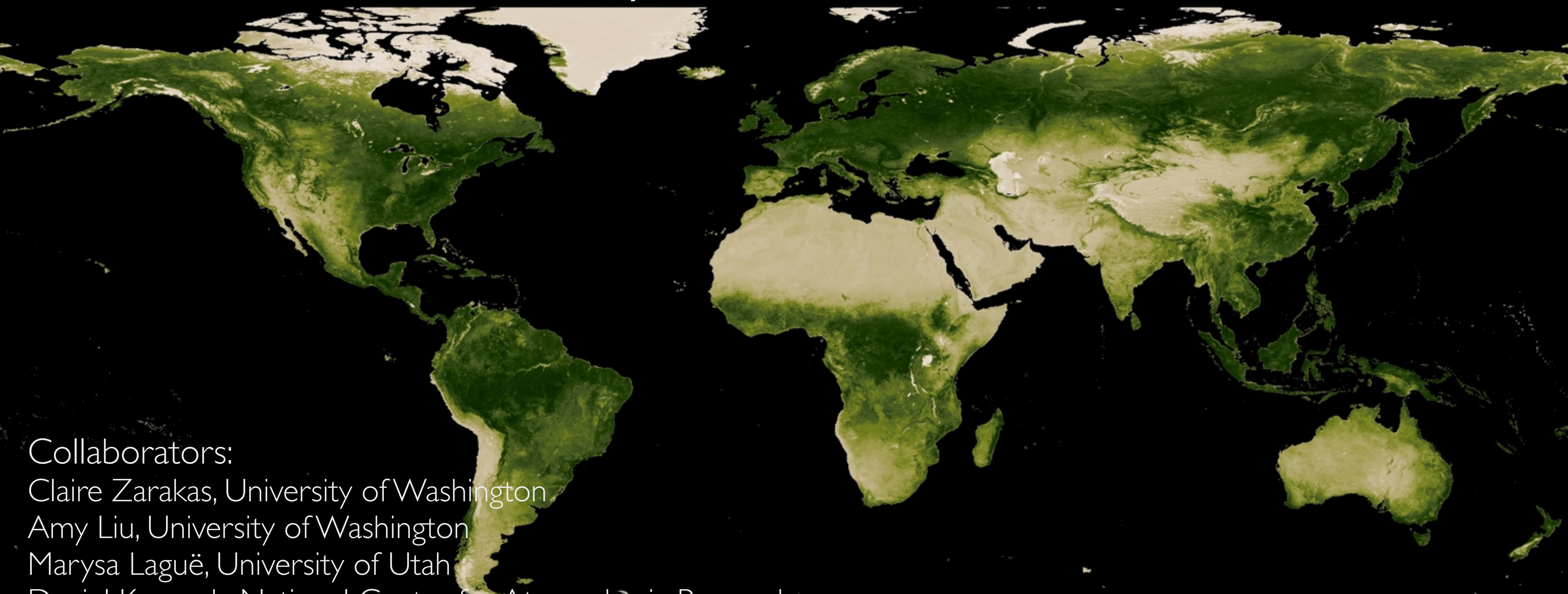
Quantifying the Role of Vegetation on Hydroclimate



Collaborators:
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Dave Lawrence, National Center for Atmospheric Research
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Charlie Koven, Lawrence Berkeley National Lab
Jim Randerson, UC Irvine
Forrest Hoffman, Oak Ridge National Lab
Gabe Kooperman, University of Georgia

Abigail L.S. Swann
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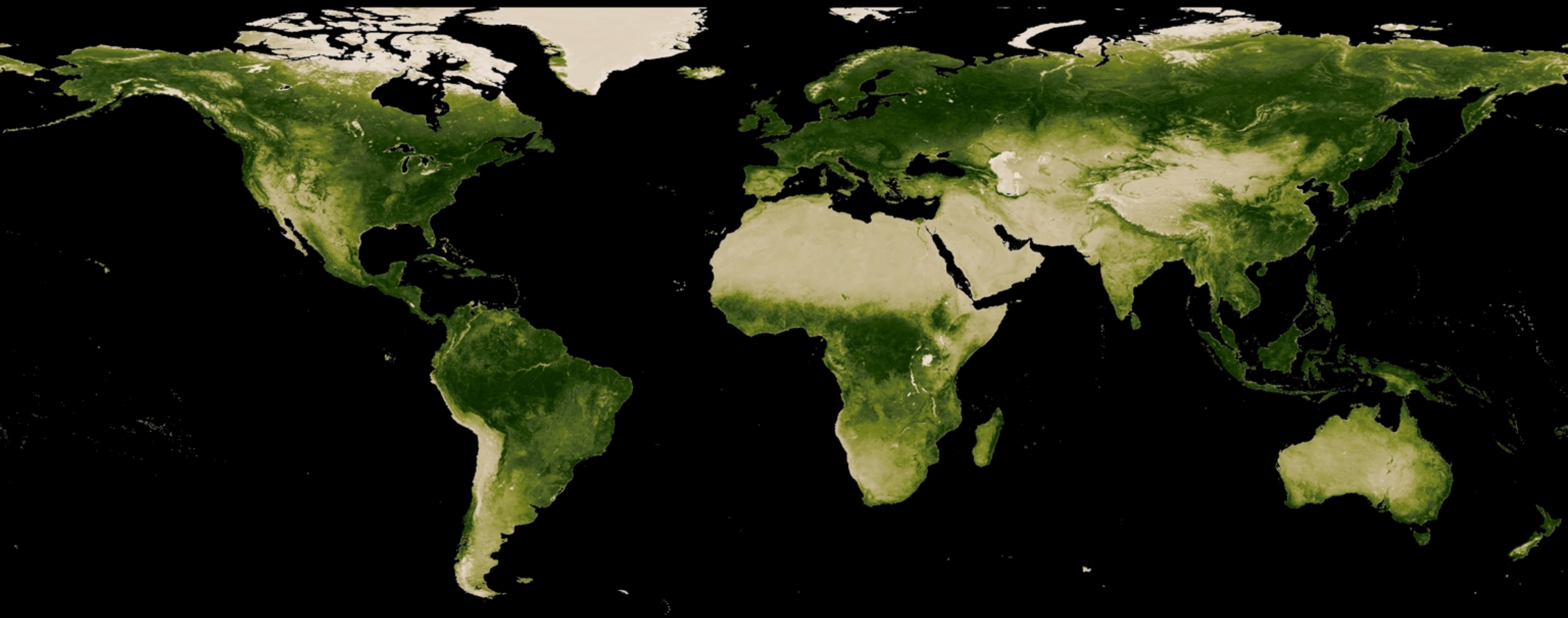
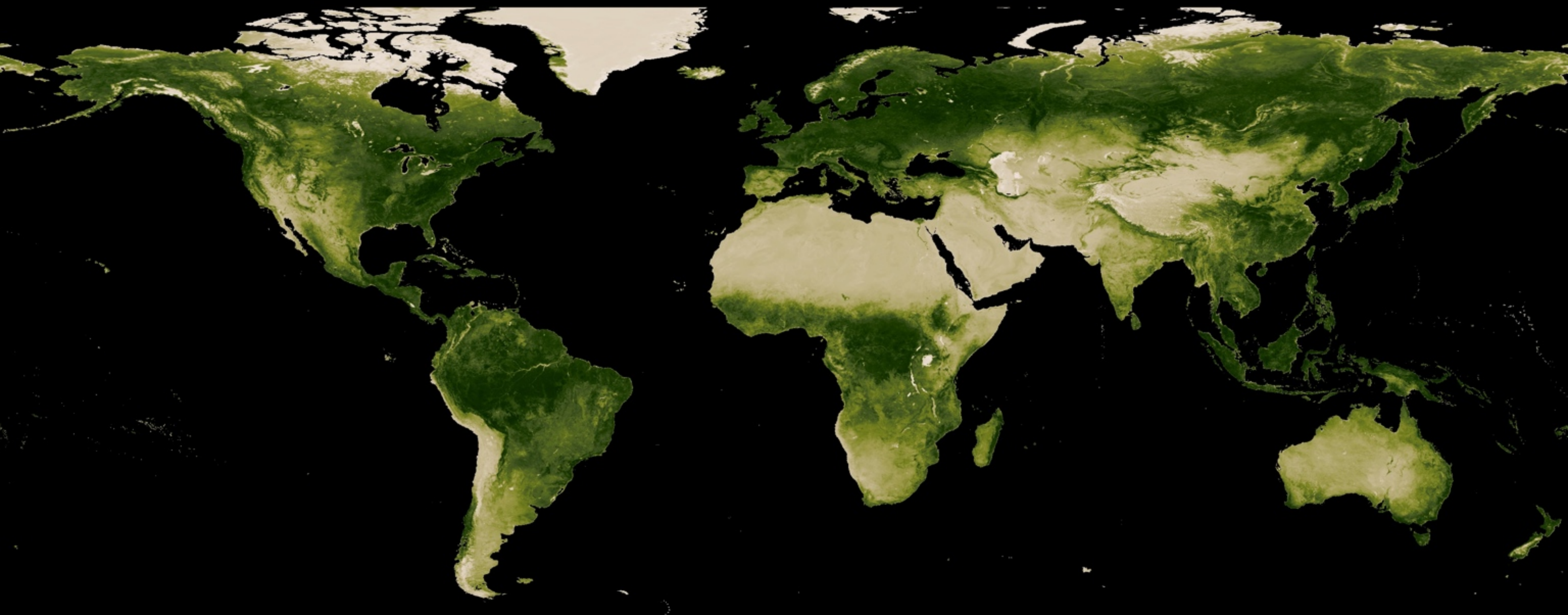
Department of Biology
University of Washington

