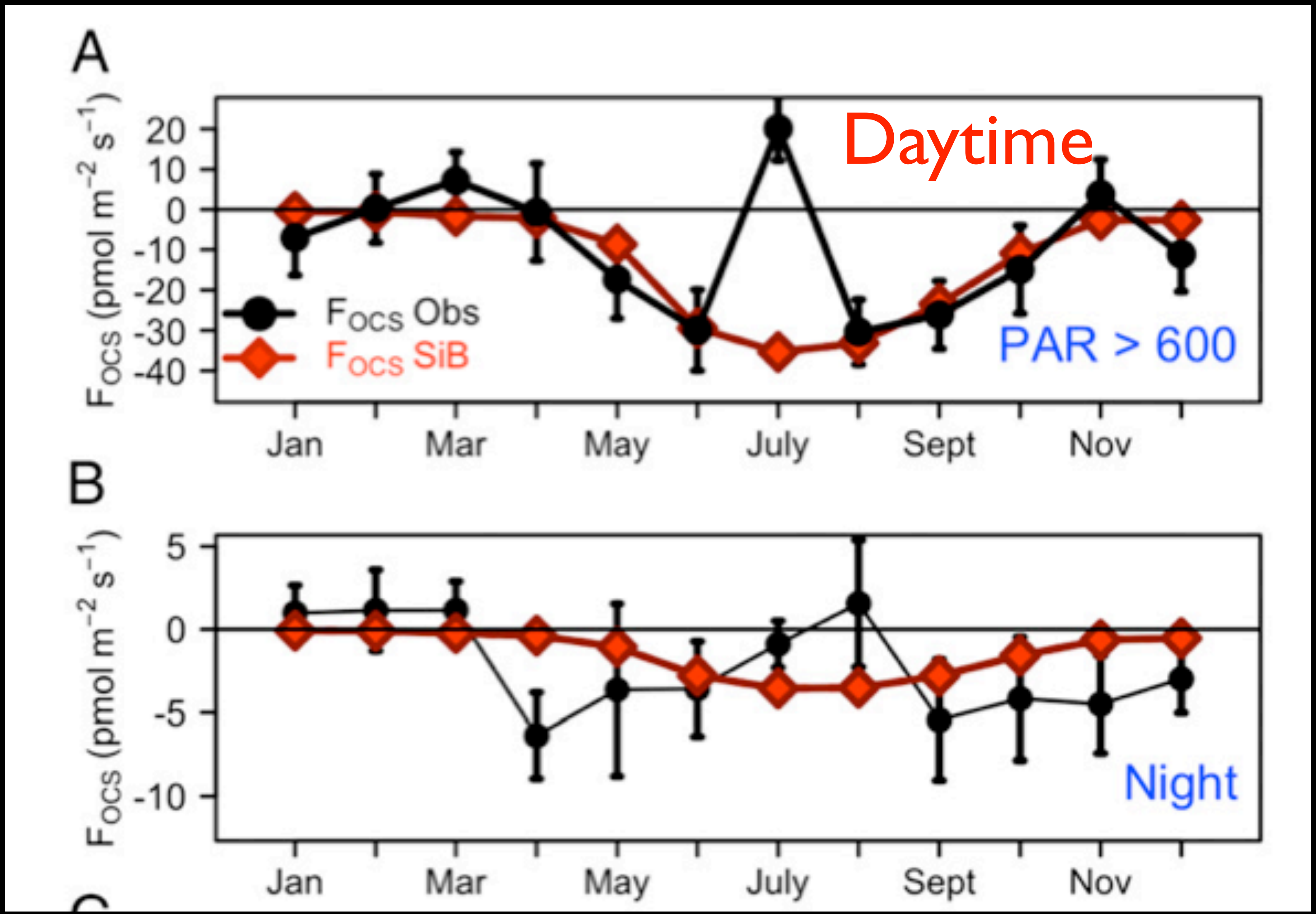



But LRU looks good!

