A Tropical Terrestrial Tipping Point: Stress vs Resilience in Land-Atmosphere Coupling

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Global Change Projections are Really Hard!

- **Physics:**

  We don't know how sensitive the climate is to given levels of radiative forcing

- **Demographics/Economics/Politics:**

  We don't know how much fossil fuel people will choose to burn in the future

- **Biogeochemistry:**

  We don't know how much CO2 will be in the atmosphere for a given rate of emissions

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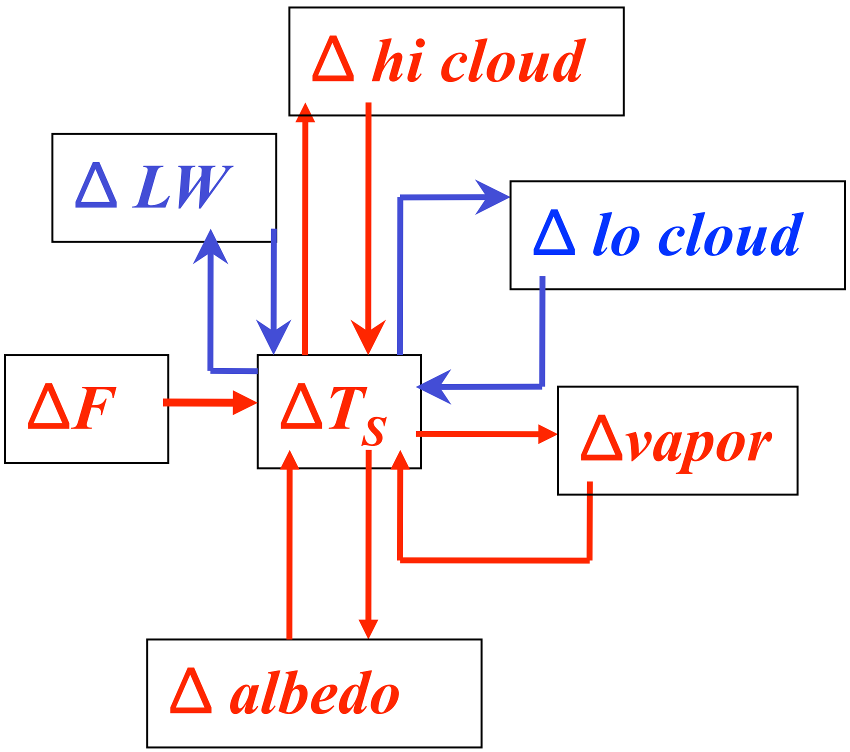
Climate Feedback Processes

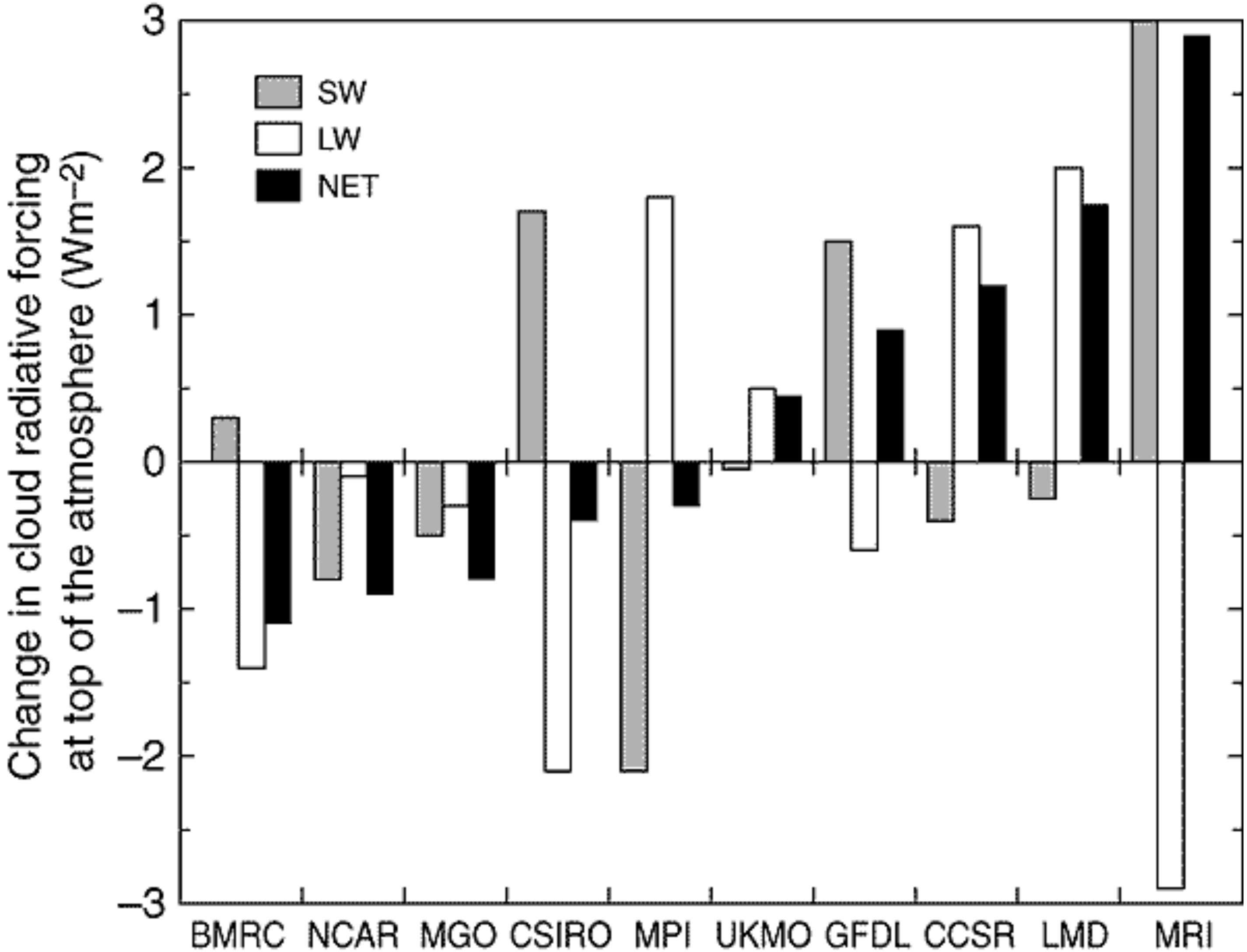
$$\Delta T_s = \lambda \Delta F$$



- Positive Feedbacks (amplify changes)
  - Water vapor
  - Ice-albedo
  - High clouds
- Negative feedbacks (damp changes)
  - Longwave cooling
  - Low clouds

Cloud Parameterization

Change in TOA Cloud Radiative Forcing for 2xCO2



Change in the Top of the Atmosphere (TOA) Cloud Radiative Forcing (CRF) associated with a CO_2 doubling (from a review by Le Treut and McAvaney, 2000). The models are coupled to a slab ocean mixed layer and are brought to equilibrium for present climatic conditions and for a double CO_2 climate. The sign is positive when an increase of the CRF (from present to double CO_2 conditions) increases the warming, negative when it reduces it.

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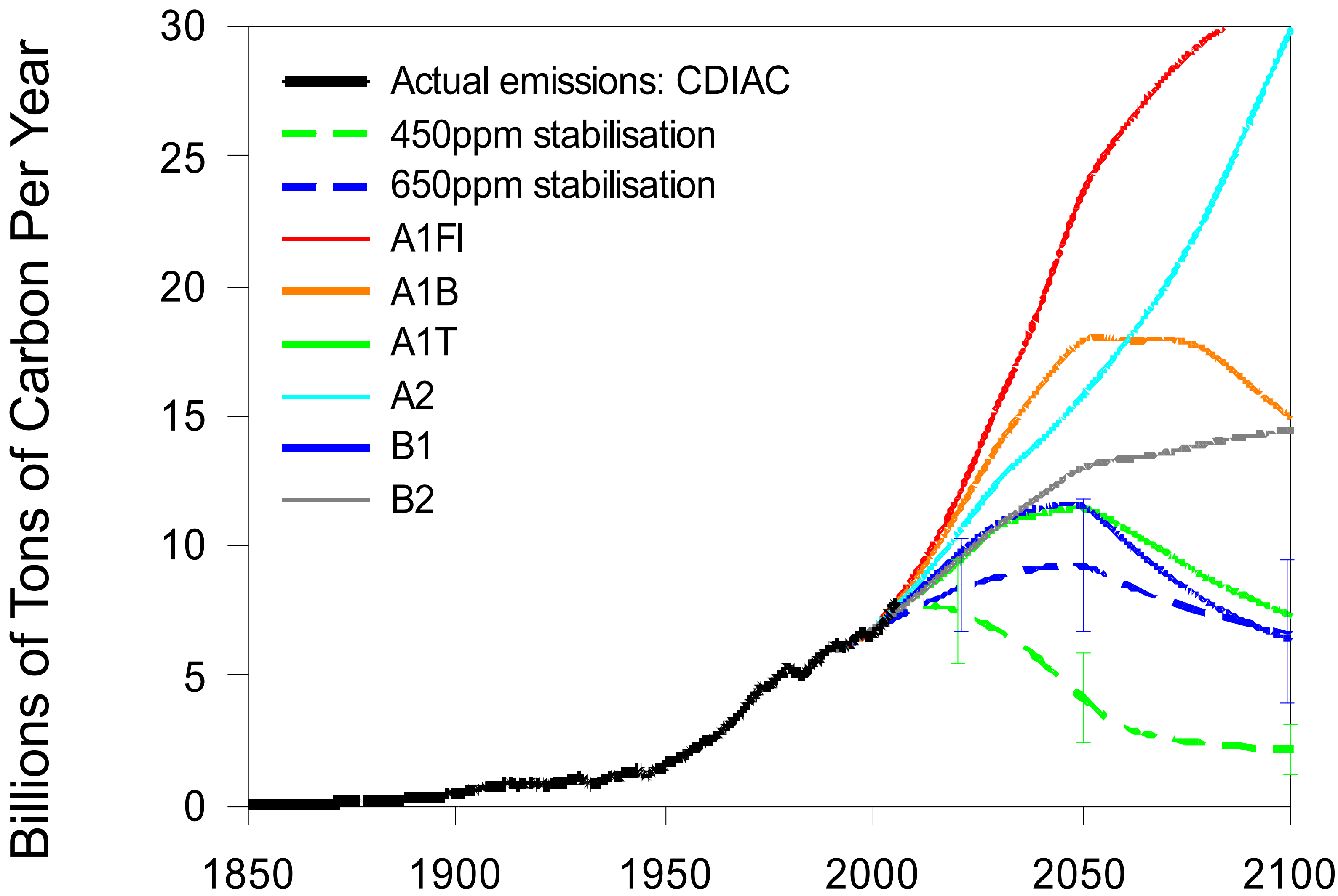
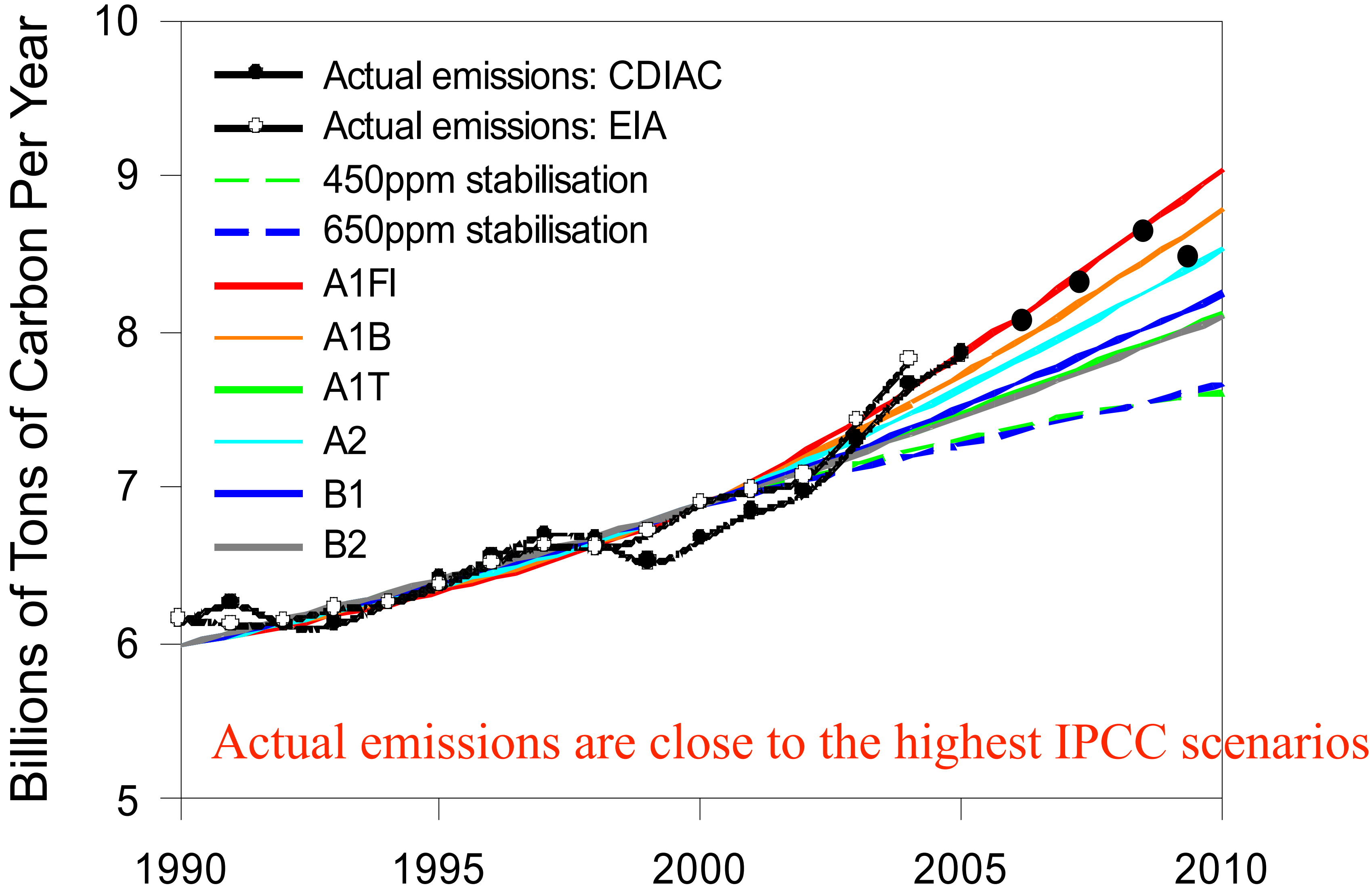
Emission Scenarios

