Amazon forest drought response: Implications for climate & the future of the Amazon

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CMMAP Team Meeting
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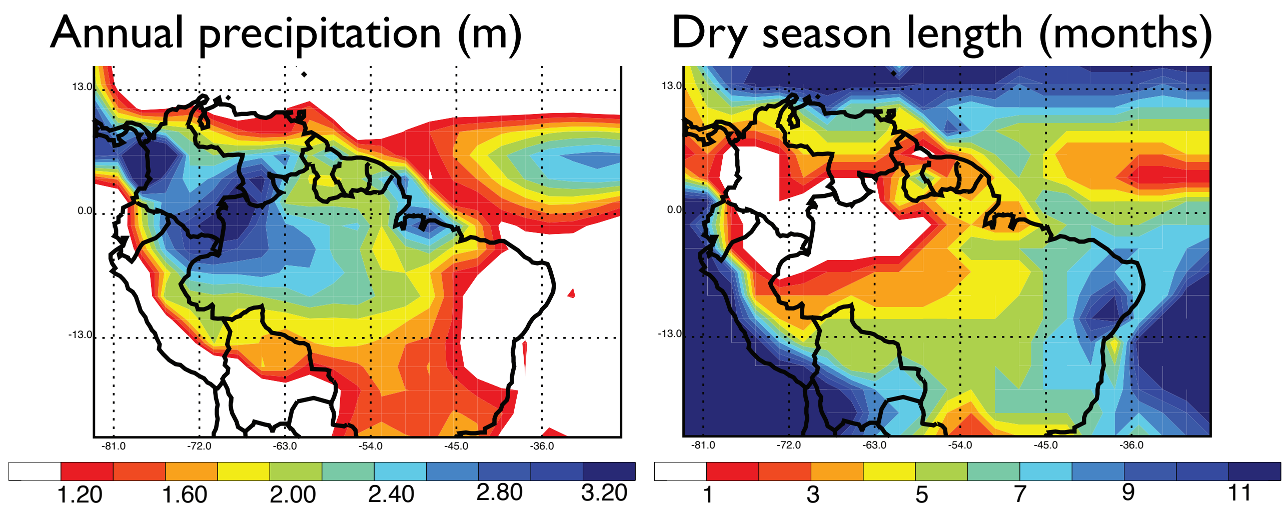
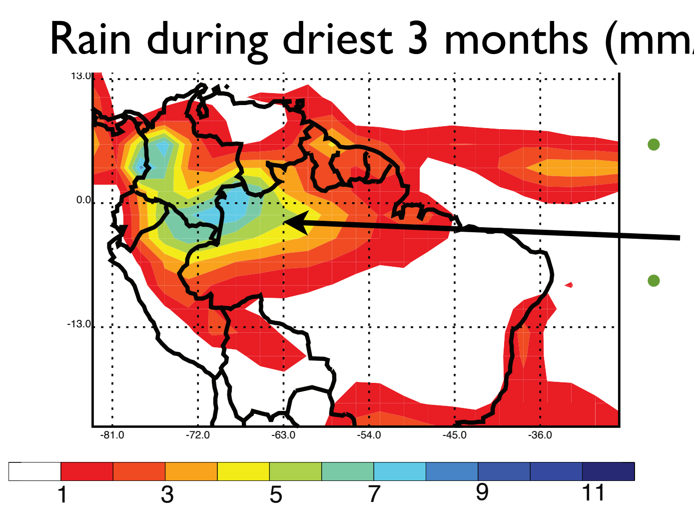
Motivation

- Amazon is very important for biodiversity, carbon storage, water, culture
- Future is uncertain due to combined threats of climate change and deforestation
- Active research of ecophysiology, trace gases, hydrology, climate, aerosols, conservation and land use.

Amazon Precipitation

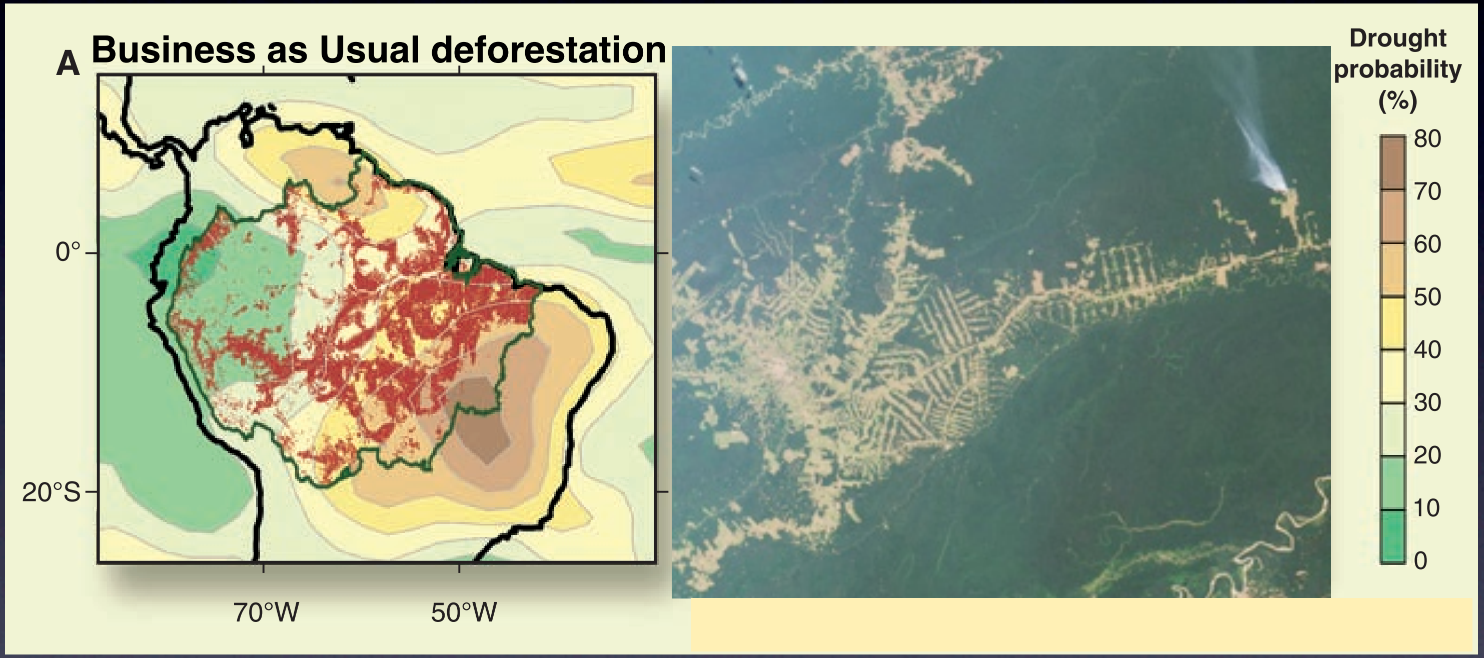




- 5 mm/day = 6 in/mo. Denver gets 15 in/yr!
- Miami gets 7.5 in/mo during summer

- Central Amazon is very wet, mild dry season
- To the south and east, annual precipitation decreases and dry season intensity increases
- Where dry season is 5-6 mo. or longer, forest transitions to savanna

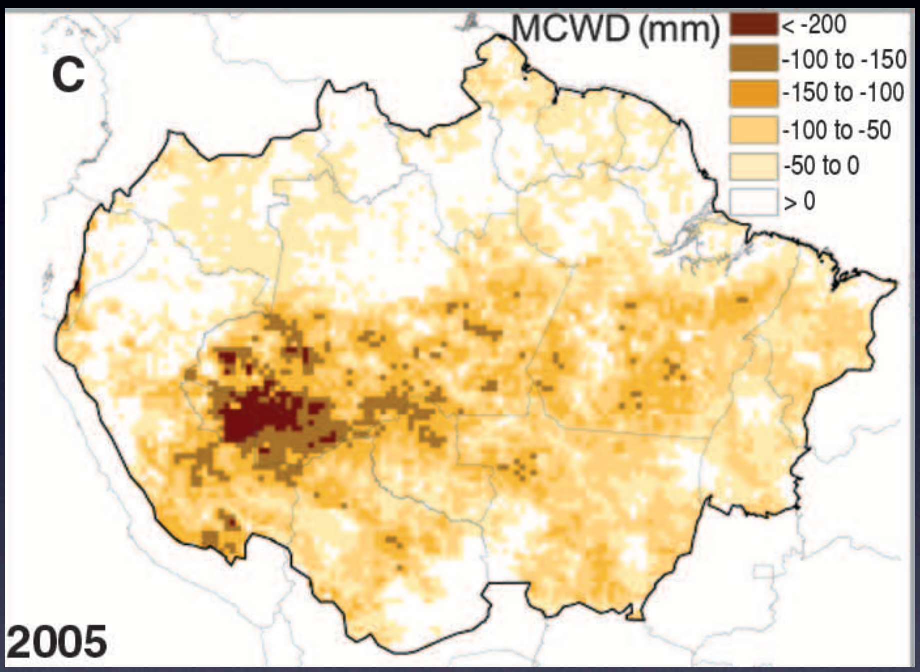
Climate change, deforestation, and the fate of the Amazon



Projections of deforestation by 2050 and probability of >20% reduction in dry season rainfall by 2100 (A1B scenario, IPCC AR4). Malhi et al., 2008, Science

- 85% of forest intact as of 2003
- Almost half could be deforested by 2050
- IPCC models predict drier climate, especially during dry season