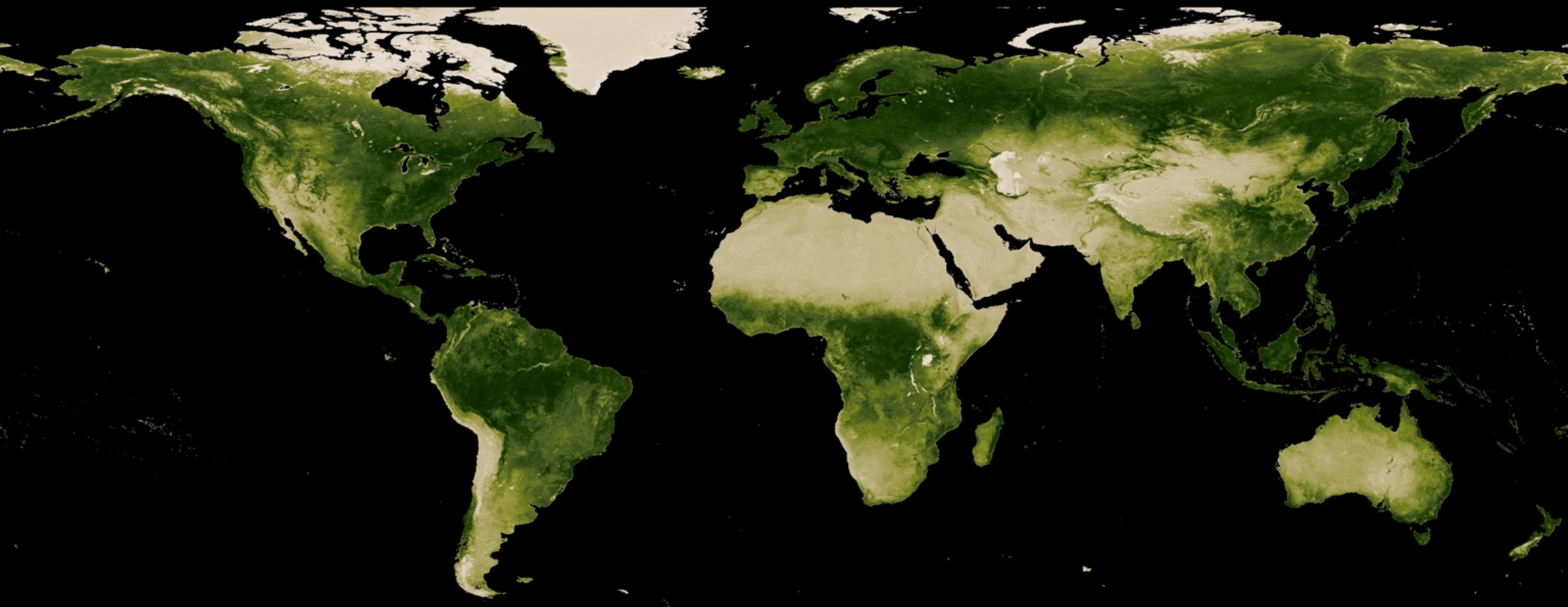
Funding from NSF & DOE



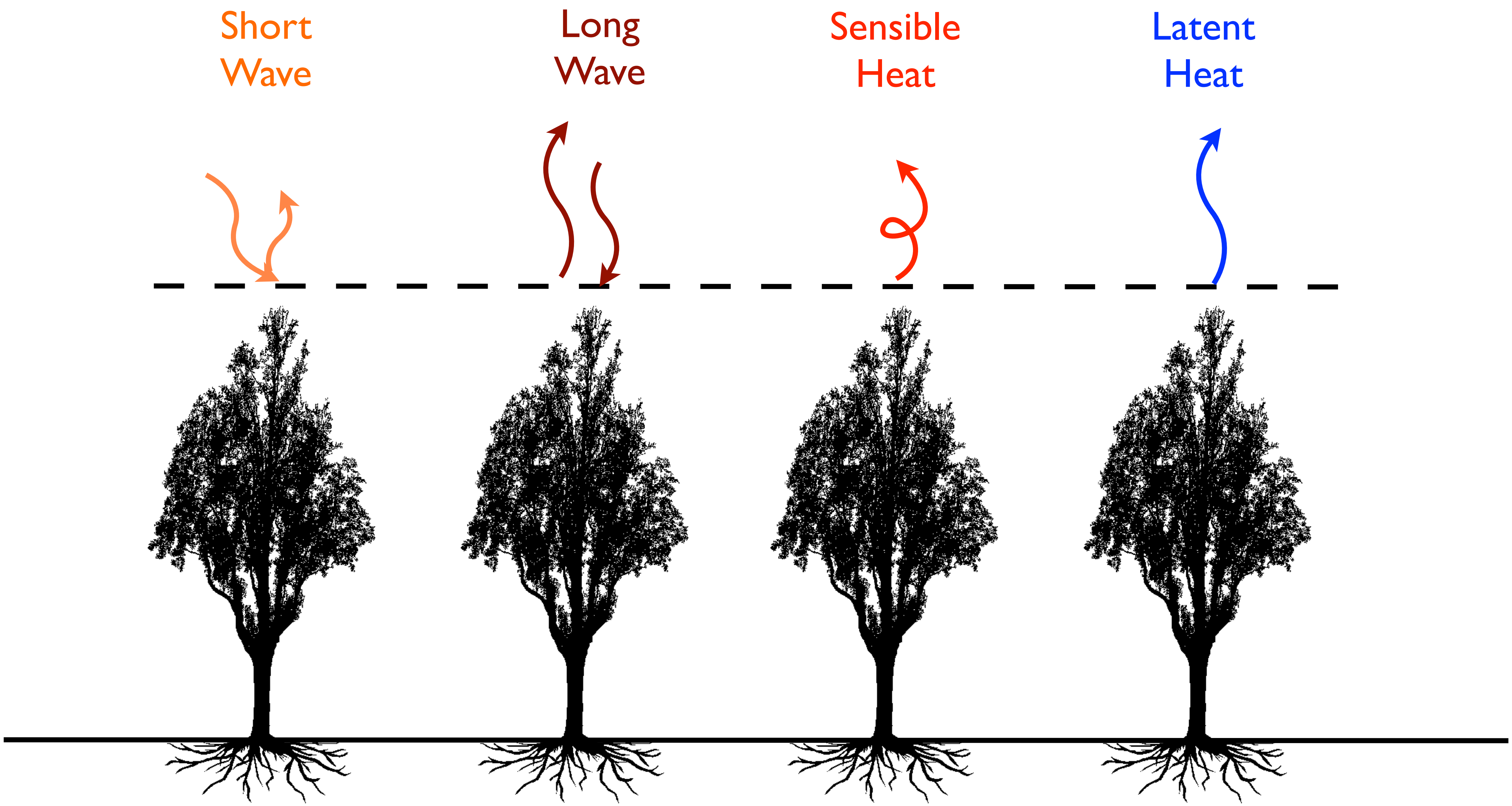
Plants ⟷ Climate



Uncertianty in *biology* matters for *climate*

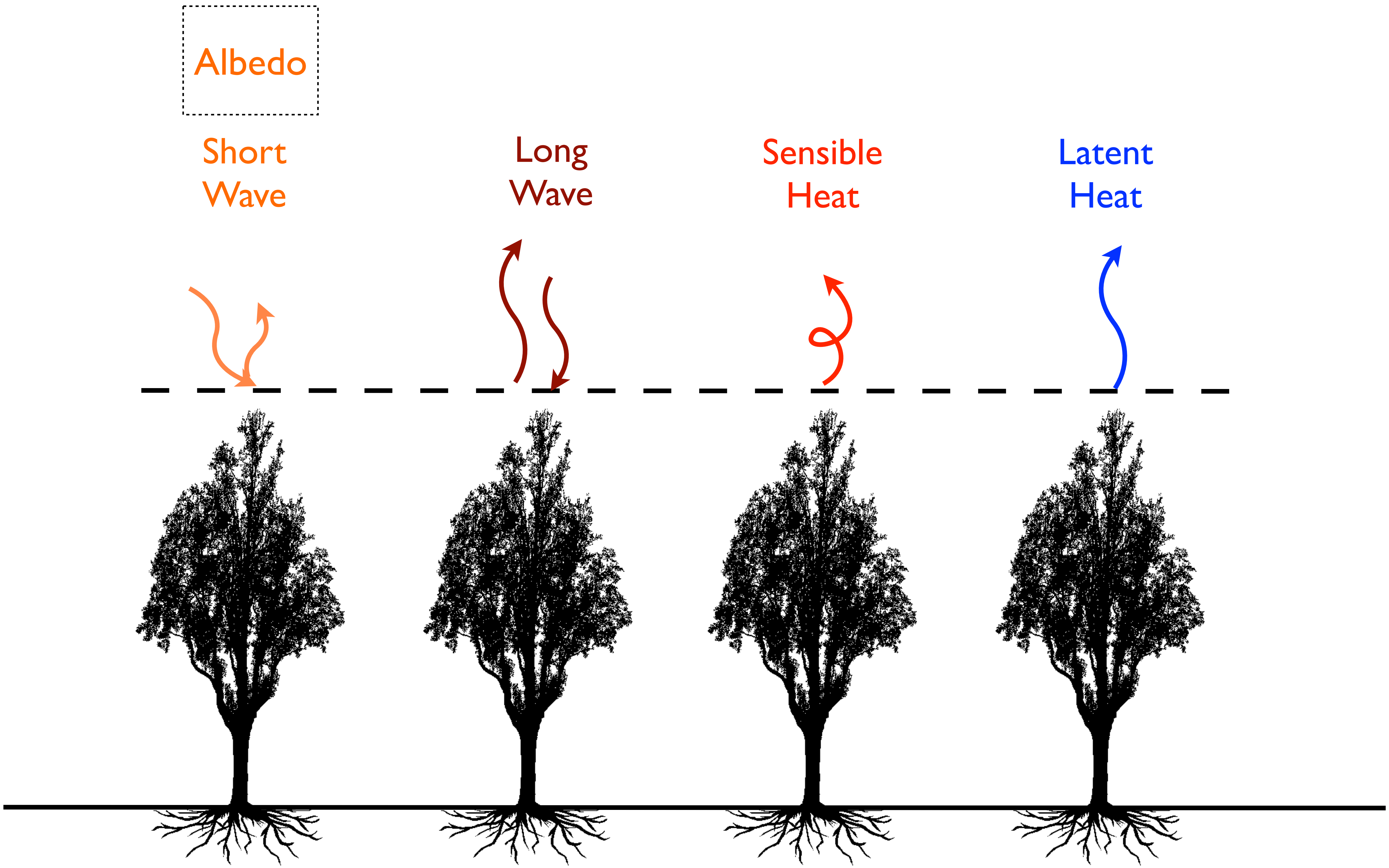


How do Plants and Climate Interact?



Terrestrial Surface Energy Budget

How do Plants and Climate Interact?



