

Effects of increased water stress in Amazon forests under climate change: Separating roles of canopy responses and soil moisture

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Credit: NASA/JPL-Caltech



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Take-Home Message

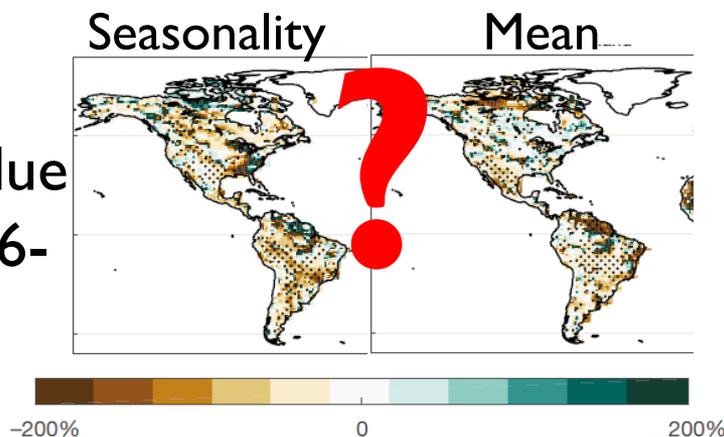
- (a) Direct (drier soil and stomatal closure) and (b) indirect (leaf shedding/LAI reduction) effects from increased water stress should be separated, which is done in this study
- In original JSBACH, LAI effects are problematic. We have improved it.
- Compared with reduction in soil moisture and LAI, NPP reduction is disproportionately large/small
- NEP reduction due to drier soil and leaf shedding are both disproportionately large
- Future droughts will induce northward shift of rainfall, threatening southern Amazon.



Bridging the gap

- Few land surface models succeeded in capturing the observed **vegetation responses** to drought (Powell et al., 2013; Joetzjer et al., 2014)
- With models, reduced NBP is found in Amazon due to future drier soil moisture (Green et al., 2019)

Simulated Net biome productivity change due to soil moisture (2056-2085; RCP8.5)



(Green et al., 2019)

- However, the simulated effects actually include **direct (soil moisture and stomatal)** and **indirect (LAI responses)** effects.
- As LAI response is poor in models, uncertainty thus exists!

Part I

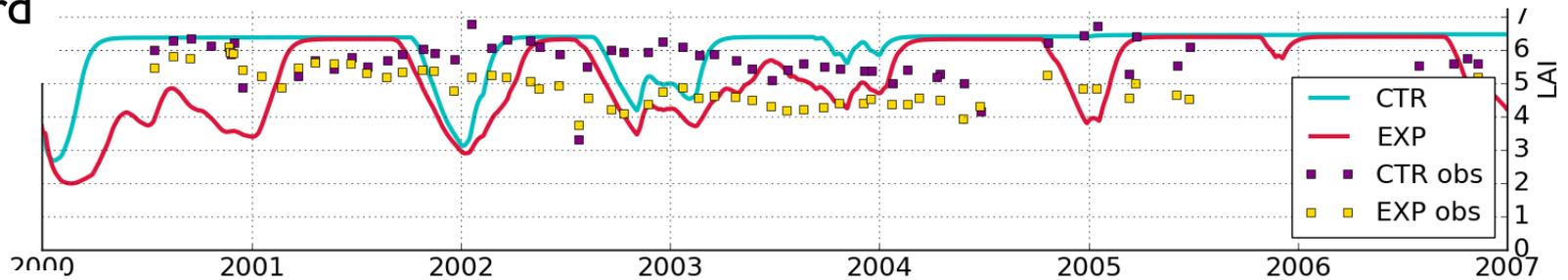
Improving drought-related leaf shedding in the land surface model JSBACH

- Method – Modify model formulation; tune the parameters with data
- Data – Throughfall Exclusion Experiments (artificial droughts in Eastern Amazon)
- The improvement includes formulation of
 - Leaf phenology (LAI)
 - Litter production

