Predicting the Future by Explaining the Past:

Constraining Carbon-Climate Feedback Using Contemporary Observations

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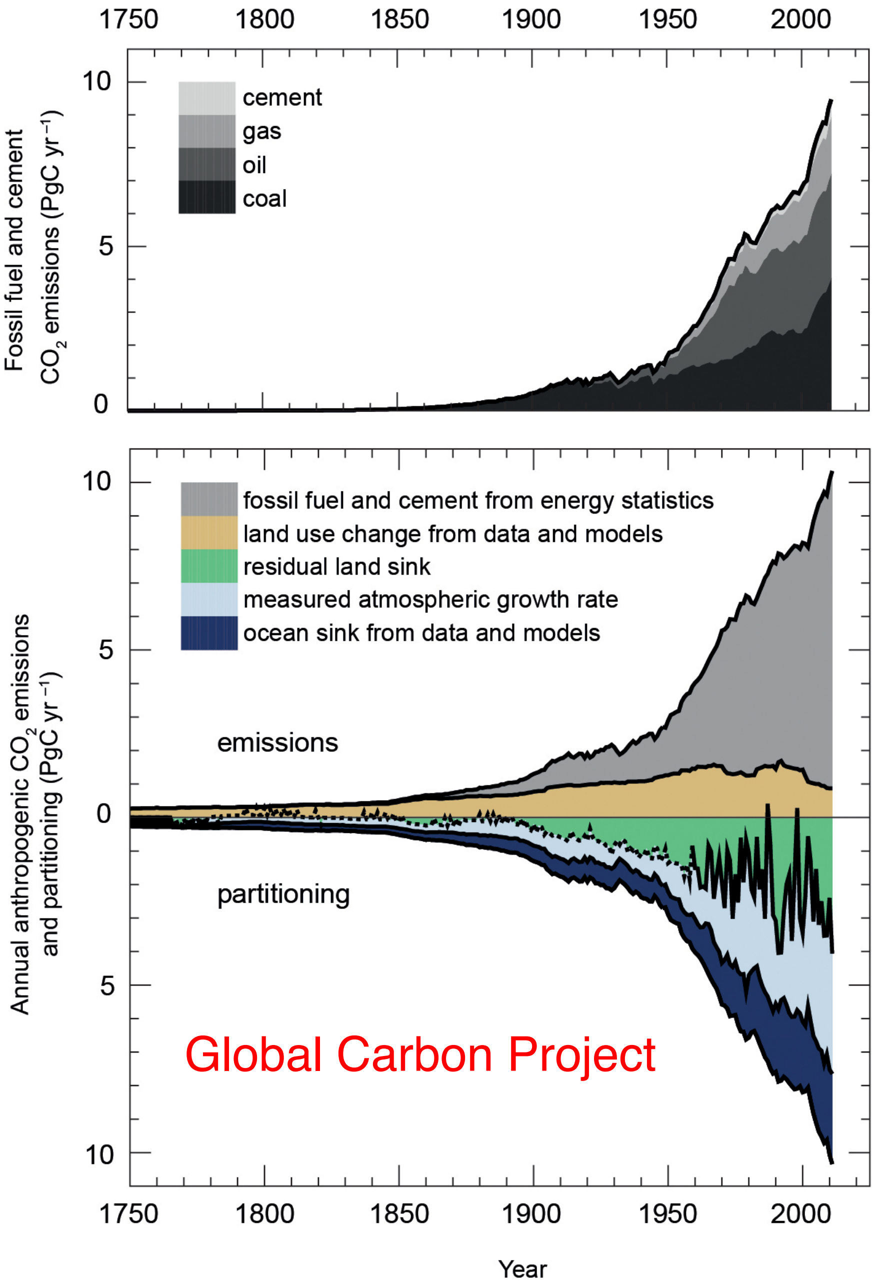
Also thanks to Joanna Joiner, NASA GSFC