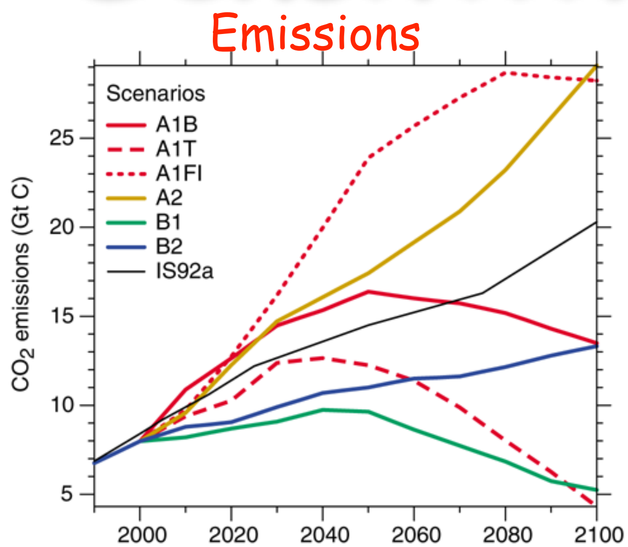


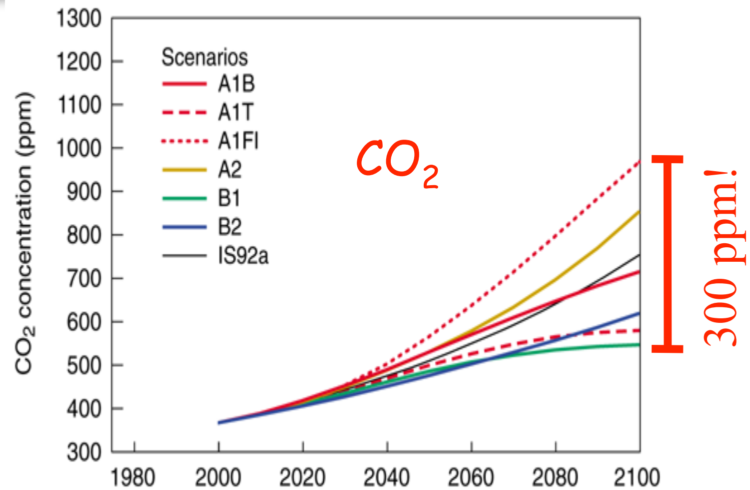
Emission Scenarios vs Reality

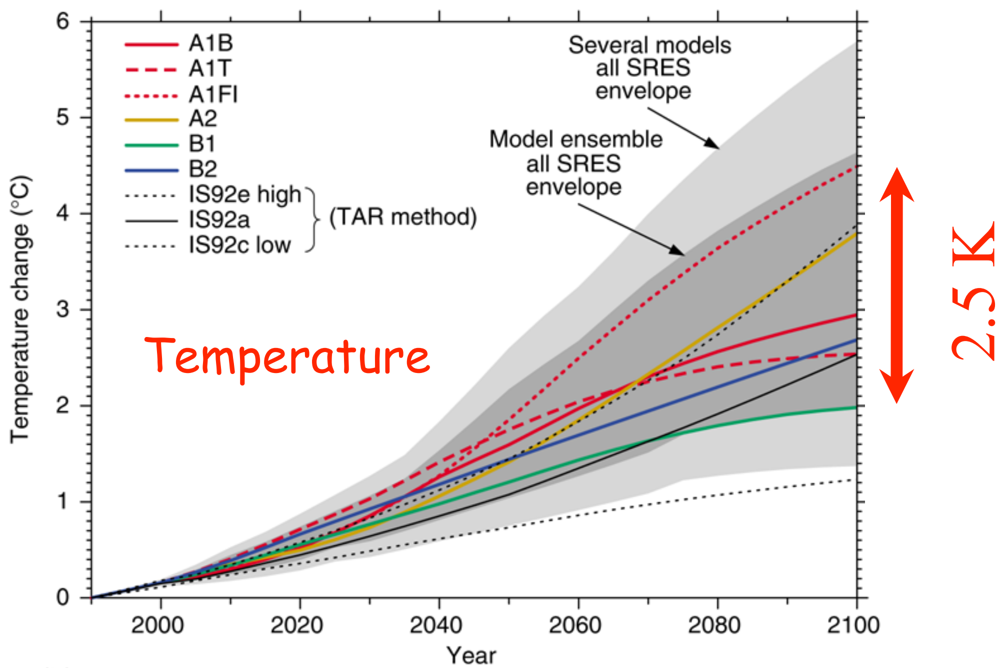


Raupach et al. 2007 PNAS, updated 12/6/2010

Sensitivity to Emissions







- Uncertainty about human decisions is a major driver of uncertainty in climate change
- Model ensemble simulated warming ranges ~ 2.5° K in 2100

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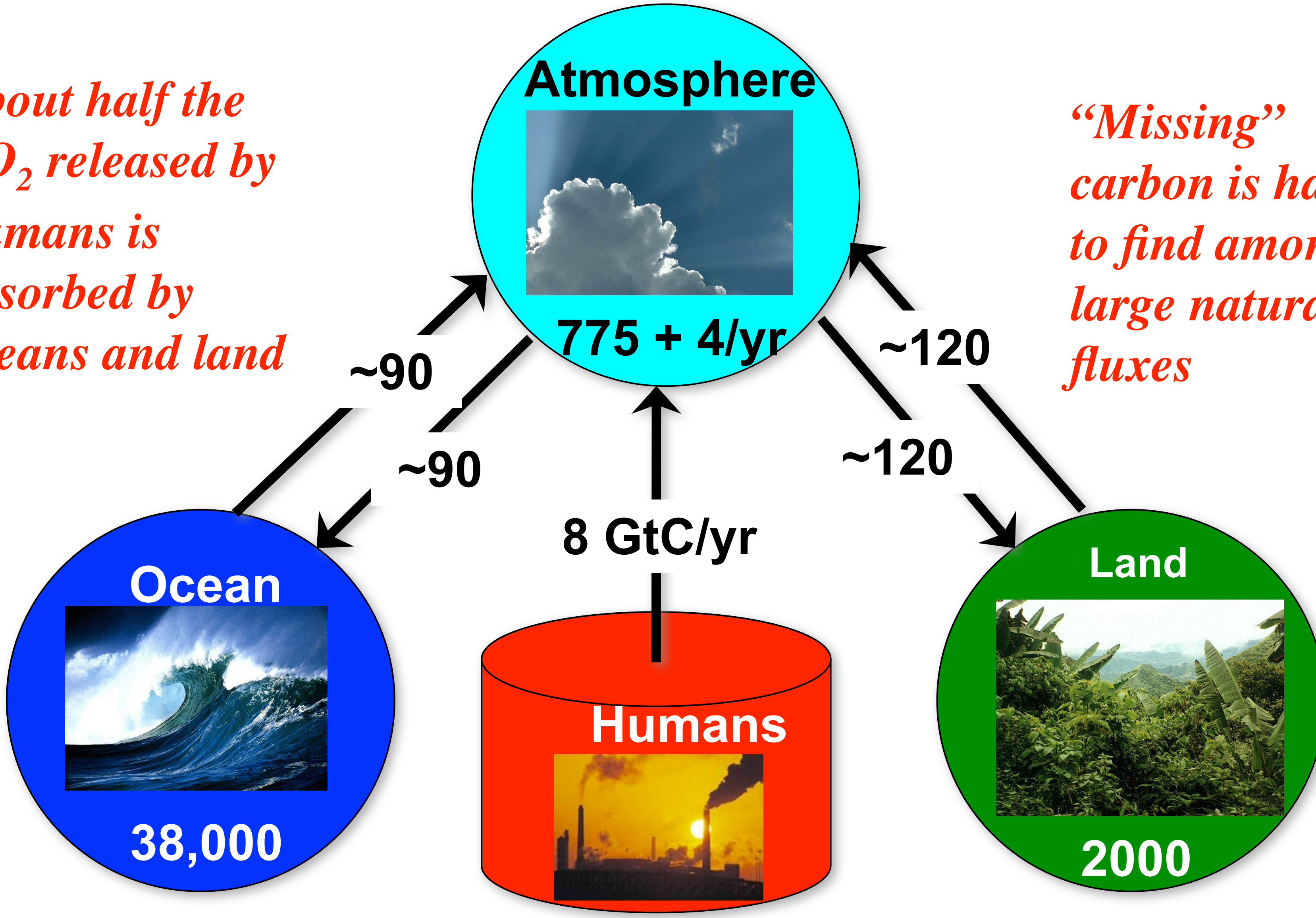
The Global Carbon Cycle

About half the CO_2 released by humans is absorbed by oceans and land



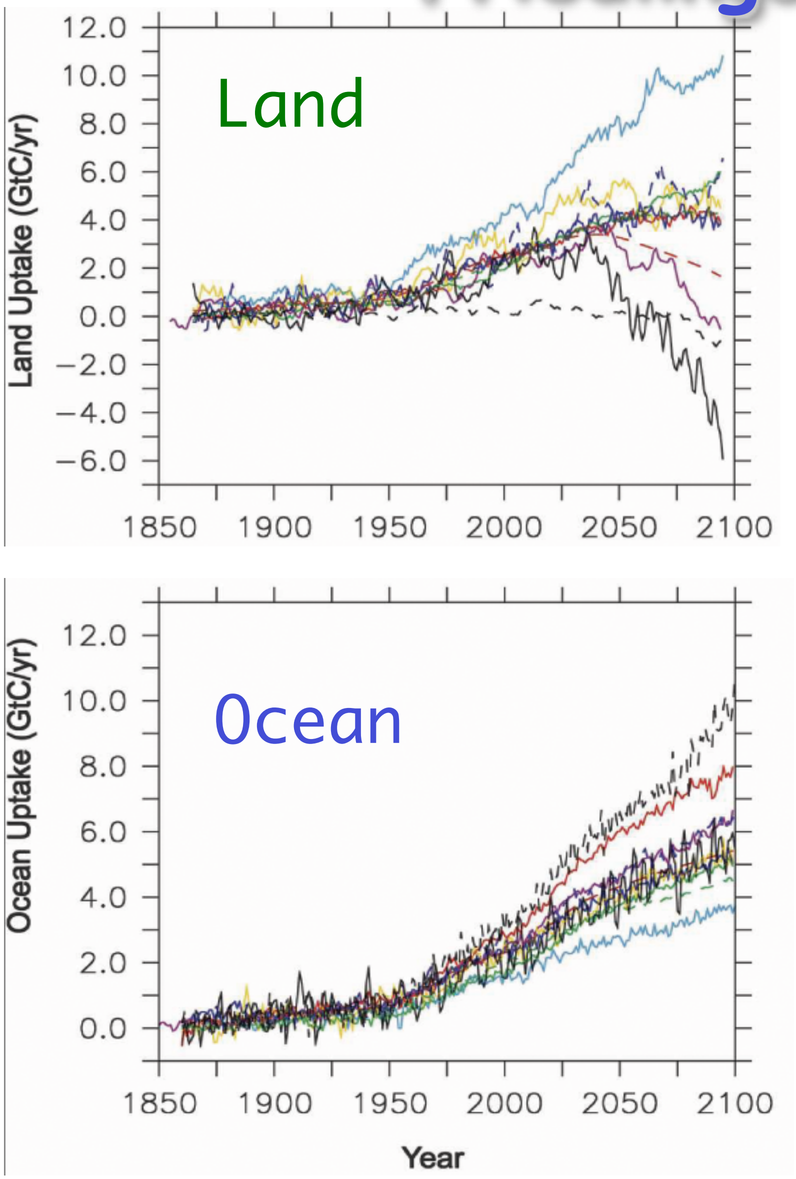
"Missing" carbon is hard to find among large natural fluxes