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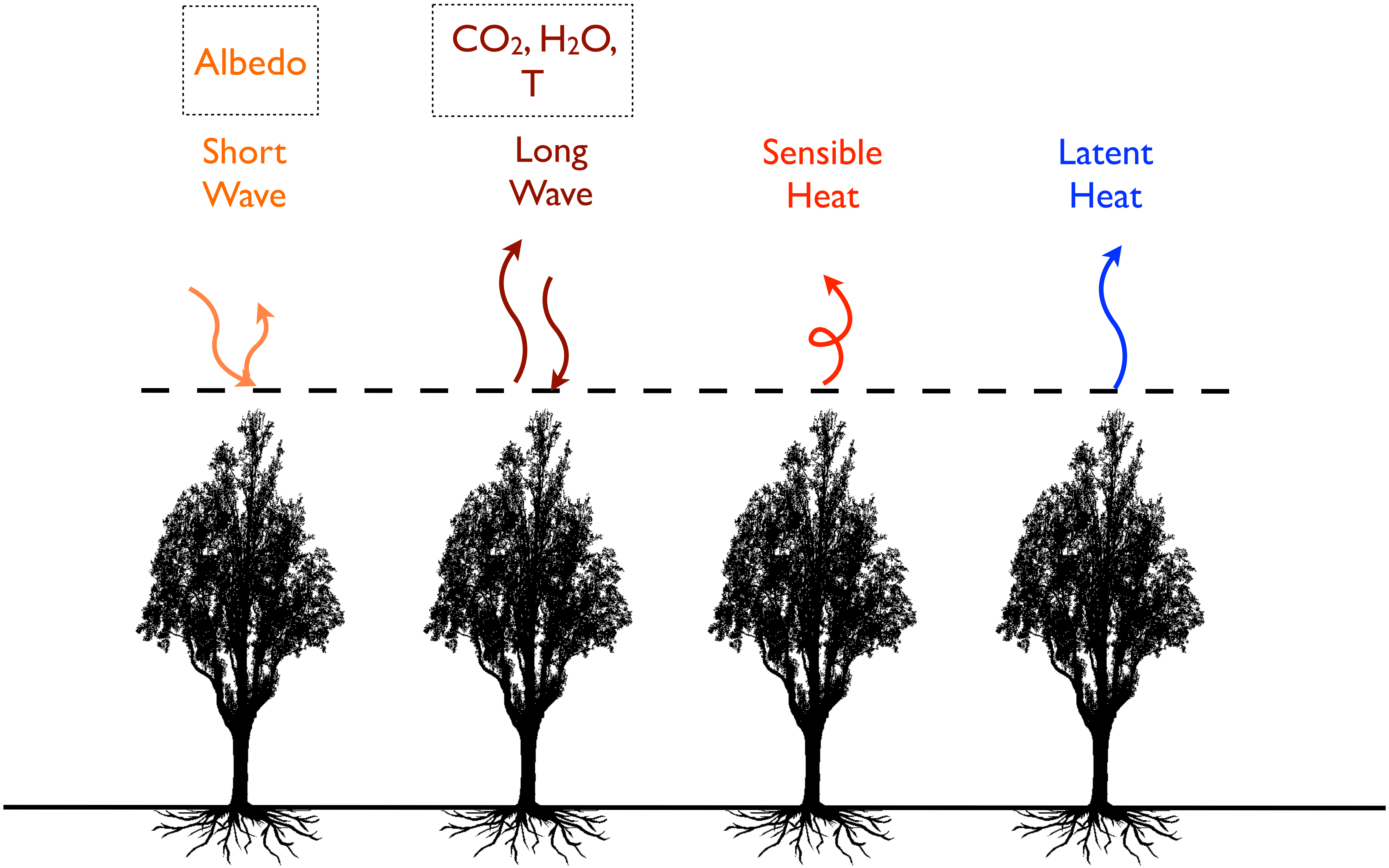
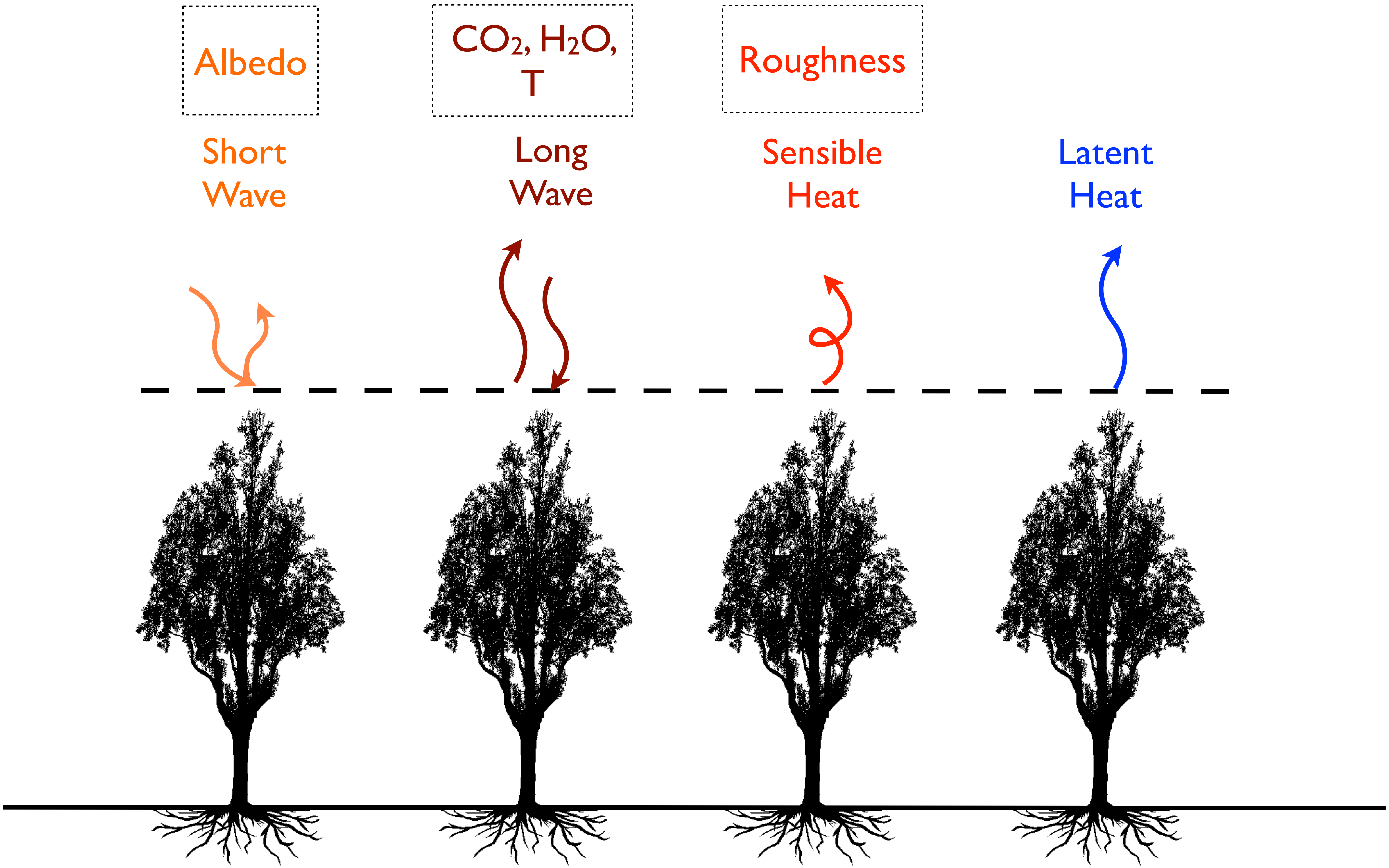


How do Plants and Climate Interact?