Carbon Sources and Sinks

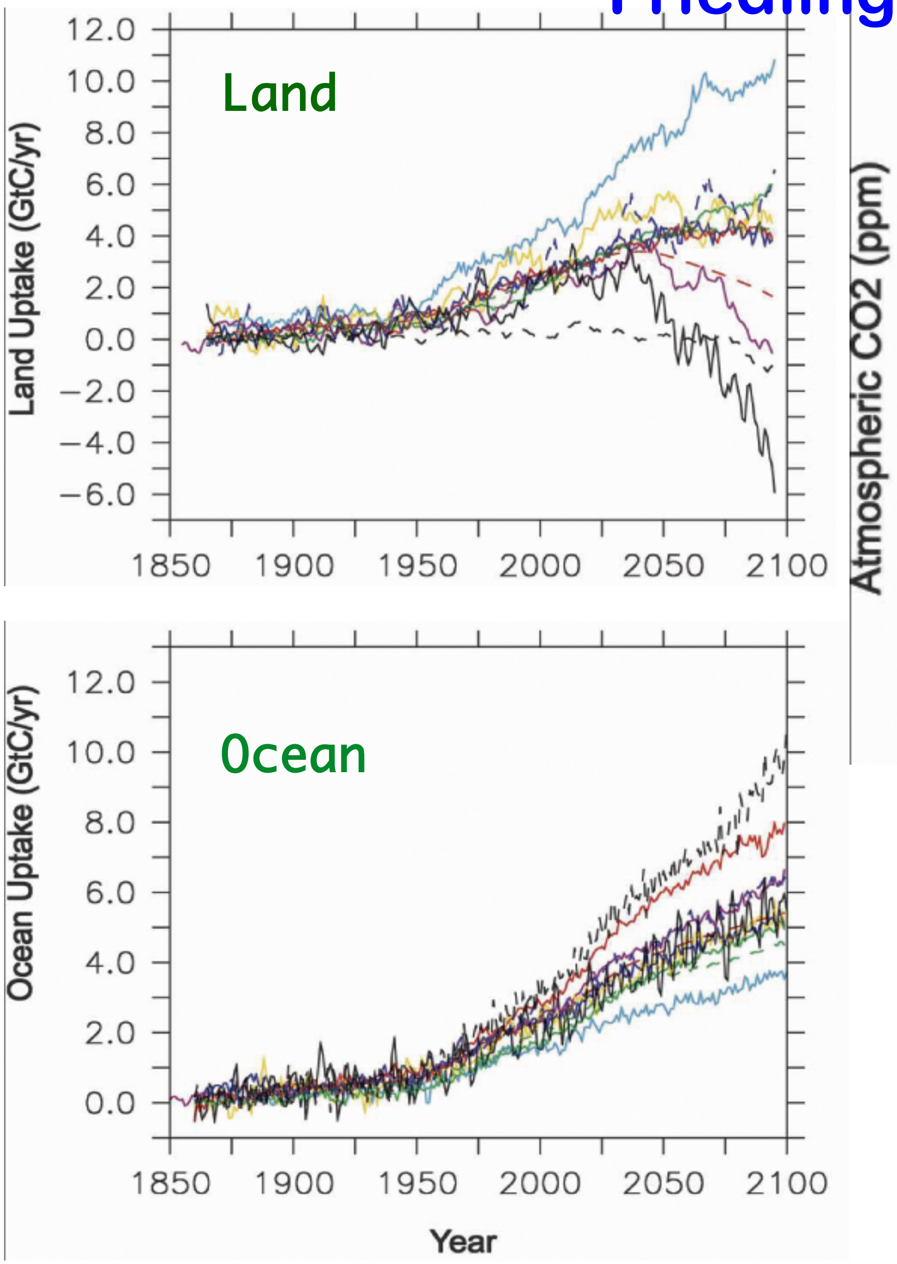


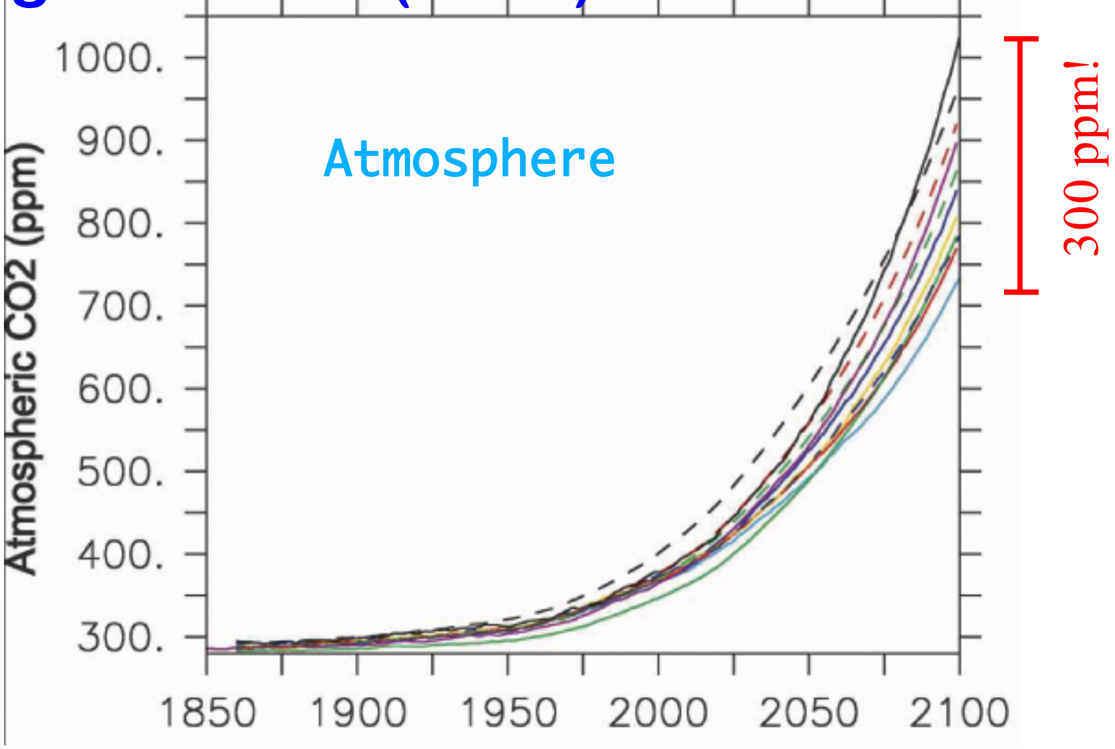
Global Carbon Project

- **Half the carbon from fossil fuels remains in the atmosphere**
- **The other half goes into land and oceans**
- **Land sink was unexpected is very noisy, and remains unreliable in future**
- **Future of carbon sinks is much harder to predict than temperatures**

Carbon-Climate Futures

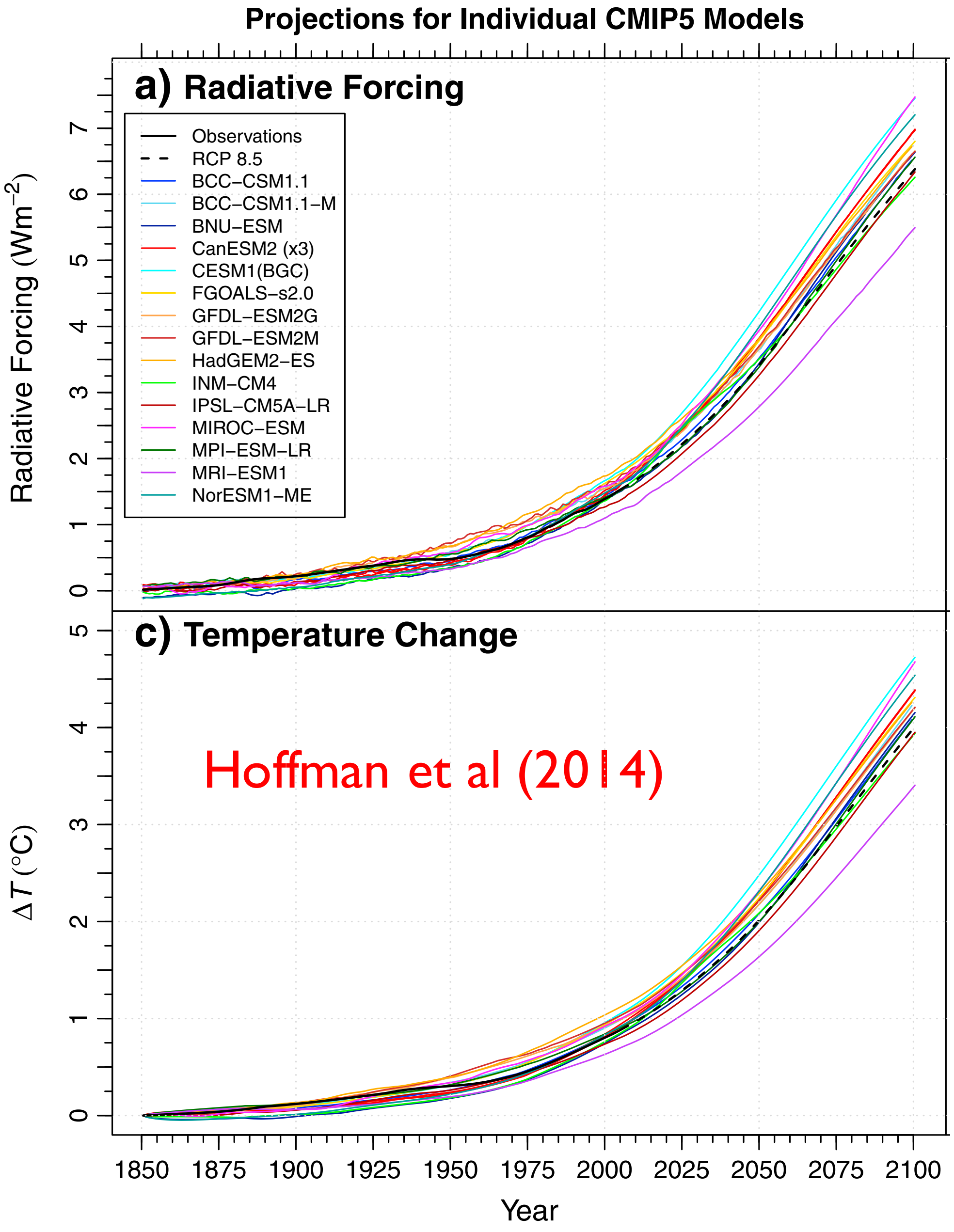
Friedlingstein et al (2006)





- Coupled simulations of climate and the carbon cycle (CMIP3, C4MIP)
- Given nearly identical human emissions, different models project dramatically different futures!
- Mostly depends on CO_2 fert & temp

Even Worse in CMIP5 !