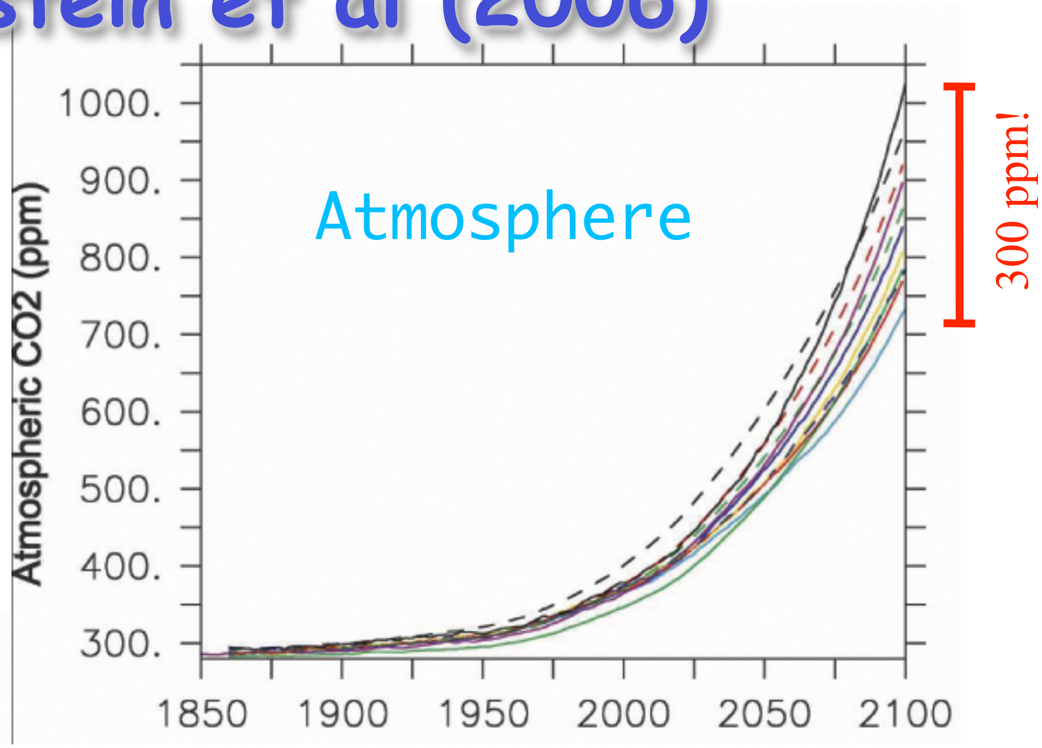
Coupled Carbon-Climate Modeling (C4MIP)

- "Earth System" Climate Models
  - Atmospheric GCM
  - Ocean GCM with biology and chemistry
  - Land biophysics, biogeochemistry, biogeography
- Prescribe fossil fuel emissions, rather than CO2 concentration as usually done
- Integrate model from 1850-2100, predicting both CO2 and climate as they evolve
- Oceans, plants, and soils exchange CO2 with model atmosphere
- Climate affects ocean circulation and terrestrial biology, thus feeds back to carbon cycle

Carbon-Climate Futures

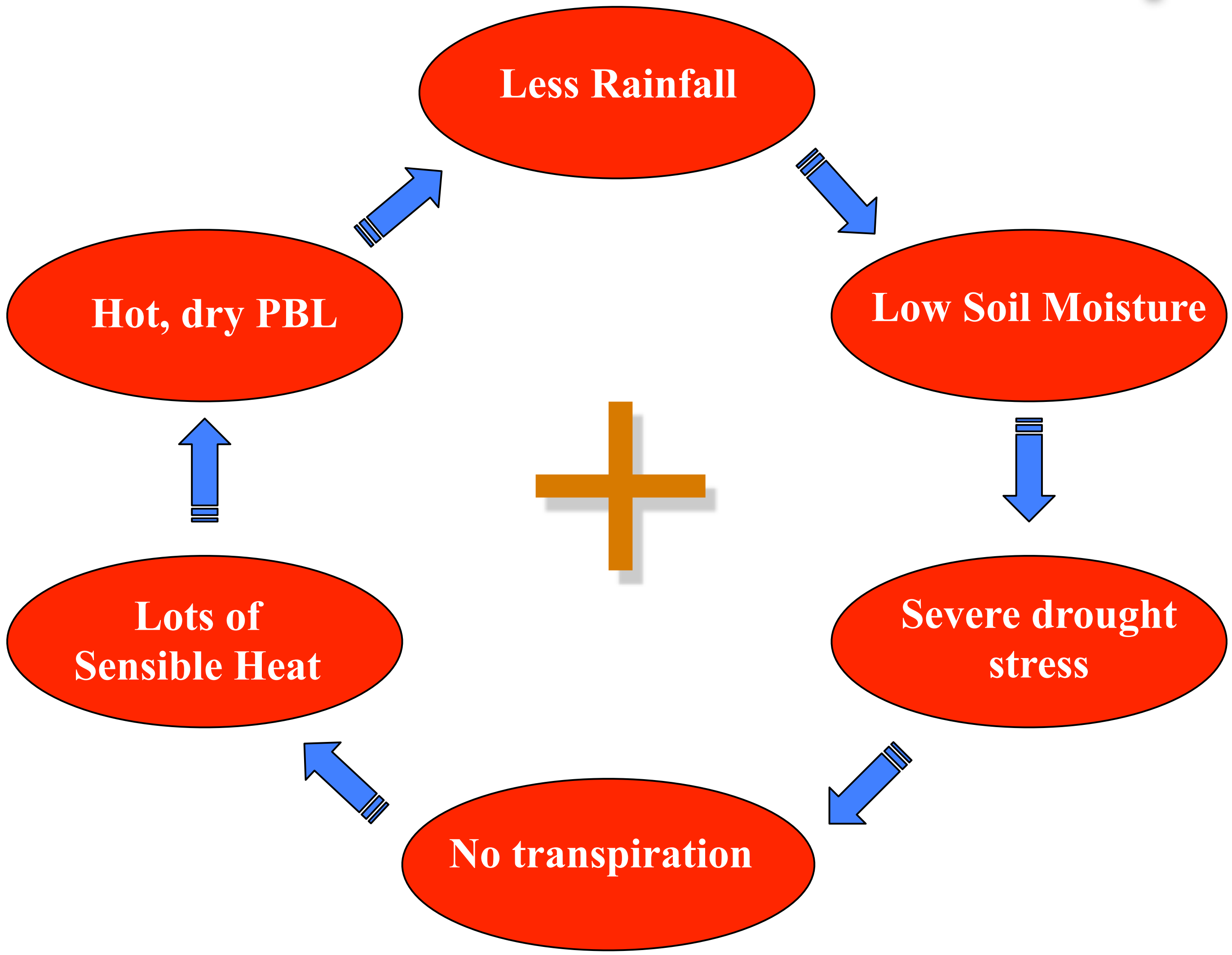
Friedlingstein et al (2006)



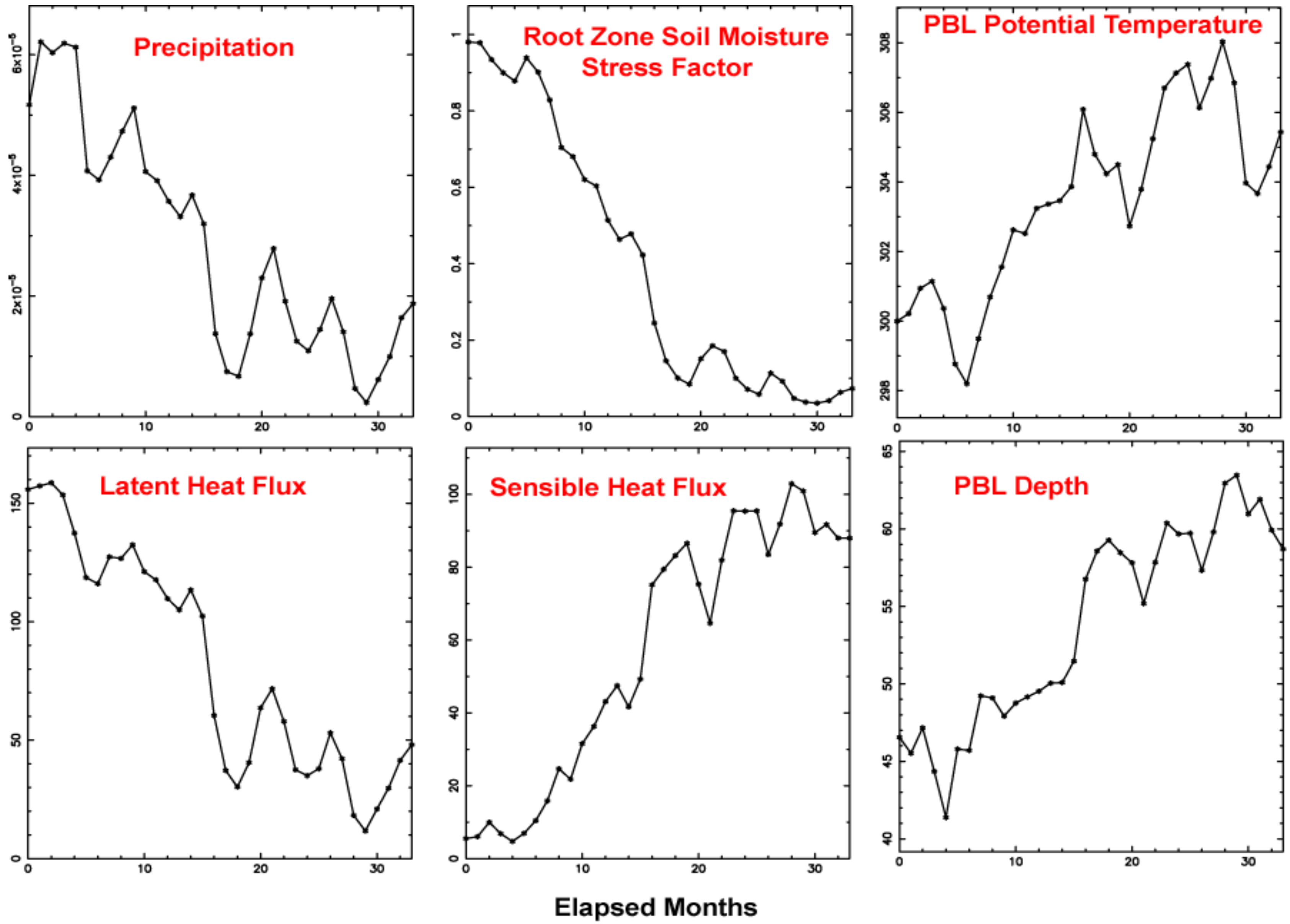


- Coupled simulations of climate and the carbon cycle
- Given nearly identical human emissions, different models project dramatically different futures!

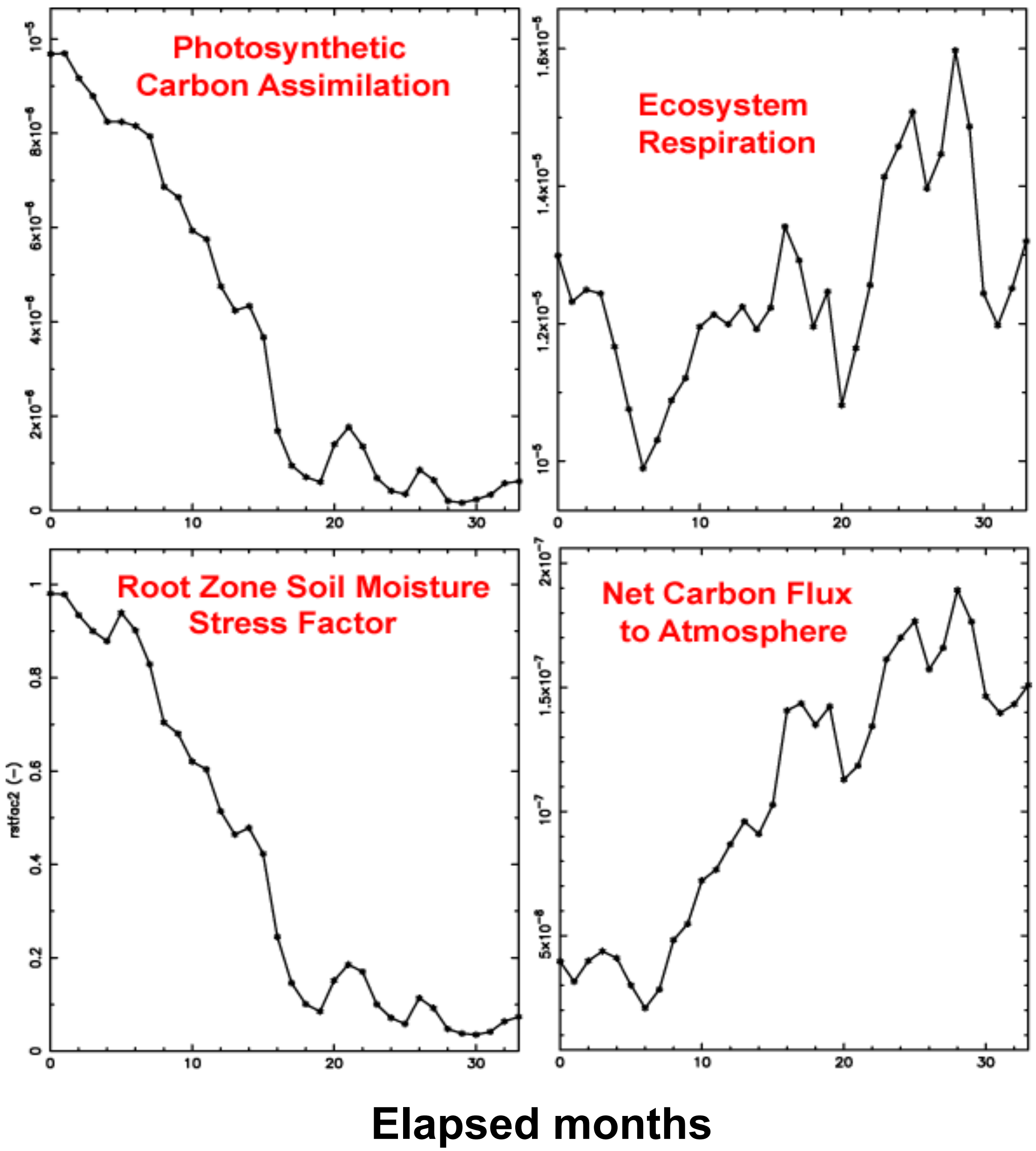
Precipitation and Ecosystem Stress: A Positive Feedback Loop