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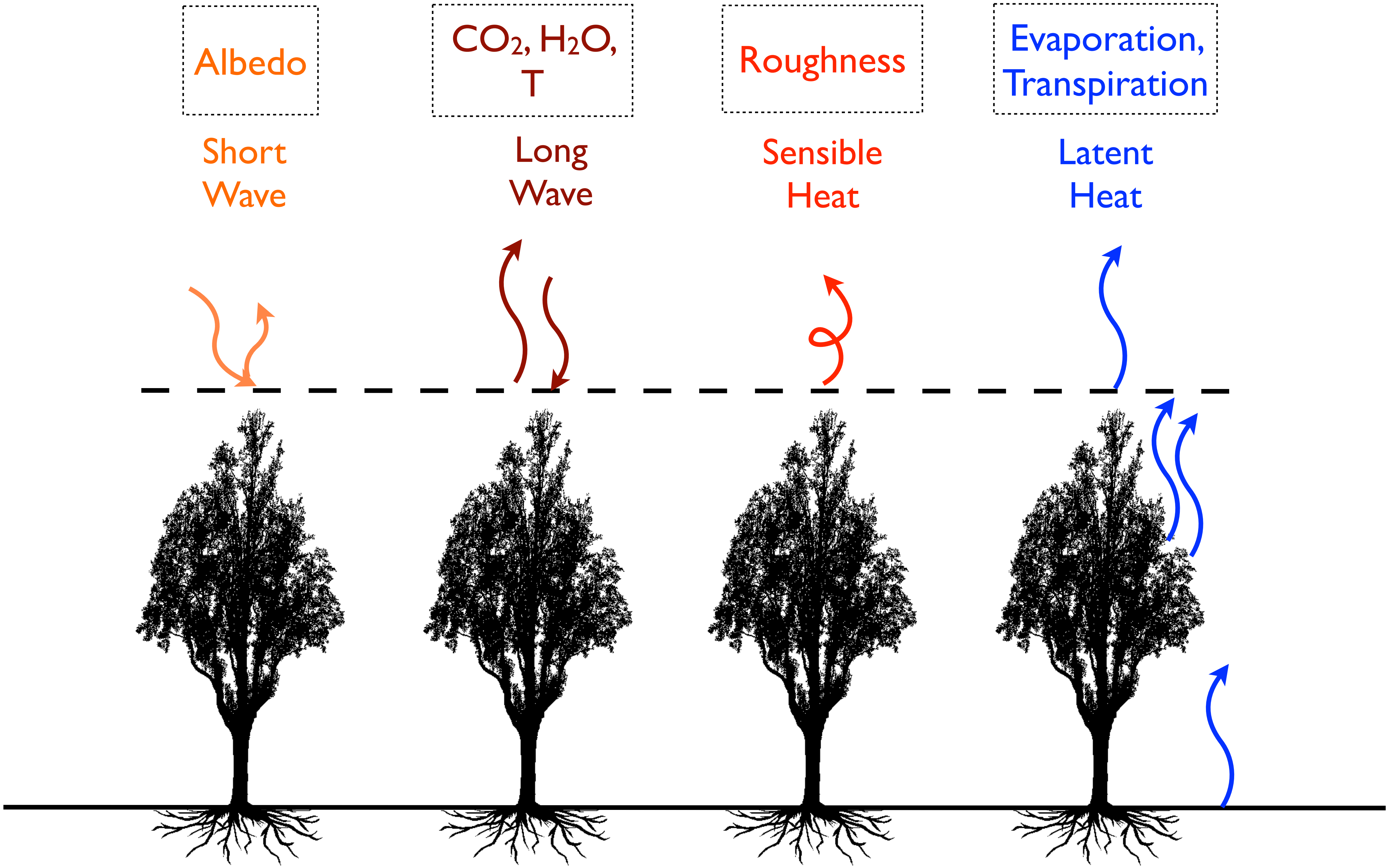
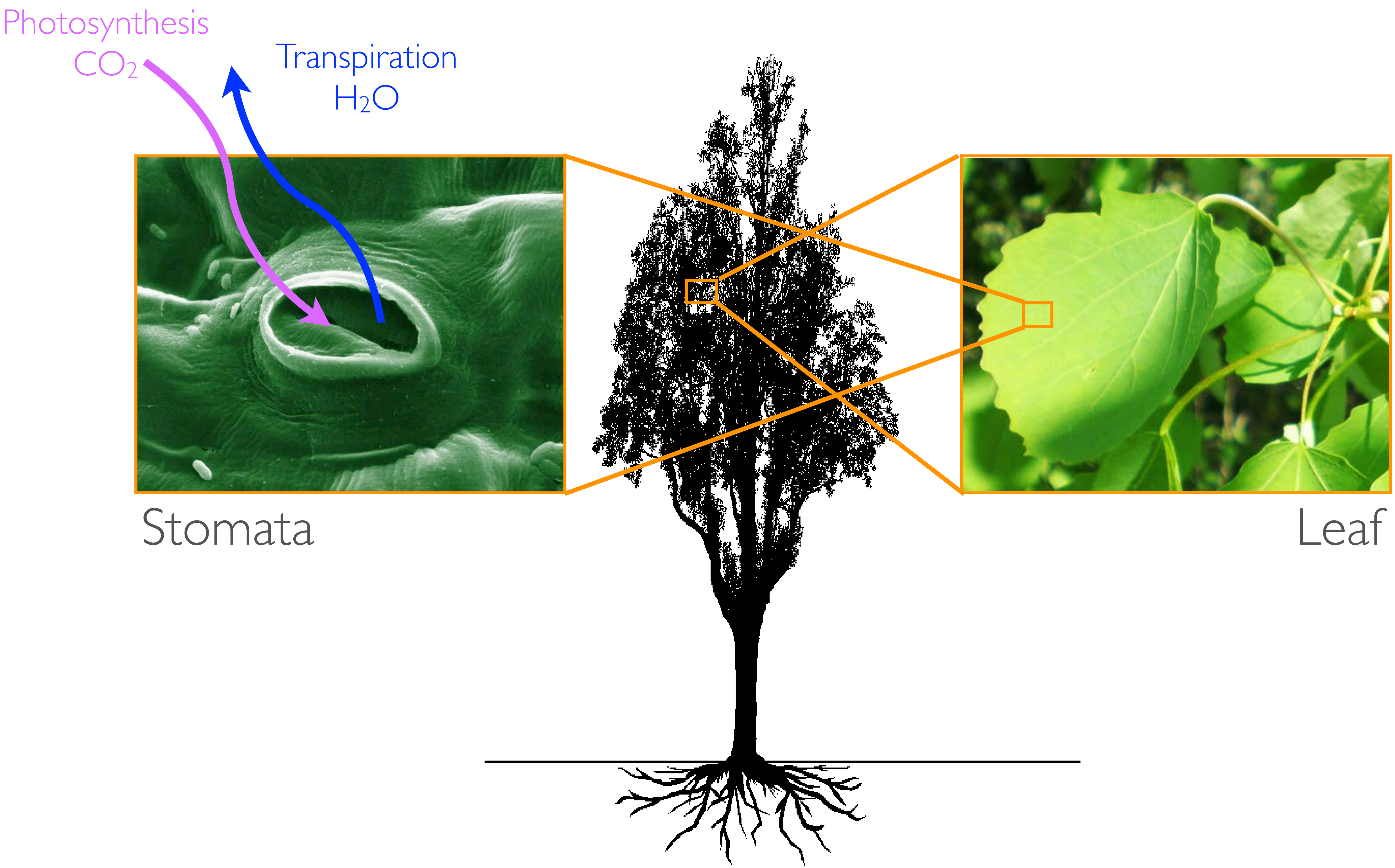
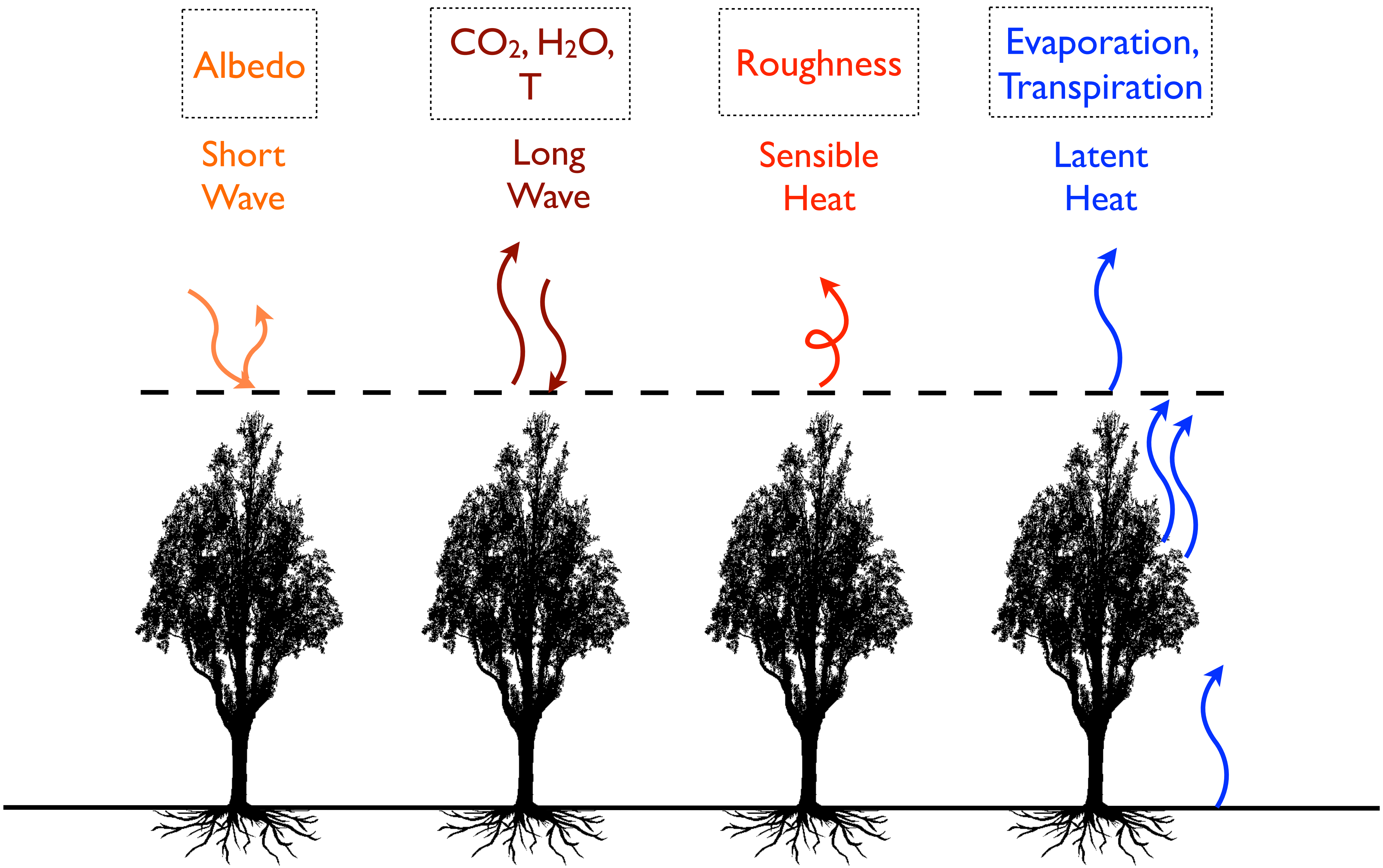