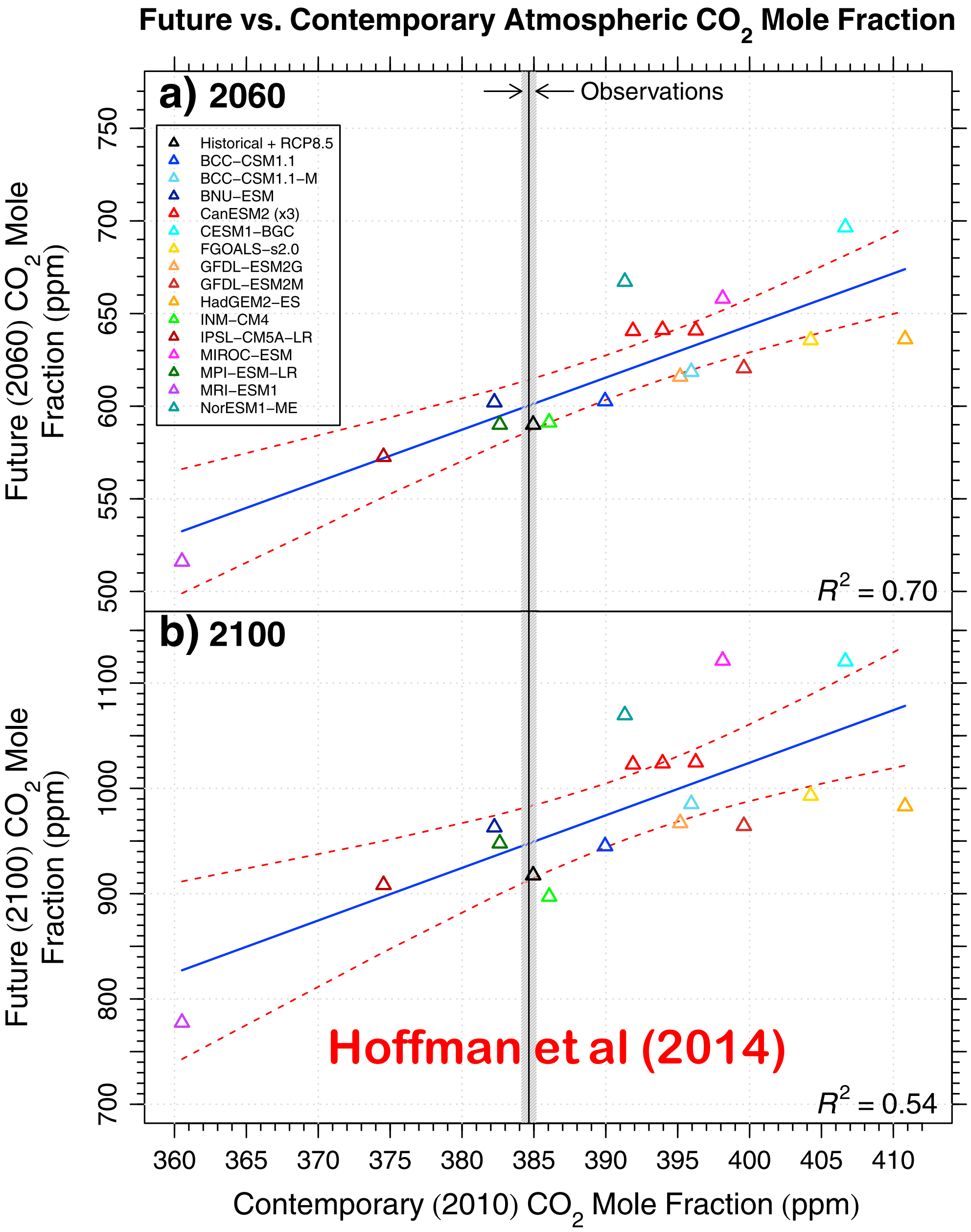


Hoffman et al (2014)

- More processes (land use, regrowth, nitrogen, fire)
- Now more than 350 ppm spread in CO$_2$!
- For identical emissions, radiative forcing varies by almost 2 W m^{-2} (more than RCP 4.5 vs RCP 6)
- Warming varies by 1.5 ° C (comparable to spread in physical climate)
- Carbon cycle impacts climate uncertainty as much as clouds or people!

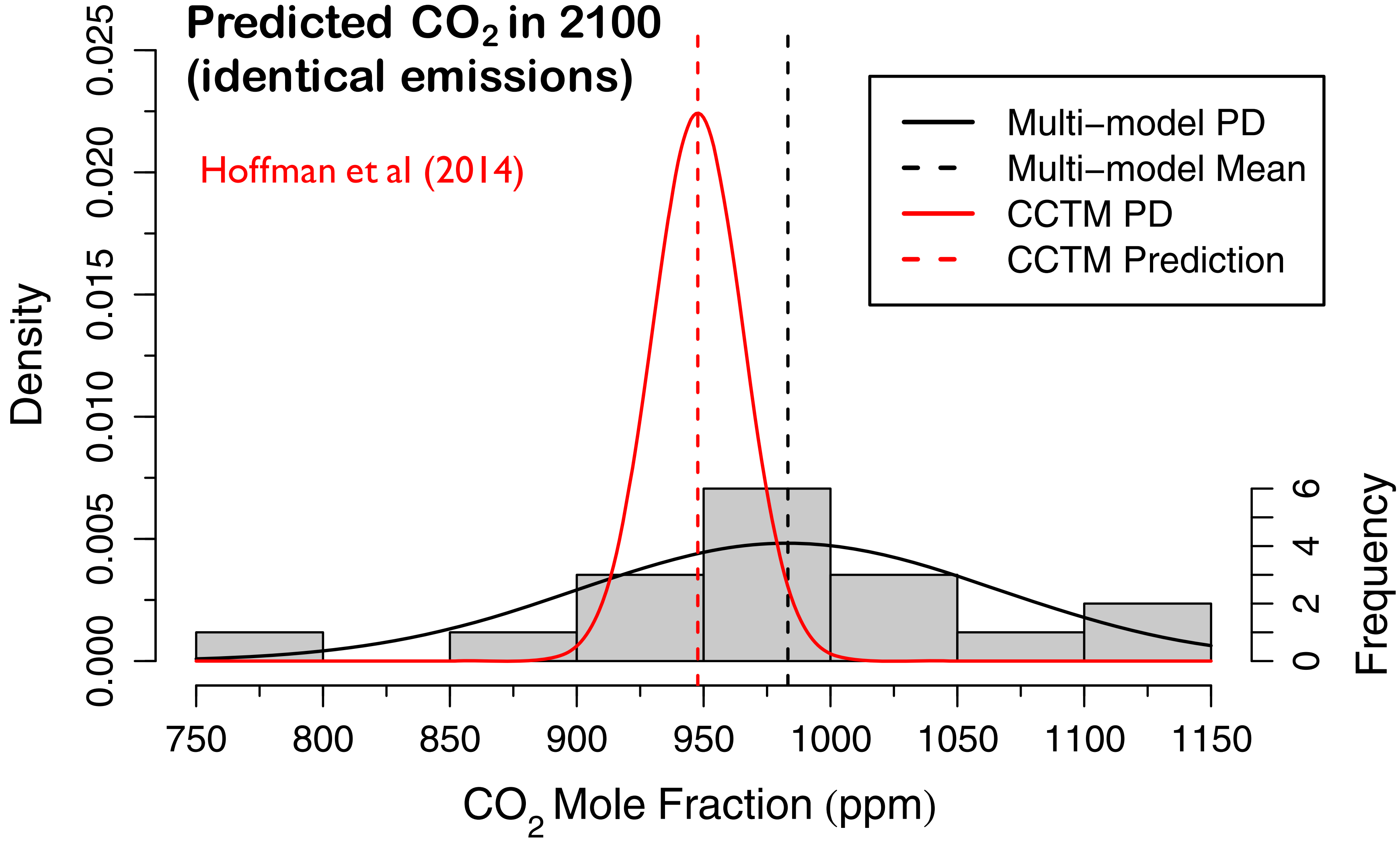
Past as Prelude

- **Models that underpredict contemporary CO_2 also predict low CO_2 in the future, and vice versa**
- **Evaluation of past carbon cycle simulations constrain future feedback**