3-year Coupled Simulation: SiB2-GCM



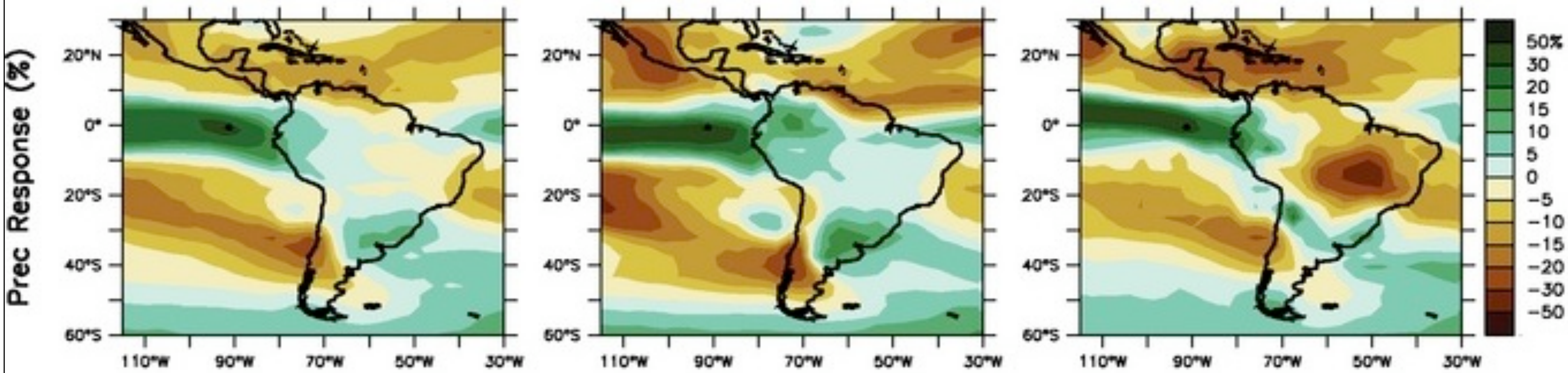
Coupled Simulation: Global SiB2-GCM



- Exaggerated drought stress feedback in coupled model
- Photosynthesis collapses, respiration increases
- Simulated forest is dying!


Tapajos National
Forest, Brazil

21^{st} Century Climate Coupling



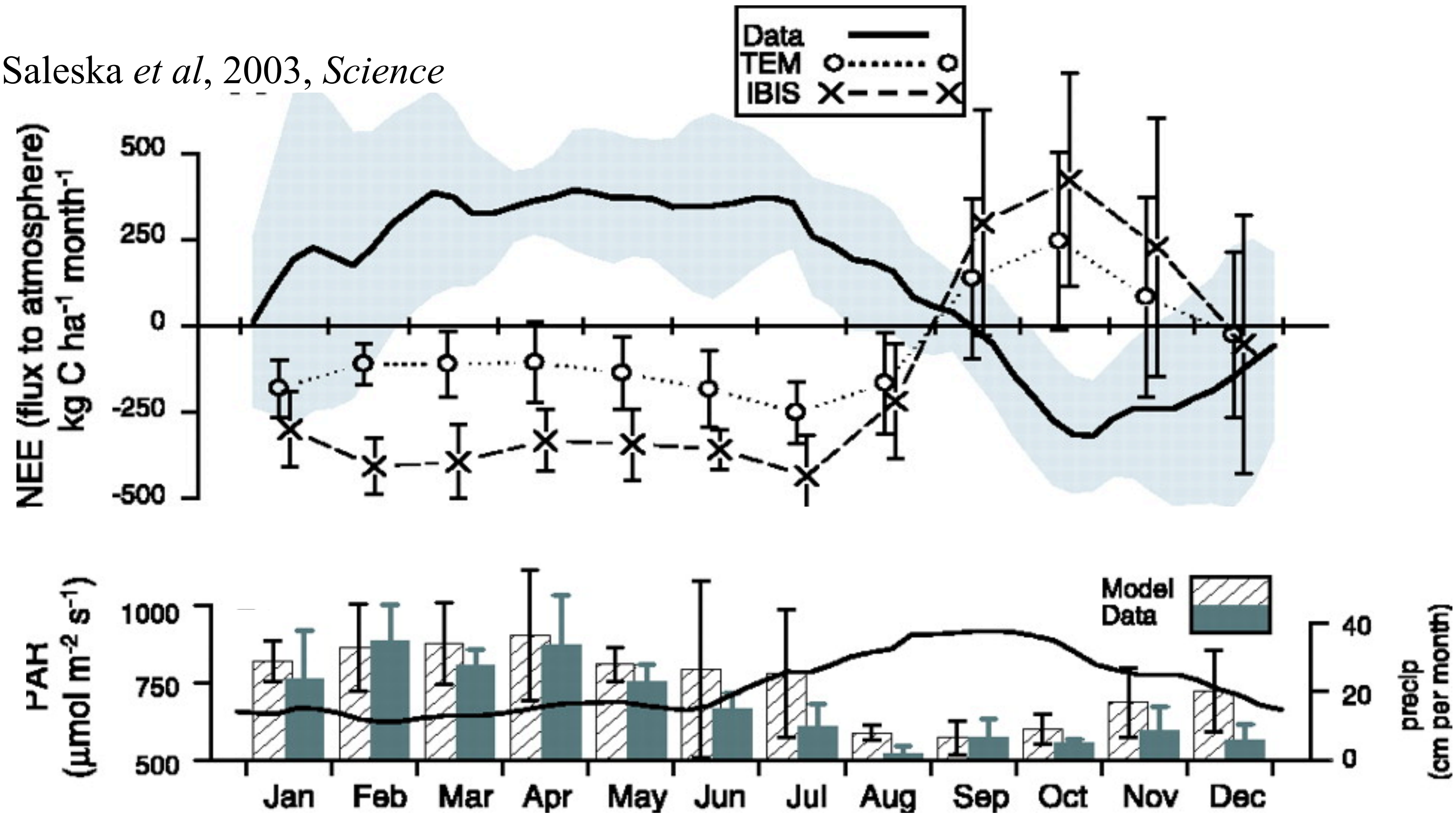
IPCC, 2007: Fig. 11.15, changes in 21st century precipitation, A1B scenario

Forest response to decreased rain could amplify drought conditions.

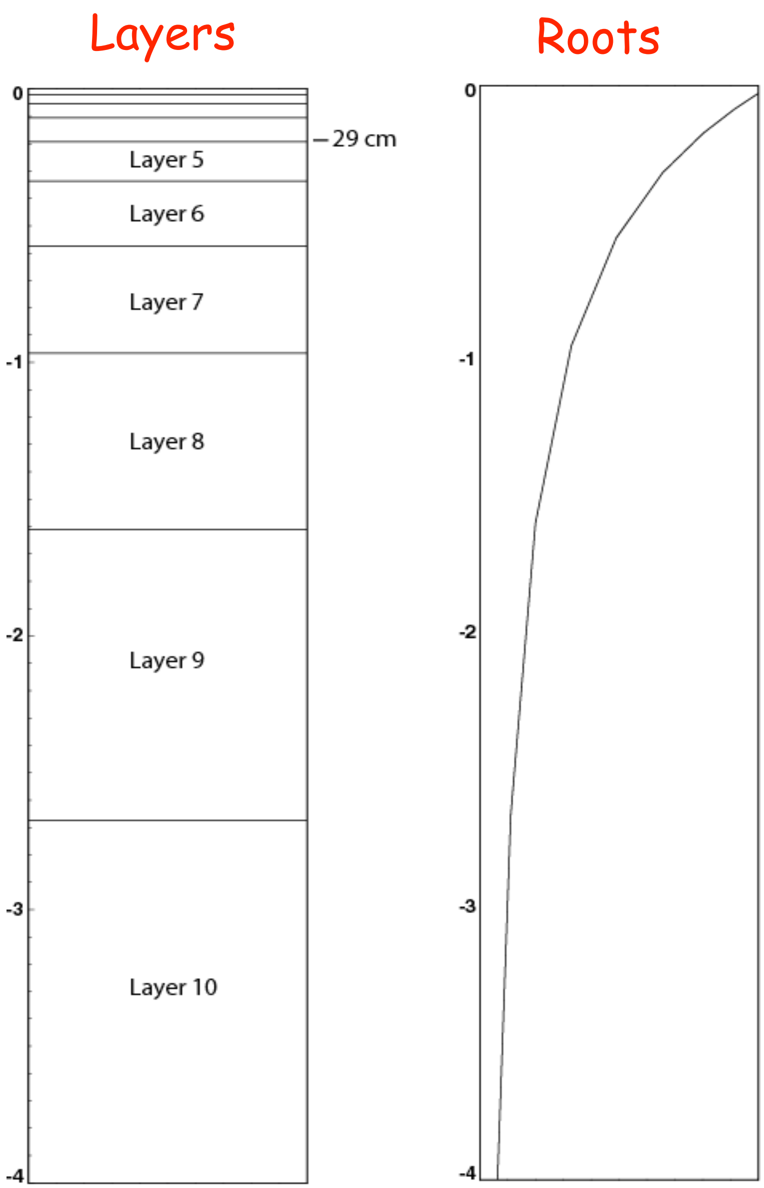
Conversion of forests to grasslands would increase CO2 forcing.

Some Models Developed For MidLatitude Forests Get Amazon Seasonality Precisely Wrong!

Saleska *et al*, 2003, *Science*



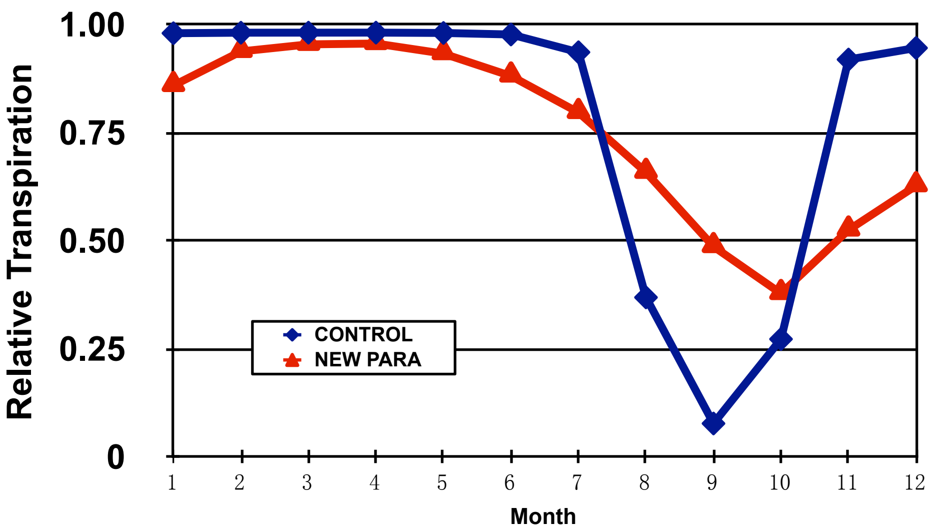
SiB3 Soil Structure

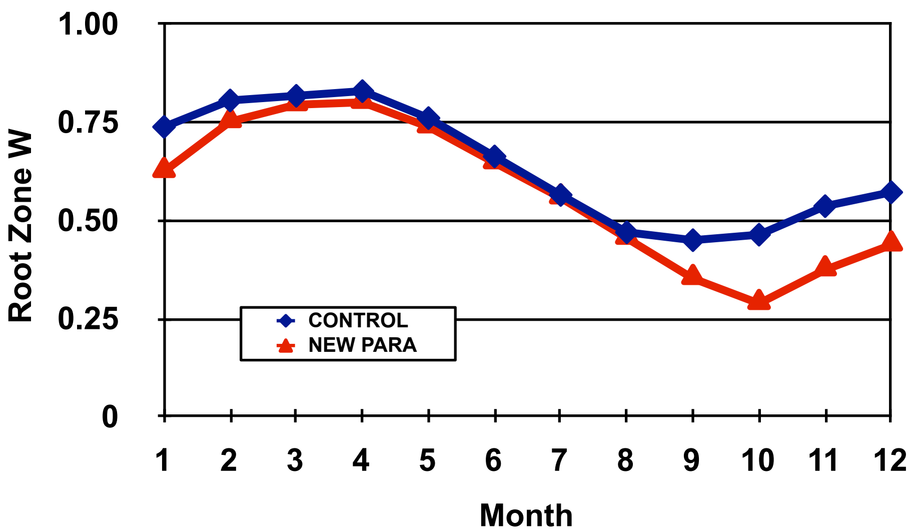


- 10 layers with exponentially increasing thickness
- Transpiration limited by total plant available water
- Transpiration distributed through root profile, weighted by water potential and root density