Carbon in, water out



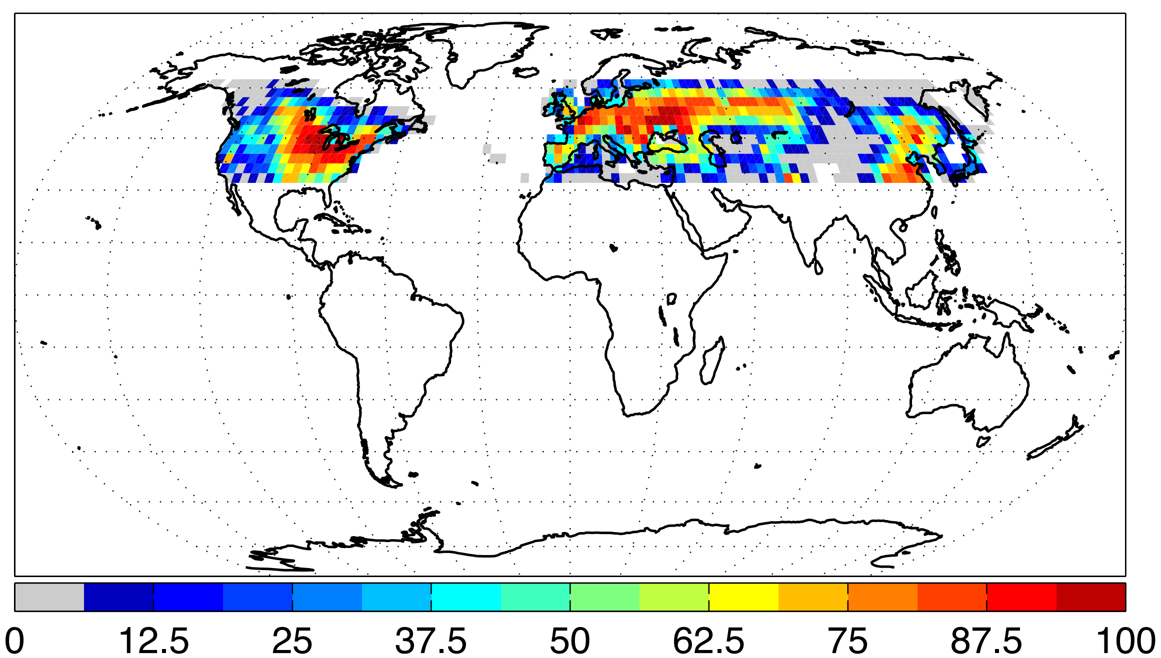
Photos: Wikimedia Commons

ΔPlants ⇒ ΔSurface Energy Budget

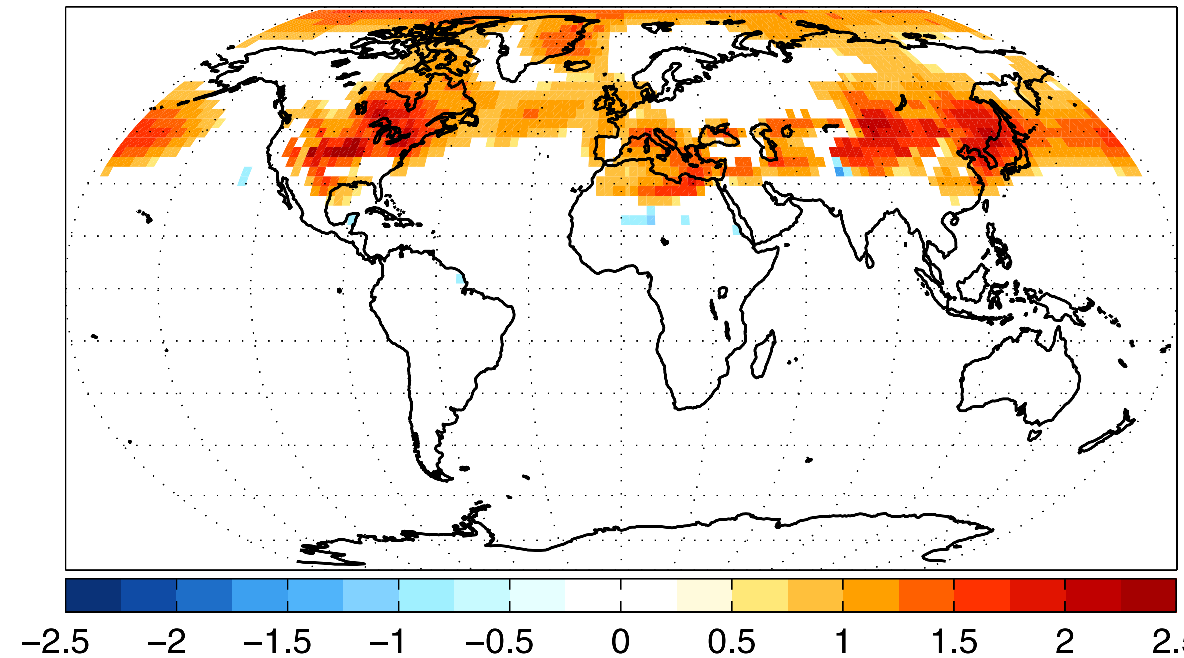


ΔForest cover ⇒ ΔClimate

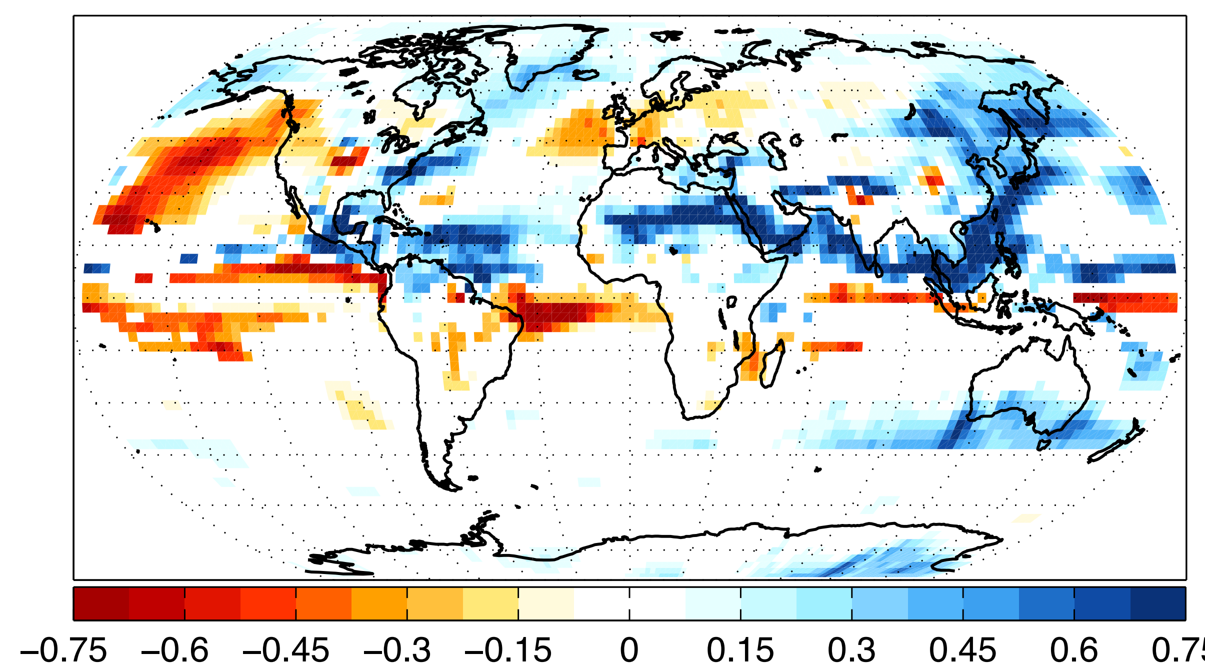
Large mid-latitude afforestation



Convert grass ⇒ trees



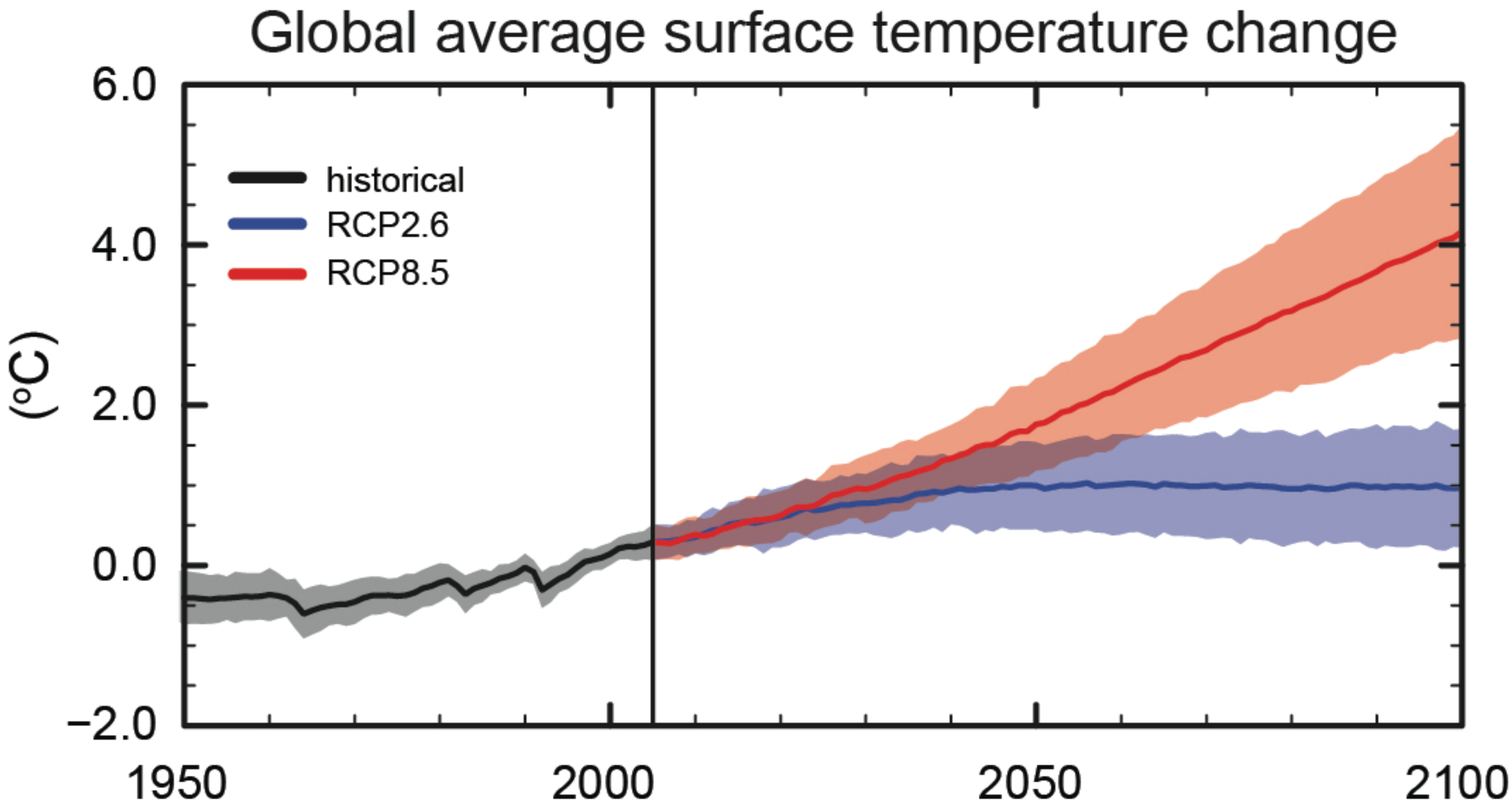
Surface temperature increases



Precipitation patterns shift

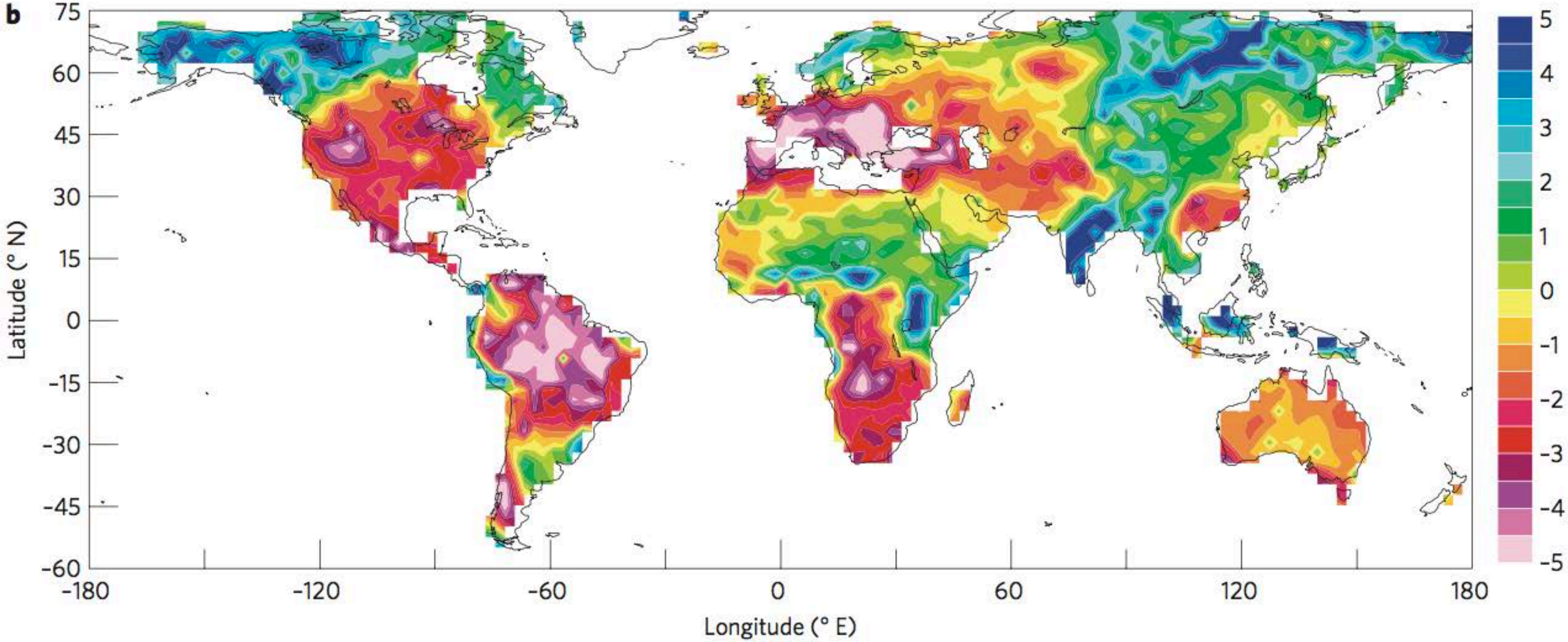
Swann et al., 2012 *PNAS;* Laguë and Swann, 2016, *JClim*