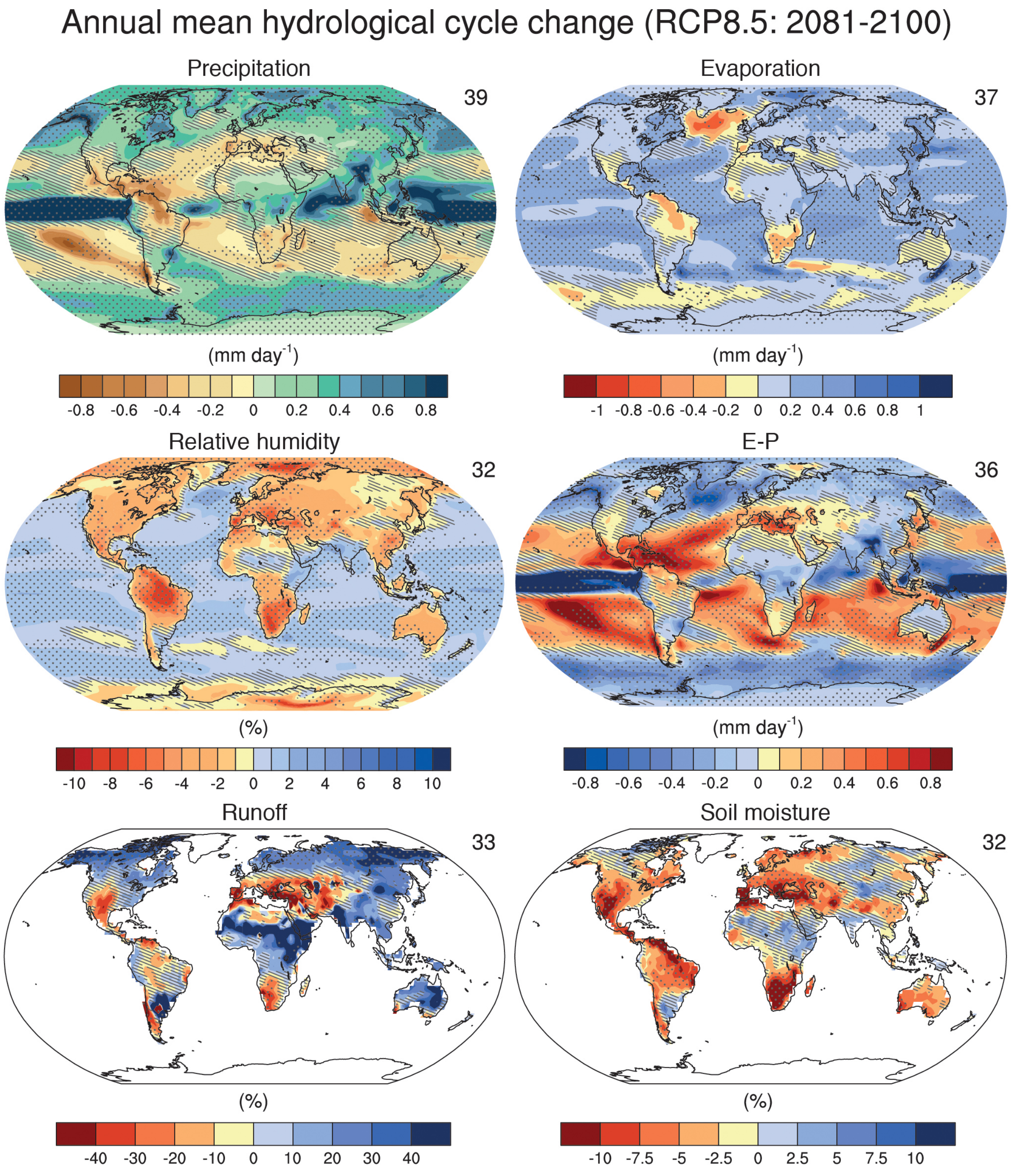


Hoffman et al (2014)

Carbon Constraint



- Fivefold reduction in model spread in 2100
- No mechanism … simple scalar multiplication of sinks



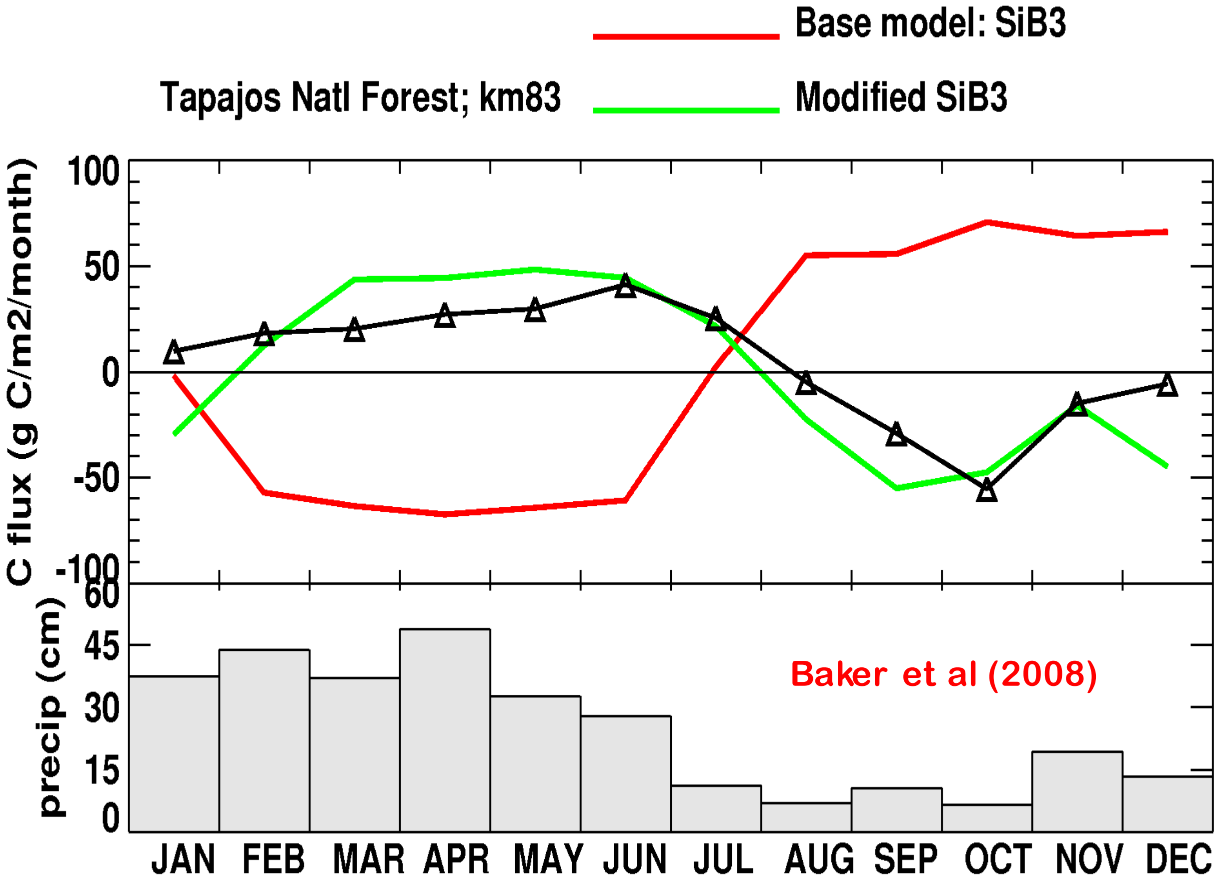
Changing Hydrologic Cycle

- **Much more rainfall over tropical Pacific**
- **Amazon gets less rain (Walker Cell)**
- **Lower RH**
- **Less soil moisture**
- **Amazon dieback in some models releases lots of CO_2**

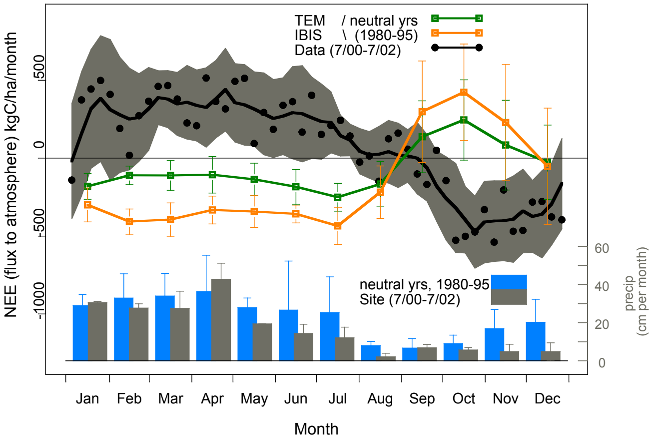
Mechanistic Constraints on Amazon Drought Response

1. Seasonal drought response
2. Space-for-time (Transect)
3. Interannual drought response
4. Severe persistent drought
5. Climatological drought

Seasonal Drought



Baker et al (2008)