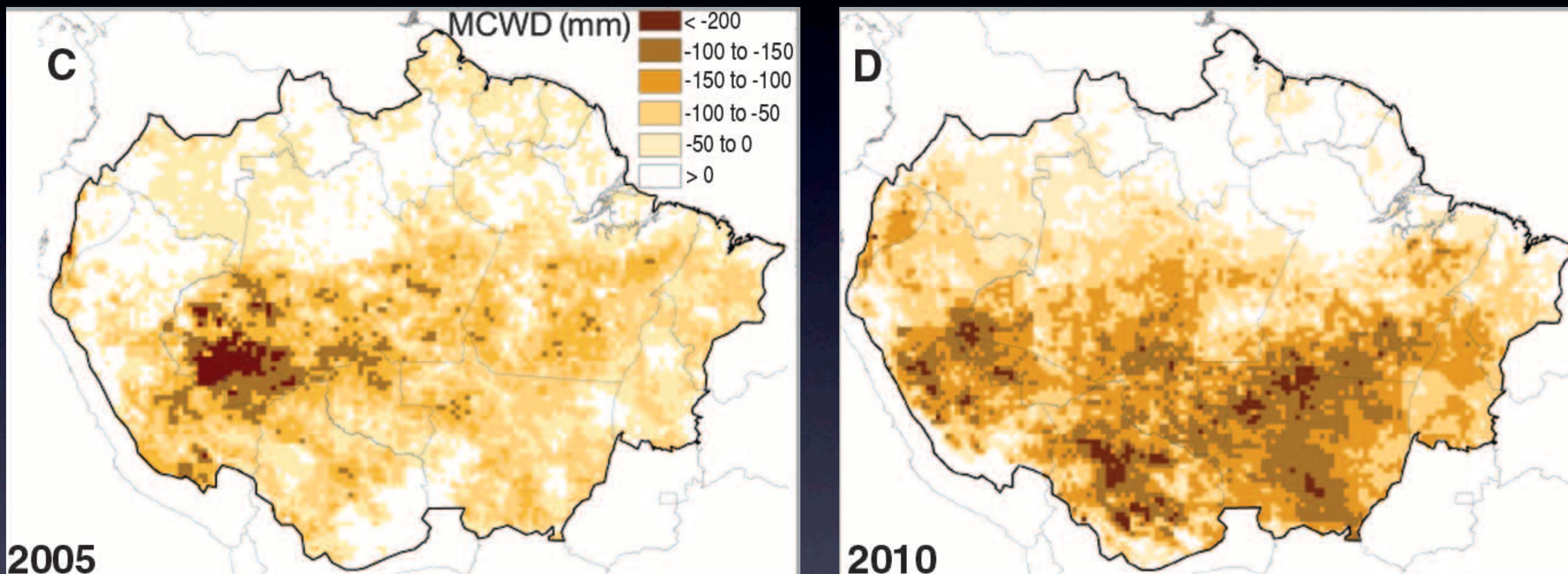
Amazon drought



2.5 million km² affected
1.6 PgC lost
1-in-100 year event

Lewis et al., 2011

Amazon drought

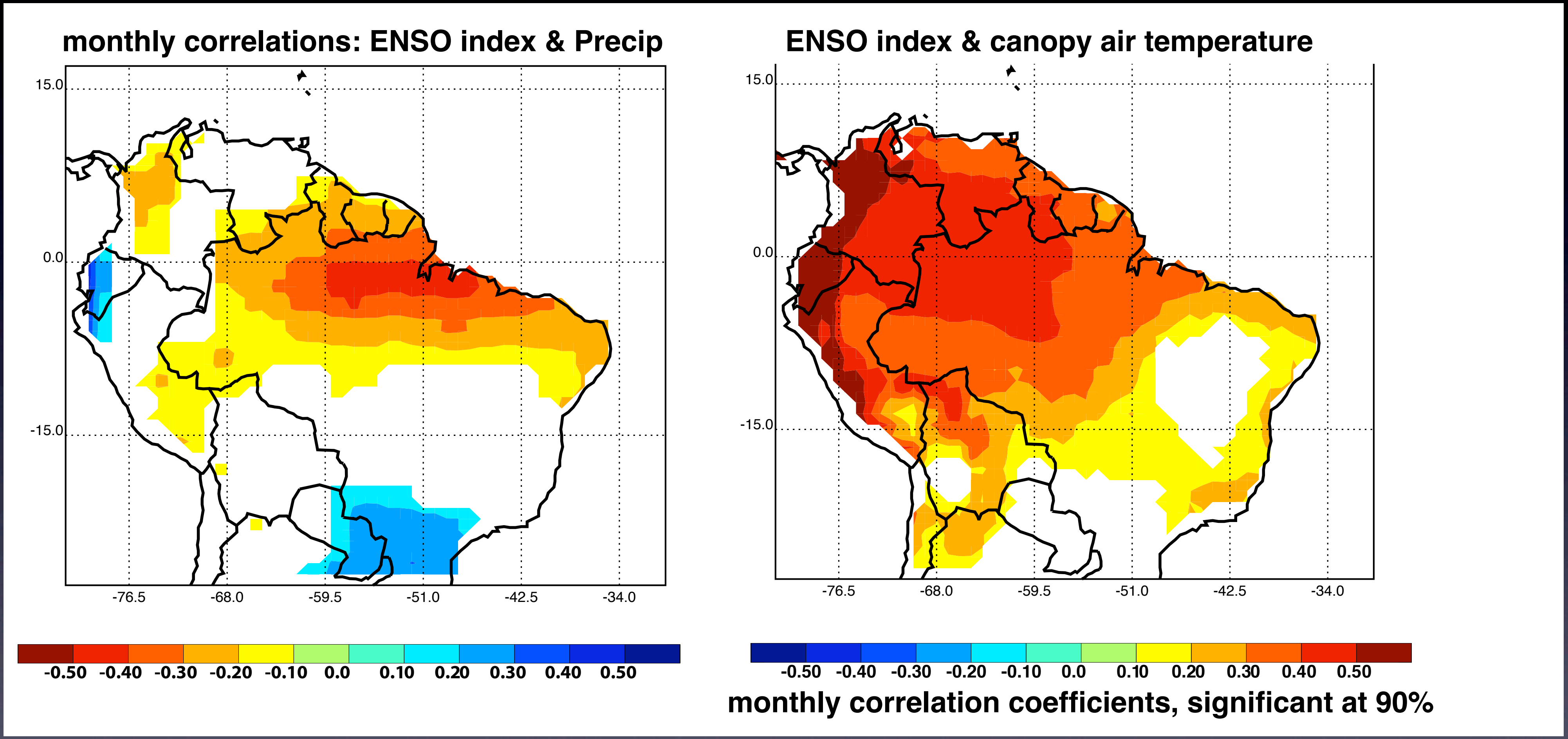


2.5 million km² affected
1.6 PgC lost
1-in-100 year event

3.2 million km² affected
2.2 PgC lost
1-in-100+ year event

Lewis et al., 2011

El Nino droughts

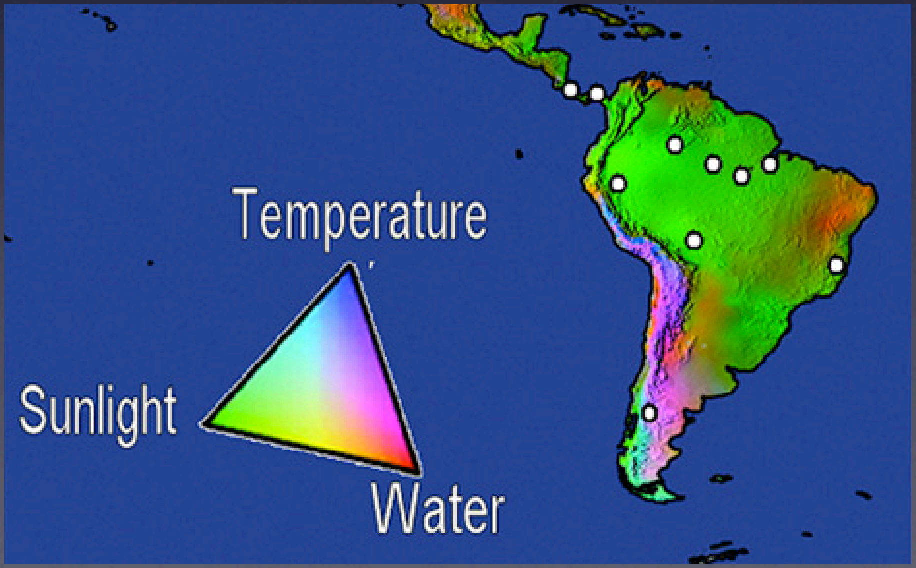


- El Nino associated with decreased precipitation, increased temperature and radiation.

ENSO index is the multivariate ENSO index (MEI)

Response to seasonal drought

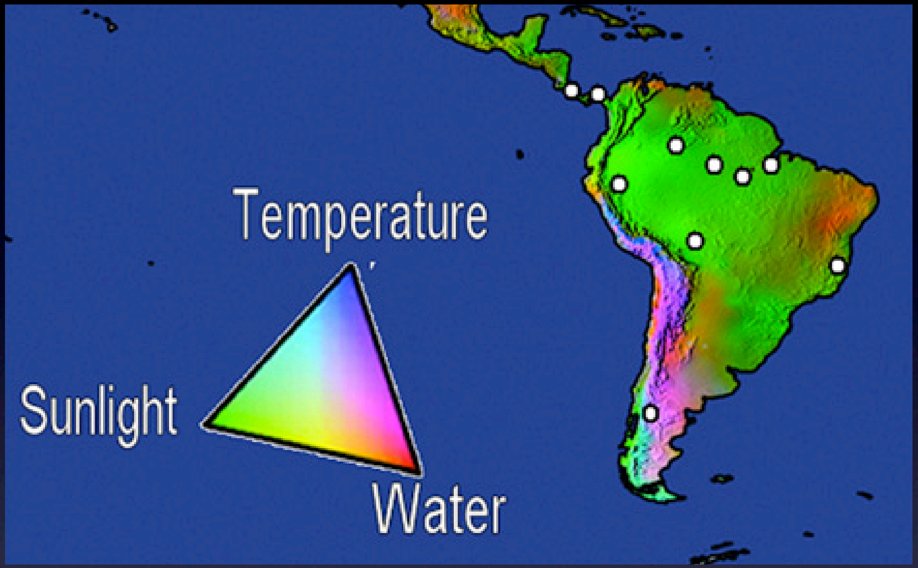
- Photosynthesis usually radiation-limited in Amazon
- Forest well adapted to seasonal 'drought' but models often don't capture this
- Deep roots are very important for accessing stored water during drought



Limiting factor on ecosystem productivity; Allen et al., 2010, *Forest Ecology and Management*

Response to strong drought

- Severe droughts increased mortality by 39-94%
- Isohydric plants regulate transpiration in order to prevent water loss, vulnerable to death by carbon starvation, especially if warm temperatures increase respiration
- Observed in Amazon trees during drought experiments



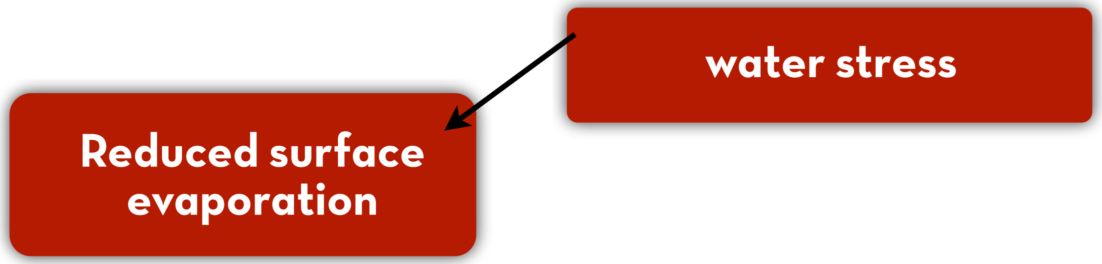
Allen et al., 2010, *Forest Ecology and Management*

** Observations show the forest is resistant to short-term drought, but susceptible to severe or long-term drought. However, many ecosystem models predict drought stress on short time scales.

Importance of stress response

water stress

Importance of stress response



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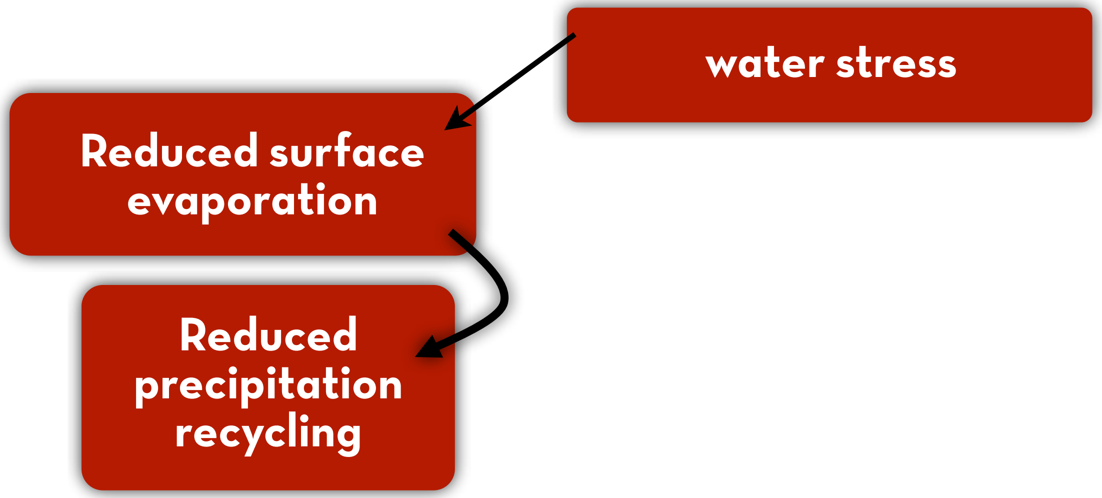

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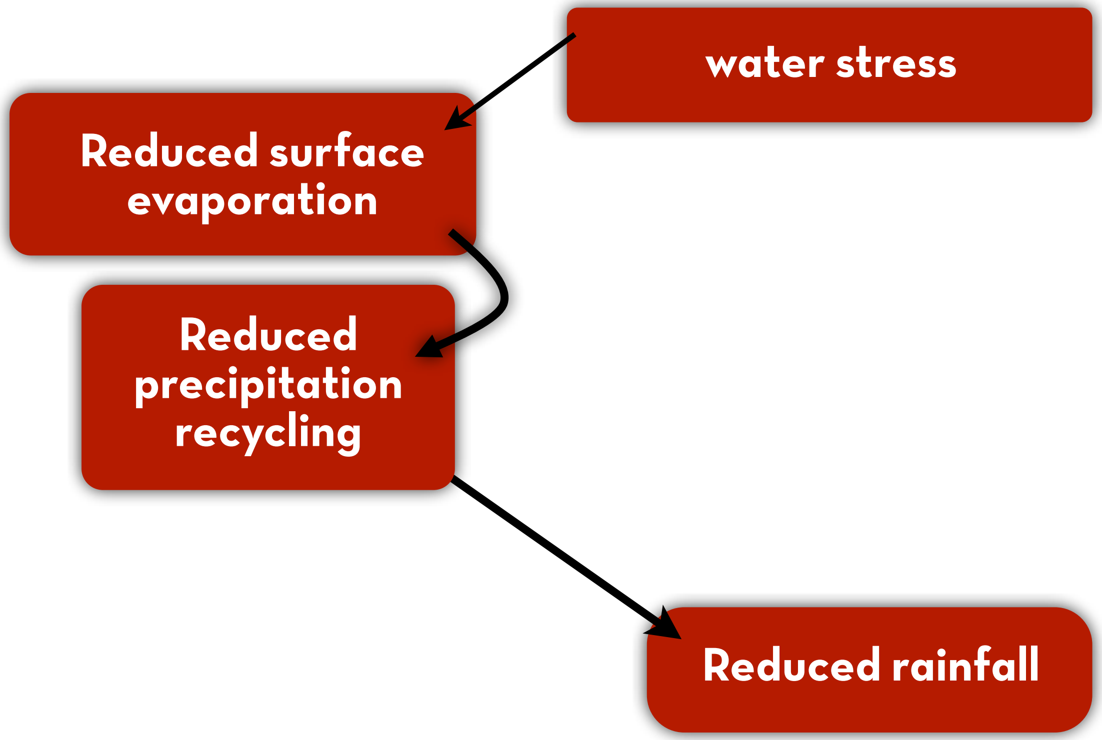