Temperatures are going up due to (mostly) +CO_2



IPCC AR5 Fig. SPM 7

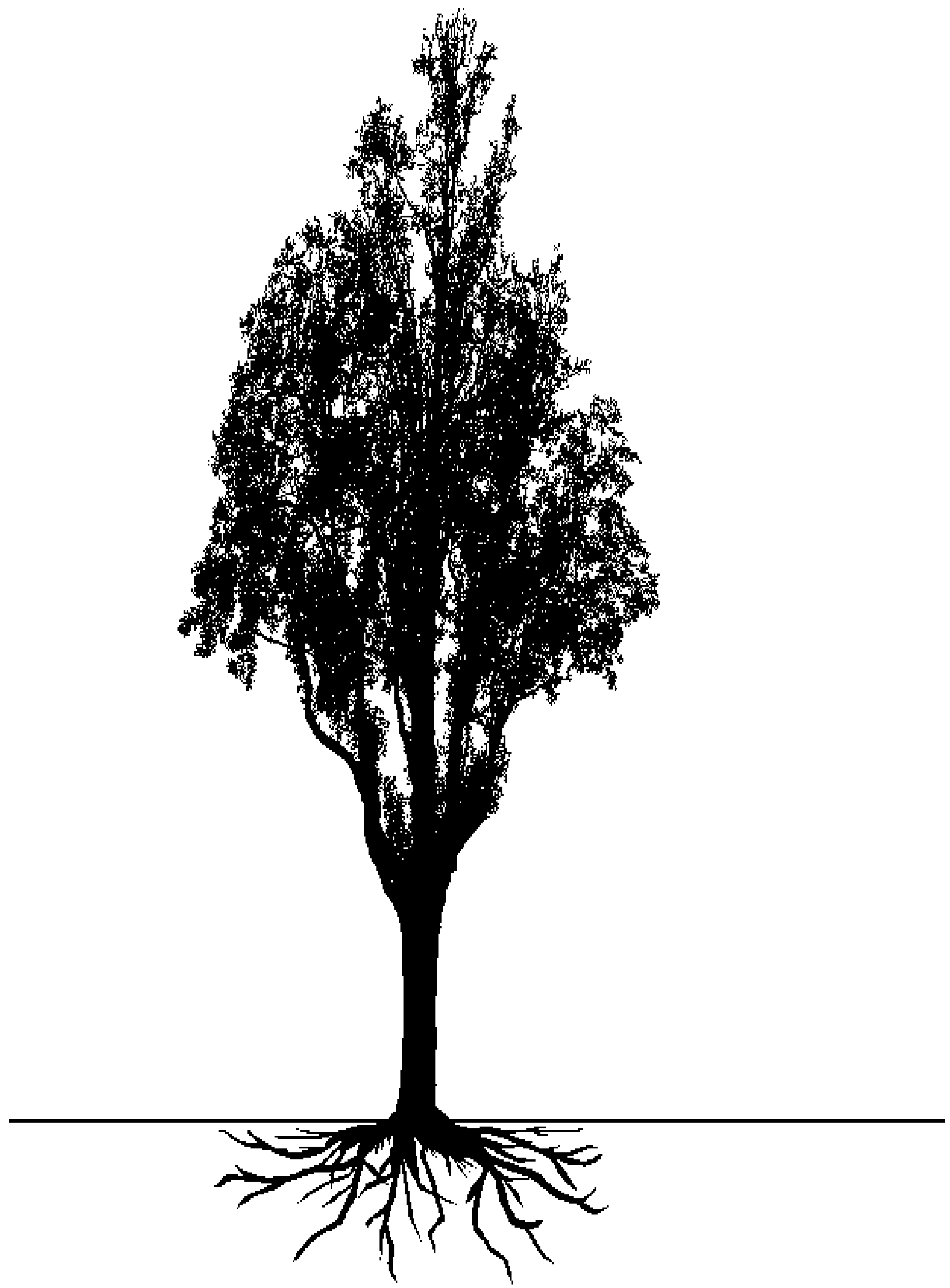
Droughts are predicted to become more severe in the future



Palmer Drought Severity Index 2080-2100 relative to beginning of century

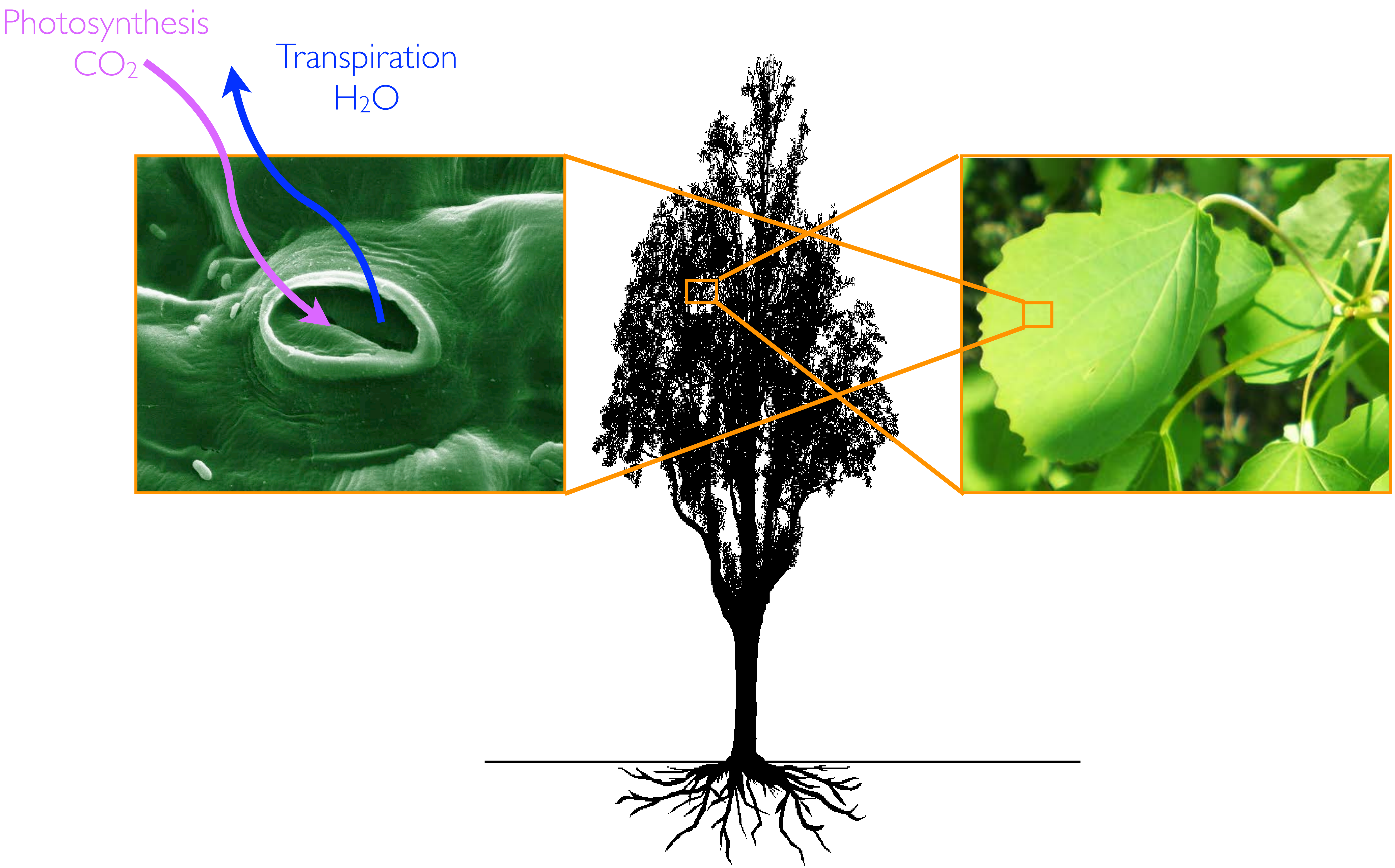
Dai 2013, *Nat Clim Change*

Think like a tree



Photos: Wikimedia Commons

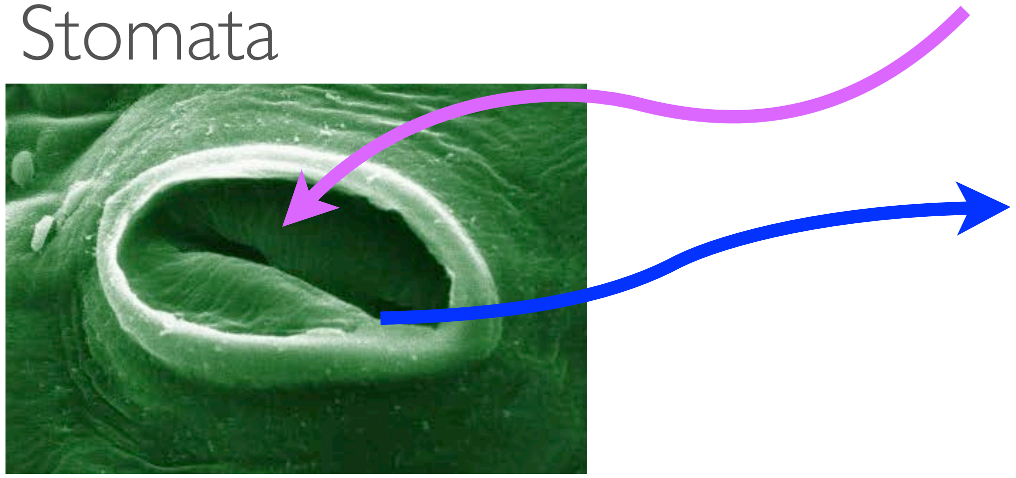
Think like a tree: Carbon in, water out



Photos: Wikimedia Commons

What controls the flux of water and carbon?

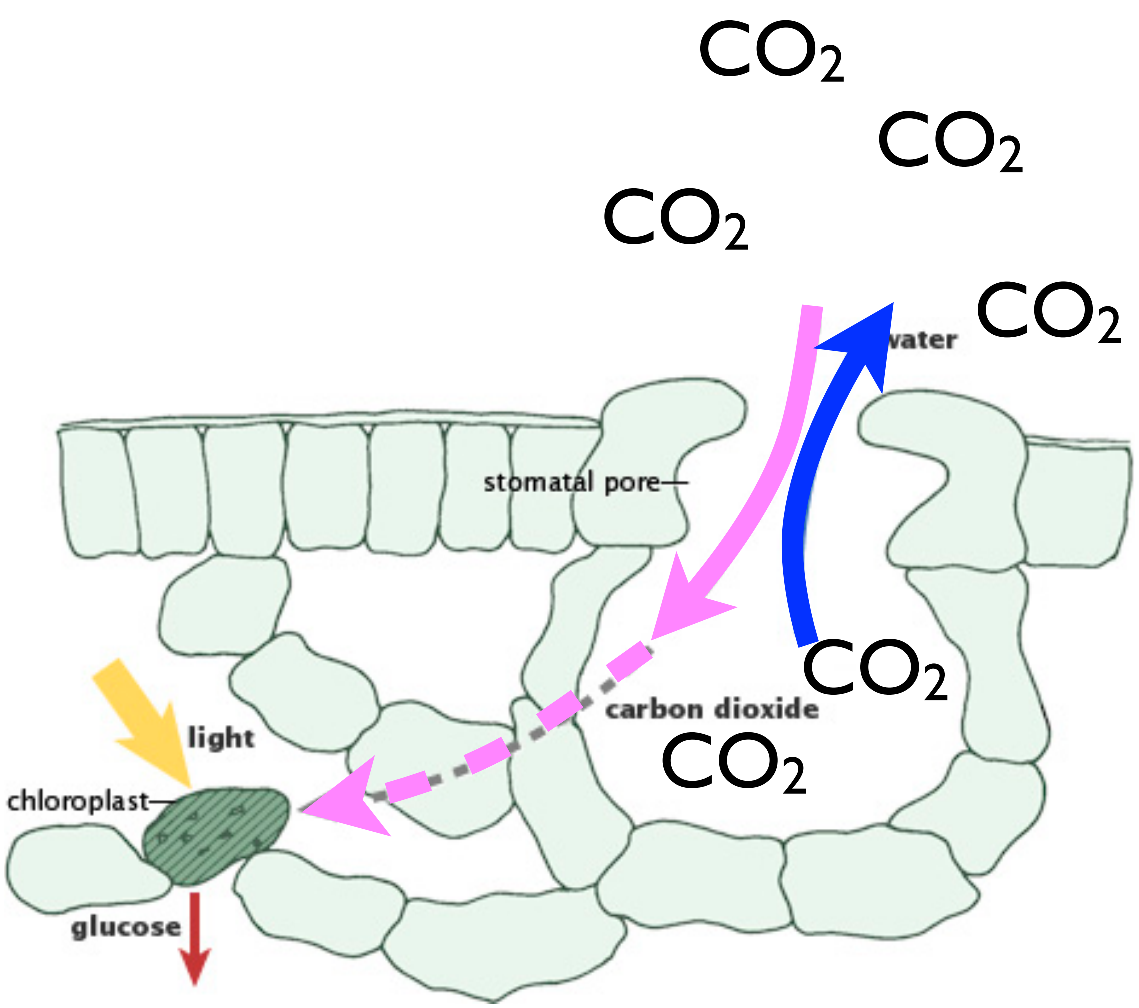
Stomata



Stomatal Conductance (g_{sw})