LRU= Leaf Relative Uptake = OCS flux / $CO_2$ flux

Observations from L. Kooijmans, U Groningen

# Site-Level Studies-Harvard Forest

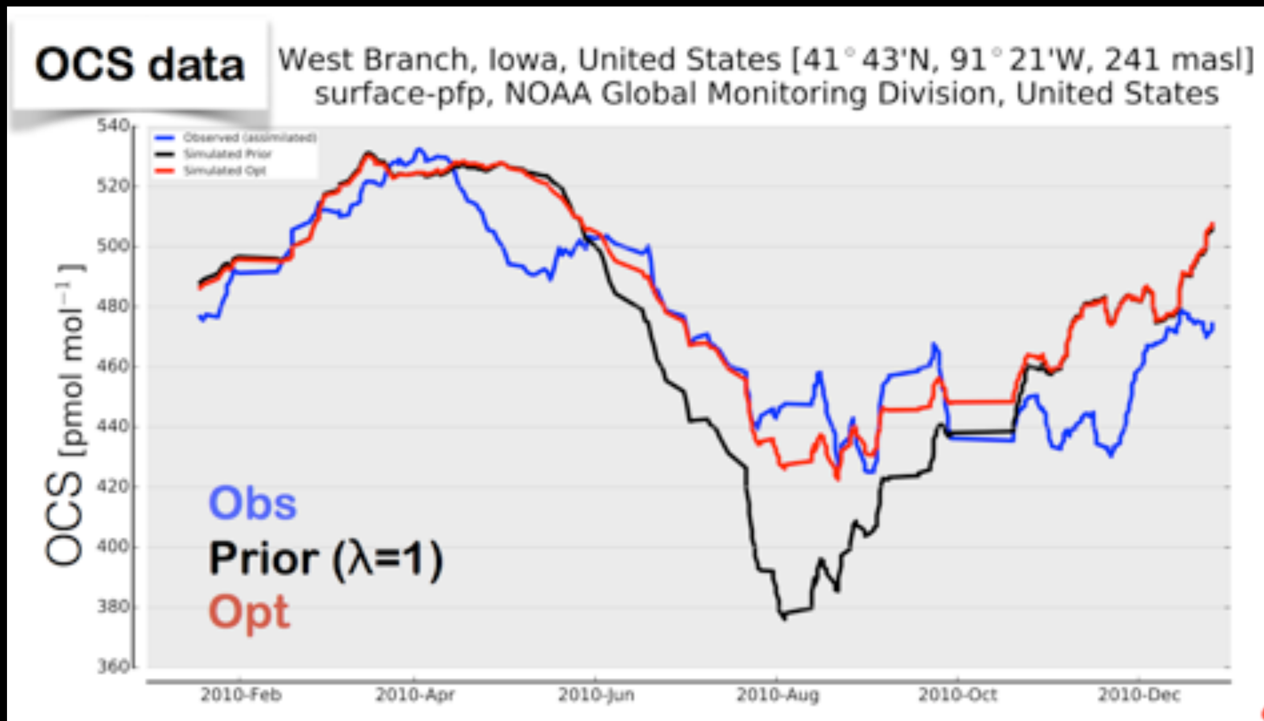


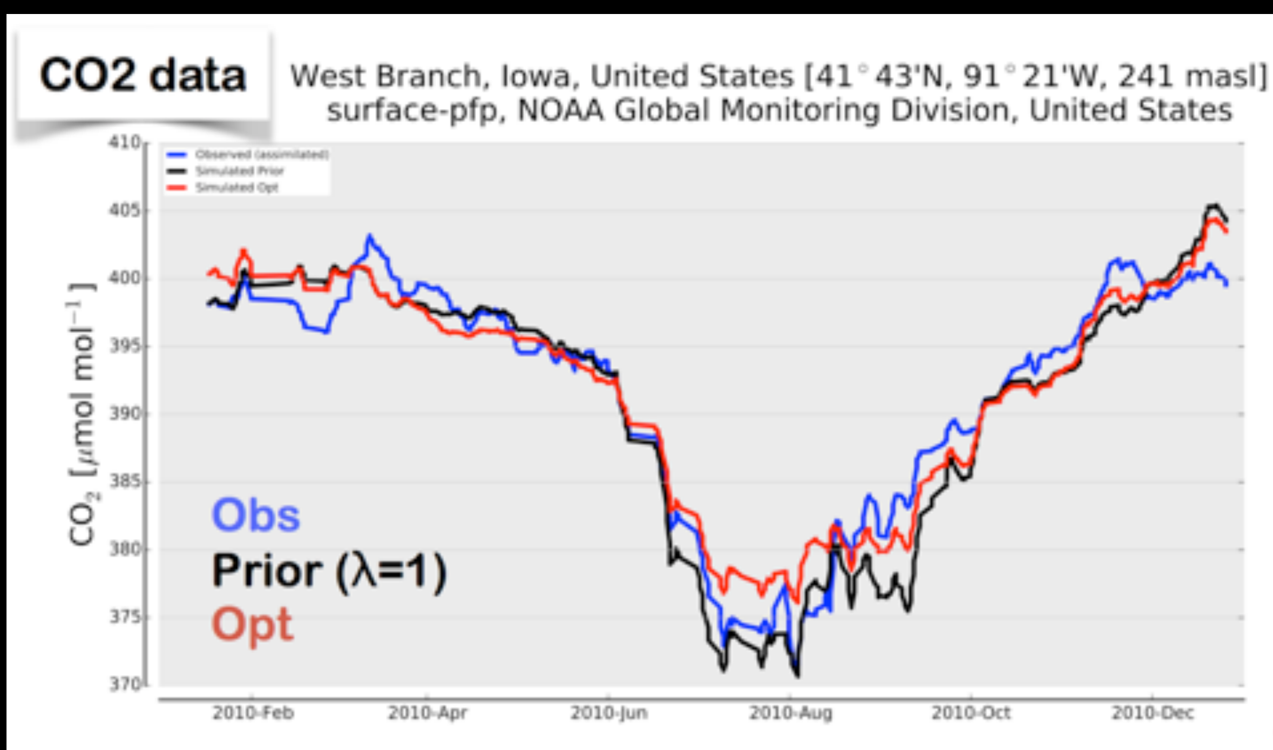

Commane et al., 2015

- Monthly Signal looks good (mostly) (A)
- Not enough uptake at night (B)
- OCS source?

All FLUXES on this plot

# Large-Scale Inversions



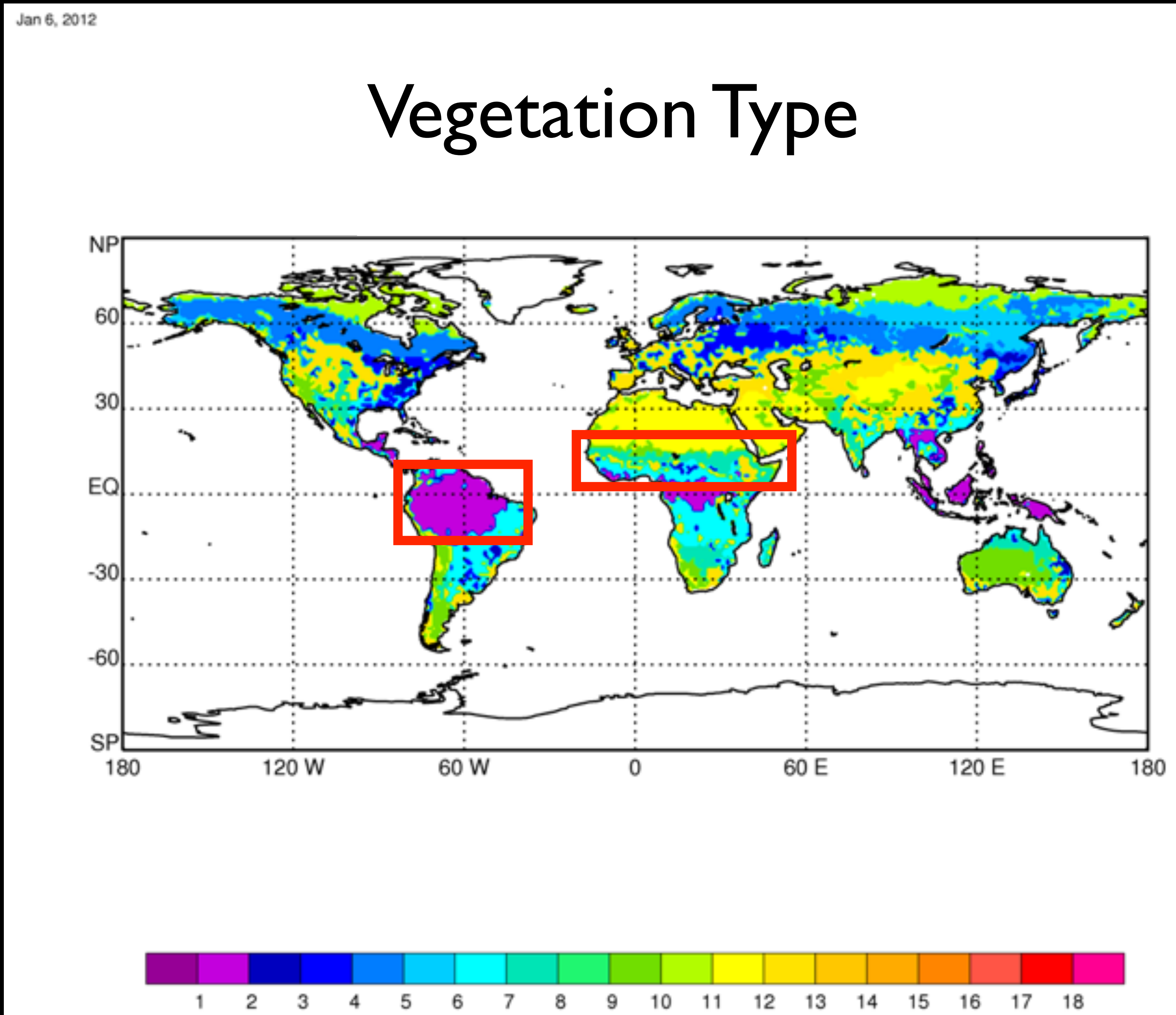




Feb 2010 Dec 2010

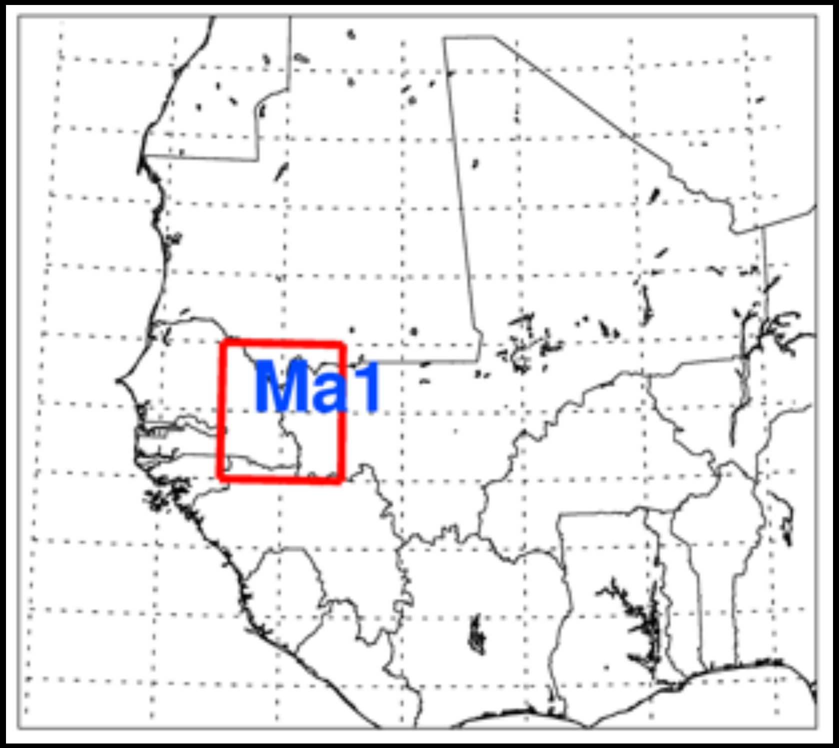
Concentrations: amount of OCS or $CO_2$ in the air