Kinder, Gentler Droughts

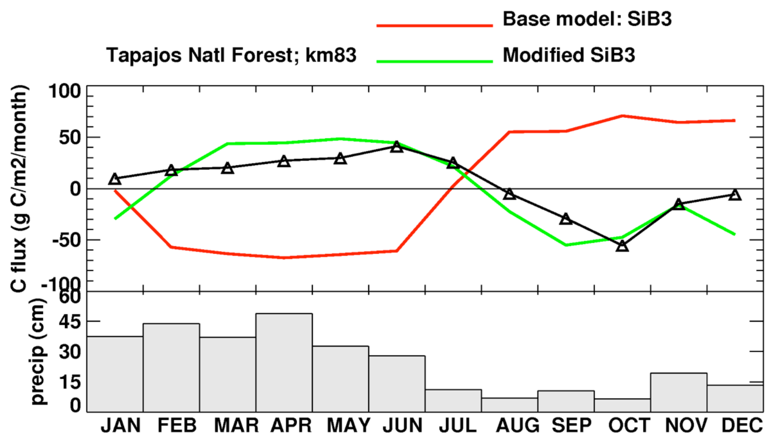
Reserva Jaru, 1993

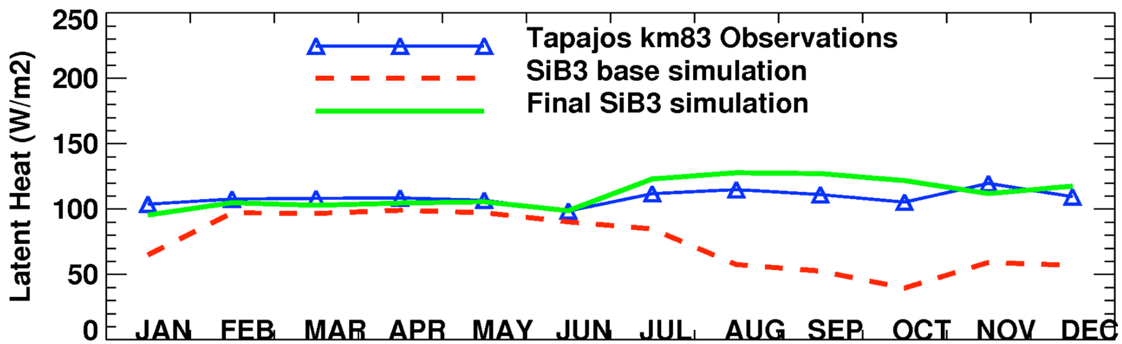


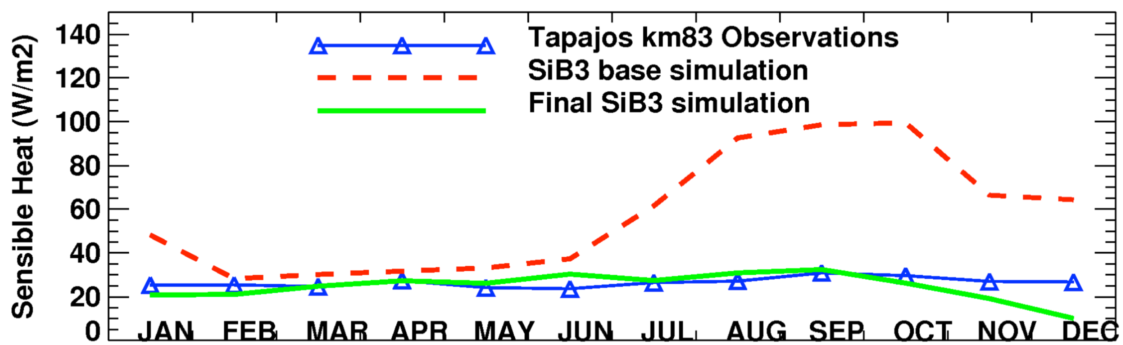


- Revised parameterization produces moderate reduction in drought stress
- Allows soils to dry further, so stress still develops
- 3 year coupled simulation still produces severe sustained drought

Impact of improved treatment of tropical root-zone physiology



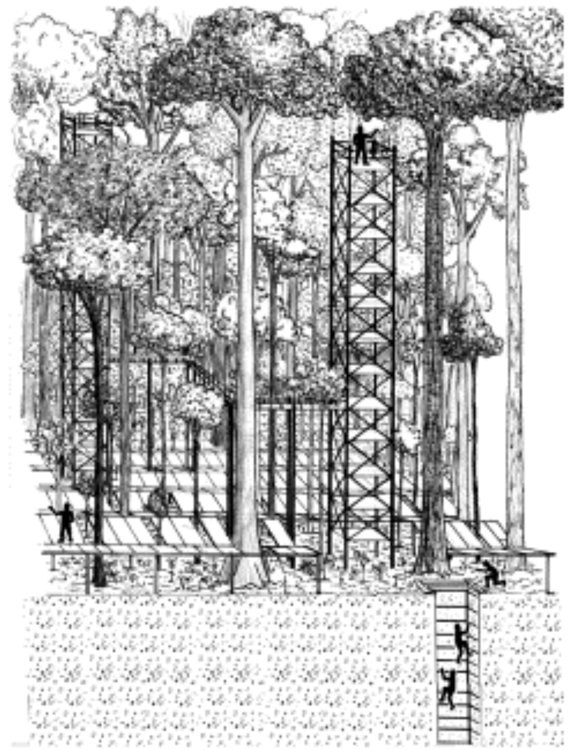





LBA
PROJETO CIENTÍFICO DE
COOPERAÇÃO INTERNACIONAL


Effects of Artificial Drought: Throughfall Exclusion Experiment (TFEE)

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.



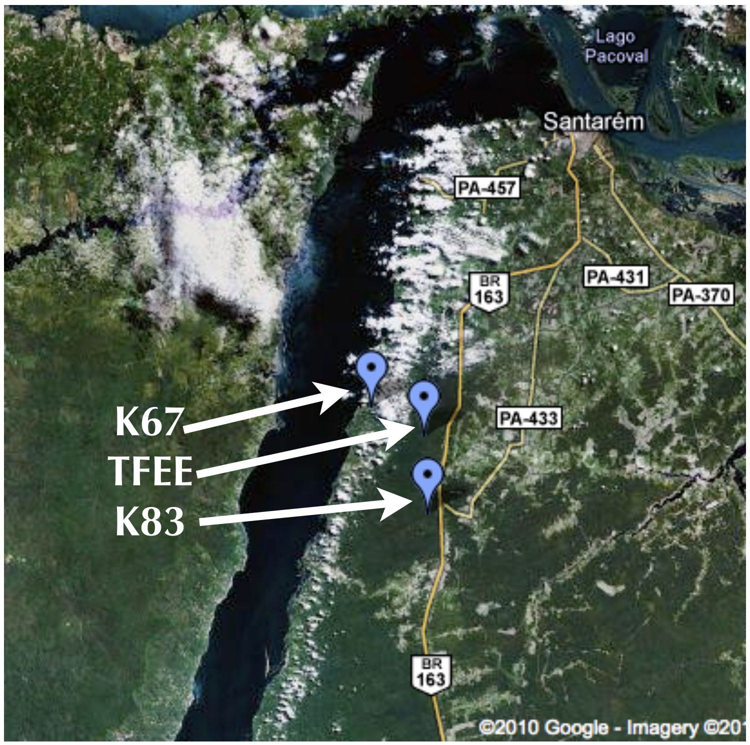

26. 7. 2001


26. 7. 2001

O que você precisa saber sobre animais peçonhentos.
PRINCIPAIS SERPENTES VENENOSAS DO BRASIL.
PRINCIPAIS ARANHAS VENENOSAS DO BRASIL.
JARARACA
CASCAVEL
SURUCUCU
CORAL VERDADEIRA
ARANHA ARMADEIRA
ARANHA MARROM
TARÂNTULA
CARANGUEJEIRAS
PRINCIPAIS ESCORPIÕES VENENOSOS DO BRASIL.


26. 7. 2001

Tapajos Forest Exclusion Experiment (TFEE)



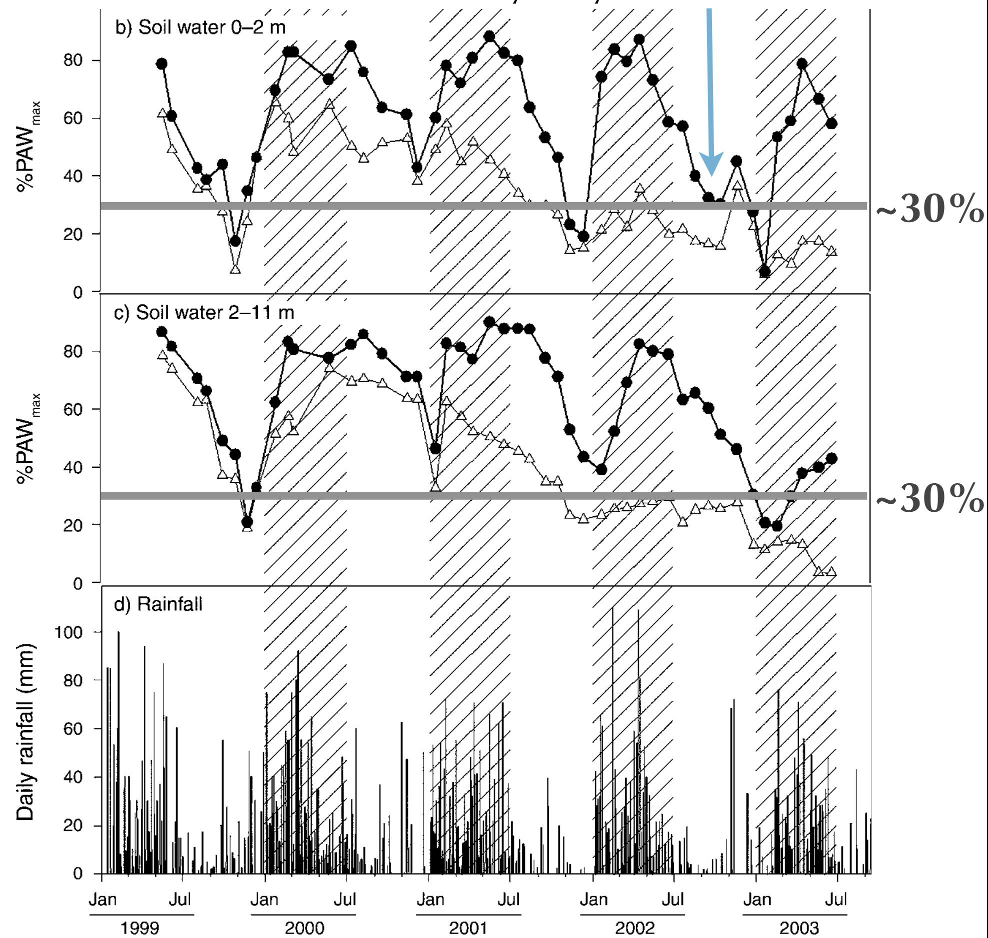
- Panels used to divert rainfall from forest floor.
- 50-60% of rainfall was diverted from 2000-2004
- Used observations from K83 tower (2001-2003) to drive SiB3, reduced rain by 60% during wet seasons

How would the Amazon respond to increased drought in the future? How resilient is this ecosystem?