$$g_{sw} = g_0 + g_1 \frac{A_n}{c_s} h_s$$

Ball-Berry Equation

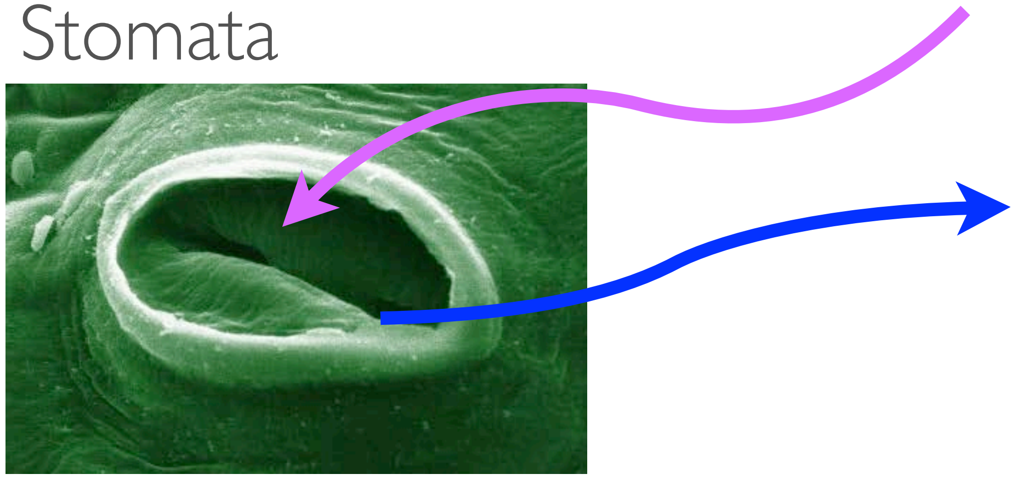


adapted from Sellers 1992

Photos: Wikimedia Commons

What controls the flux of water and carbon?

Stomata



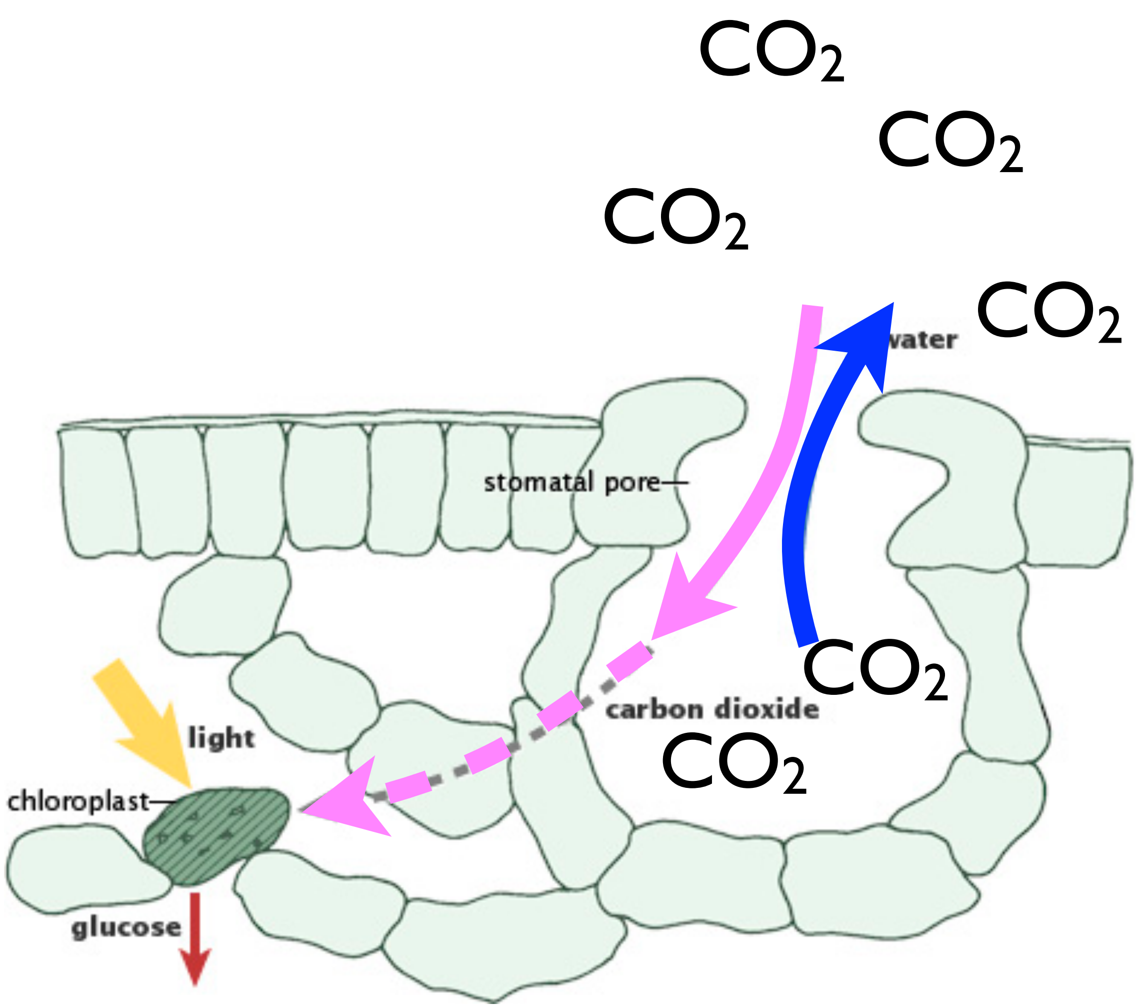
Photosynthesis CO_2

Transpiration H_2O

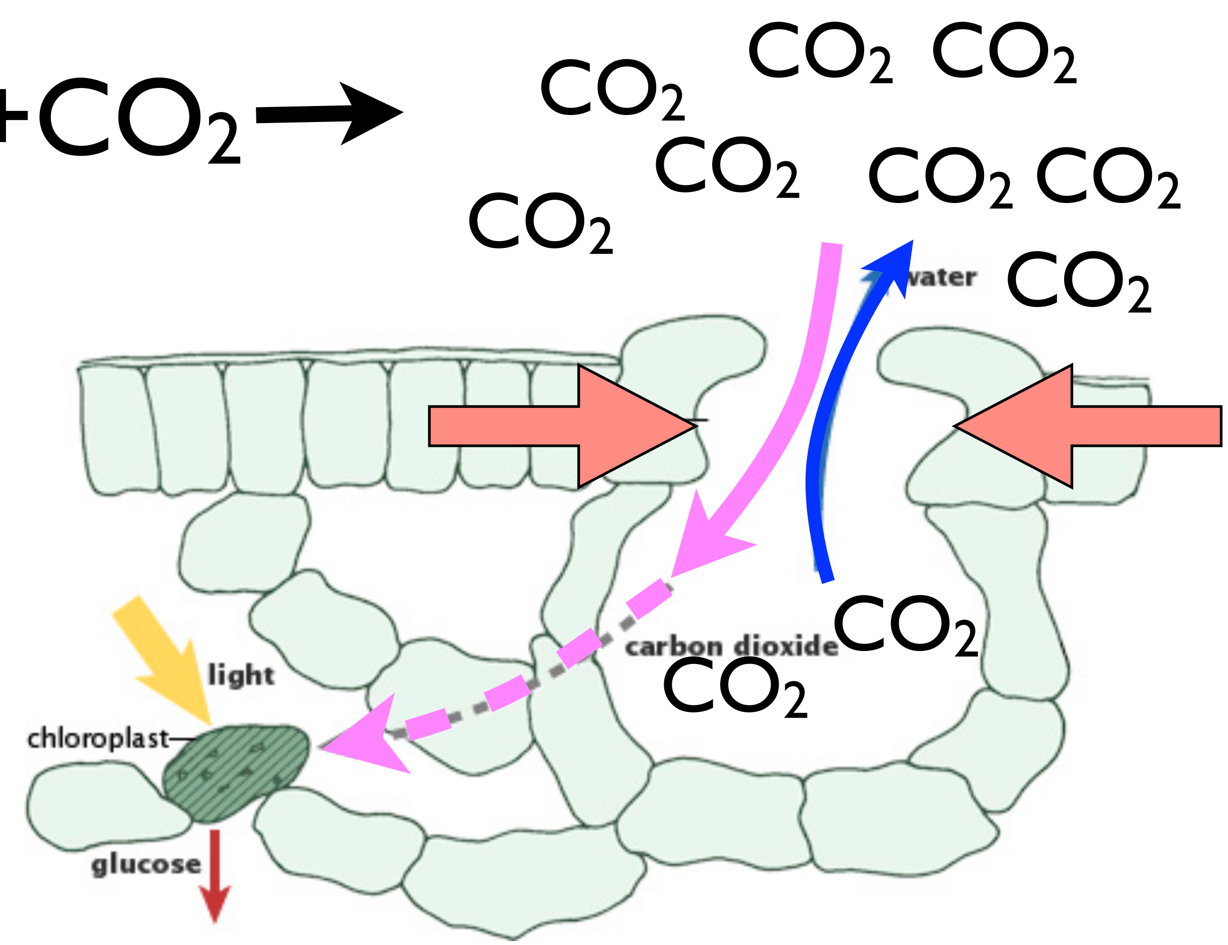
Stomatal Conductance (g_{sw})