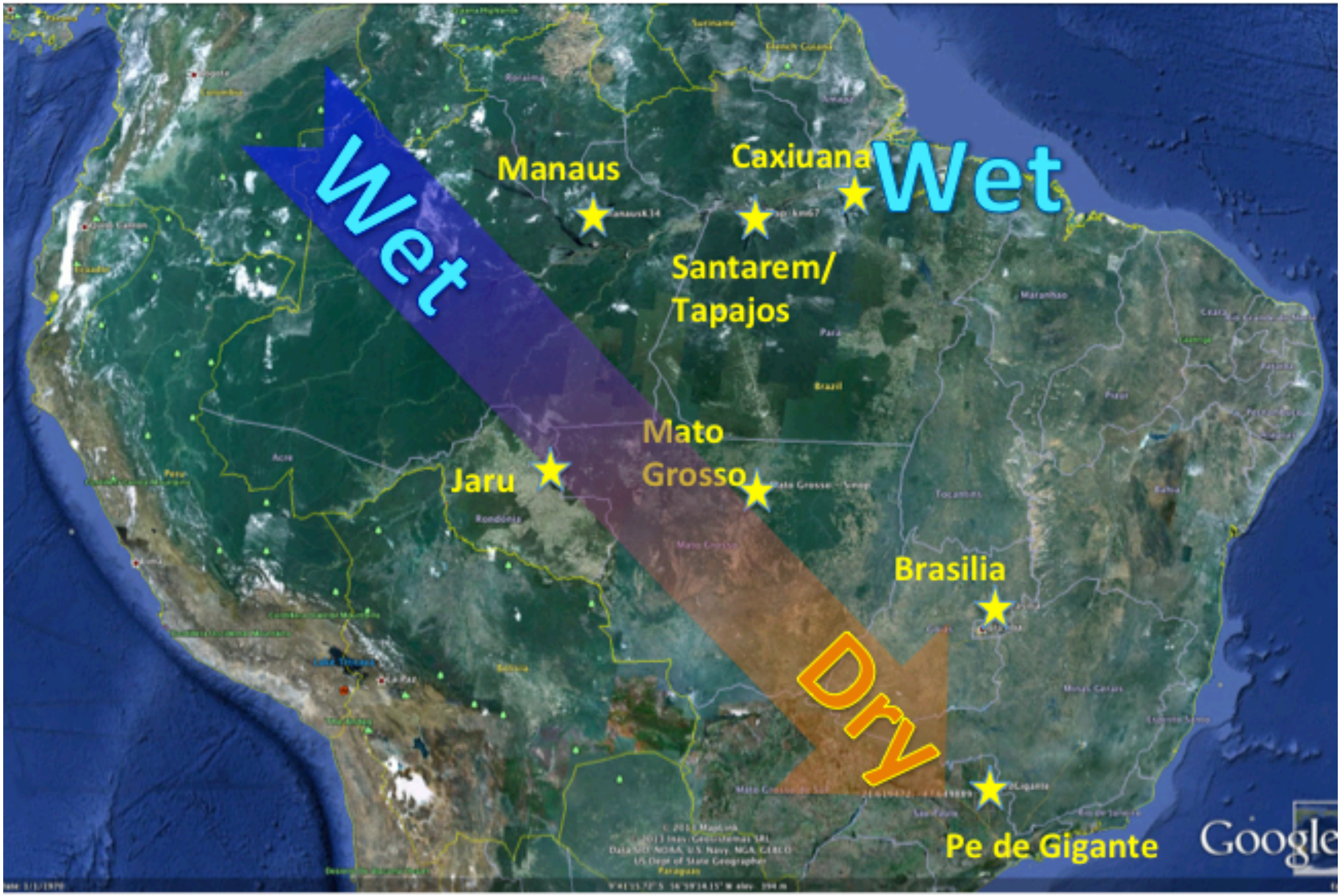


Model output is mean of 4 gridpoints: -54.5 > longitude > -55.5, -2.5 > latitude > -3.5, for neutral years 1980-81,1984-85,1990, & 1993-95.
Data is from Tapajos, km67 site (2.85 S, 55 W, from 10-Apr-01 to 08-May-02) & km83 site (3.05 S, 55 W, from 1-Jul-00 to 1-Jul-01).

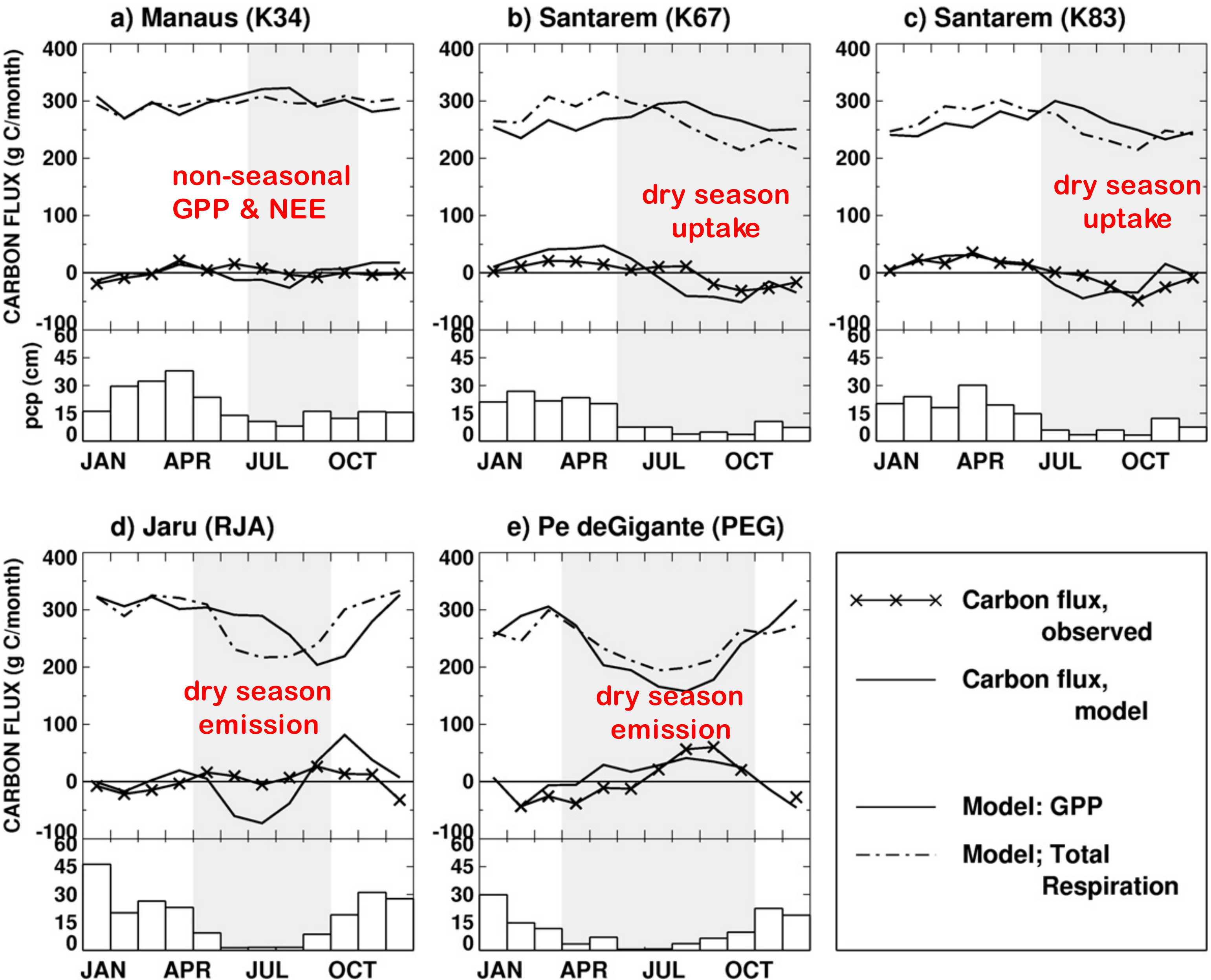
Saleska et al (2003)

- Dry season CO_2 uptake, wet season CO_2 release
- A decade ago, most models got this badly wrong!
- Most now account for root uptake at depth