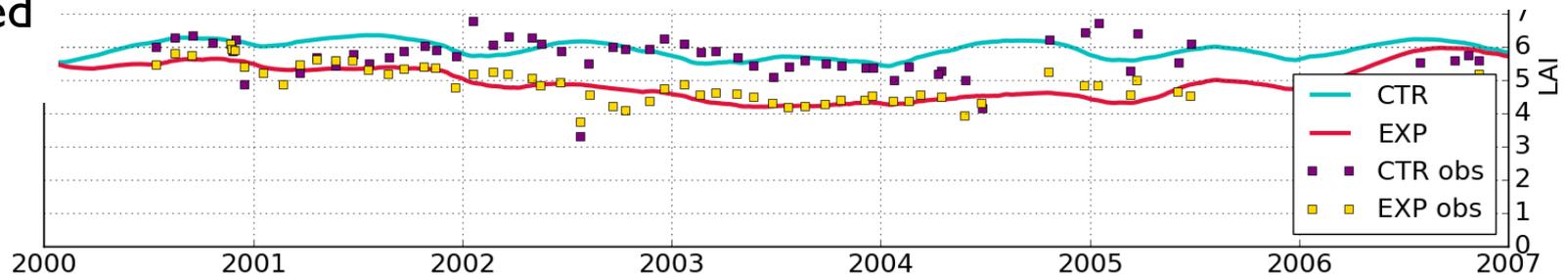
Evaluation on standard/modified JSBACH

LAI

Standard



Modified

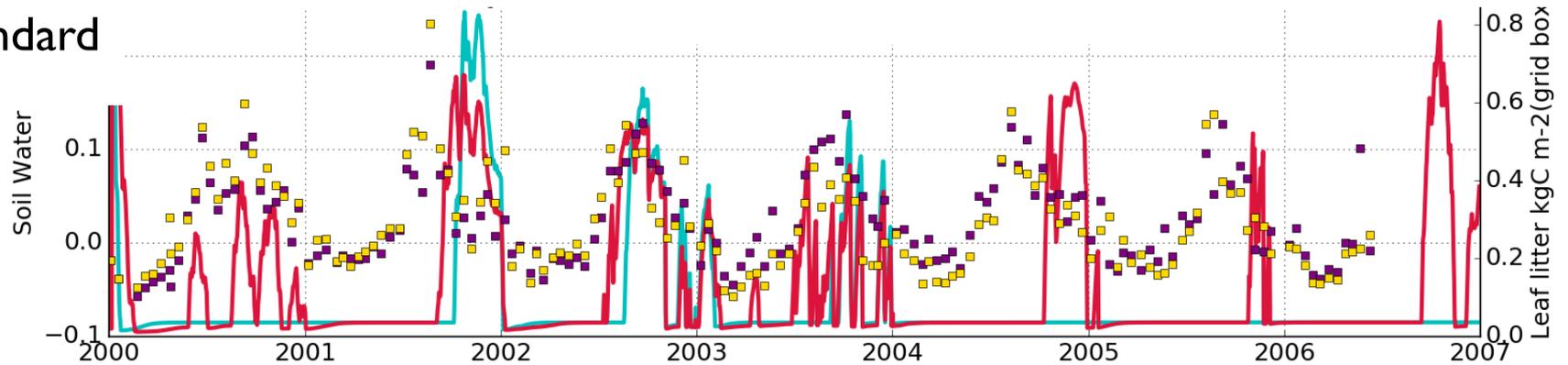


(Dots: observations; Lines: simulations)

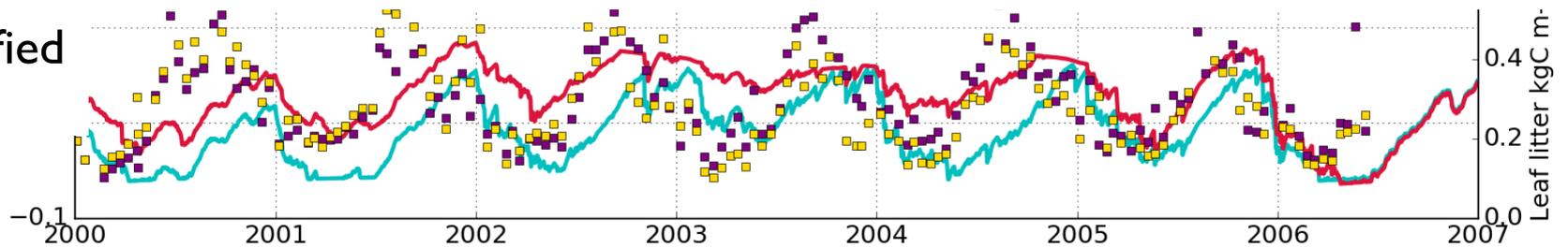
Evaluation on standard/modified JSBACH

Leaf litter

Standard



Modified



(Dots: observations; Lines: simulations)