Measurements taken in Iowa

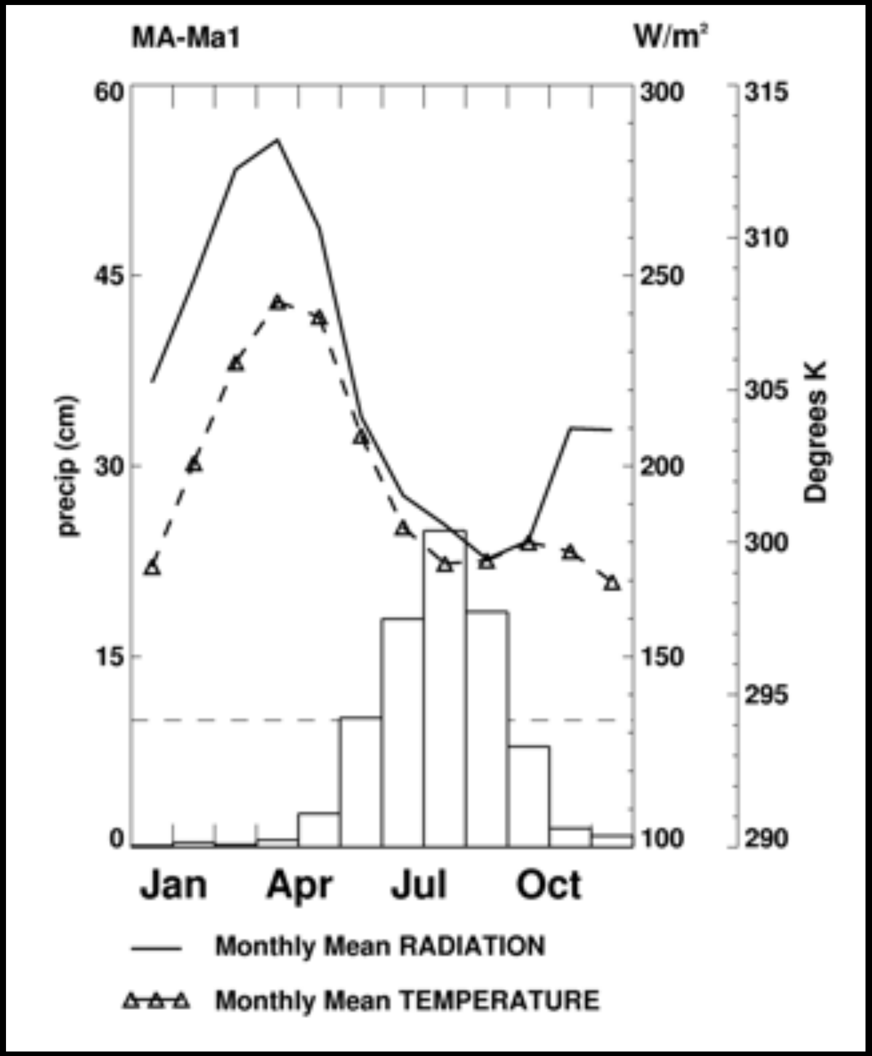
- Too much OCS uptake (top)
- 'Prior' $CO_2$ looks good (bottom)
- OCS efflux from agricultural soils? What about Harvard?




- SIF Studies
  - Sahel
  - Tropical South America (Goldilocks)