Defining Thresholds in Resilience

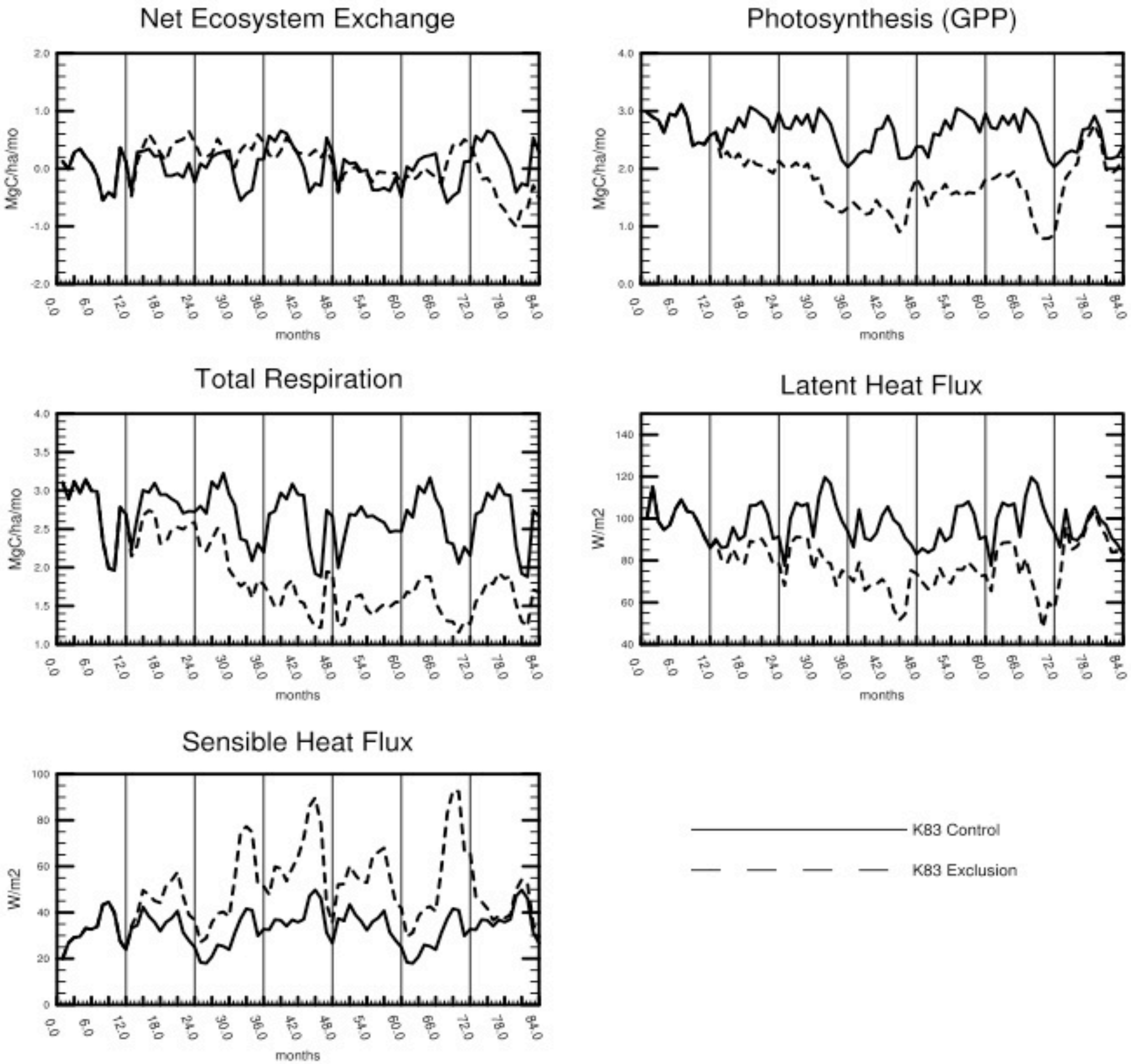
- Plotted: % of maximum plant available water (PAW)
- Observed threshold occurred in Nov. 2002, after PAW was only 30% of its maximum value for over a year.

Dramatic increase in med-large tree mortality (dry season 2002)



From Nepstad et al. 2007

5 Years of (Simulated) Hell



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

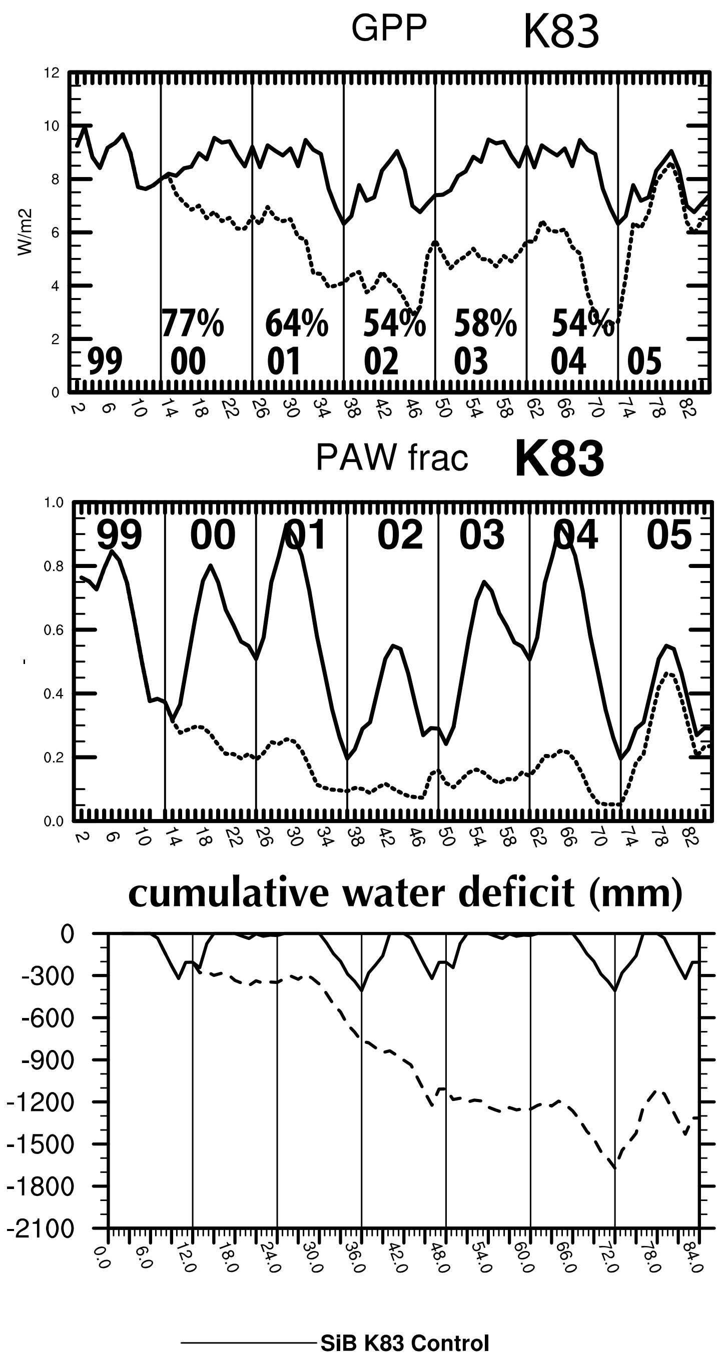
Impact noticeable from year 2, but drops in GPP & Resp cancel

Response stabilized from years 4-6

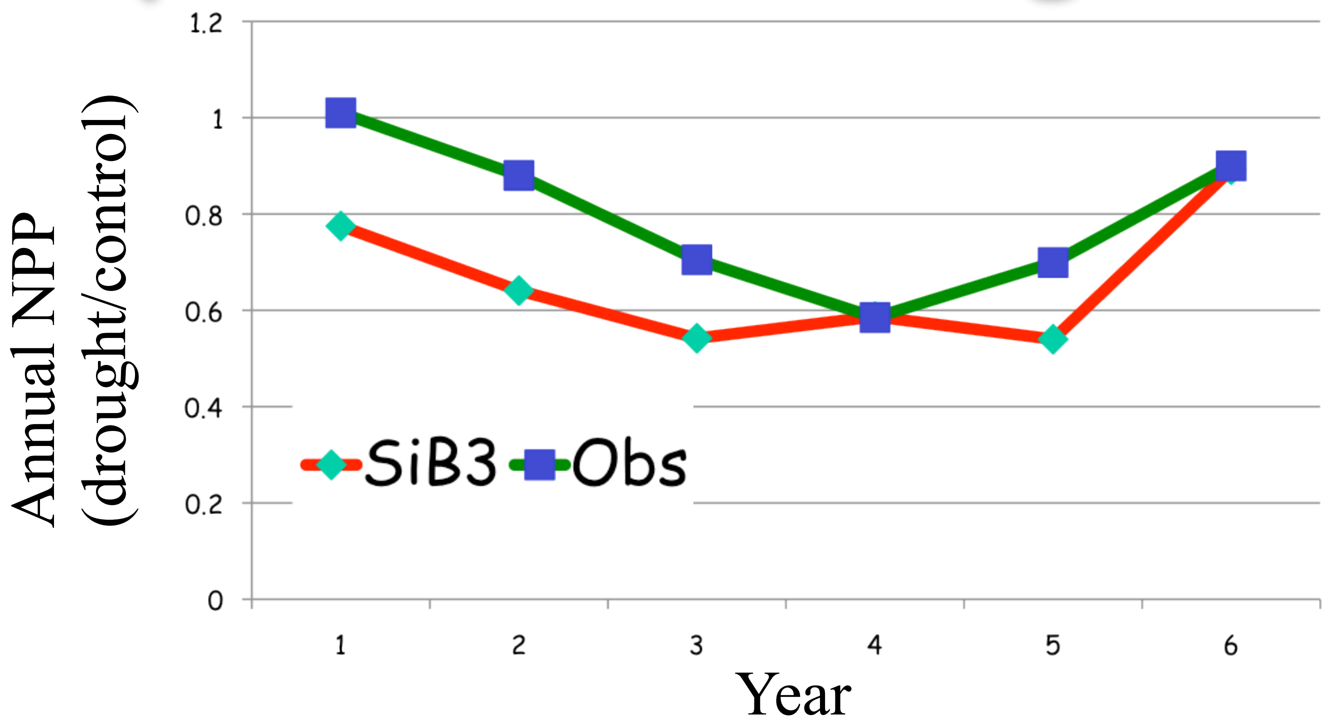
Recovery in year 7

Thresholds in SiB

- Initial decrease in GPP related to PAW: never recovers after first dry season
- 10% drop in GPP in 2001 related to strong increase in water deficit (accumulated P-E)
- Forest shifts from light-limited to water-limited during drought