Space-for-Time: Amazon Transect



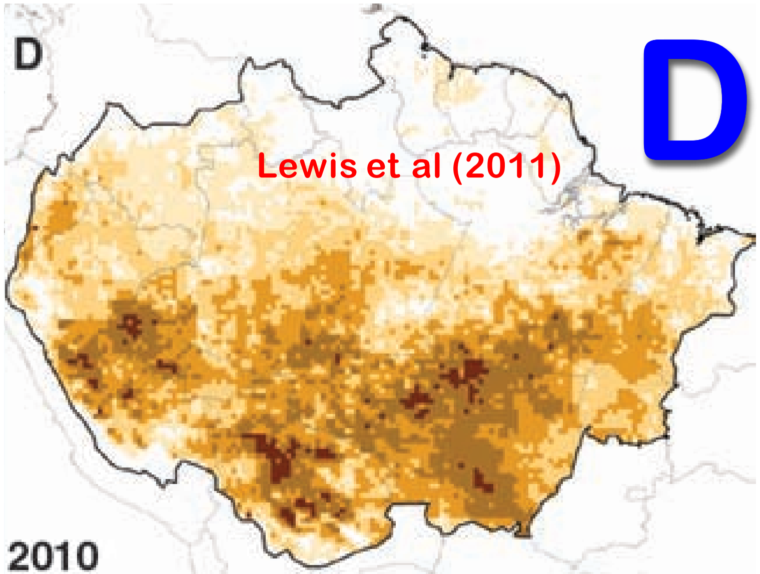
Amazon Transect



Baker et al (2013)

- Less annual precip and longer dry seasons from NW to SE
- Transition from aseasonal GPP to dry season uptake to wet season uptake

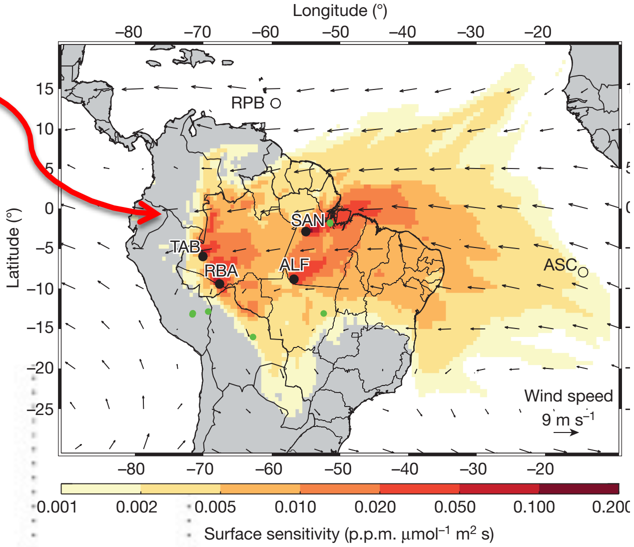
Severe Interannual Drought: 2010



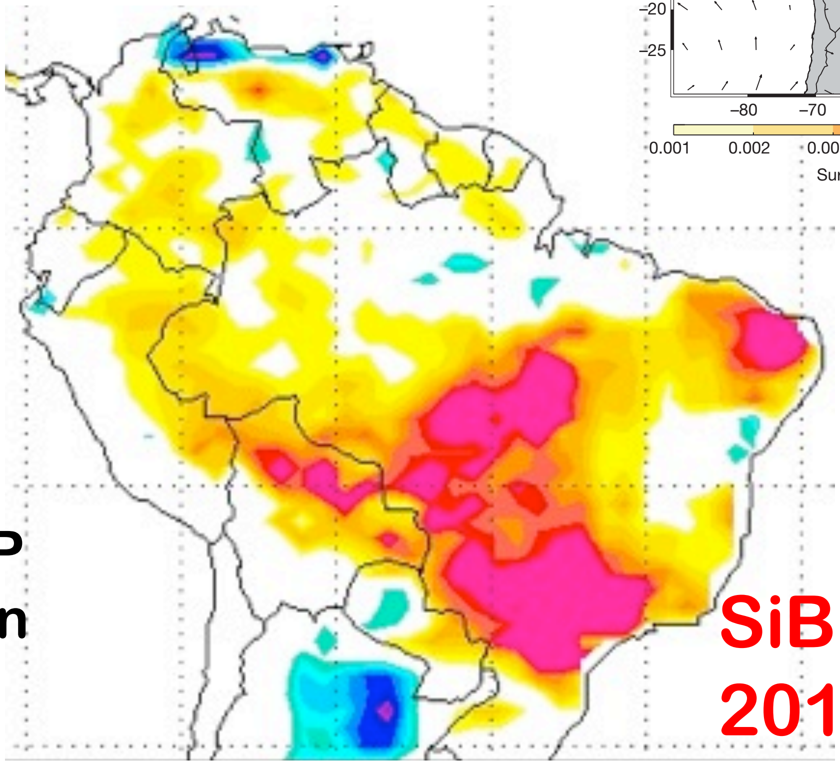
Lewis et al (2011)

Precip – Evaporation Deficit
Lewis et al (2011)

Gatti et al (2014)
CO2 flux footprints



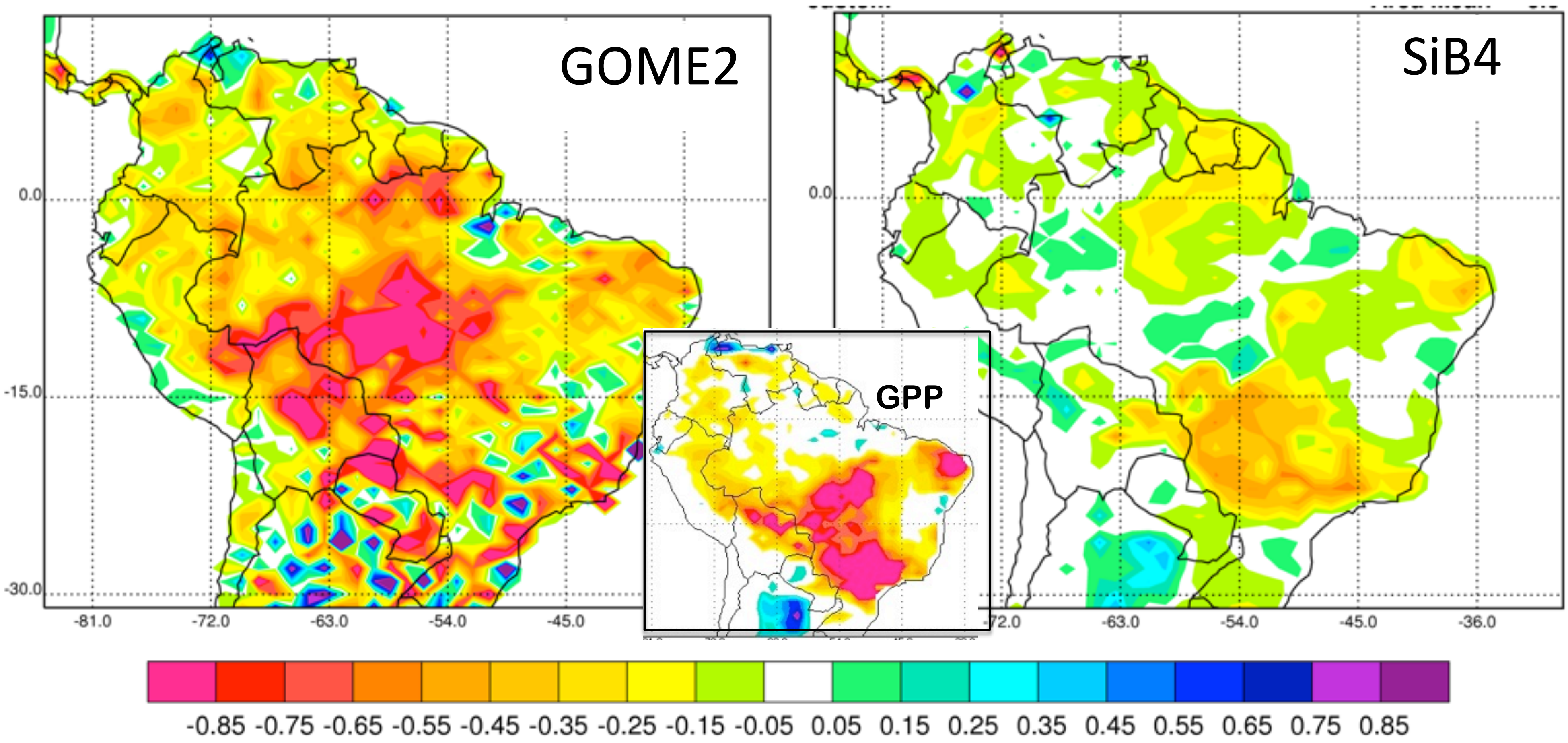
- Lowest Amazon flow ever measured at Manaus
- Basin-wide NEE reduced by 0.5 GtC yr^{-1} estimated from CO$_2$ vertical profiles
- Severe depression of GPP simulated across southern Amazon and Cerrado



