Why does Amazon precipitation decrease in the physiological response to increased CO$_2$?
CMIP precip. projections: Drier Amazon, wetter Andes

Vera et al. (2006, BAMS)
Physiological response: Stomata constrict when $\text{CO}_2$ increases

- Stomata lose water through evapotranspiration
- When $\text{CO}_2$ increases, stomatal conductance decreases, and evapotranspiration decreases

Test in climate models by increasing $\text{CO}_2$ in land model only
- Atmosphere and ocean code don’t “see” changes
Physiological response: Approx. half of Amazon precip. change

- Lots of work on this response, mostly at the global/continental scale

  **inexhaustive list:**
  - Abe et al. (2015, *Clim. Dyn.*)
  - Lu et al. (2016, *Sci. Reports*)
  - Swann et al. (2016, *PNAS*)
  - Skinner et al. (2017, *J. Clim.*)
  - Skinner et al. (2018, *N. Comm.*)
  - Lemordant et al. (2018, *PNAS*)
  - Richardson et al. (2018, *GRL*)


![Diagram showing enhanced and weakened ascent with moist static energy advection and decreased ET, drier boundary layer.](image-url)

- Applies at multidecadal to century-long timescales
**Model Simulations**

- Constant equinox setup (neglect seasonality)
- Increase CO₂ immediately; hold constant

**WRF 3.9**

Forced by NCEP2 6-hourly 1979–2016

- 50 km: 10-day (x10)
- 2 km: 10-day (x1)

**CESM 1.2.2 (with CAM5, CLM4)**

Fully-coupled global runs at 2° res.

- 30-day (x10)
- 10-year (x1)

**Control run:**

- land = 400 ppm CO₂
- atm. = 400 ppm CO₂

**Phys. run:**

- land = 1000 ppm CO₂
- atm. = 400 ppm CO₂
Amazon dec. within first day, Andes inc. over synoptic timescale

- Phys. CO₂ minus control CO₂
  - Dipole precip. change pattern arises within the synoptic timescale (fast)
  - Precip. decreases over Amazon within 24 hours (mainly first afternoon)

Meridional mean between 10°S and 10°N
Precip. change dipole consistent across model, resolution, time

- Precip. change dipole arises within first 10 days of 50-km WRF simulation
- WRF 2-km simulation also shows Amazon decrease, Andes increase (topographically sensitive)
- Similar change in CESM:
  - 10-day mean
  - 30-day mean
  - 10-year mean

**Land precipitation change (10°S–10°N)**
Hypothesized mechanism

**first 24 hours**
- Orange: cloud decrease
- Blue: cloud increase

- Deep convection shifts later in day
- Less deep convective precipitation overall due to drier bdy. layer
- Deeper, shallower cumulus convection
- Decreased ET, drier boundary layer

**synoptic and long-term timescale**
- Orange: moisture decrease
- Blue: moisture increase

- Enhanced ascent
- Weakened ascent
- Moist static energy advection
- Decreased ET, drier boundary layer
Take-home points

When stomata close in response to increased CO₂:

- Precip. decreases quickly over Amazon, increases more slowly over Andes
- Dipole response of precip. consistent across global and regional climate models
- Driven by boundary layer effects on convection and subsequent moisture export by low-level jet
- Mechanism may help better understand CESM biases and end-of-century uncertainty over Amazon
10-day mean response in WRF 50-km runs

- **Δ precipitation**: mm day$^{-1}$
- **Δ transpiration**: mm day$^{-1}$
- **Δ latent cooling**: W m$^{-2}$
- **Δ 2m air temperature**: °C
- **Δ boundary layer ht.**: m
- **Δ column water vapor**: mm

Difference between physiological and control forcing, averaged over 10-day simulations

CO$_2$,phys. – CO$_2$,cont.
Amazon/Andes future precip. change + bias patterns are similar

RCP8.5 annual mean precip. change
2070-2100 minus 1960-1990

annual mean historical biases
1960-1990 minus GPCP

Obs. annual mean precipitation and 850 hPa winds (1980–2010)

CMIP5 end-of-cent. change

CMIP5 model mean bias
Precip. changes due in part to physiological response

- Sizeable fraction of precip. change over Amazon is from physiological response.


Swann et al. (2016, *PNAS*)

CMIP5 1% CO$_2$ inc. per year

- CO$_2$ increased in land only
- CO$_2$ increased everywhere

- Moisture decrease
- Moisture increase

Andes
Amazon

Enhanced ascent
Weakened ascent

Moist static energy advection