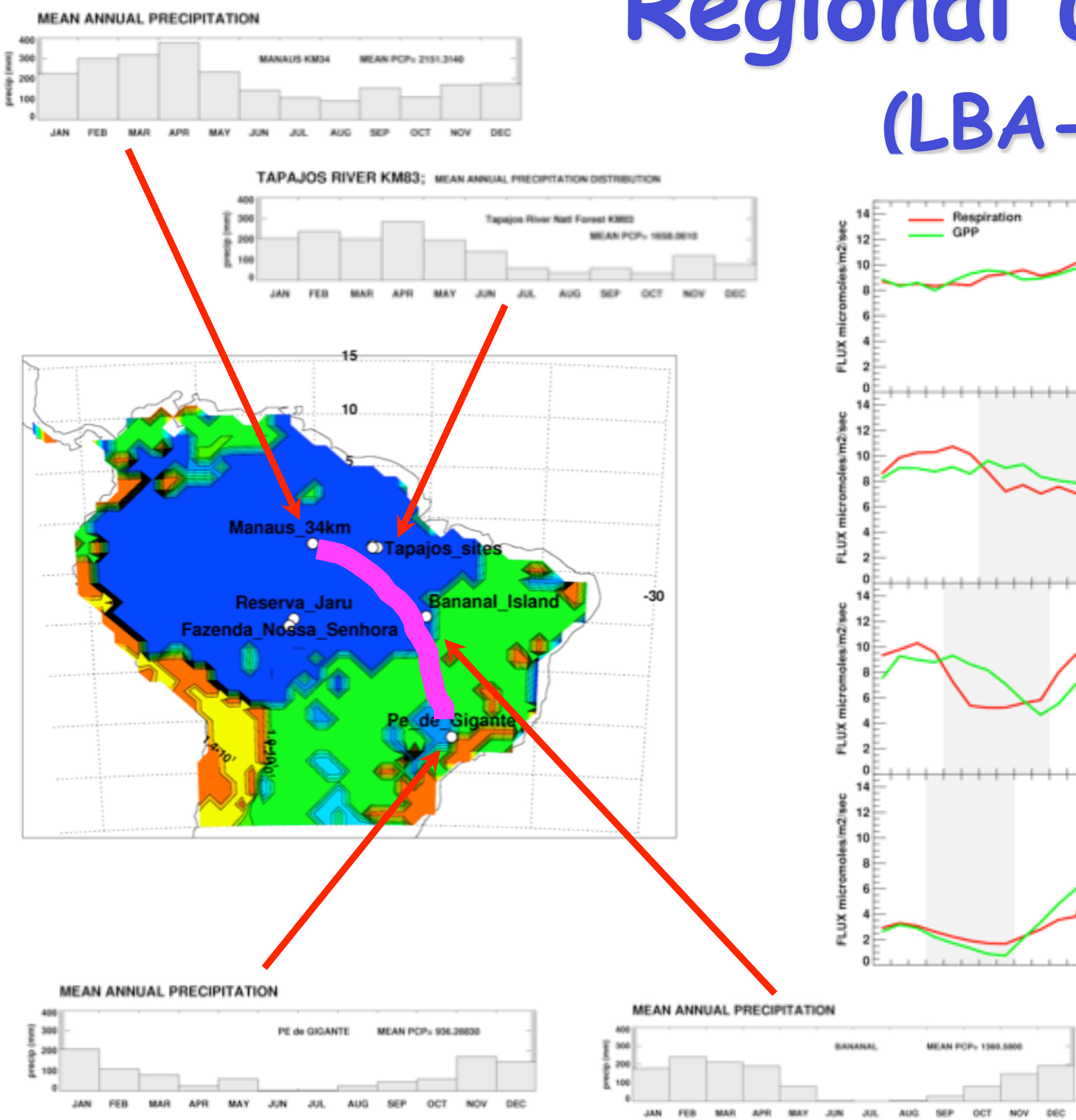


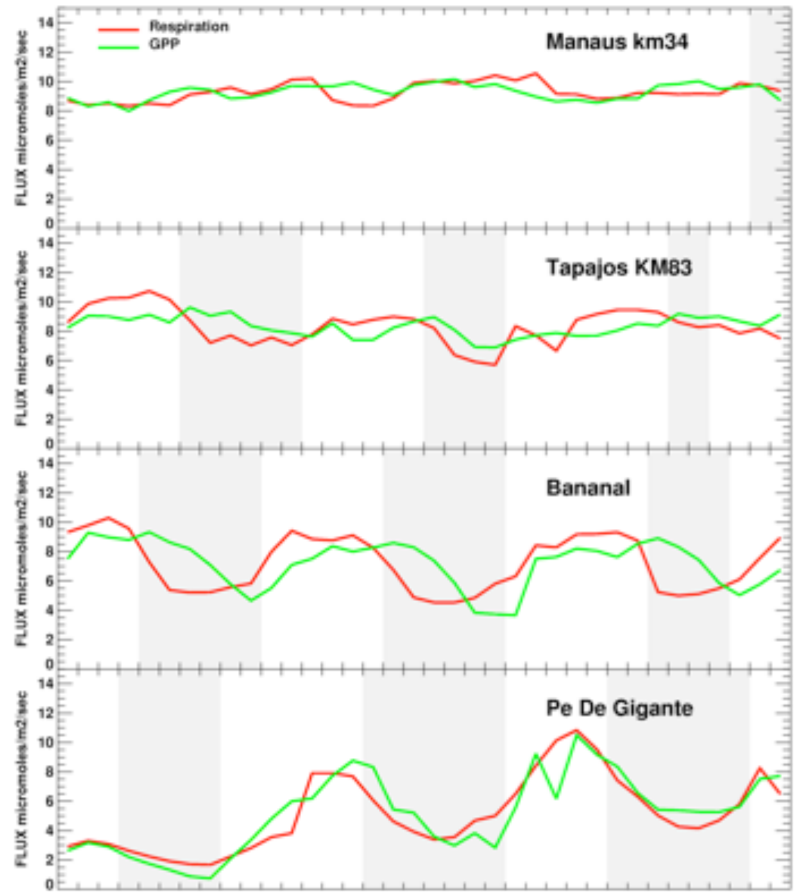
Experimental Drought Response



- Even after modification for less stress, SiB3 responds too strongly to imposed drought stress in first three years
- Long-term response and recovery pretty good

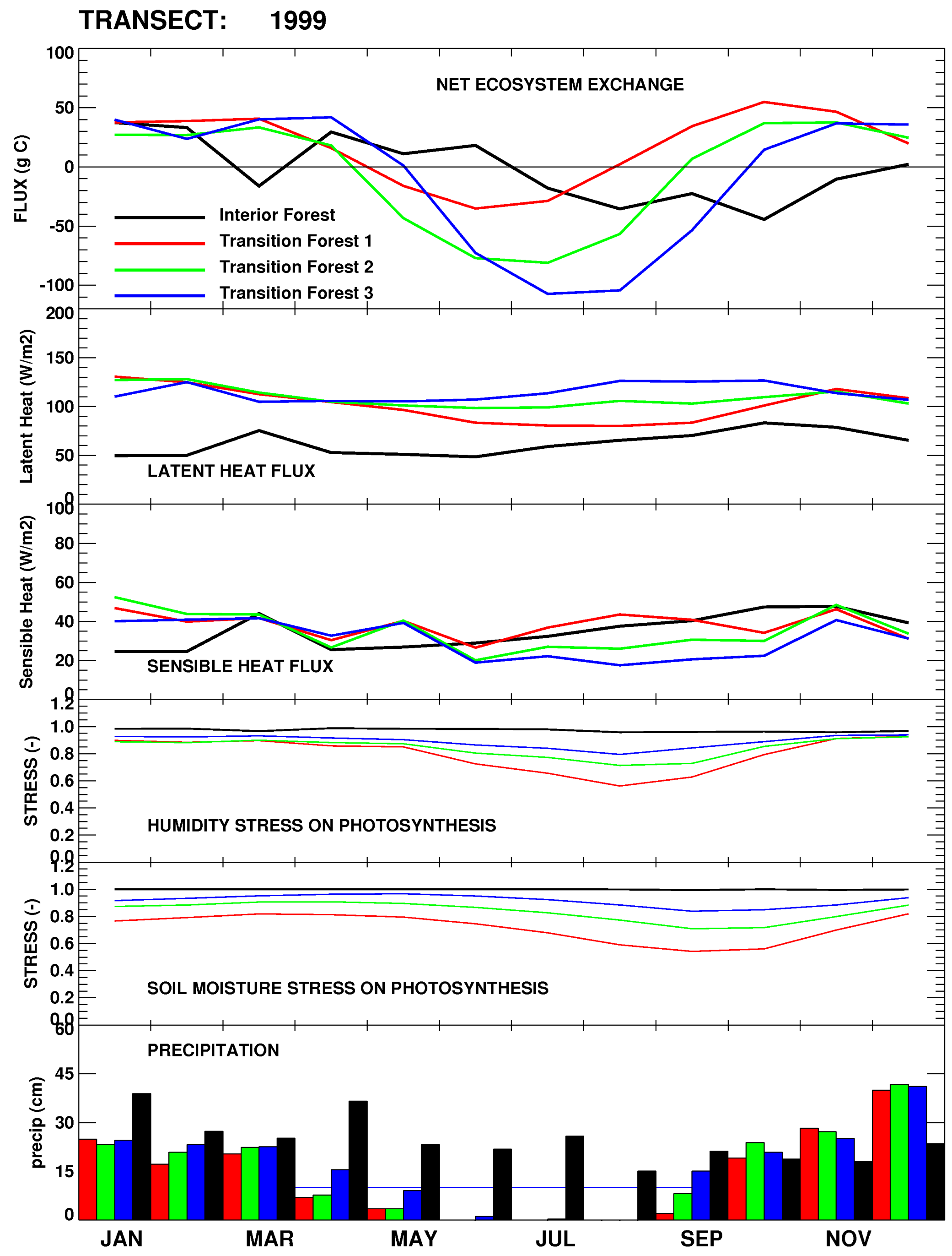
Regional Gradients
(LBA-MIP)

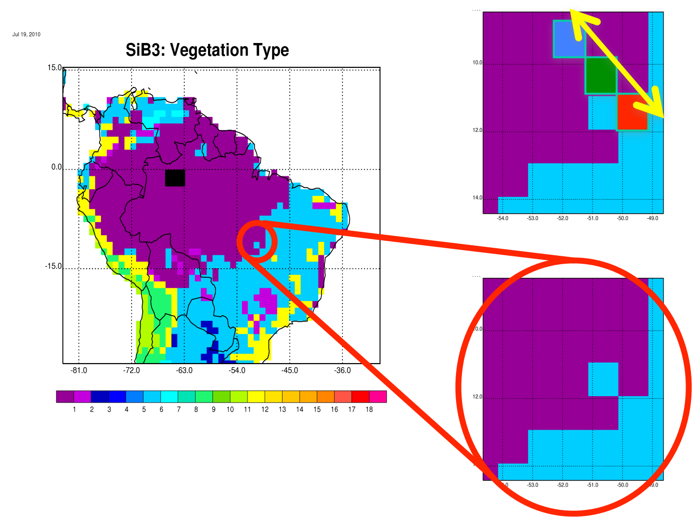




Baker et al (2010)