Part II

- Coupled Land-Atmosphere simulations
- Separate the roles of (a) direct (drier soil and stomatal closure) and (b) indirect (leaf shedding/LAI reduction) effects under future climate
- Separating (a) and (b) gives insights as (b) has been poorly simulated by models
- Study biogeophysical effects

Experiment design

	GHG forcing	Soil moisture	LAI	LAI effects
EXP1	RCP 8.5	Interactive	Interactive	(G)+(S)
EXP2	RCP 8.5	1971-2000 climatology	Interactive	(G)
EXP3	RCP 8.5	Prescribed from EXP1	Prescribed from EXP2	(G)

(G) RCP8.5 GHG forcing (S) Future soil moisture

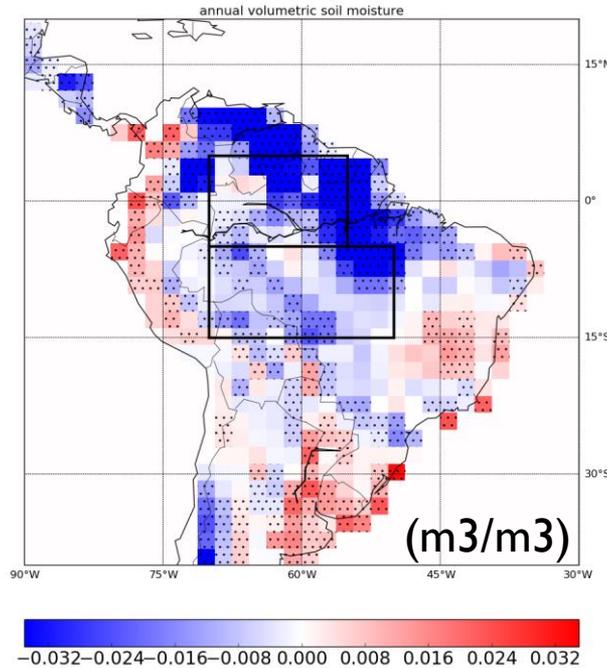
- (EXP3 – EXP2): **direct effects** of soil moisture and stomatal response
- (EXP1 – EXP3): **indirect effects of LAI**
- Differences are taken over (2070 – 2085)
- Simulations from an ensemble of 5 members are analyzed.
- For comparison, another set of experiments is also run with standard JSBACH

Results

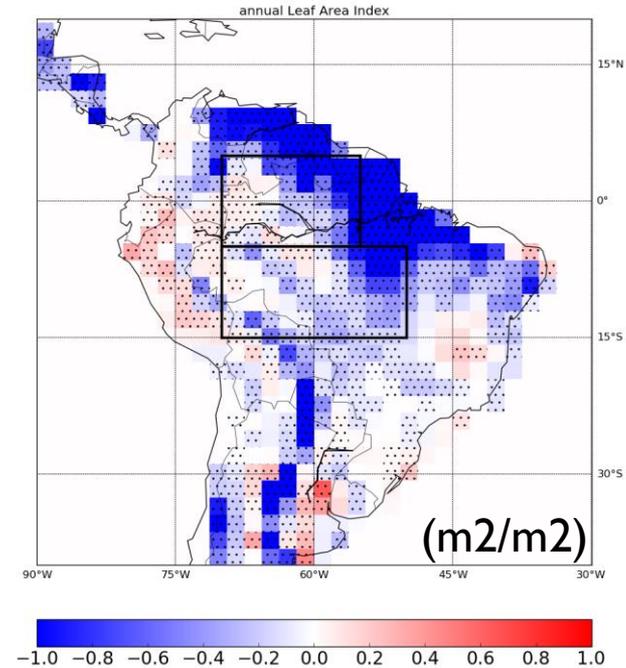
1. Future drier soil and resultant lower LAI (under RCP8.5)
2. Negative biogeochemical effects (reduced C sink)
 - **Direct effects** are much stronger than **LAI effects**
3. Biogeophysical effects: Northward shift of precipitation caused by **direct effects**

Future drier soil and resultant lower LAI

Soil moisture (EXP3-EXP2)



LAI (EXPI-EXP3)