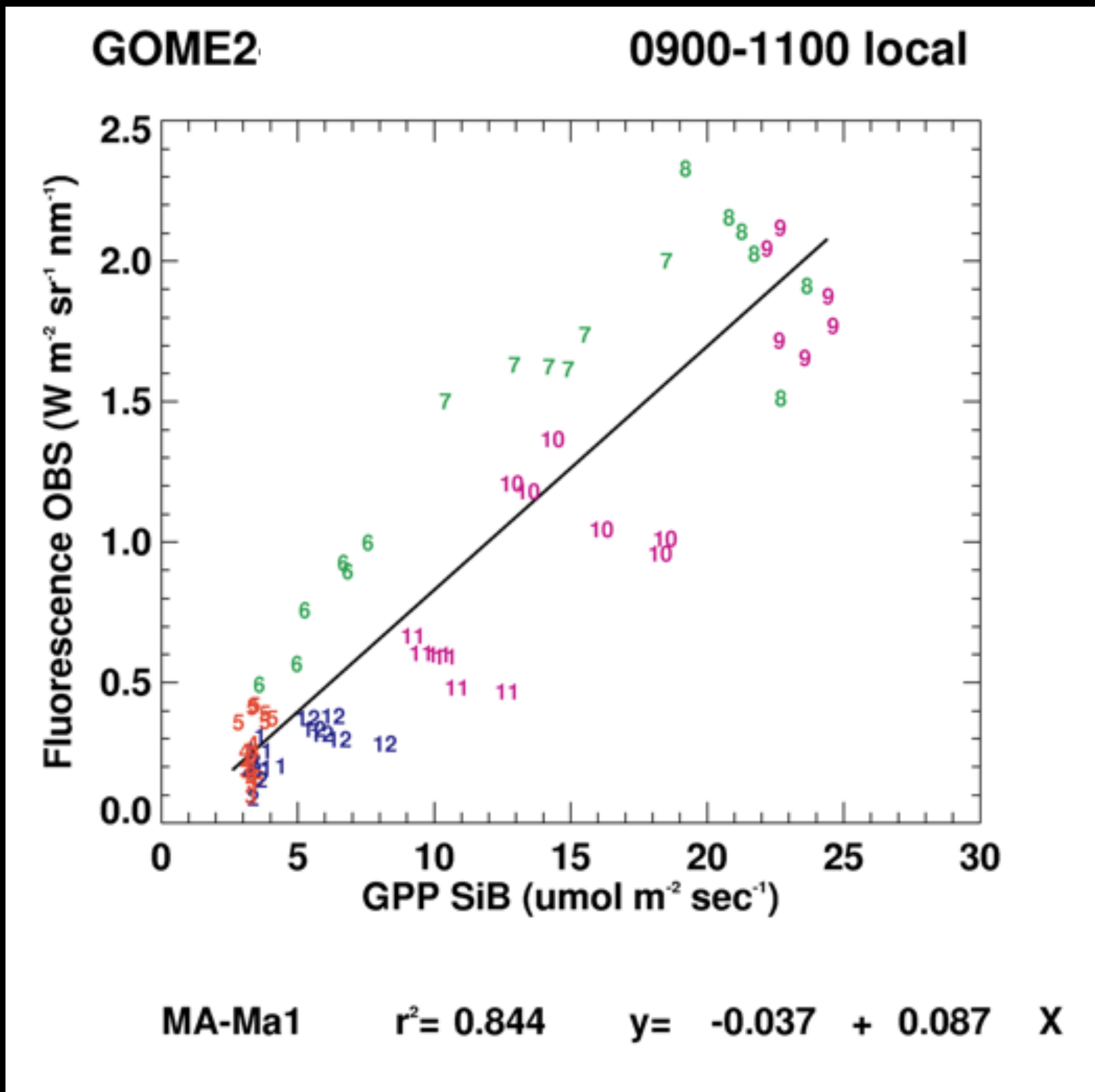



# Sahel



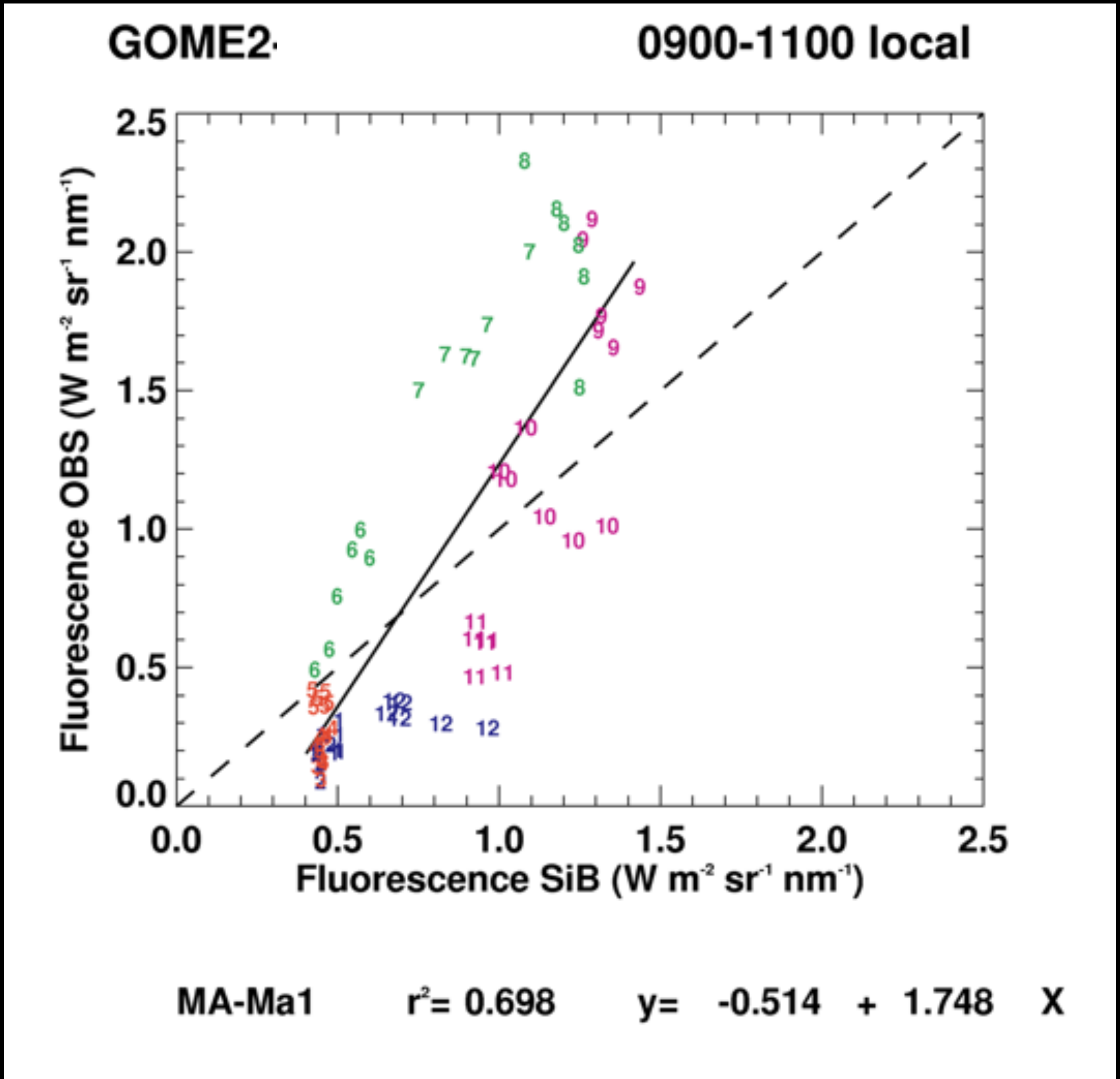

- Extremely seasonal
- Poorly observed
- Politically unstable

# Sahel: Obs SIF vs Model Photosynthesis



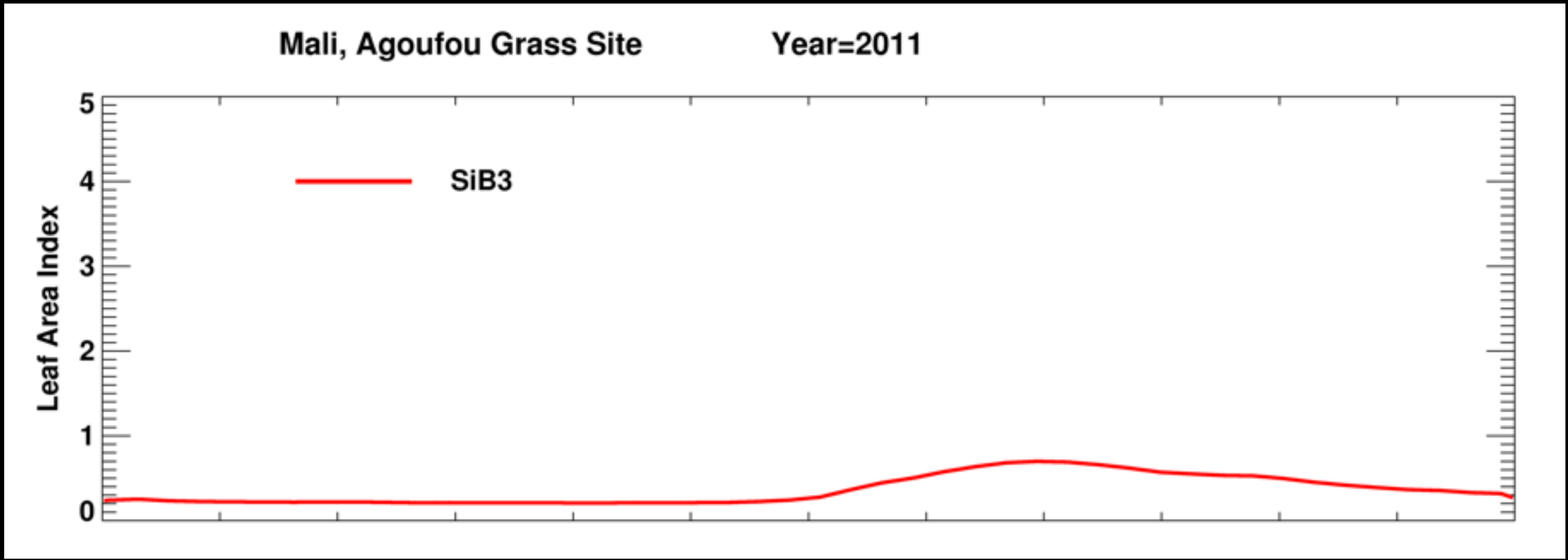

- Month indicated by number
- 6 years of data
- 'Greens up' in rainy season

# Sahel: Obs SIF vs Model SIF




- 1:1 line would be perfect
- Model does not capture start of season
- Model does not have large enough SIF
- Leaves?