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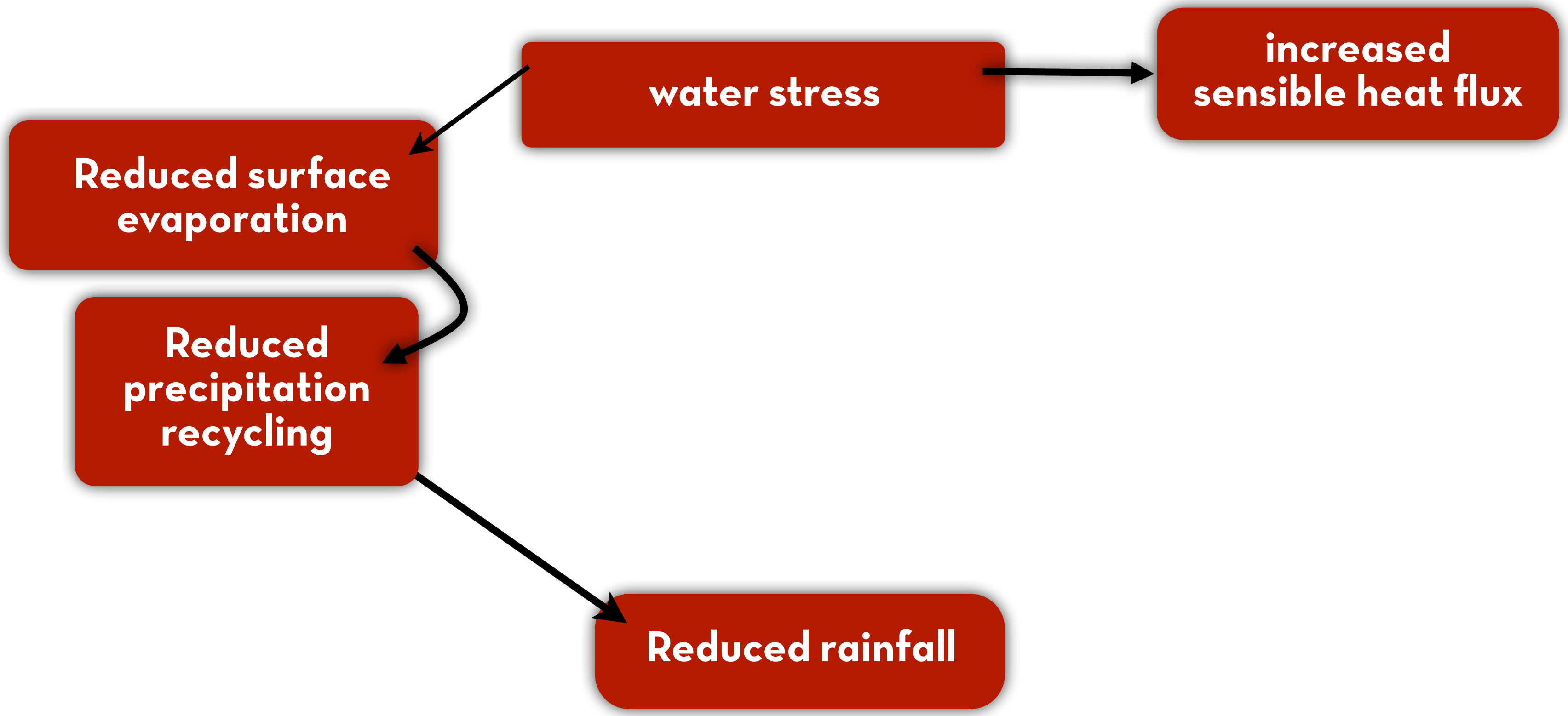

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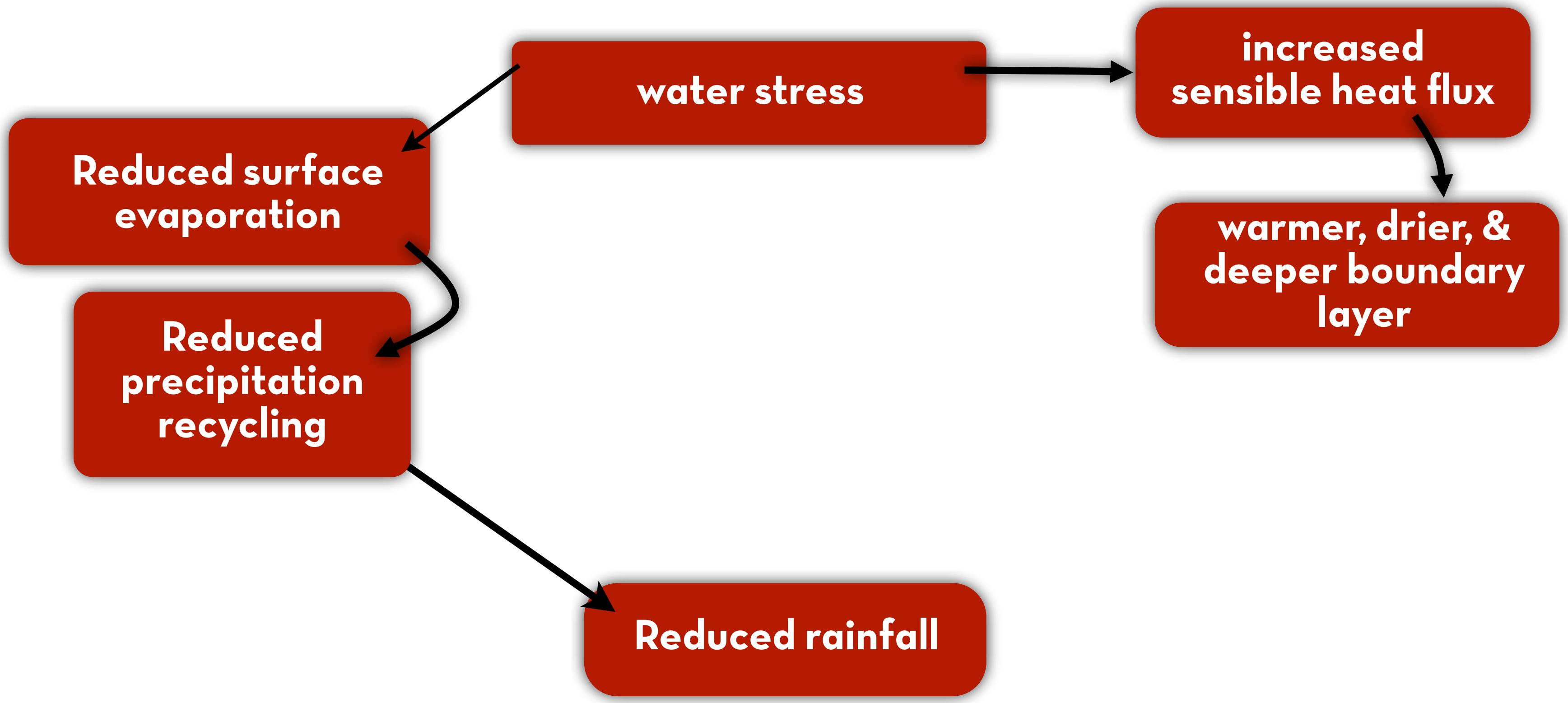

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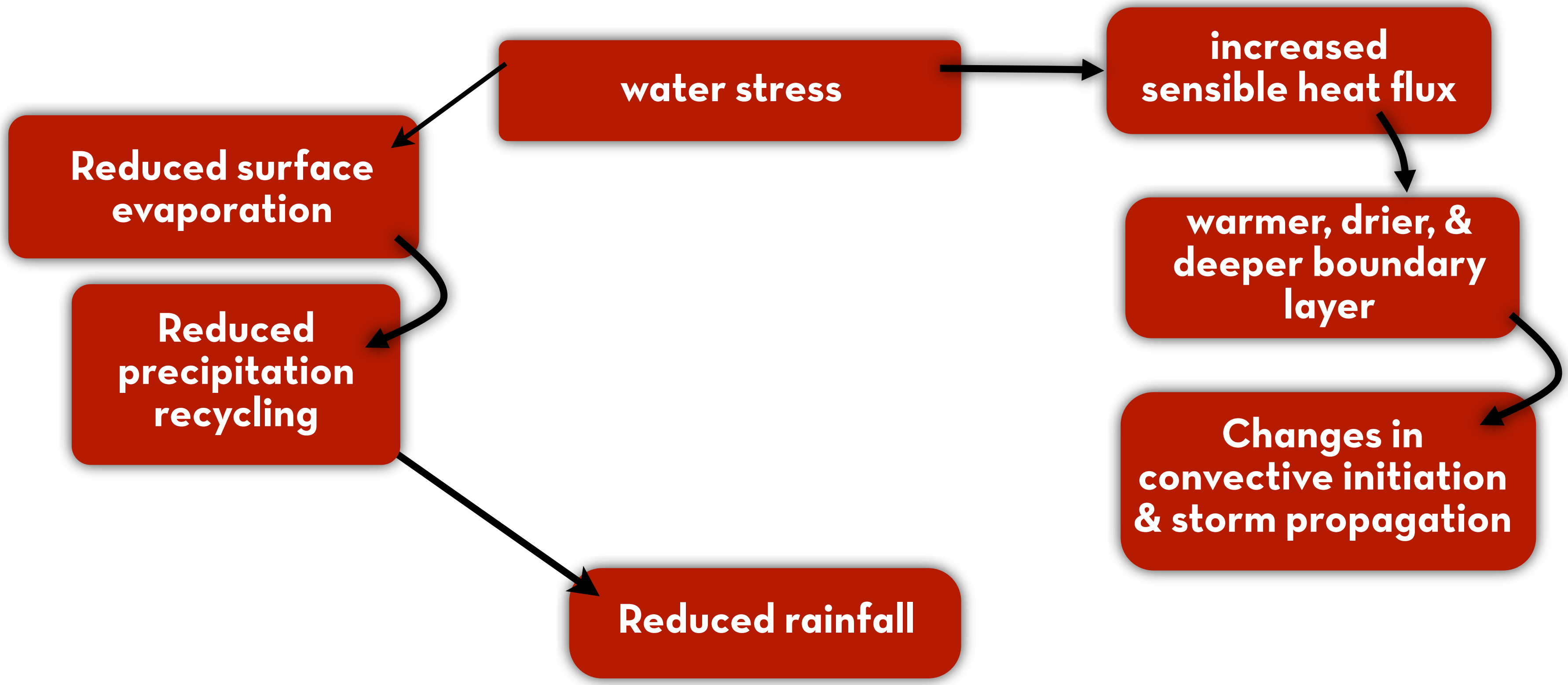

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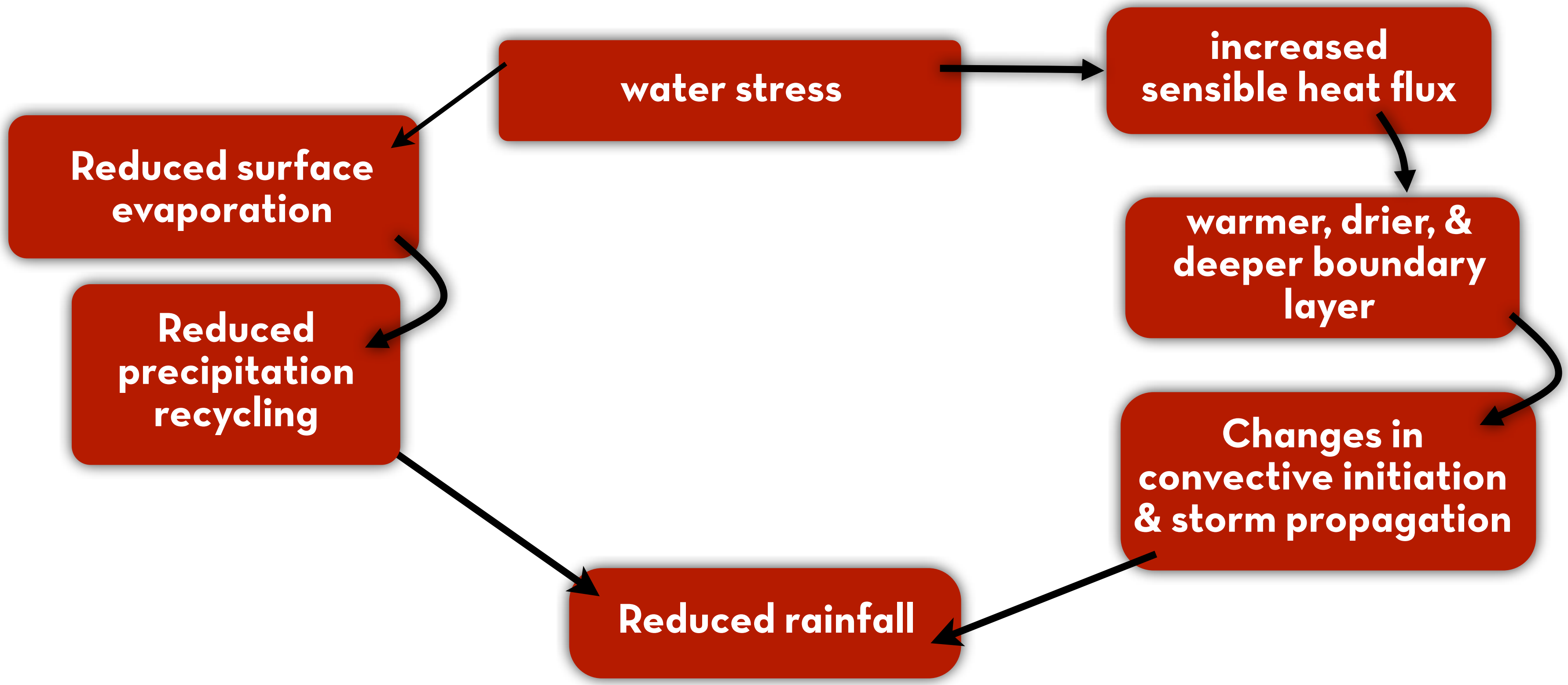