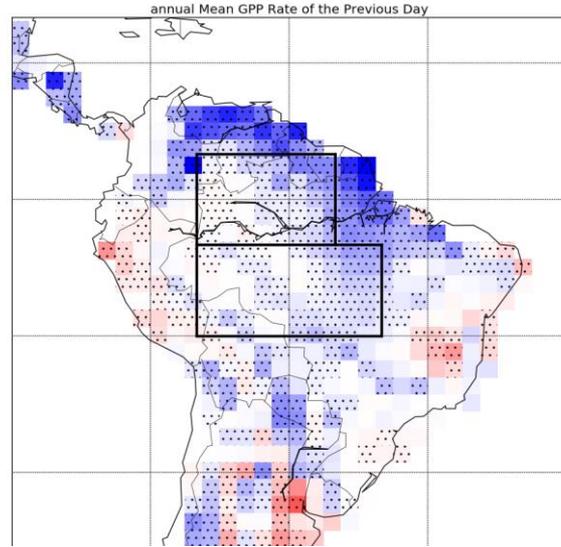
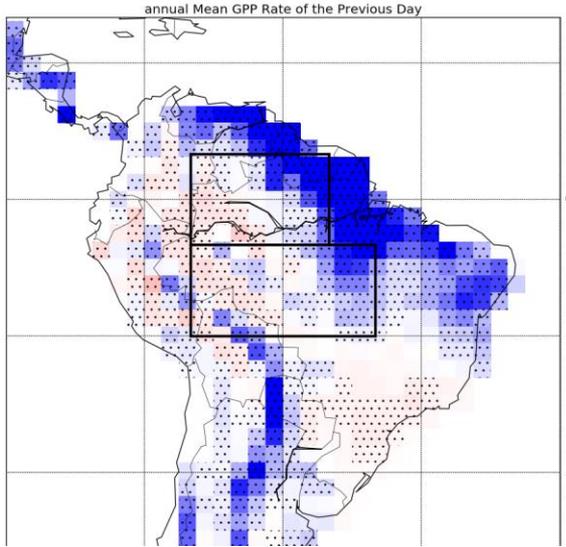
- Soil moisture and LAI both reduced for about 5~10% (Basin-wide average: **-6.0%** and **-7.0%**)
- We attribute the differences between simulations to these perturbations

Effects on GPP and R_{auto}

Direct effects

LAI effects

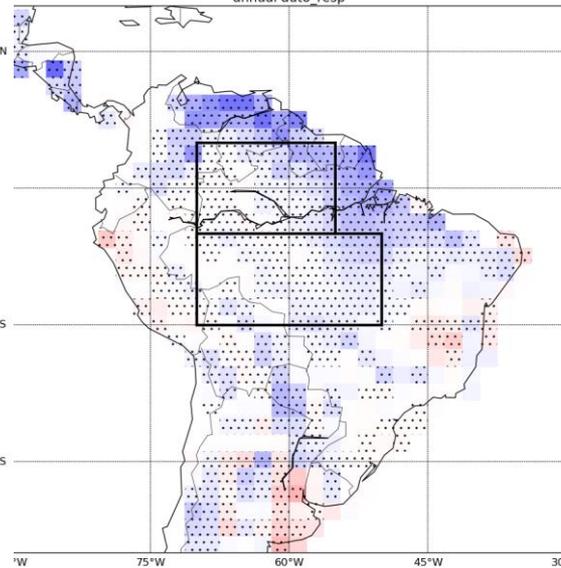
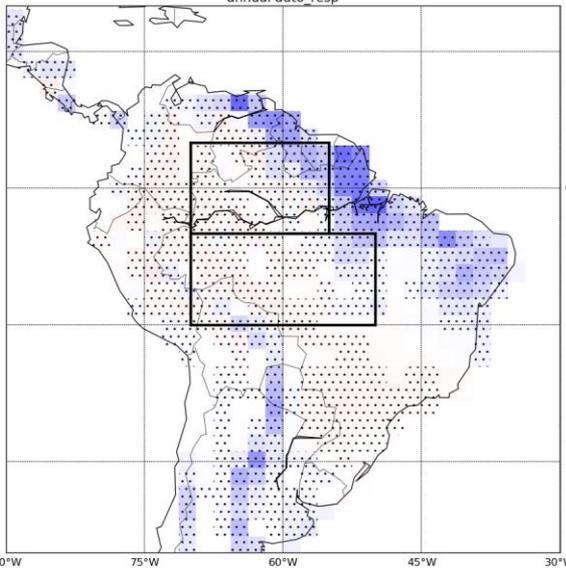
GPP



Δ GPP from direct effects: also **-6.1%**

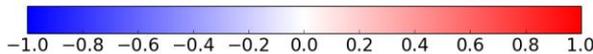
Δ GPP from LAI effects: **-3.1%**; only 1/2 of direct effects.