Annual Cycles: Interior Forest vs. Cerradão

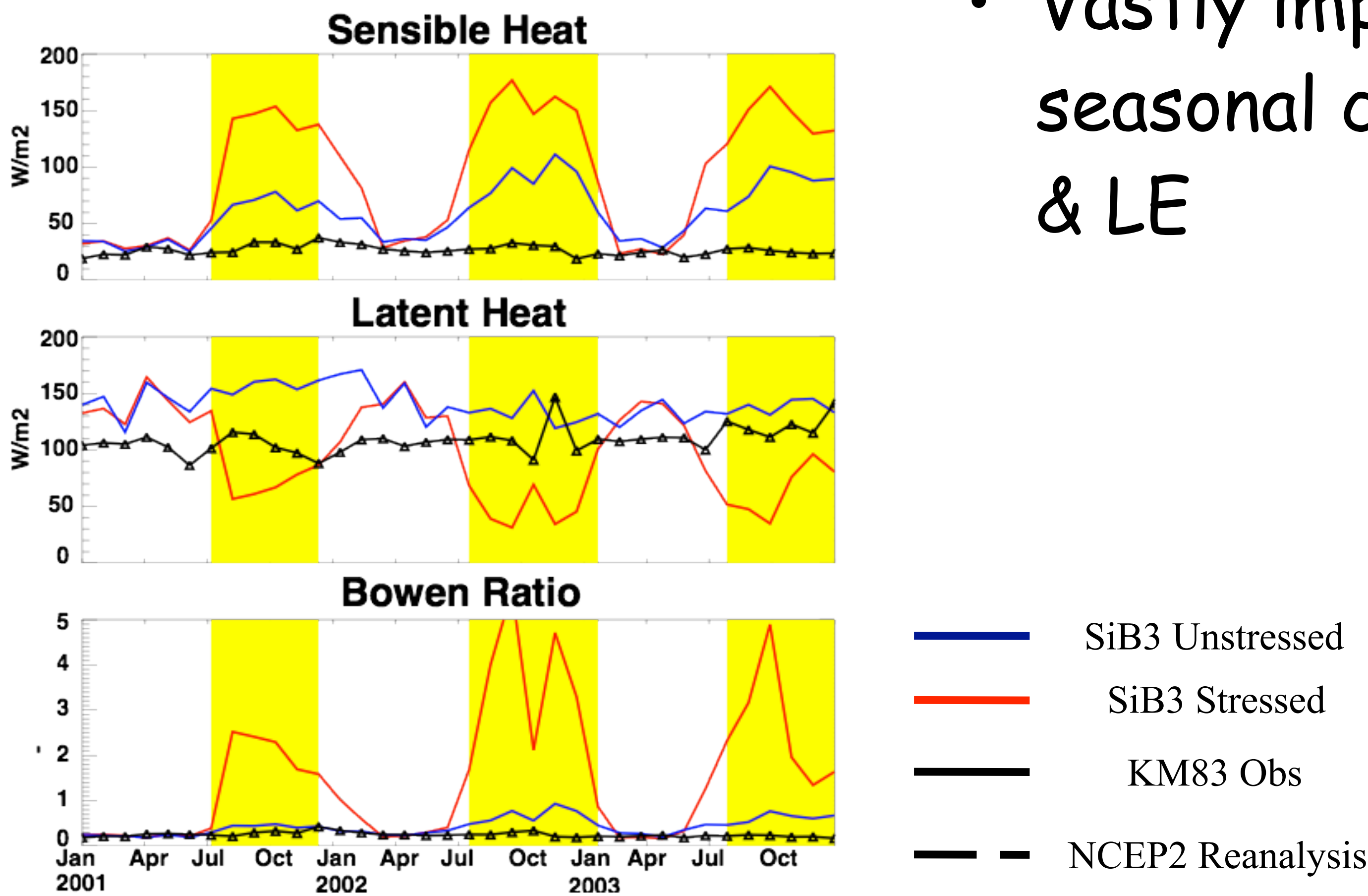




Single Column Model

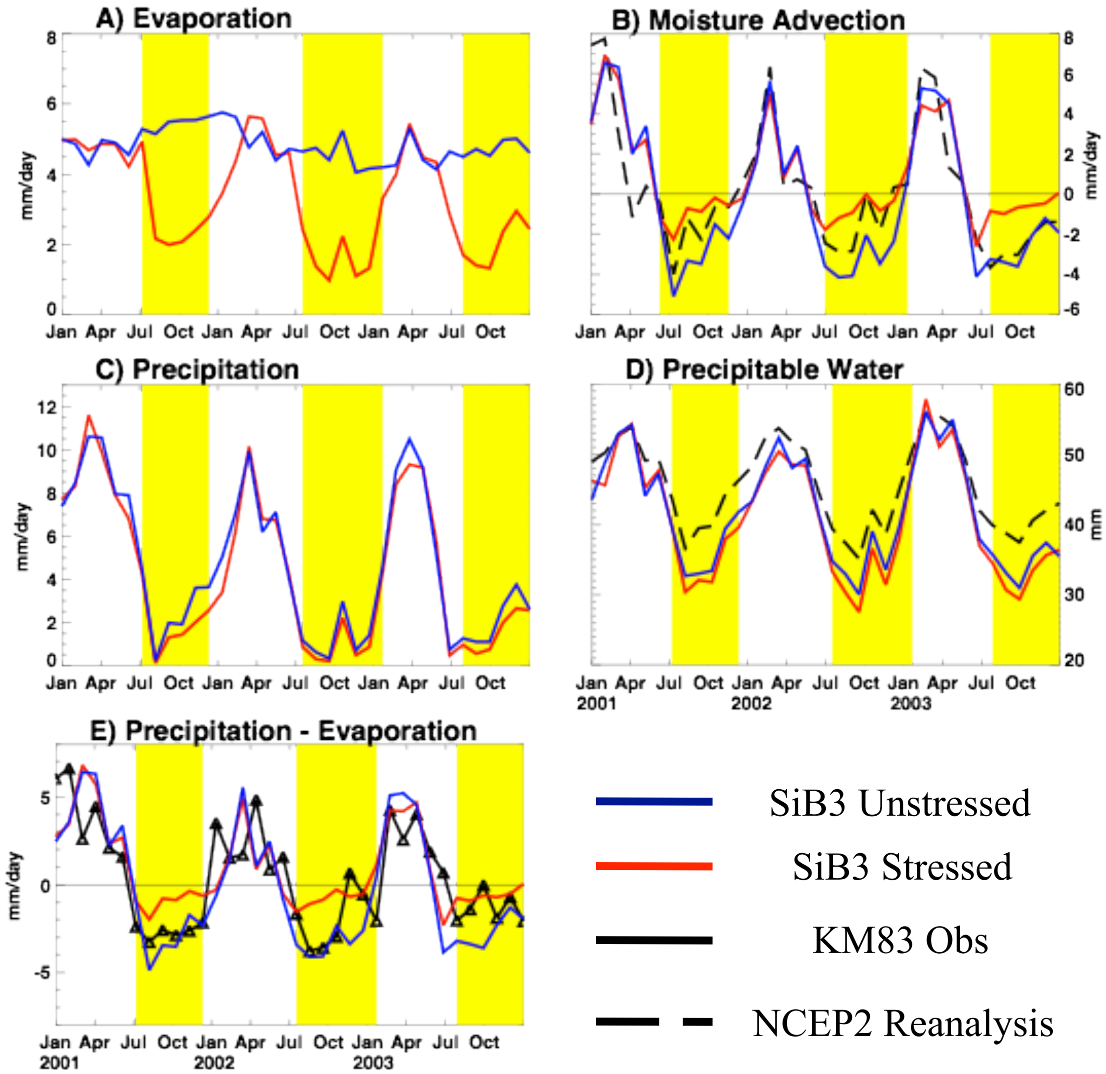
- Simulates the forest and atmosphere of one grid column centered at 3S, 55W
- Location of flux tower with half-hourly observations from 2000-2004
- Run model 2001-2003
- Same code as global model except no dx or dy
- Lateral boundary conditions set w/ “relaxation forcing” using NCEP2 reanalysis

Single Column Model



- Vastly improved seasonal cycle of H & LE

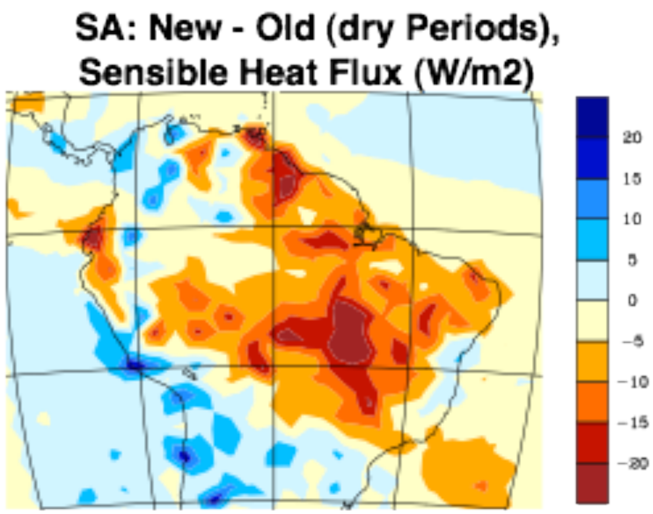
Single Column Model

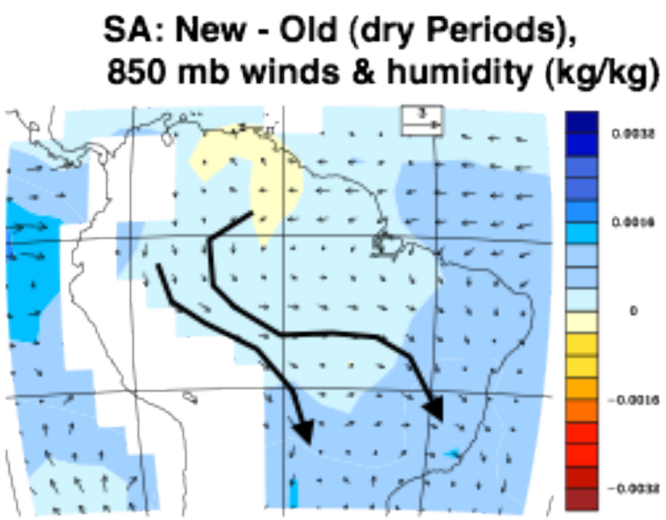


- Much greater advective transport of water vapor to regional atmosphere!

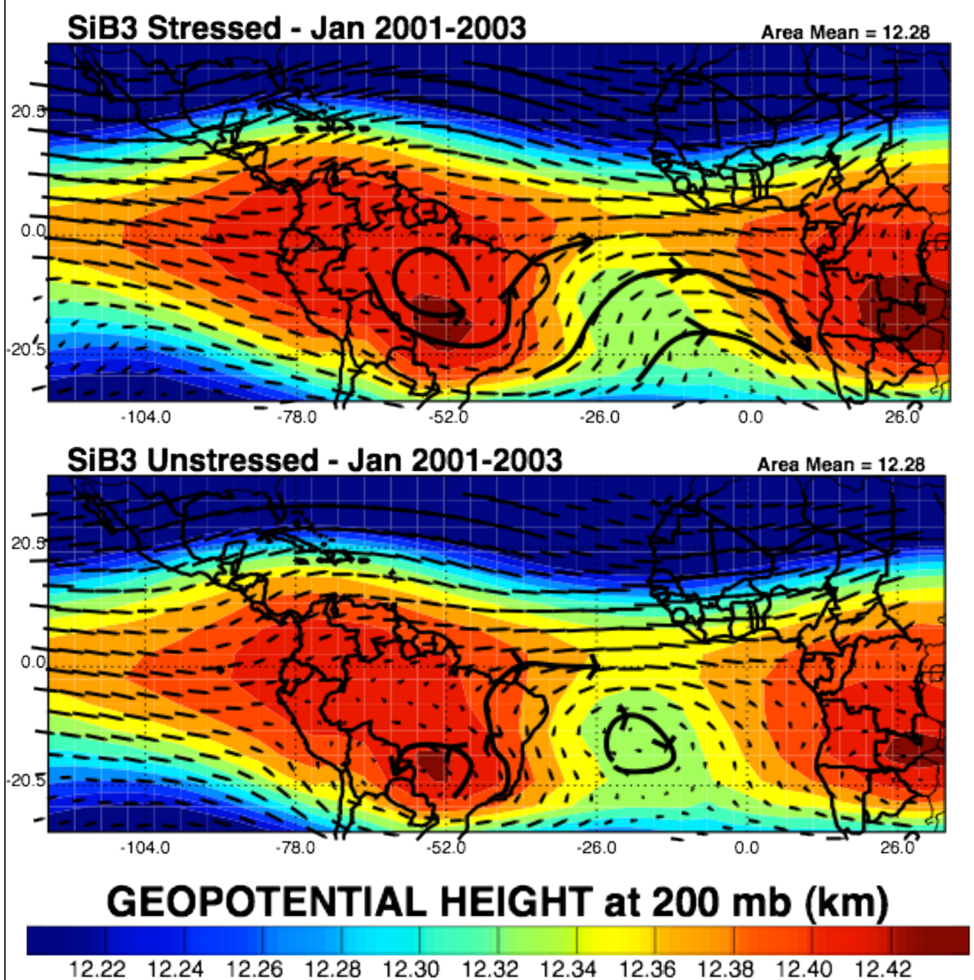
Fully Coupled Global Simulations

- Reduced sensible heat
- Enhanced latent heat
- Changes in winds and water vapor advection
- More realistic precipitation and seasonal GPP

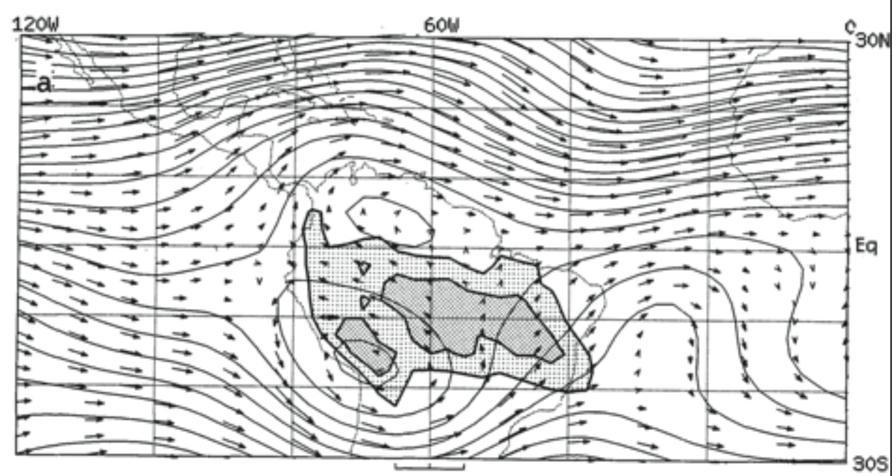




Impact of Roots on Upper Tropospheric Circulation



Improved simulation of Bolivian High and Nordeste Low



Obs from Horel et al. 1989: Jan 1-5, 1980-1987. 200mb geopotential height, wind vectors, & OLR

More Resilient Climate System

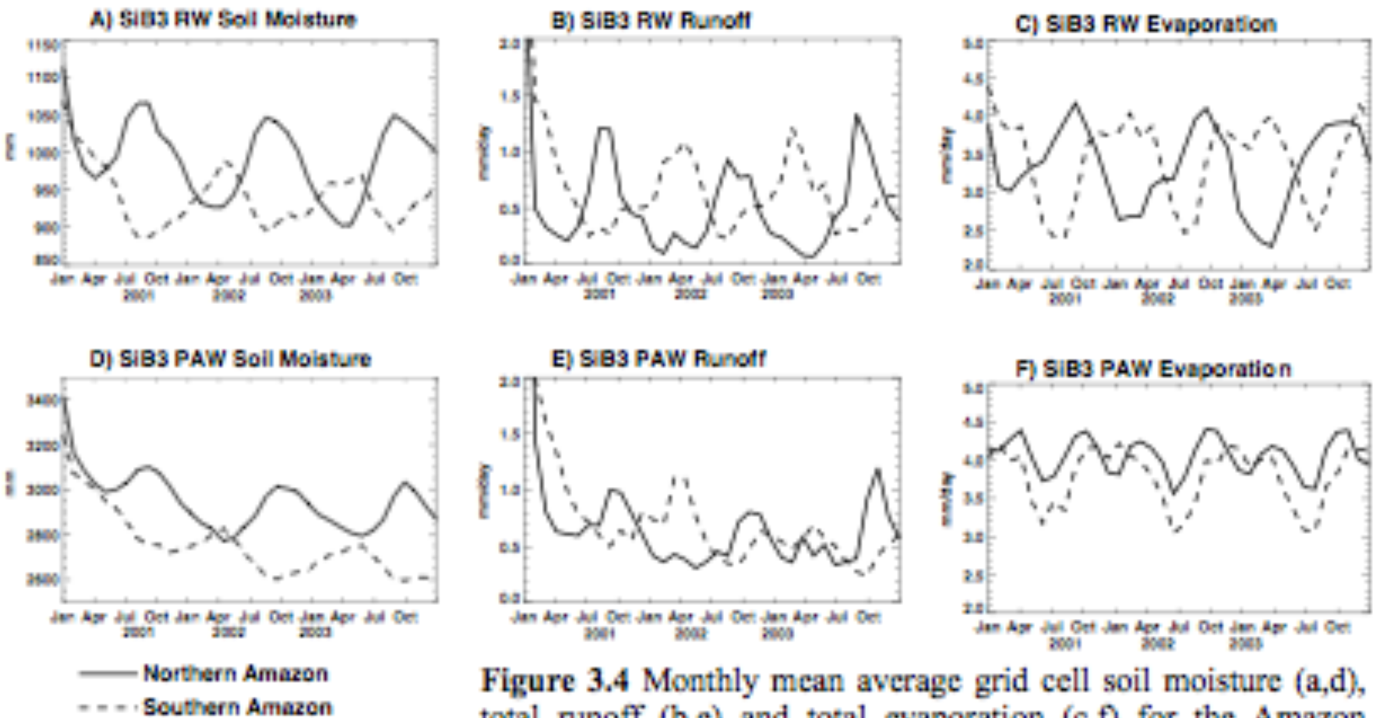


Figure 3.4 Monthly mean average grid cell soil moisture (a,d), total runoff (b,e) and total evaporation (c,f) for the Amazon region from 2001 to 2003. Both models are initialized at 90% saturation but SiB3 PAW has a deeper soil and thus more soil moisture.

- Hydrologic cycle and carbon cycle equilibrate to a much more reasonable climate
- Interannual variability is reasonable

Summary

- Feedback between cycling of carbon and water in tropical forests are one of the key sources of uncertainties in 21st-Century climate (equally important as humans and clouds!)
- Exaggerated physiological stress can lead to very unrealistic climate feedback!
- Many models overestimate vulnerability of tropical forests to drought stress
- Improved treatment of root function can improve model performance at local, regional, and global scales