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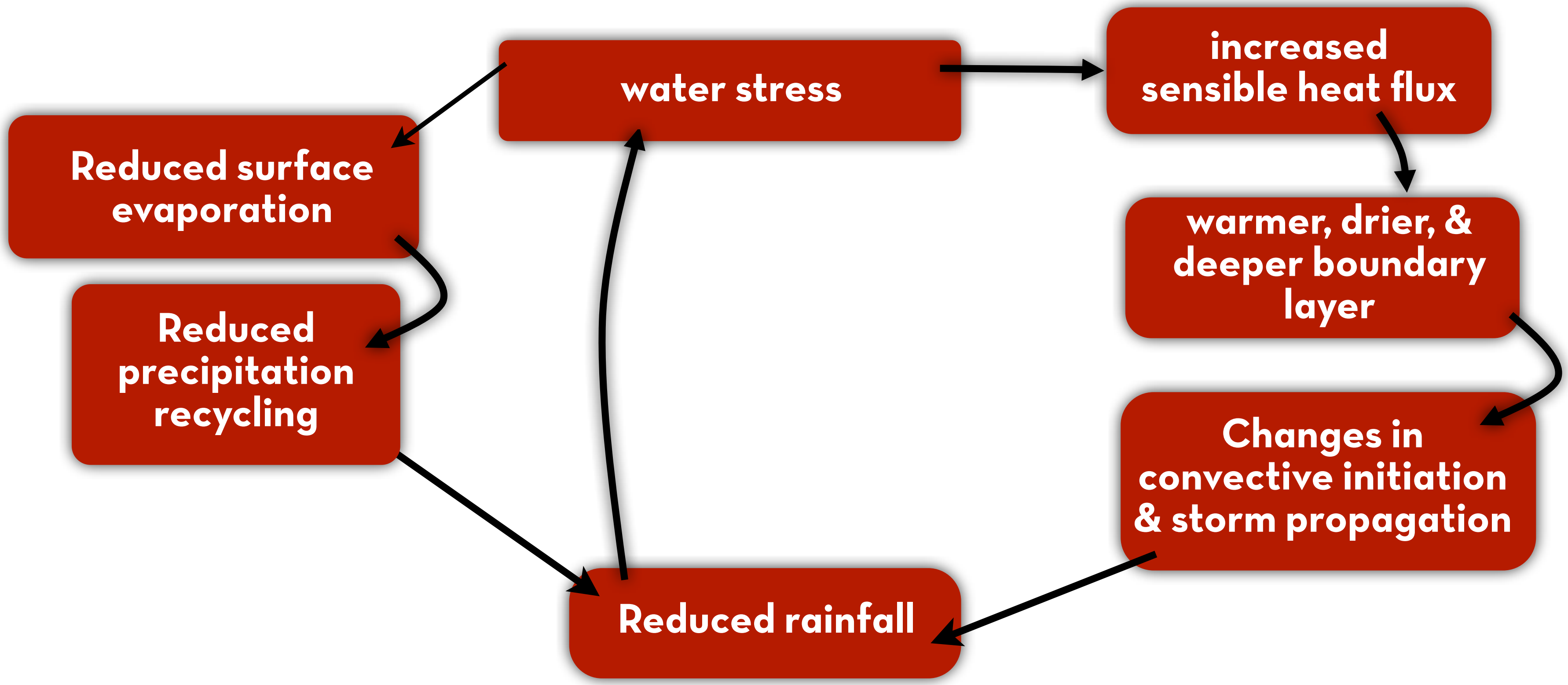

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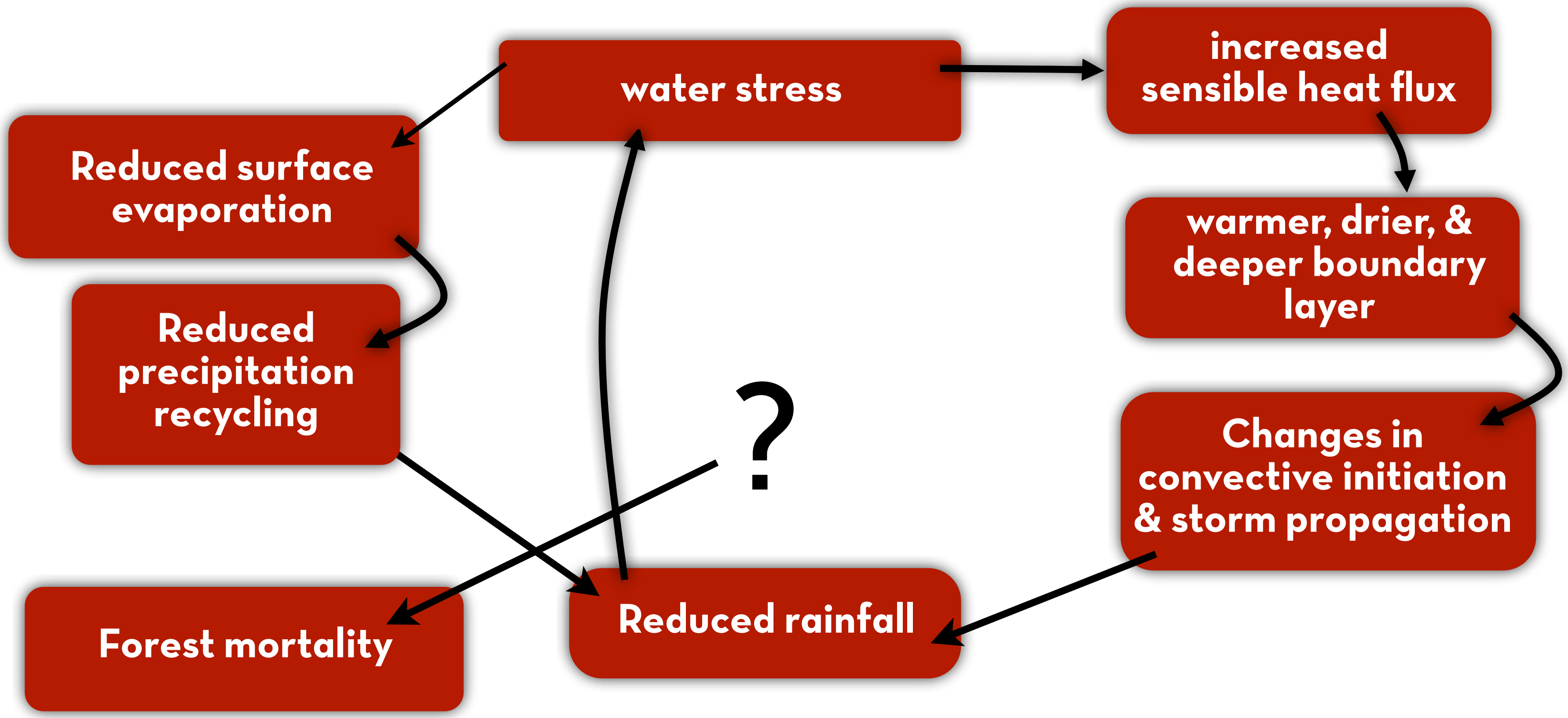

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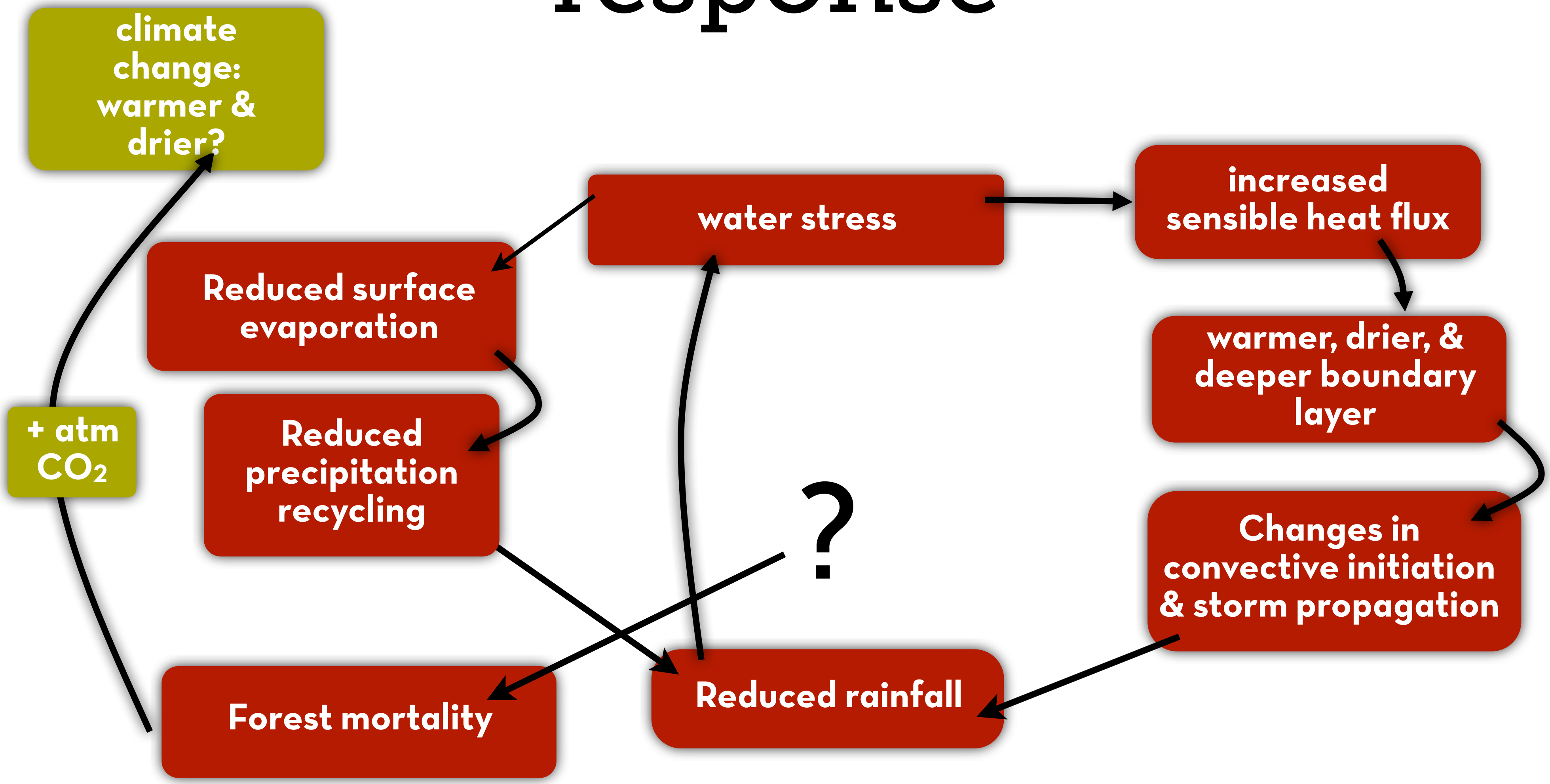