R_{auto}



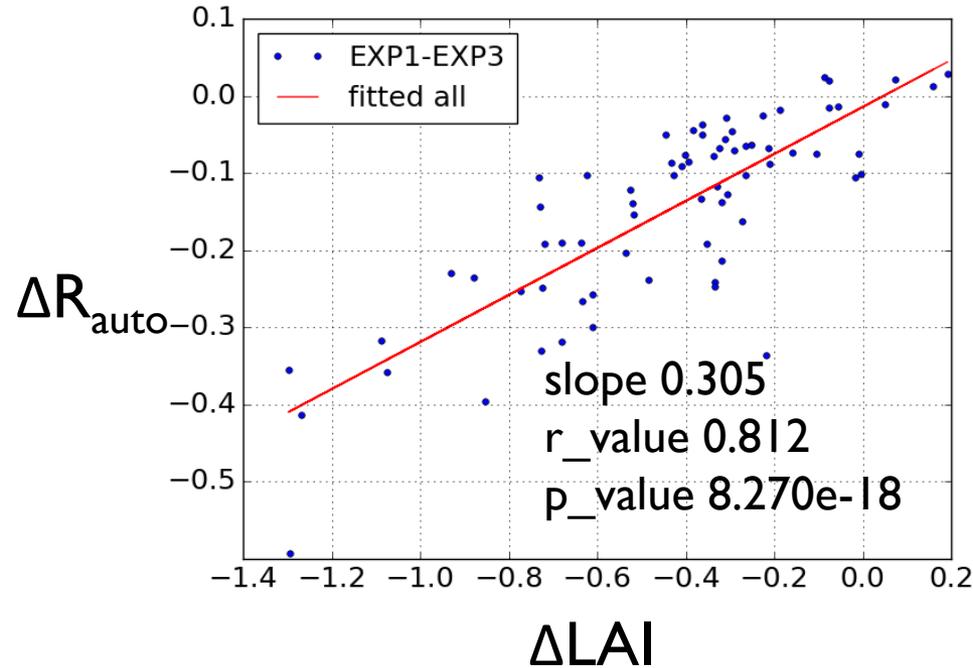
ΔR_{auto} from direct effects: **weak (-0.9%)**