SiB Sept GPP:
2010 - 2009

Chrlorophyll Fluorescence

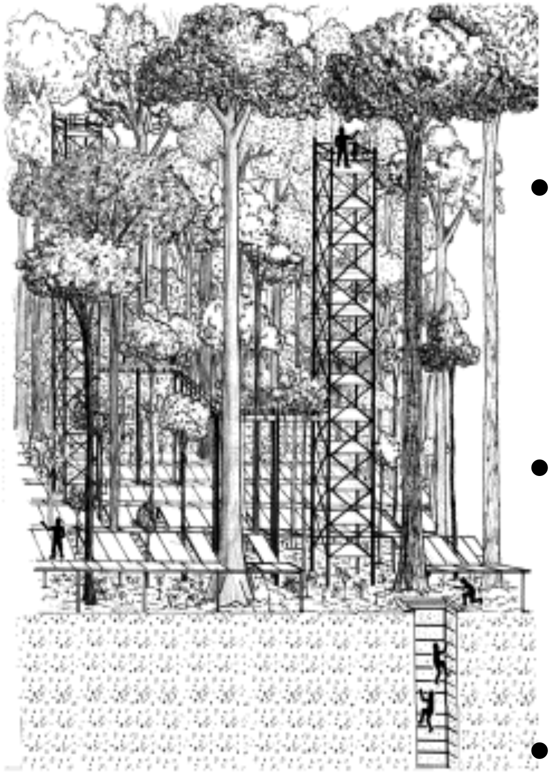
Sept 2010
Minus
Sept 2009



Solar-Induced Fluorescence (W m^{-2} Sr^{-1} nm^{-1}) Sept 2010 – Sept 2009 retrieved from GOME2 (Joanna Joiner, pers comm.) and simulated by SiB4

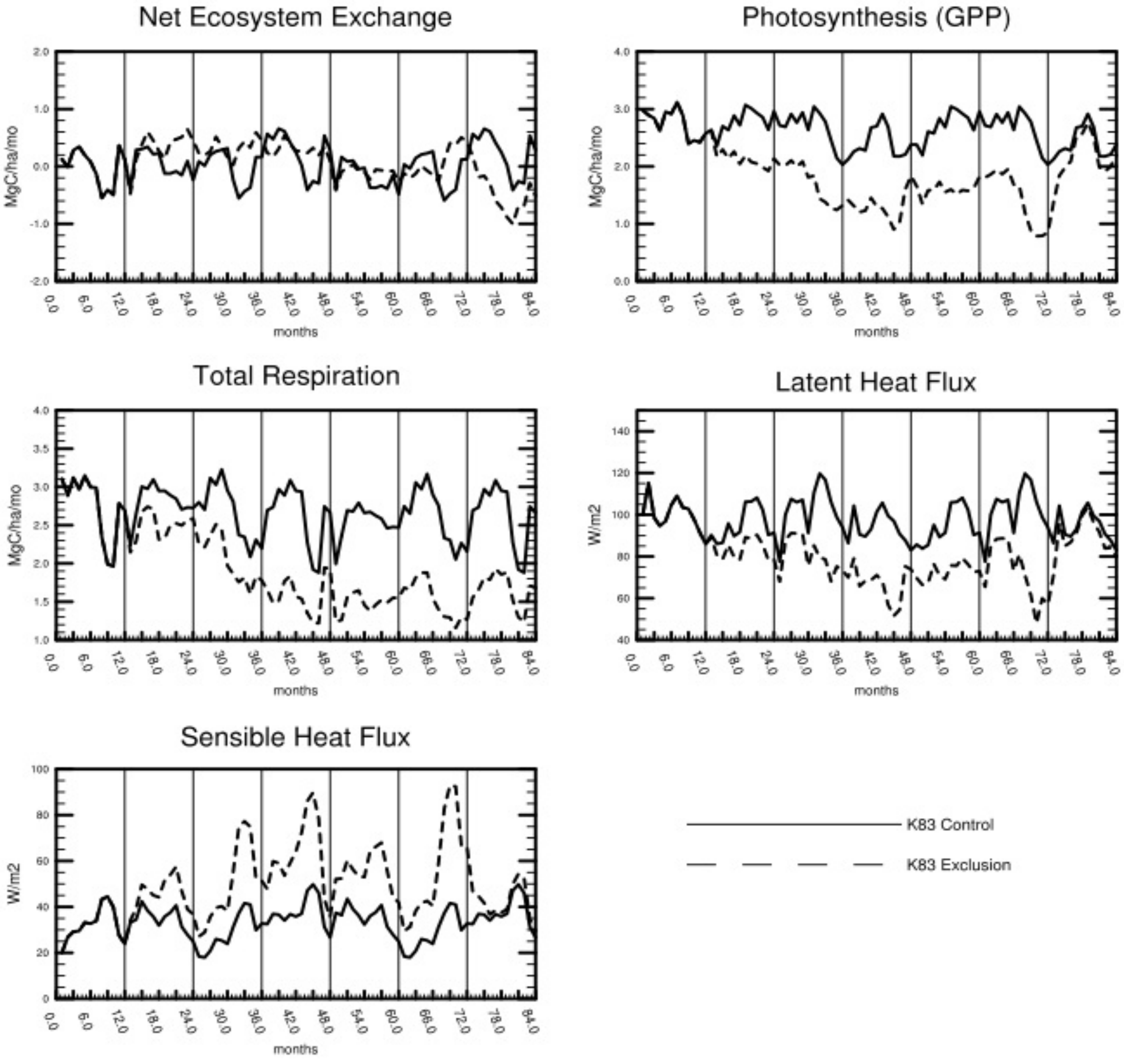
Persistent Drought

Figure 1.1 Panels prevent rainfall from reaching the forest floor in the rainfall exclusion experiment. View from above (top) and below (bottom) the panels. Photo courtesy Woods Hole Research Center.



- Panels used to divert rainfall from forest floor.
- 50-60% of rainfall was diverted from 2000-2004
- Used observations from tower (2001-2003) to drive SiB, reduced rain by 60% during wet seasons