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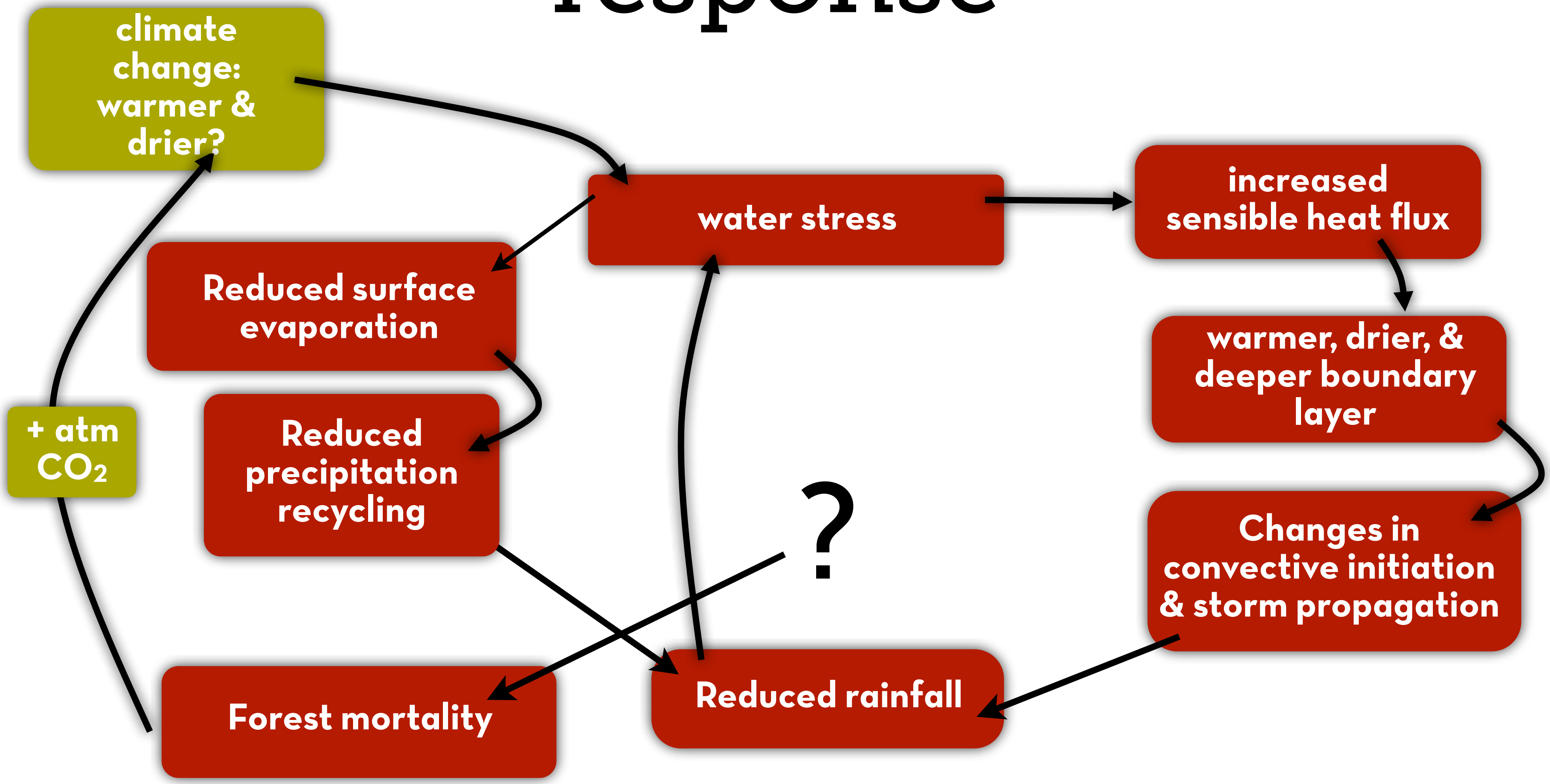


Motivation

- What is the future of the Amazon?
- *How does the forest respond to drought conditions?*
- *What are implications of response for the climate and climate change?*

Take-home messages

- Not all forests respond the same to drought
- Ecosystem models can represent spatial heterogeneity in stress resistance
- Increased stress resistance can decrease drought intensity

Outline

- Site level synthesis of forest response to severe drought (using ecosystem model: SiB3)
- Revised stress resistance for SiB3
- Coupled simulations (using SiB3 and BUGS5 GCM)
- Implications & scientific questions for Amazonia

Simple Biosphere (SiB) Model

- Ecosystem model that represents plant processes like photosynthesis, respiration, and tracks water through the air, canopy, and soil.
- Potential photosynthesis rates are weighted by stress factors (temperature, humidity, and soil moisture stress)

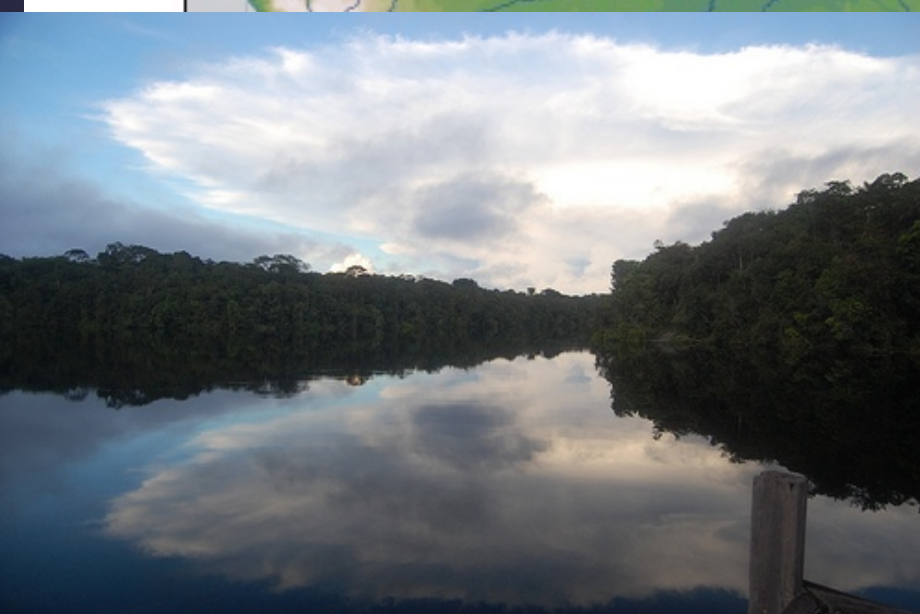
Part 1: Site level simulations

- How well do we understand Amazon forest stress response during extremely dry conditions?

Methods

- Offline SiB3 run using meteorology from observed severe drought experiments

Rainfall exclusion experiments



System of panels prevented rainfall from reaching forest floor from 2000-2004 at Tapajos, and 2002-2008 at Caxiuana

Rainfall exclusion experiments

Important conclusions:

1. Some forests can resist drought for 2-3 years
2. Not all forests respond the same to soil water limitations

- Mortality, LAI, and soil respiration more impacted at Caxiuana

Why would Caxiuana be more sensitive?

	tapajos	caxiuana
rainfall exclusion	wet season only	year-round
site meteorology	drier, longer dry season	wetter, shorter dry seasons
water table	100m deep	As shallow as 10m during wet season
root profiles	Roots observed to 12m	Roots observed to 8m, stony laterite layer at 3-4m

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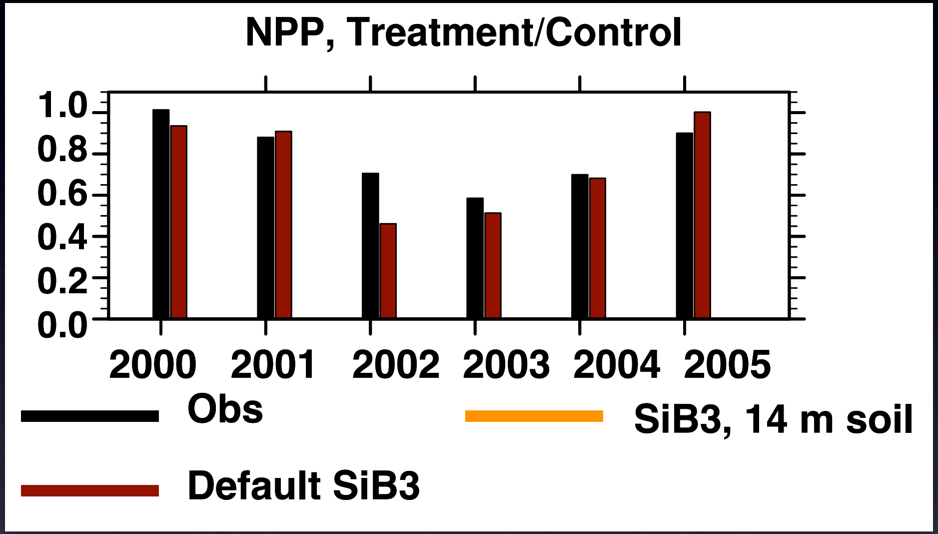
The forest at Tapajos has both the need and the ability to develop deeper roots than at Caxiuana

Simulated drought experiments

- Offline SiB3 run using meteorology from observed severe drought experiments
- Default experiments use 10m soil
- Tapajos: 50% reduction during wet season only in rainfall from 2000-2004
  1. Sensitivity test: Run with a deeper soil to represent higher drought tolerance observed here. 14m soil
- Caxiuana: 50% reduction in rainfall from 2002-2005
  1. Sensitivity test: Run with a shallower soil to represent lower drought tolerance observed here. 2m soil

Tapajos Exclusion

- NPP reduced by 30% in 2002, and by 42% in 2003.
- Default SiB3 reduces by 54% and 48%.
- Drought effect on NPP is closest with 14m soil.



NPP = net primary productivity

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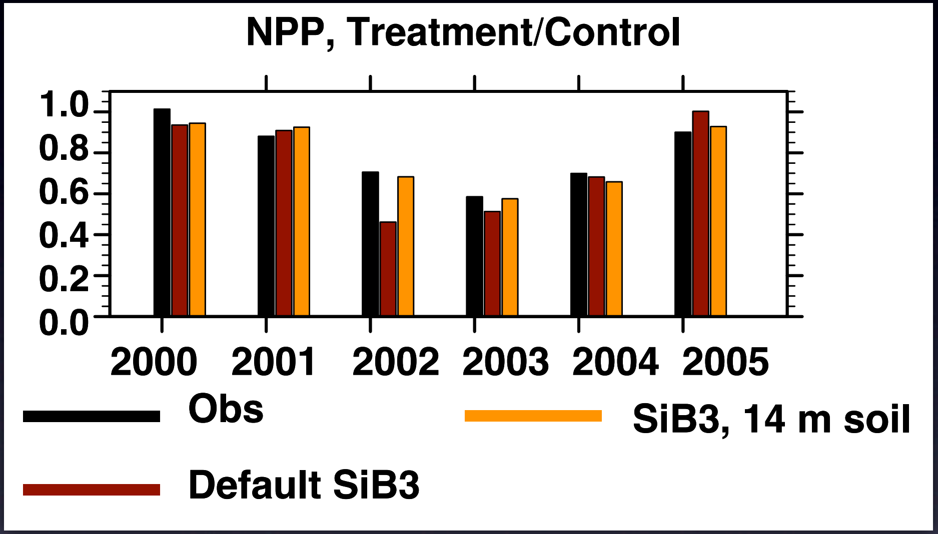
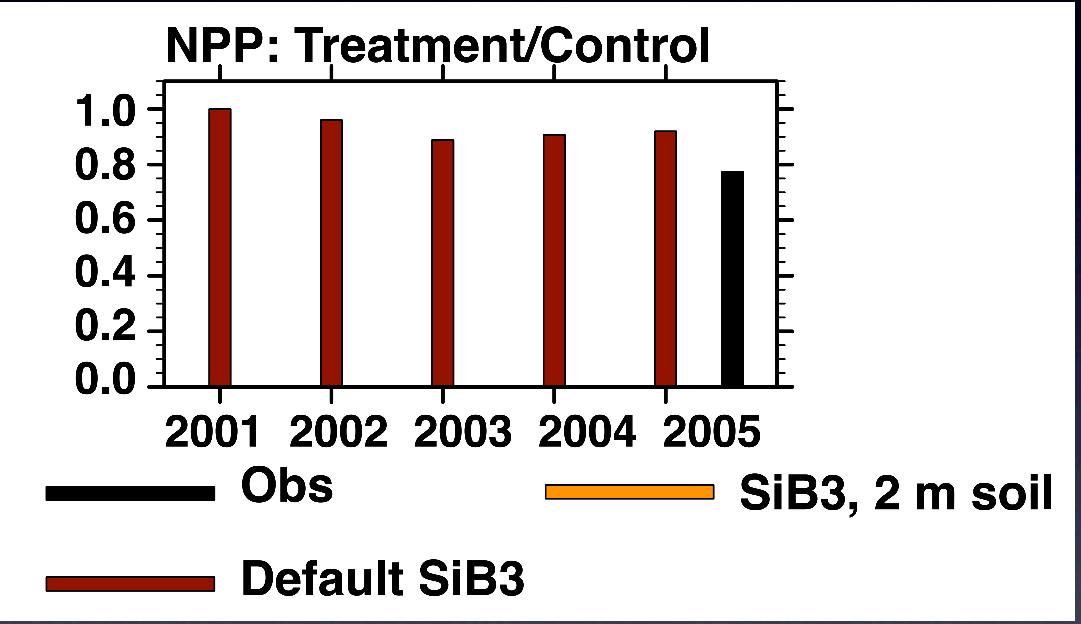


NPP = net primary productivity

Caxiuana Exclusion

- Measured NPP reduced by 23% in 2005.
- Default SiB3 decreased by 10% (02-05).
- 2005: 2m soil reductions in NPP were exactly same as observations.