ΔR_{auto} from LAI effects: **strong (-3.9%)**

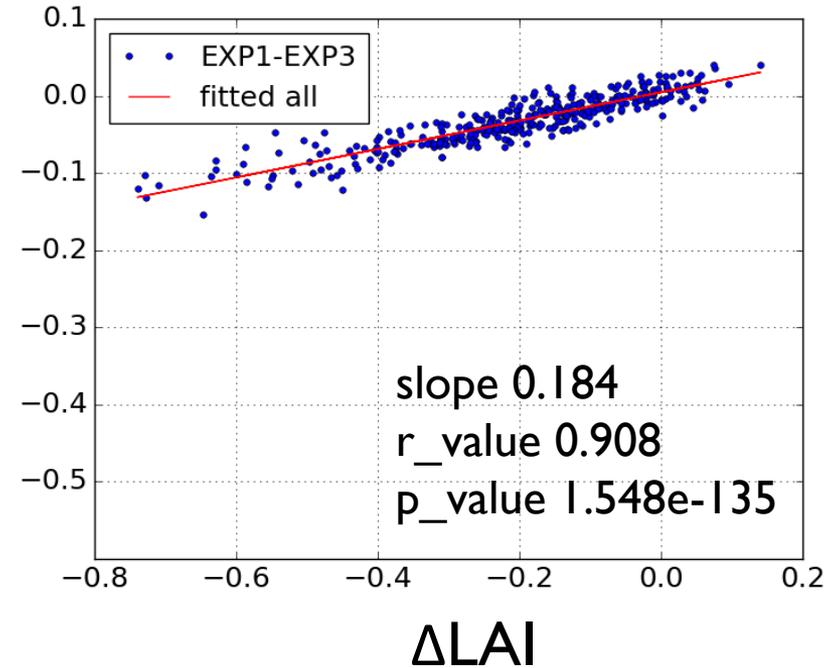


R_{auto} : Modified model is more reasonable

Standard JSBACH



Modified JSBACH



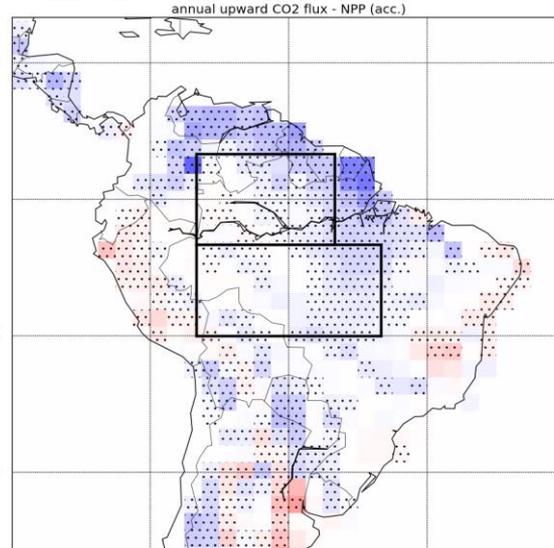
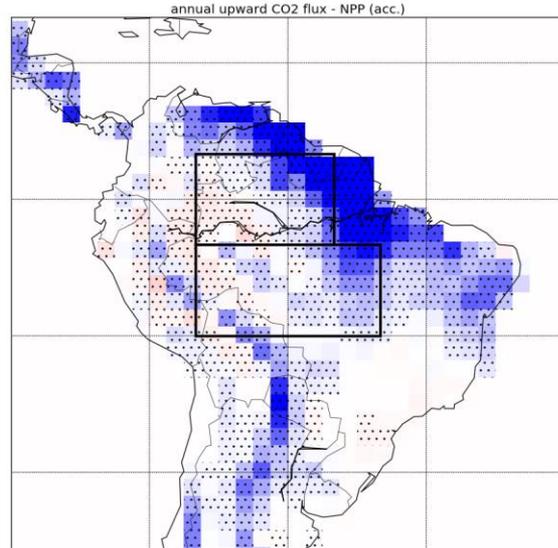
- Meir et al. (2008) reported $-0.084 \text{ kg/m}^2/\text{yr}$ of leaf and woody respiration with $-0.5 \text{ m}^2/\text{m}^2/\text{yr}$ of LAI (corresponding to slope of 0.169)
- Much closer now in modified JSBACH!

Effects on NPP, and R_{soil}

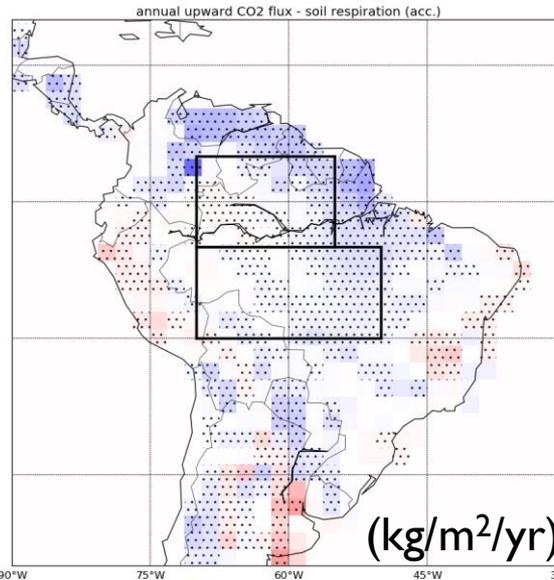
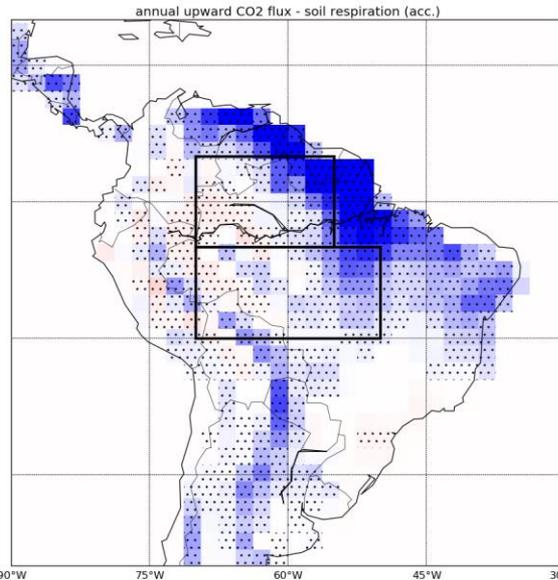
Direct effects