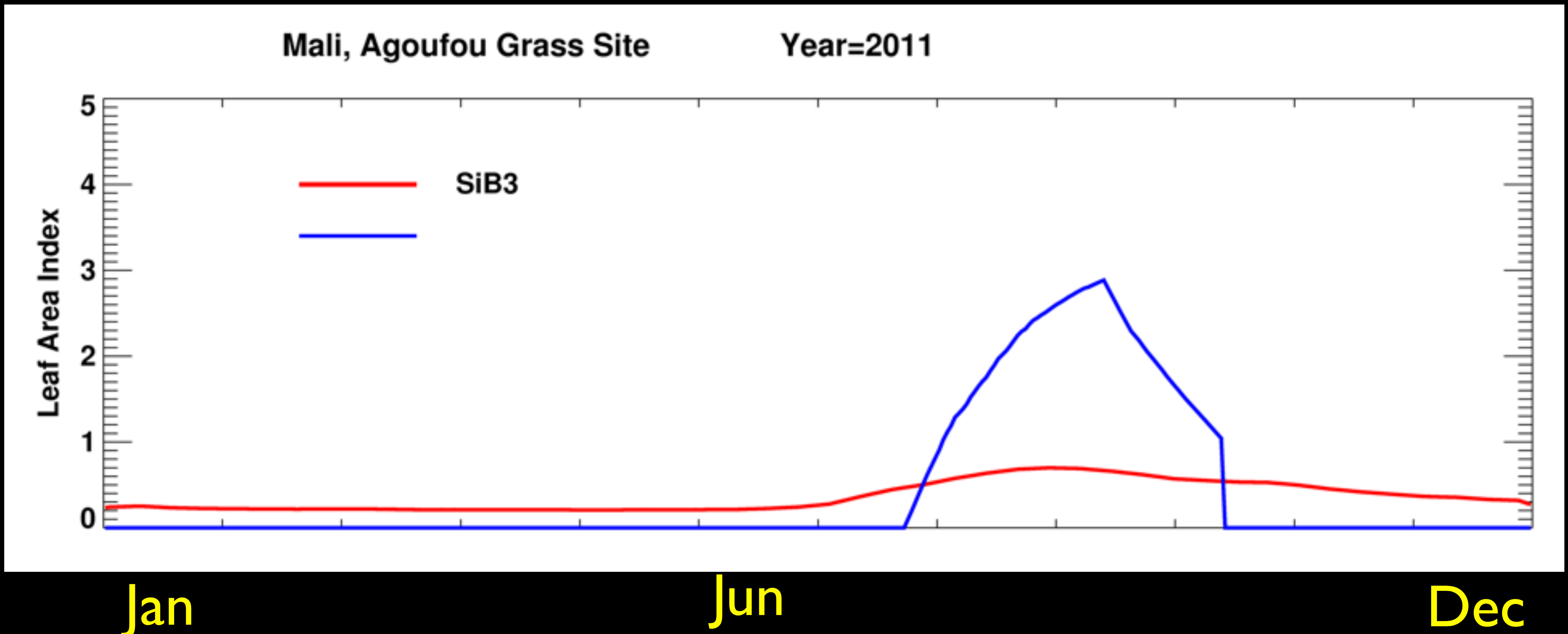
# Leaf Area




Jan Jun Dec

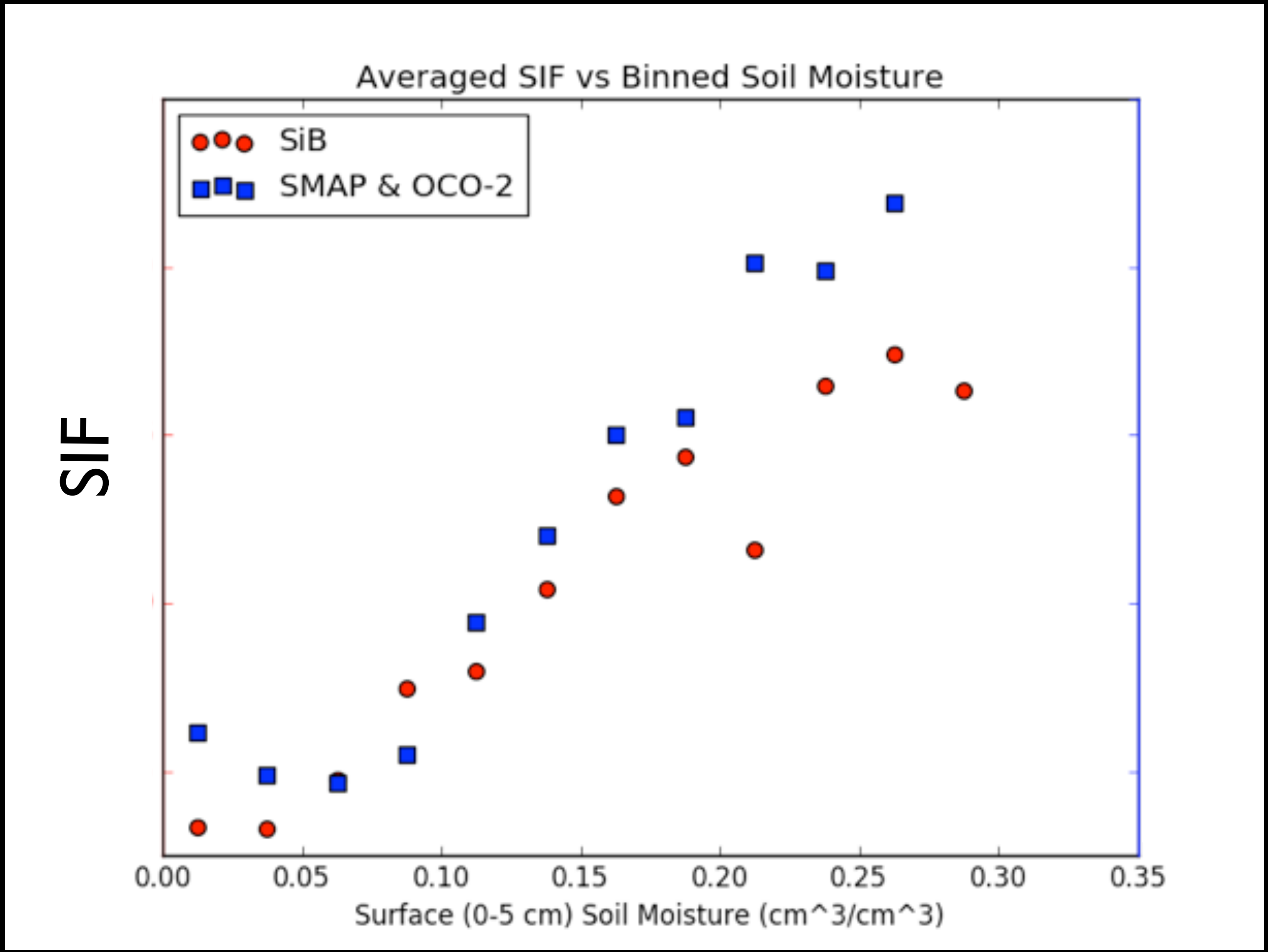
- The LEAF AREA used in the model is very low
- Very little response to seasonality

# Leaf Area




- We expect a rapid GREEN UP following the onset of seasonal rains
- Observations support this

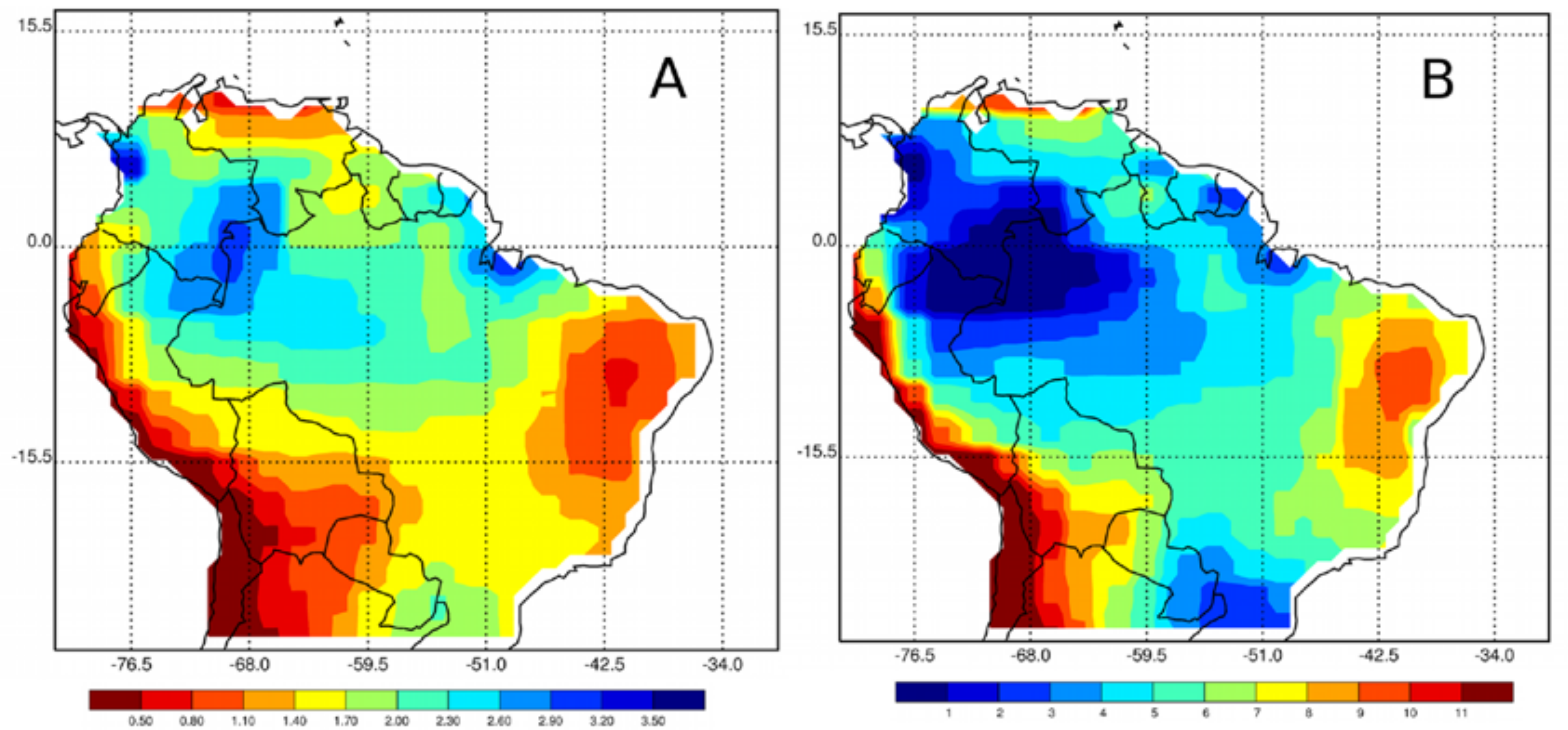
# New Model of Phenology (leaves)