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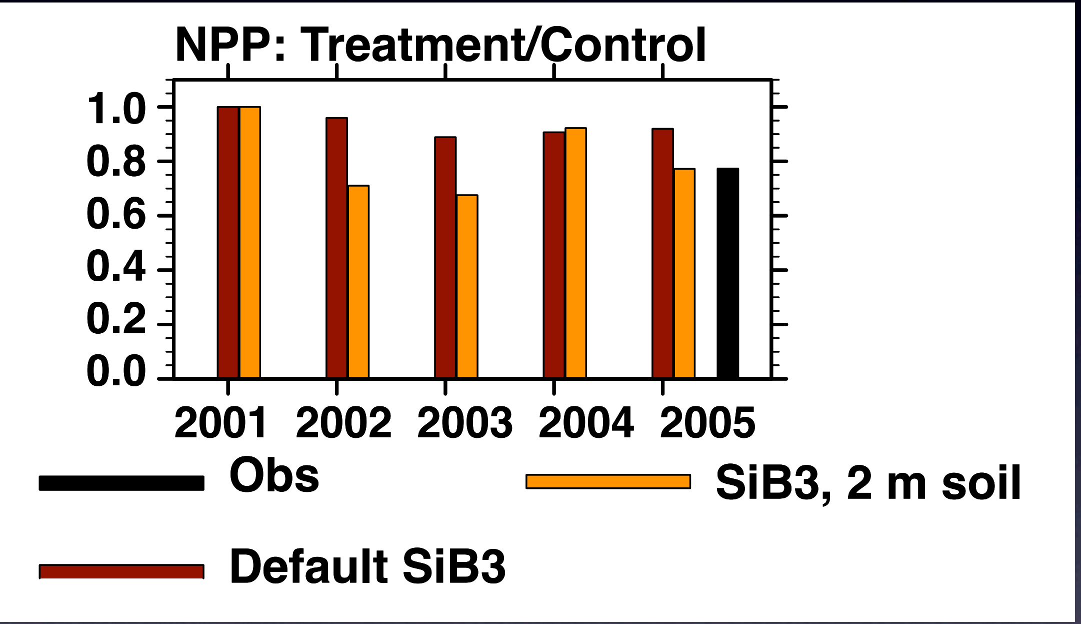


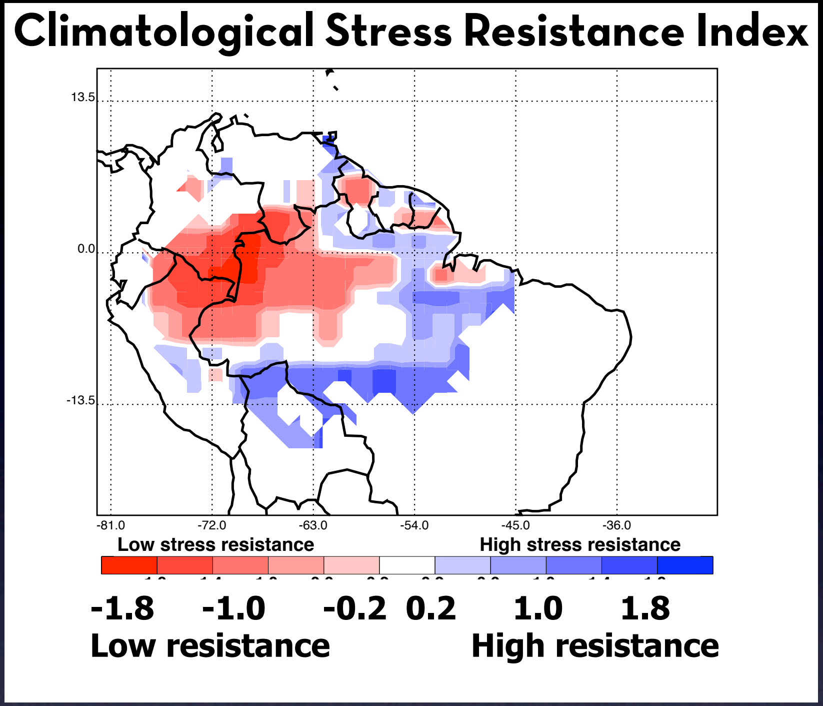
Lessons from exclusion experiments

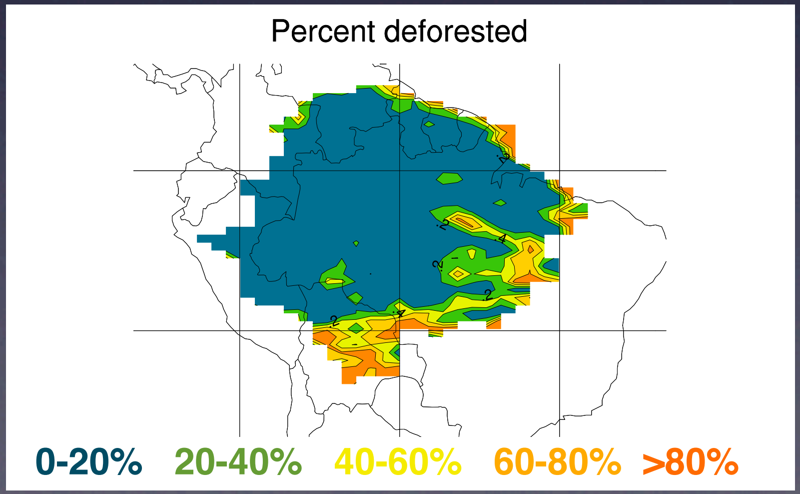
We get the best results by using a deeper soil at Tapajos and a shallower soil at Caxiuana - suggesting a way forward for representing variations in tropical forest drought tolerance

Part 2: Modeling Stress Resistance

- Hypothesis: Drought resistance is a function of precipitation climatology, soil texture and forest cover
- Increase/decrease stress resistance by increasing/decreasing soil moisture reservoir
- Real forests adapt to drought through a variety of mechanisms. We parameterize the effect of these adaptations by adjusting soil depth

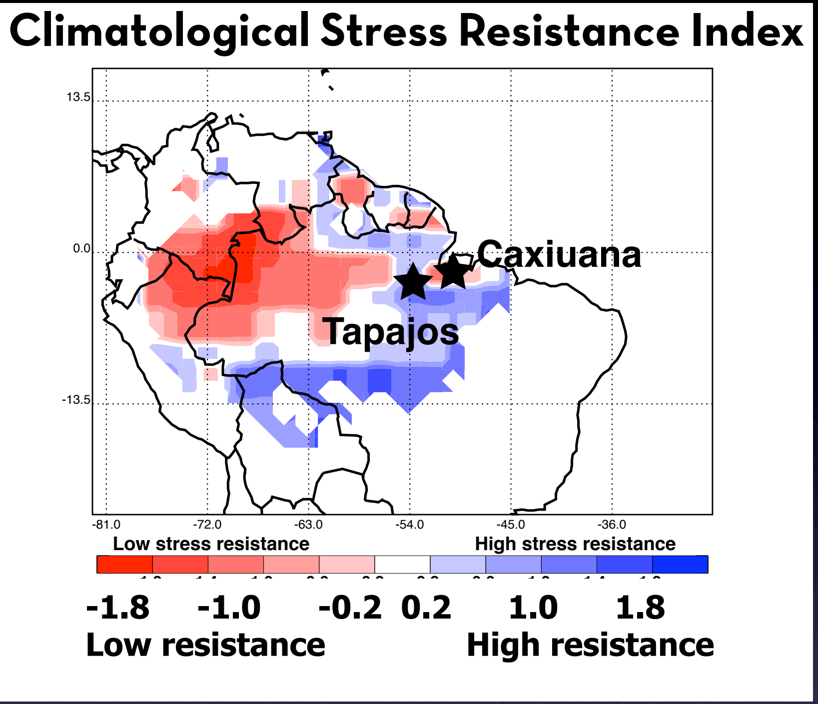
Calculating stress resistance

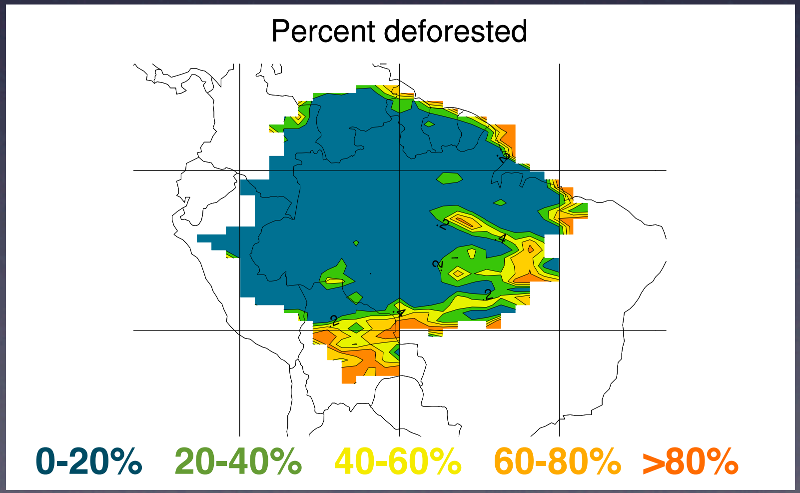




- Use climatological Stress Resistance Index and optimal root depths at two exclusion sites to relate the CSRI to a map of soil depths.
- Also consider forest cover and soil texture

Calculating stress resistance





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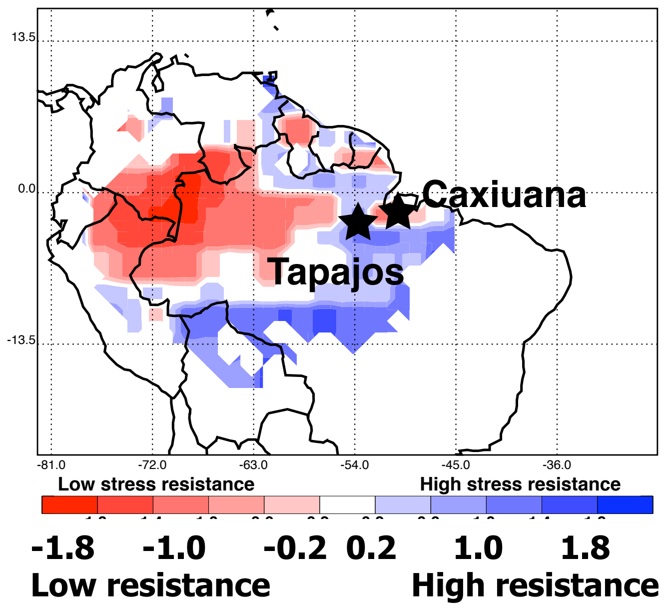
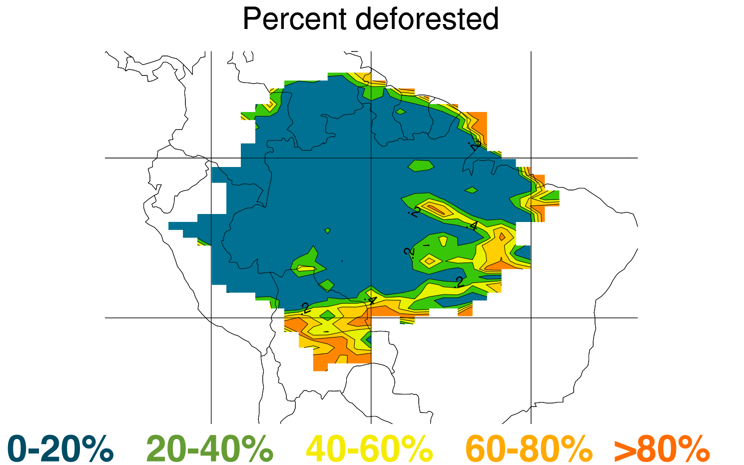
Calculating stress resistance

Climatological Stress Resistance Index





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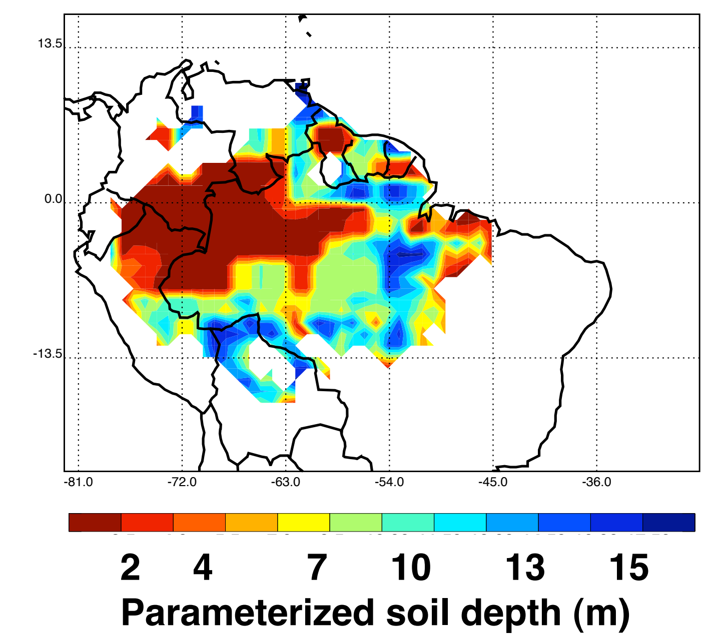
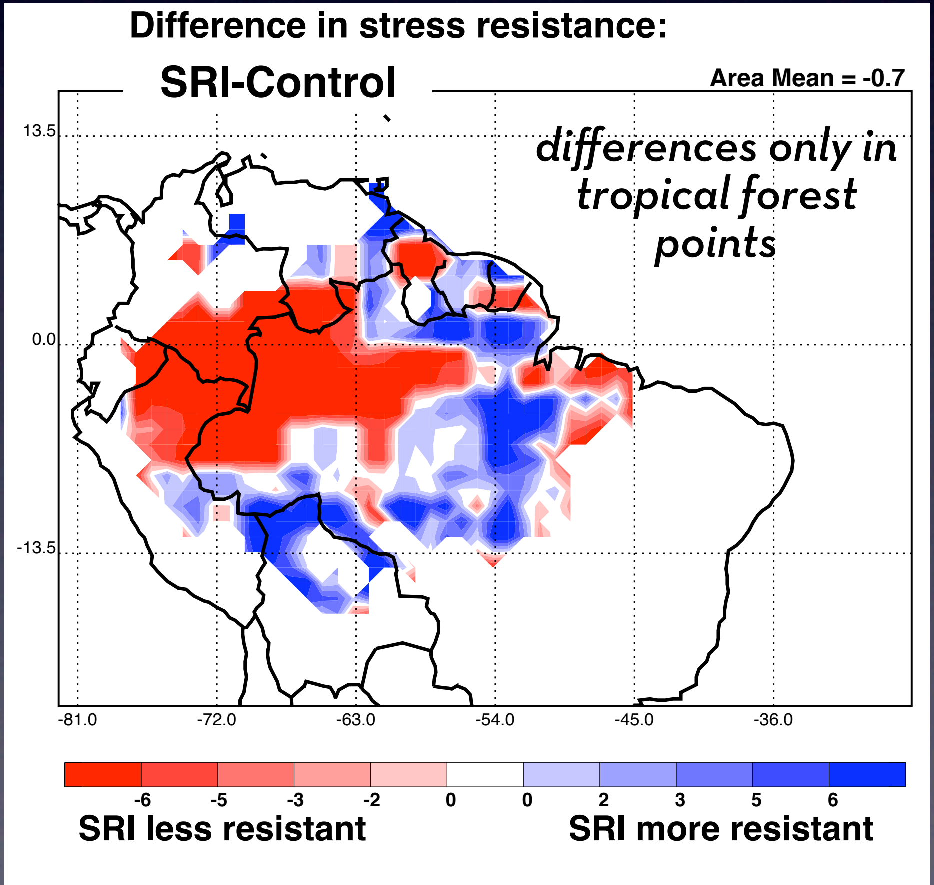
Total Stress Resistance Index