LAI effects

NPP



R_{soil}



: different responses in ΔGPP & Δr_{auto}

ΔNPP from direct effects: **-10.0%**

ΔNPP from LAI effects: **-2.5%**

Disproportionately **large/small** compared to **6%/7%** reduction of soil moisture/LAI

ΔR_{soil} is slightly less than ΔNPP

-9.4% vs. -2.1%

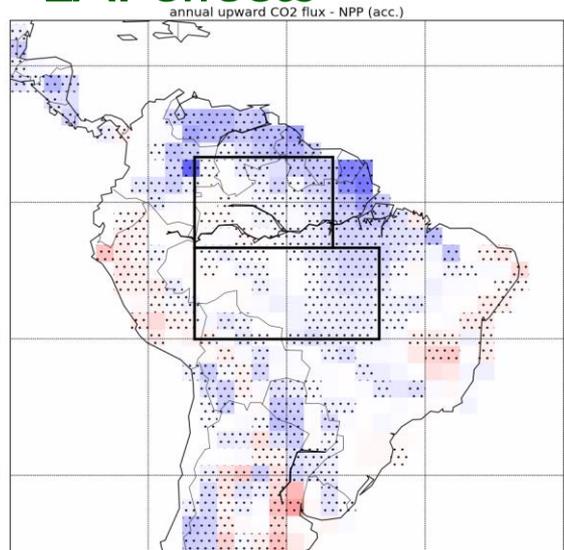
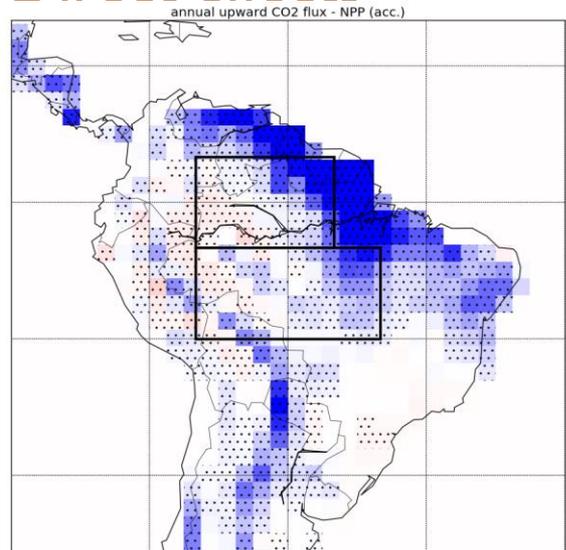


Strong reduction of NEP

Direct effects

LAI effects

NPP



Δ NEP

-25.4% vs.

-13.4%

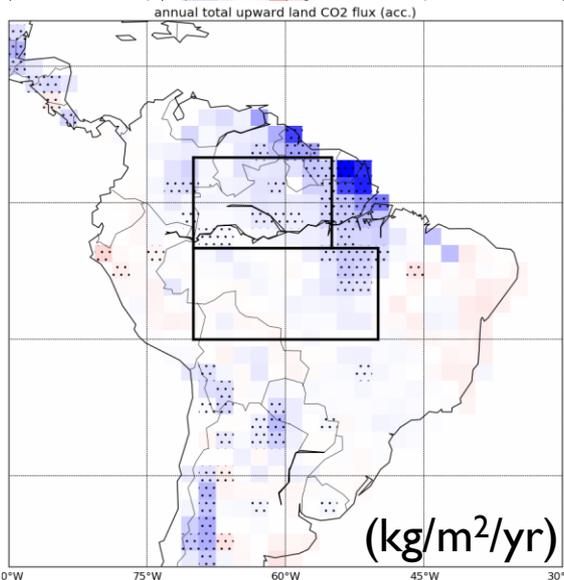
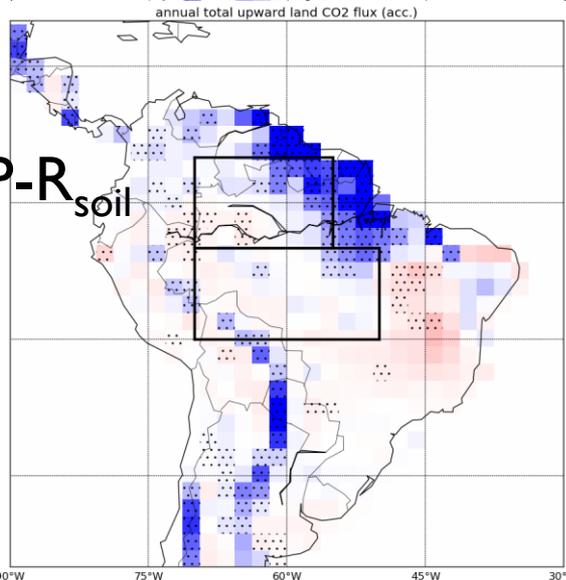
Not scalable to
change in