Katherine Haynes and Dakota Smith

- Rapid rise in MODEL SIF when soil starts to moisten

# Amazon Basin

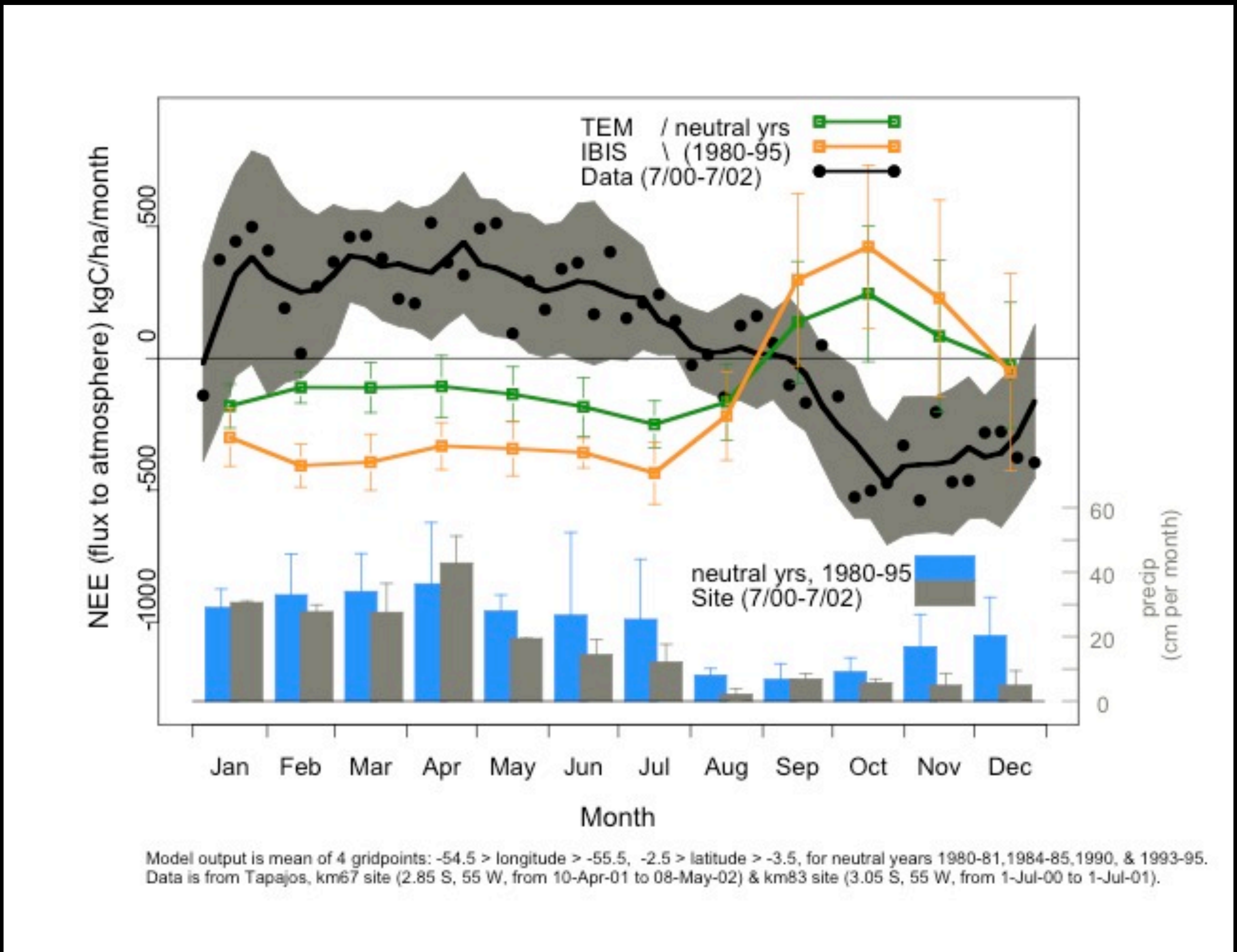



Annual Rainfall, meters

# months rainfall < 100mm

GPCP rainfall data

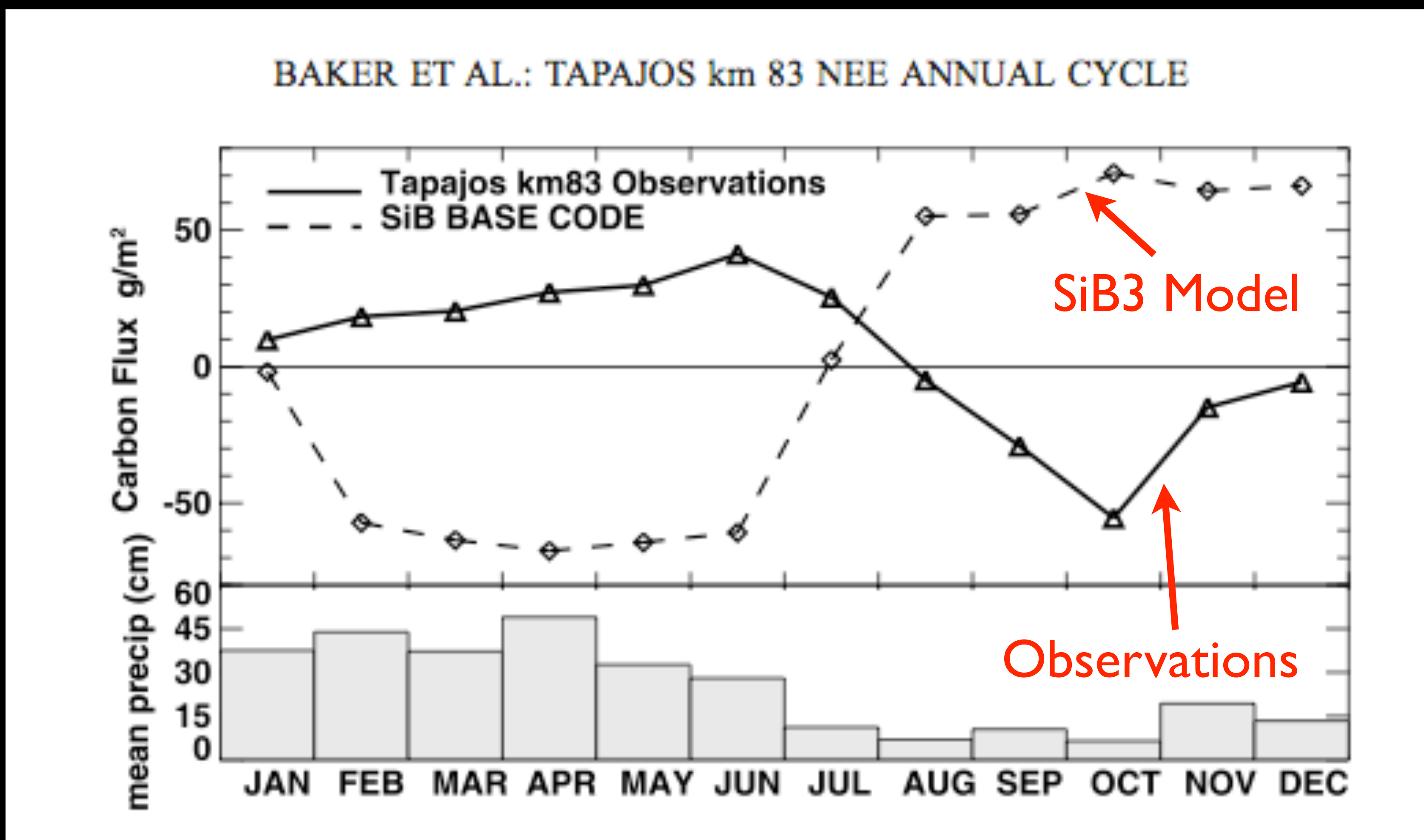
# Amazon Basin




Saleska et al., 2003

- OBSERVATIONS: carbon into the ecosystem during the dry season, into the atmosphere during rainy season
- MODELS: the exact opposite