Part 3: Coupled model simulations

- 3 versions of SiB3 with varying stress resistance are coupled to the BUGS5 GCM and run from 1997-2006
- Resolution is about 250 km

MODEL	Treatment of water stress
Control	Soil depth 10m
SRI	Parameterized soil column depth
Stressed	Lowest stress resistance, soil depth 3m

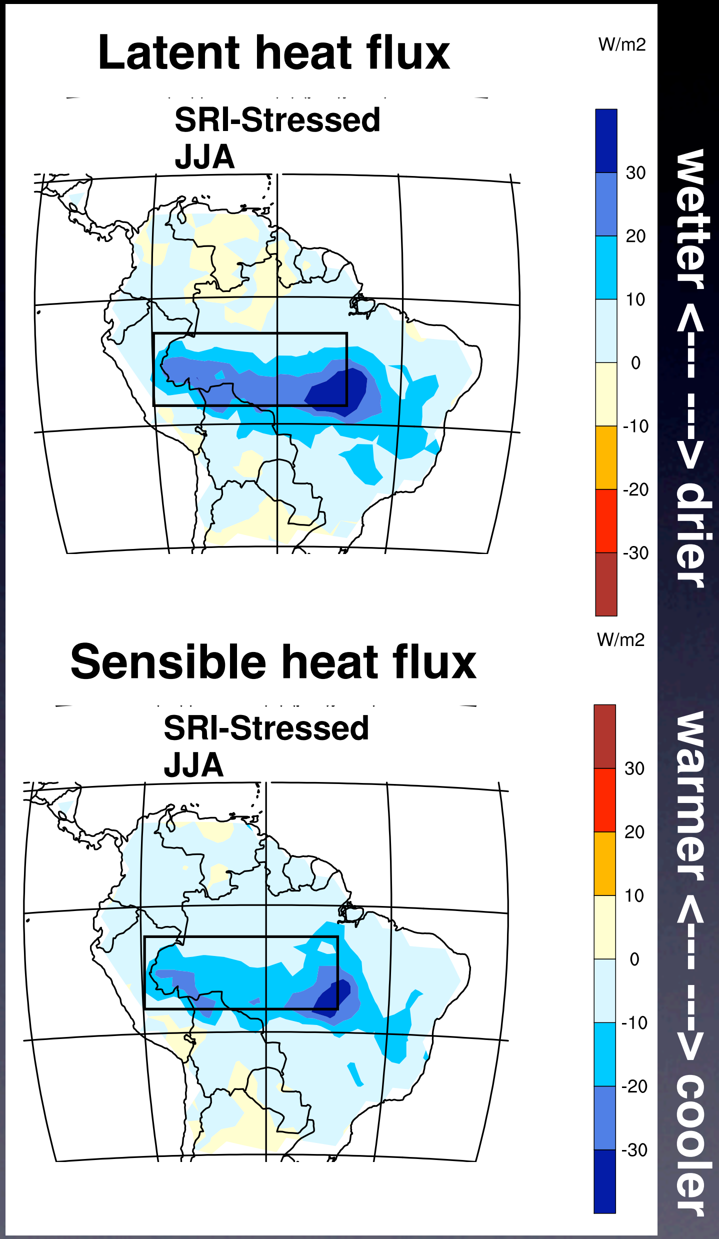


Coupled model simulations

- Does increased stress resistance lessen drought intensity?
- Does stress resistance impact circulation outside of Amazonia?

Dry season surface fluxes

- Increased drought tolerance in SiB3 SRI = higher LH (up to 1.7 mm/day), lower SH
- Results in cooler, more moist boundary layer in SiB3 SRI
- Define "southern Amazon region" as 5-14S; 285-310

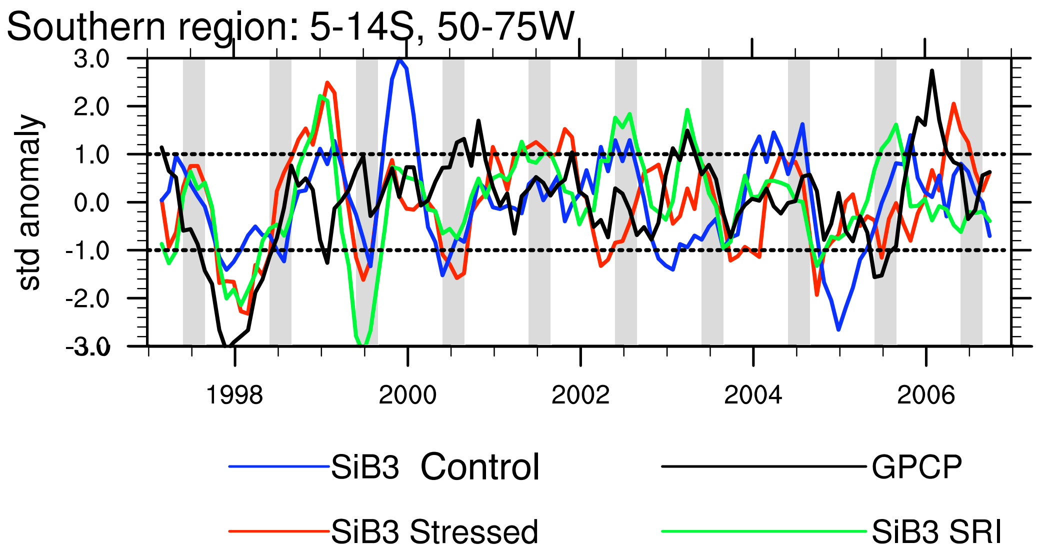


Defining southern Amazon regional droughts

SiB3 Stressed	SiB3 Control	SiB3 SRI
Nov. 97 - June 98	Nov. 97 - Jan. 98	Apr. - May 97
June - Aug. 99	**June - July 00**	Nov. 97 - Apr. 98
June - Sept. 00	Dec. 02 - Feb. 03	**May - Sept. 99**
Apr. - May 02	Nov. 04 - Apr. 05	Oct. - Nov. 04
Oct. 03 - Feb. 04		
Oct. - Nov. 04		

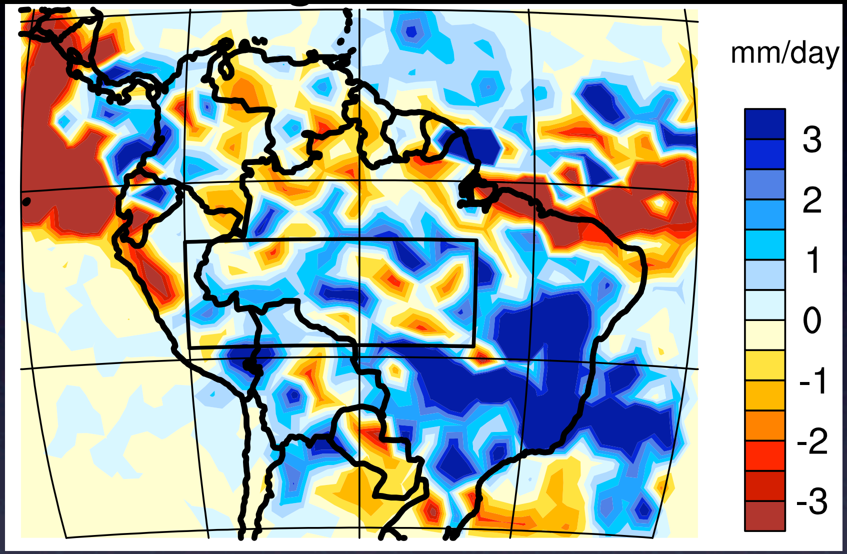
Observed droughts during 97/98 El Nino and 2005 drought

- Differentiate between wet season droughts and dry season droughts.
- Next: composite precipitation and other variables during these months.



wet season droughts (97/98)

Difference: SiB3 Control - SiB3 Stressed
Precipitation



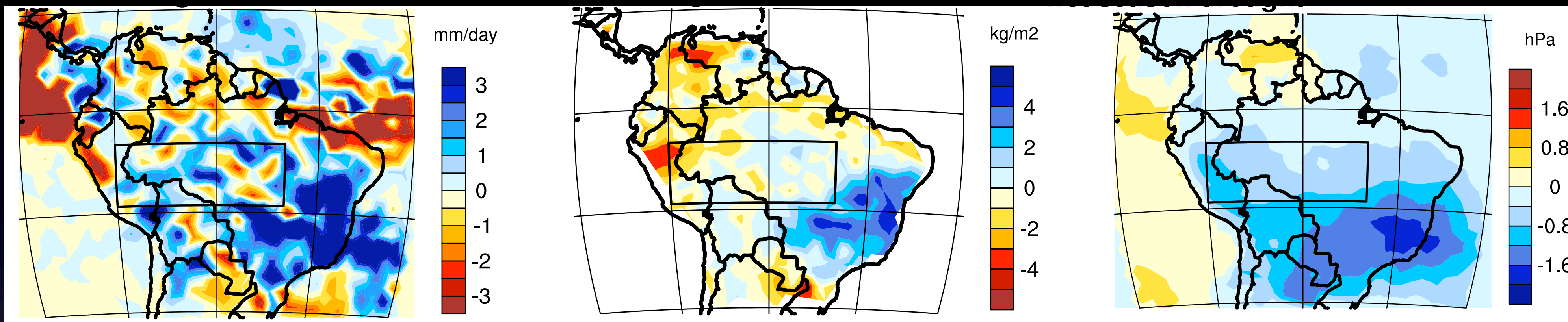
- Increased stress resistance in SiB3 Control leads to stronger precipitation.
- Stronger rising motion at 500 hPa indicates stronger convection.
- Interesting differences to the southeast! ...

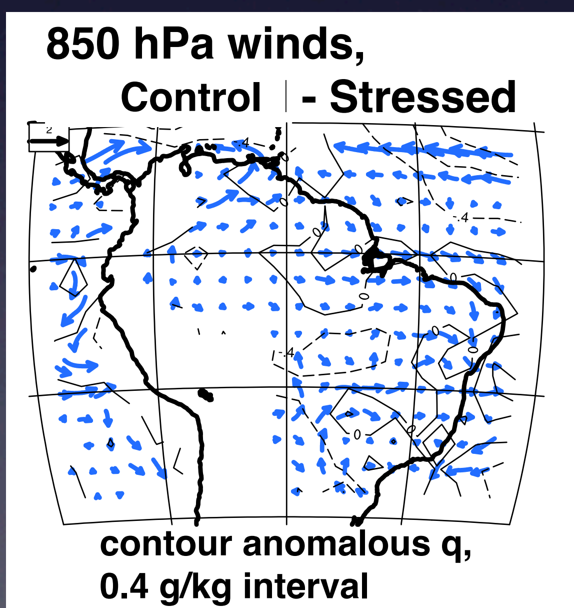
mm/day	SiB3 Stressed	SiB3 Control	SiB3 SRI	GPCP
Average precipitation	6.6	7.2	7.0	7.3

wet season droughts (97/98)