5 Years of (Simulated) Hell



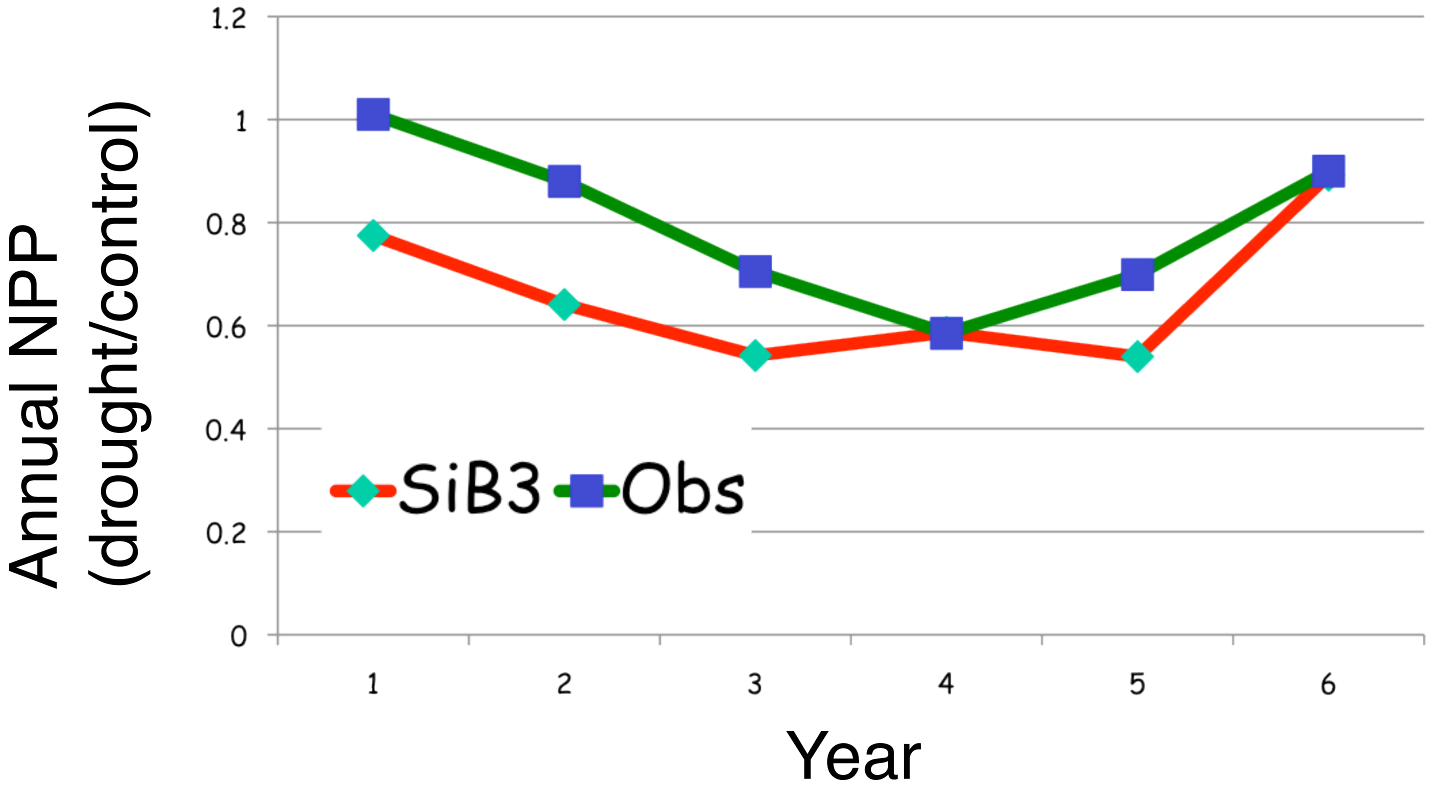
Year 1: Normal
Year 2-6 Drought
Year 7: Normal

Impact noticeable from year 2, but drops in GPP & Resp cancel

Response stabilized from years 4-6

Recovery in year 7

Simulated Response to Persistent Drought

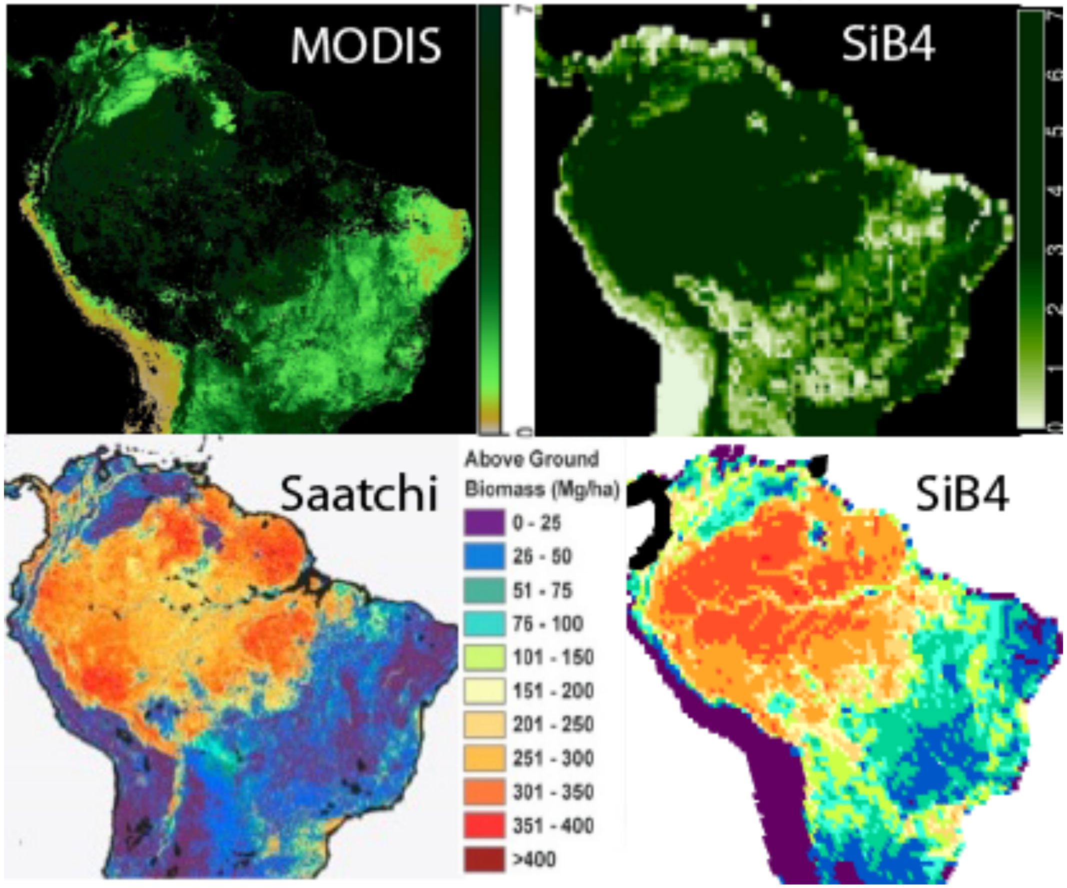


- Model responds too strongly to imposed drought stress in first three years
- Long-term response and recovery pretty good

Climatological Drought Response

- **Position of Forest-Cerrado ecotone is a result of long-term adjustment to climate and disturbance**
- **Dynamic global vegetation models (DGVM) must simulate this boundary**
- **Evaluate physiology, allocation, competition, disturbance**
- **Most relevant timescales for climate change**

Leaf Area & Biomass: January 2008



Summary

- Carbon-climate feedbacks are among the most uncertain emergent phenomena in Earth system models
- Contribution to spread in radiative forcing is as great as clouds, radiation, and aerosol, even comparable to unknown FF emissions
- Mechanistic constraints on carbon-climate feedbacks may reduce ESM spread more than any other near-term priority
- Example: Amazon drought response benchmarks
  - Seasonal drought and Amazon Transect (flux towers)
  - Severe Interannual Droughts (new observations of SIF)
  - Persistent Droughts (Throughfall Exclusion Experiments)
  - Climatological drought response (Dynamic Simulation of Forest-Cerrado Ecotone)

Presentations

1. **Denning -- Multiscale L/A work after CMMAP**
2. **Ian Baker – Subgrid-scale variations of soil moisture**
3. **Parker Kraus – Site simulations with SiB-SAM**
4. **Jian Sun – Global land-atmosphere coupling in SPCAM**
5. **Gordon Bonan – Multilayer Canopy Model**

Post-CMMAP Land-Atm Work

- DOE ASR: Effects of land-atmosphere heterogeneity on convective organization at ARM in SASL, MASL, MAML
- DOE ESS: Climate Feedback and Tropical Forests
- NASA: Soil moisture heterogeneity via “bins”
- NSF SSI: Flux Coupler “Lite” for CLM-SAM, CLM-WRF
- UCI: Mike Pritchard NSF CAREER award
- UCI: Gabe Kooperman PostDoc Fellowship
- NCAR: Multilayer Canopy Work