soil moisture and LAI
(only -6.0% & -7.0%)!!

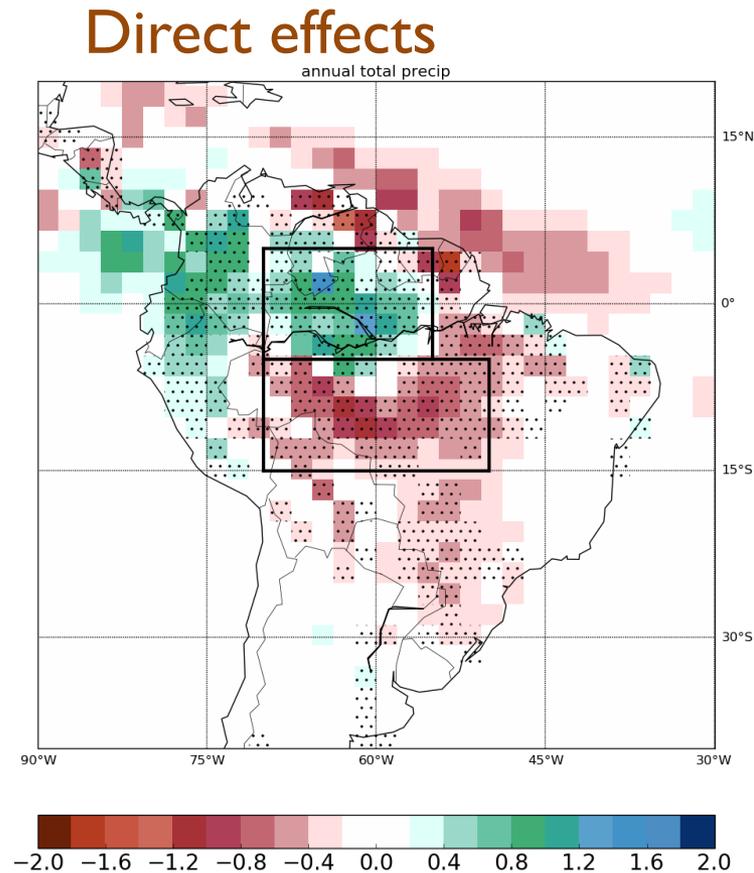
But uncertainty is
large

NEP

=NPP - R_{soil}



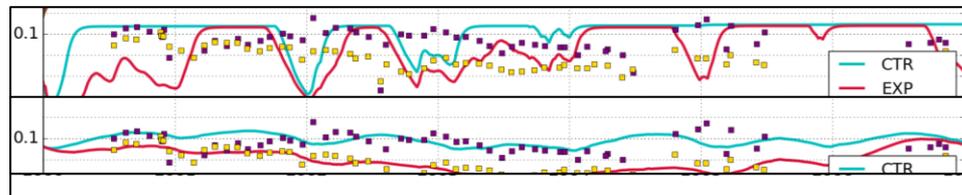
Biogeophysical effects: Shift of rainfall



- Direct effects induce northward rainfall shift; LAI effects on rainfall are negligible.
- Related to atmospheric dynamic feedback

Summary

- Improvement in JSBACH simulating drought response in Amazon forests.



- **Direct (drier soil and stomatal closure)** & **indirect (leaf shedding/LAI reduction)** effects of drought are separated.
- BGC effects from **direct effects** are 2 – 4x of **LAI effects**
- Δ NEP is **4x/2x** of reduction in **soil moisture/LAI** (both amplified, but with large uncertainty)
- Direct effects induce northward shift of rainfall, threatening southern Amazon.
- Without good representation of **LAI effects**, results from previous studies should be interpreted carefully.