Difference: SiB3 Control - SiB3 Stressed

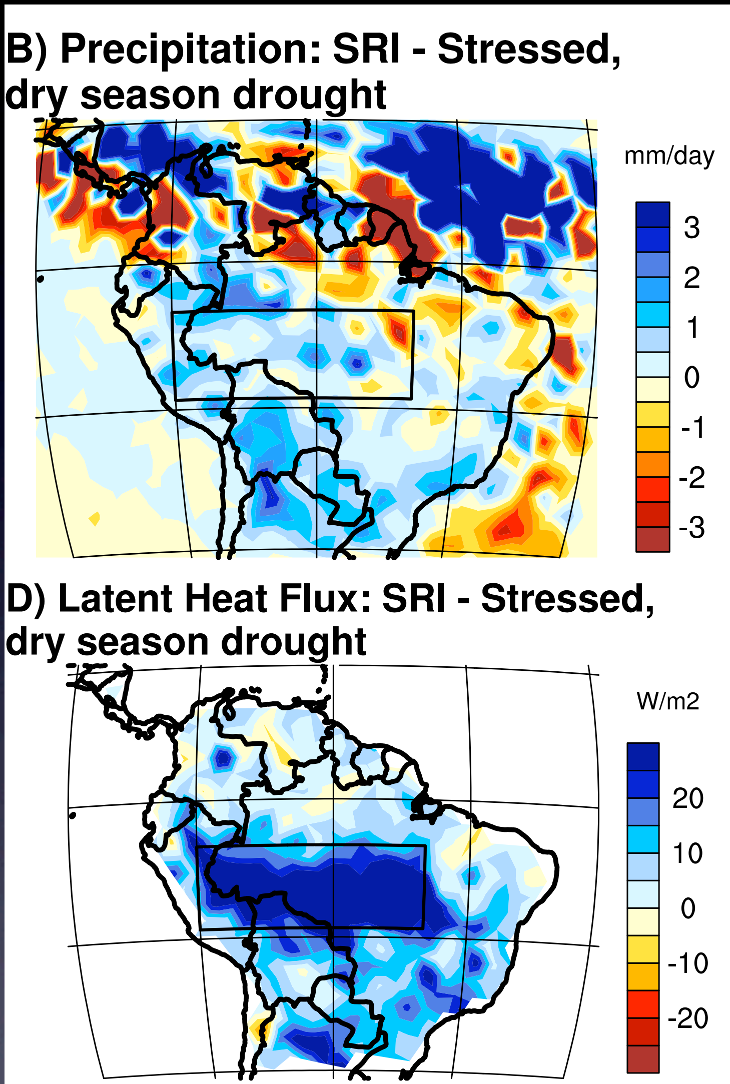
Precipitation **Precipitable water** **surface pressure**





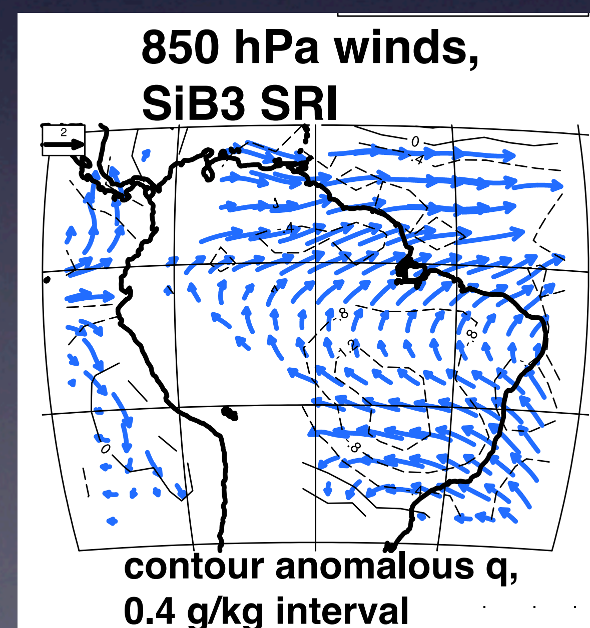
- Up to 5 mm/day more rainfall in southern Brazil in SiB3 Control
- Higher latent heat flux, more precipitable water
- Stronger convergence at 850 hPa, and lower surface pressure

Dry season droughts (1999)



(mm/day)	SiB3 Stressed	SiB3 SRI	GPCP
Average precipitation	2.3	2.6	3.3

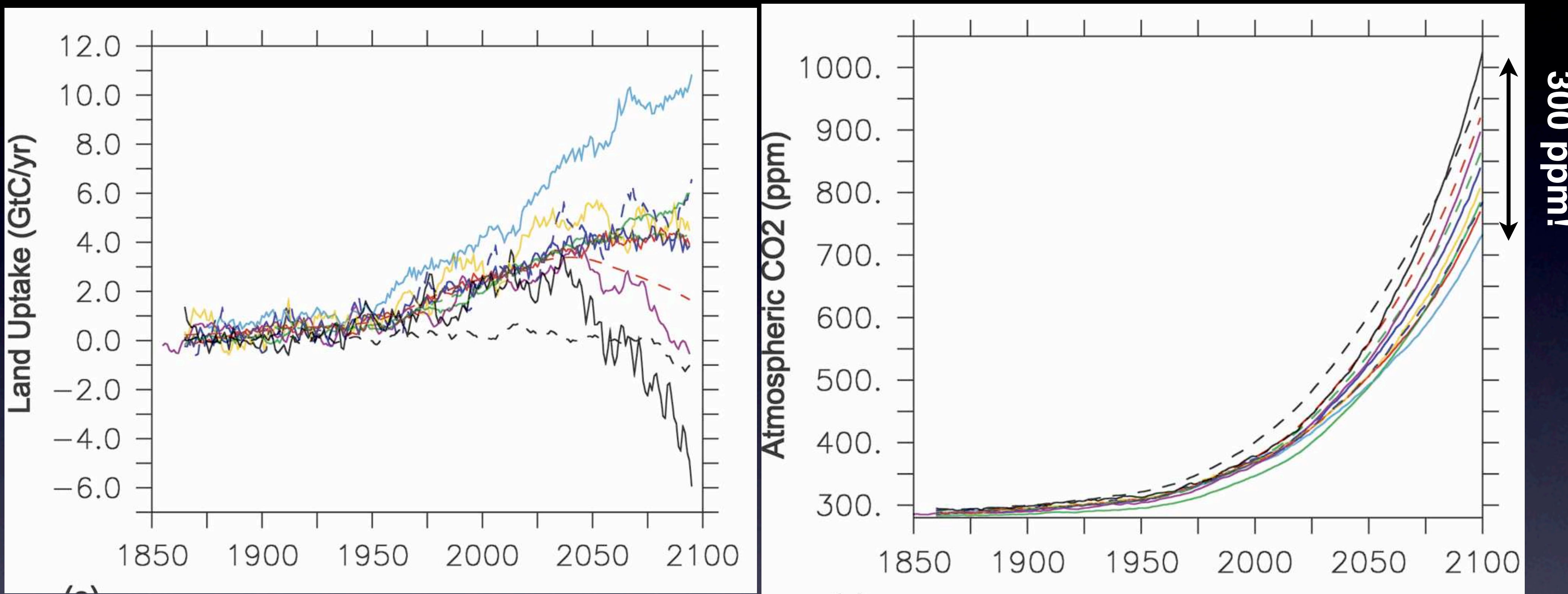
- Higher latent heat in SiB3 SRI (on average by 1.2 mm/day)
- anomalous dry air advection into Amazon
- Latent heat effect wins and important for maintaining relatively high precipitation during the drought



Research Conclusions

- Two forests that underwent imposed multiyear drought had very different responses:
  - Tapajos forest took longer to respond, possibly due to the forest being more adapted to drought conditions.
  - Caxiuana forest is adapted to wetter conditions and so was more susceptible to drought.
- A spatially varying “stress resistance index” can represent effects of climate, forest cover, and soil texture on drought tolerance.
- Forest stress resistance has implications for carbon fluxes and circulation
- Increased stress resistance can decrease drought intensity, and impact precipitation patterns in southern Brazil.

Implications for coupled models

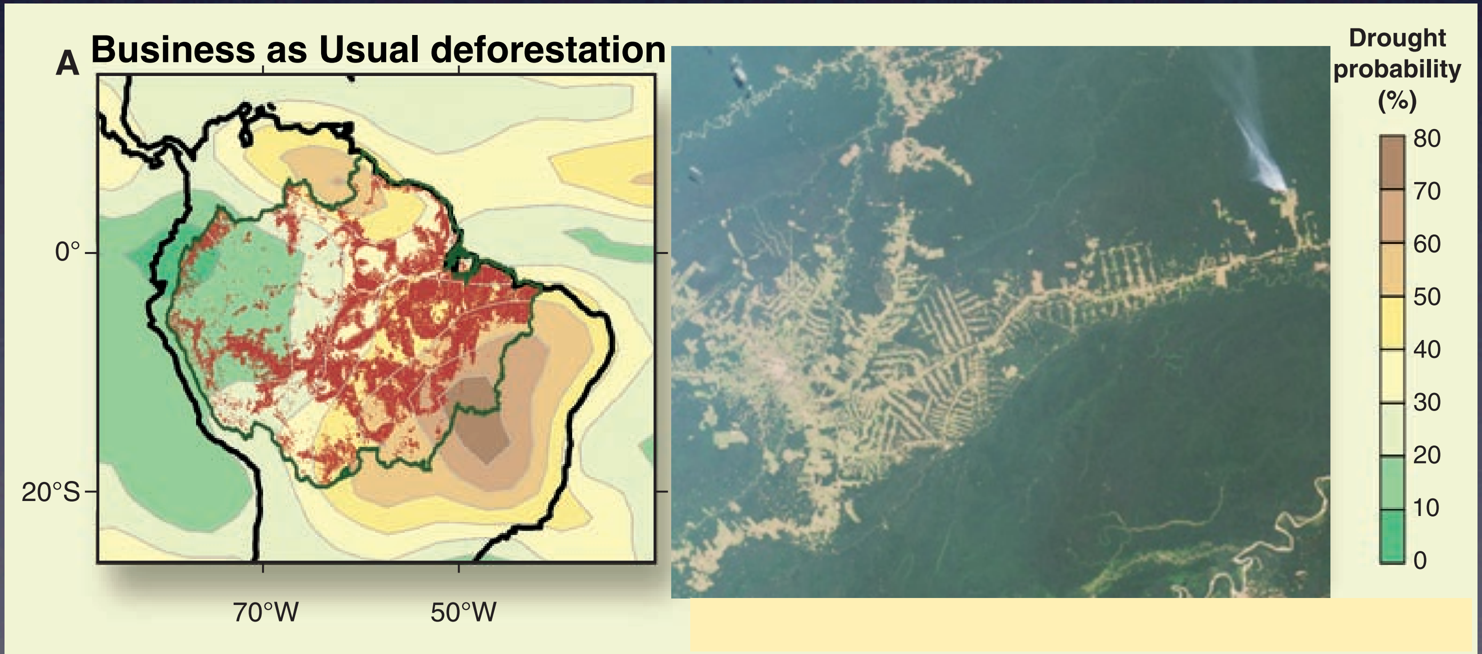


- Due to feedbacks in the vegetation-atmosphere system, how the Amazon responds to drought is extremely important!
- How can better representing drought tolerance in models improve these predictions?

Friedlingstein et al, 2006

Transition Forests

- Southern edge of the Amazon is where deforestation is focused. Transitional forests between "ever-wet" and seasonal climates.

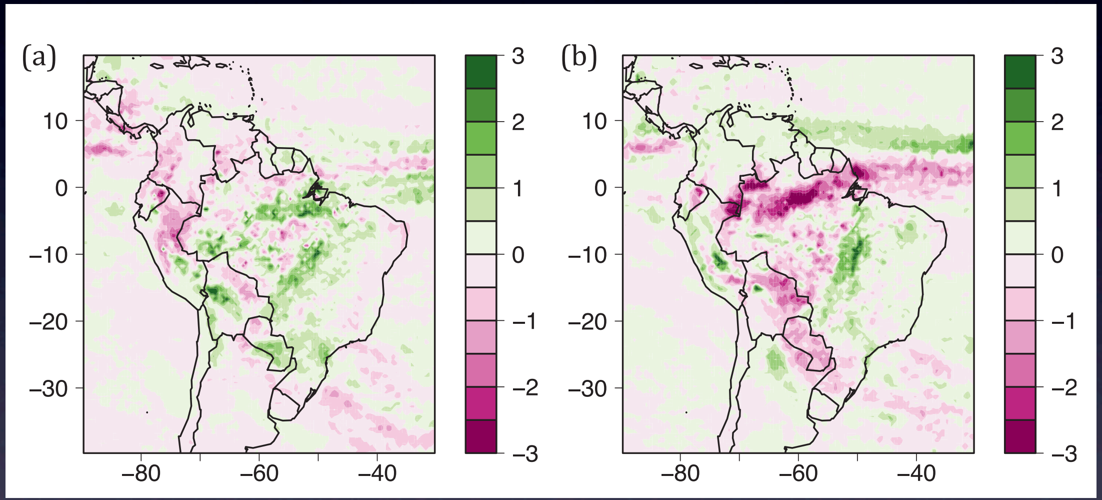


Deforestation

- Moderate deforestation could increase convection
- Threshold deforestation level where precipitation decreases
- Severe implications for remaining ecosystem

Precipitation changes due to:

Business as usual defor. Total deforestation



Medvigy et al, 2011

Aerosols, Clouds & Climate

- Biomass burning during the dry season
- Green Ocean-Amazon campaign: cloud-aerosol-precipitation interactions downwind of Manaus

Implications

- How we represent drought stress can affect the conclusions we make about the future of the Amazon. IE:
    - It's doomed! (based on results from SiB3 Stressed)
    - Everything will probably be okay (according to control SiB3)
    - It depends on where you are in the forest, and how much forest remains undisturbed (SiB3 SRI)
- It is imperative for as much of the forest to remain intact as possible, due to the ability of forest to impact precipitation and circulation.