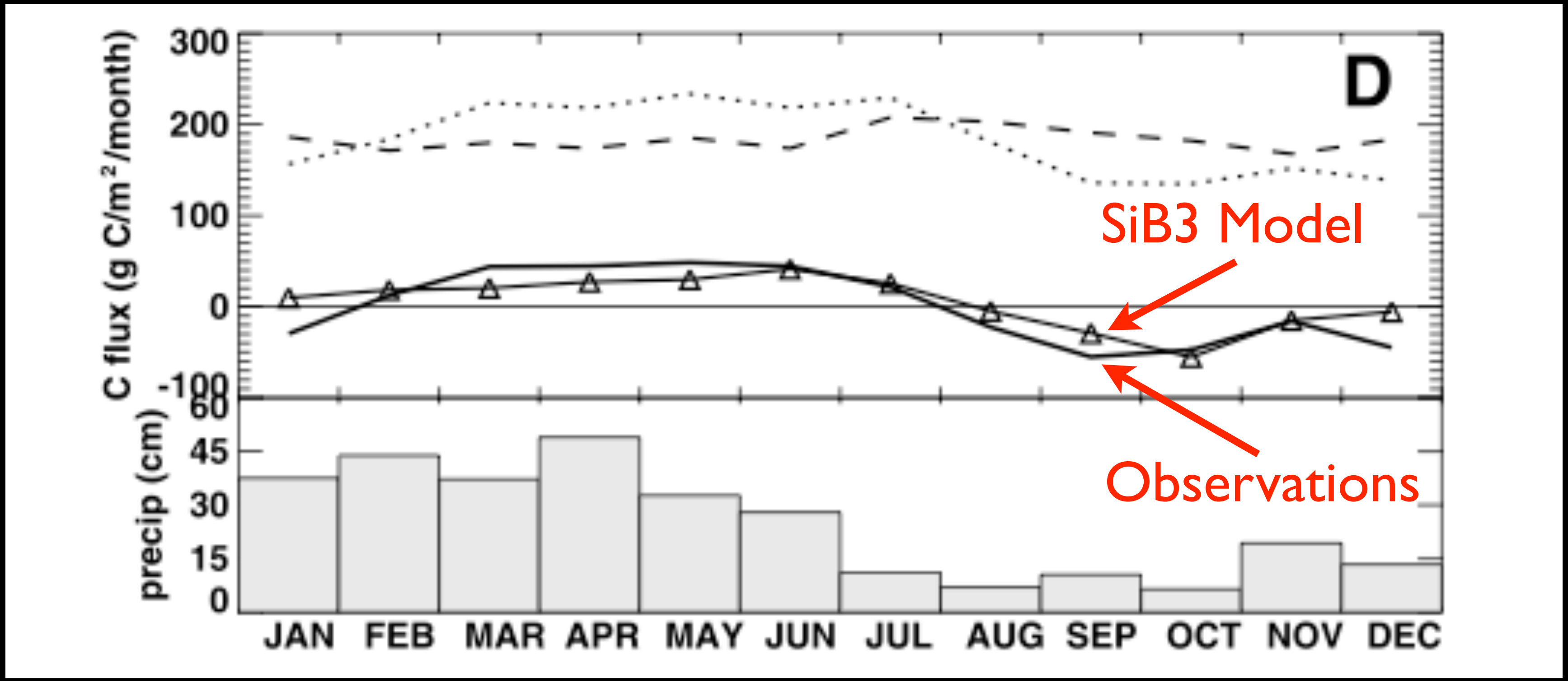
# Amazon Basin




Baker et al., 2008

- Our model had opposite seasonality too

# Amazon Basin




Baker et al., 2008

- We fixed our carbon flux problem!
  - Deeper Soil
  - Soilwater depletion by roots
- Then we ran the model for the entire region
- How did the model respond to the 2010 drought?

# Amazon Basin-2010 drought

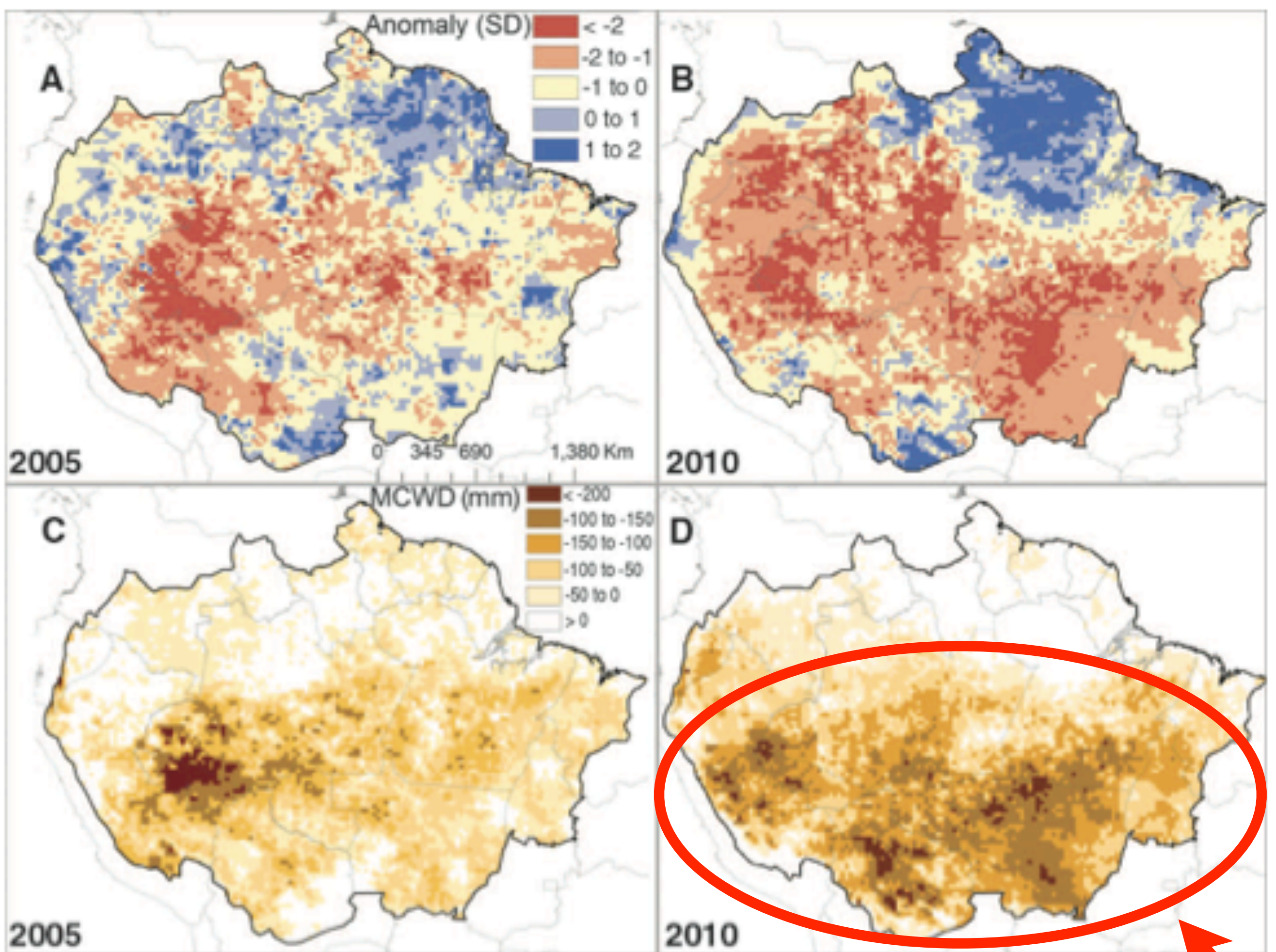


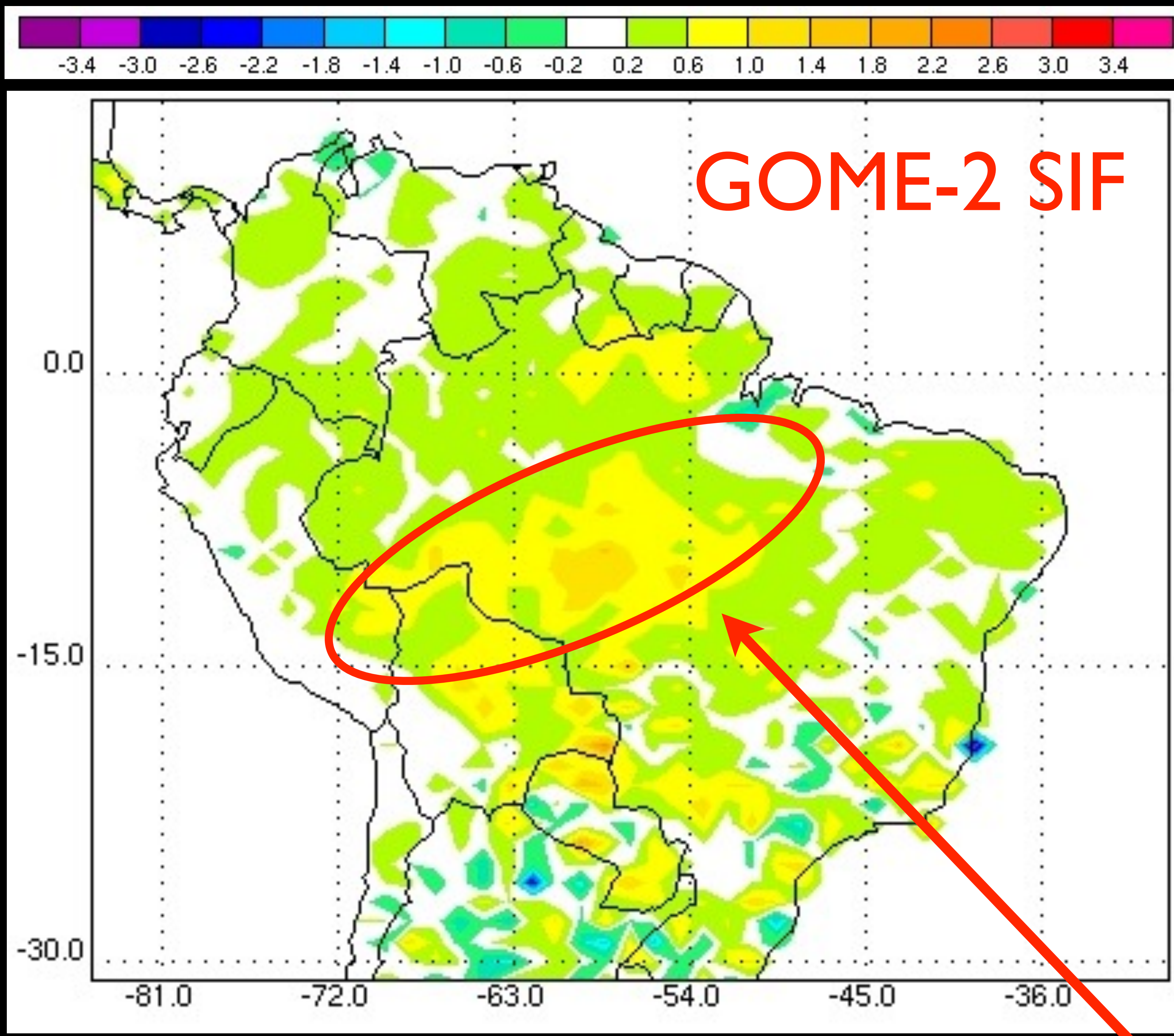

**Fig. 1.** (**A** and **B**) Satellite-derived standardized anomalies for dry-season rainfall for the two most extensive droughts of the 21st century in Amazonia. (**C** and **D**) The difference in the 12-month (October to September) MCWD from the decadal mean (excluding 2005 and 2010), a measure of drought intensity that correlates with tree mortality. (A) and (C) show the 2005 drought; (B) and (D) show the 2010 drought.

Lewis et al., 2011

Water Deficit

- Droughts in 2005 (no SIF) and 2010
- 2010 drought most extreme in Southern Amazon Basin

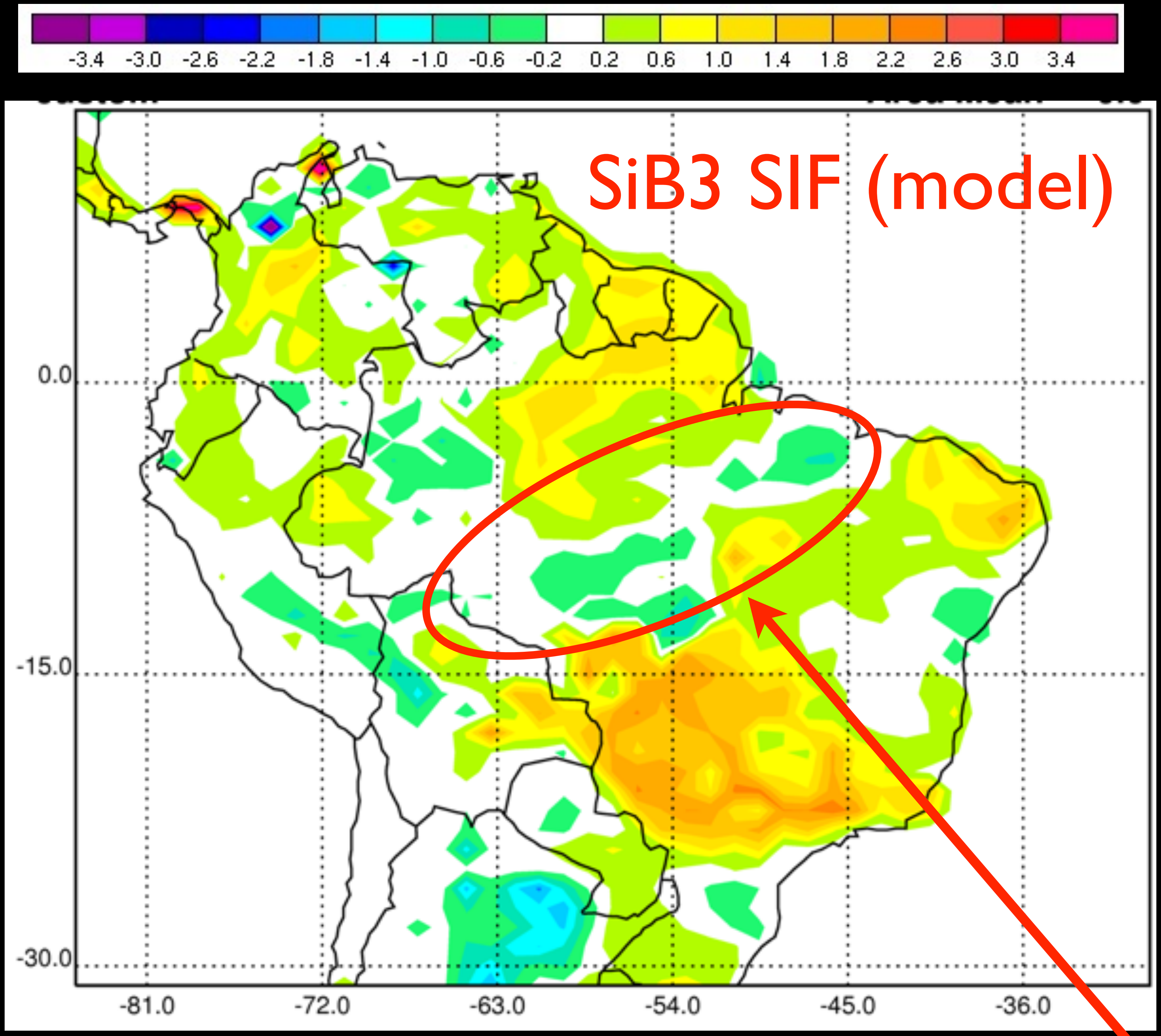
# Amazon Basin-2010 drought




- September 2010 SIF subtracted from September 2009
- Can see the 2010 Drought in GOME-2 SIF
- Significant reduction in SIF in southern part of the Amazon Basin Forest

Drought as recorded by GOME-2 SIF

# Amazon Basin-2010 drought




- No sign of drought in our model SIF
- We appear to have made our model too drought-resilient

This is where we should see the drought

# Conclusion

- Carbon cycle models are important for:
  - Evaluating current ecosystem behavior
  - Predicting the future of the $CO_2$ sink
- OCS and SIF allow us to observe nature in new ways, use that information to evaluate our models
- There is no 'silver bullet' that will answer all our questions; progress is incremental
- Frequently, the results are unexpected