$$g_{sw} = g_0 + g_1 \frac{A_n}{c_s} h_s$$

Ball-Berry Equation



→ $+CO_2$ →

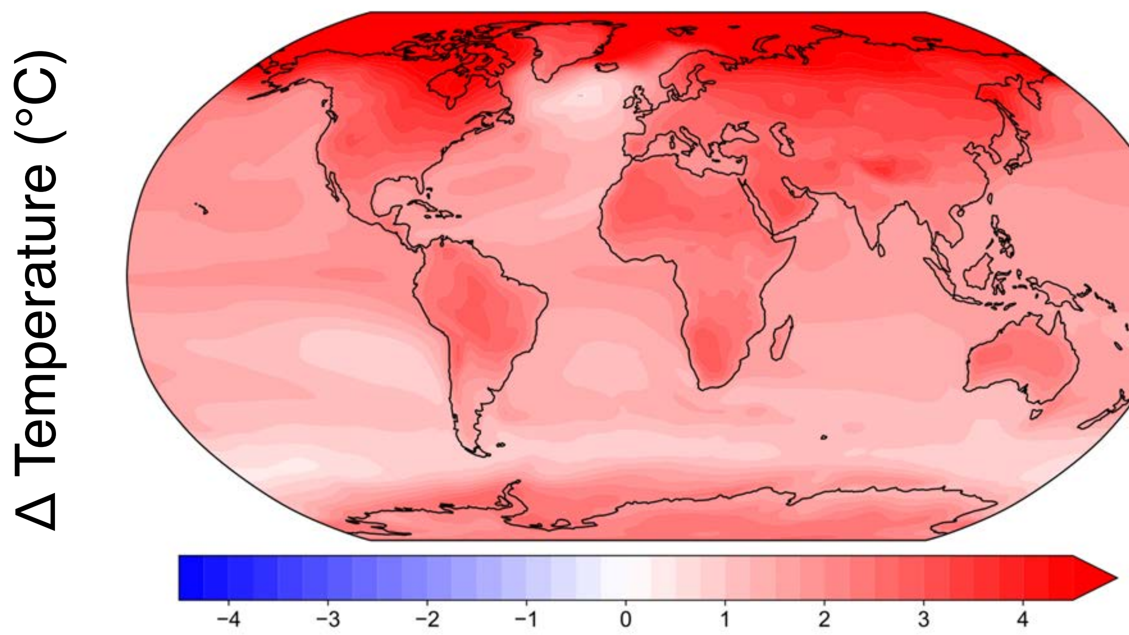


adapted from Sellers 1992

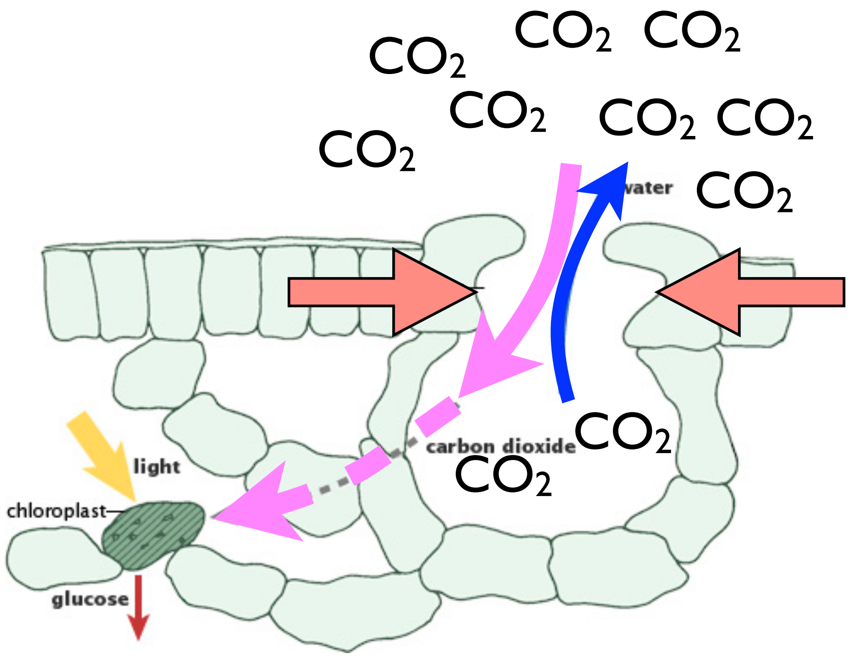
Photos: Wikimedia Commons

CO_2 has multiple effects

Radiative:



Physiological:



Increase in temperature in 12 CMIP6 models due to $2xCO_2$

Separate Radiative vs. Physiological effects

Radiative: Atmosphere "sees" CO_2, but plants don't

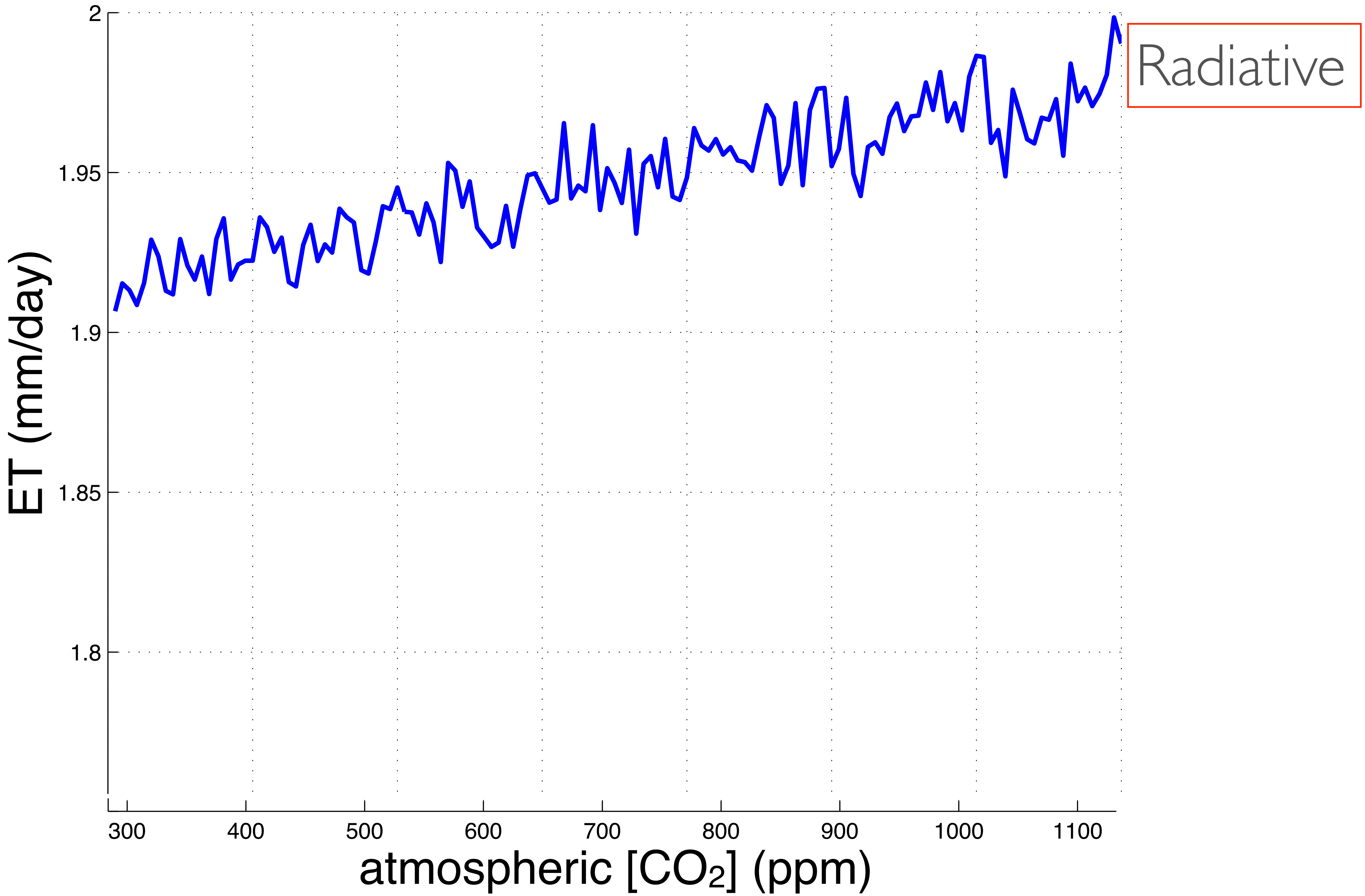
Physiological: Plants "see" CO_2, but atmosphere doesn't

Fully Coupled: Both Atmosphere and Plants "see" CO_2

following Sellers et al. 1996

Use 7 models from CMIP5 with 4X CO_2 increasing at 1%/yr

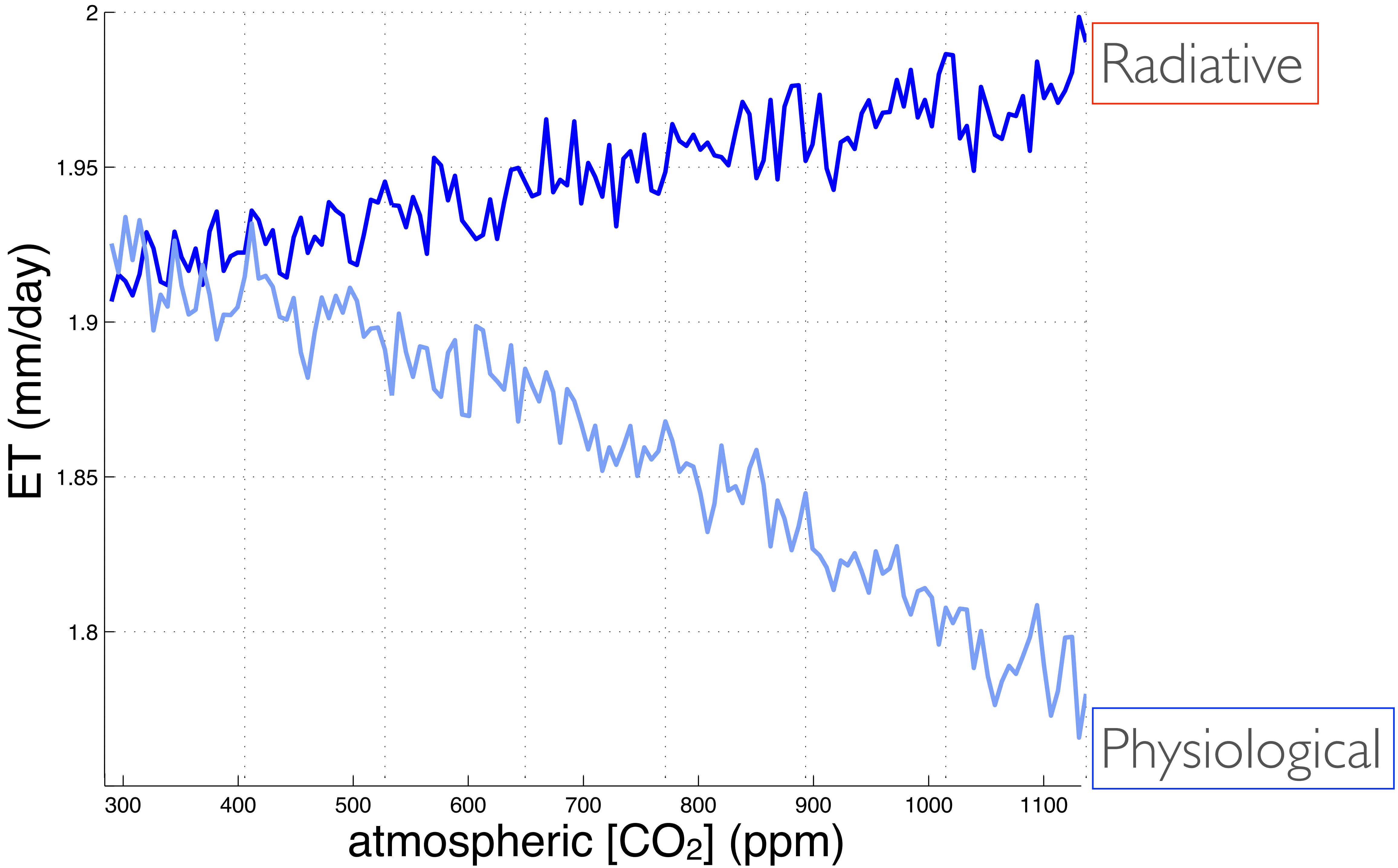
ET goes up from Radiative effects of CO_2



Multimodel mean for land area 45S to 45N

Swann et al. 2016 *PNAS*

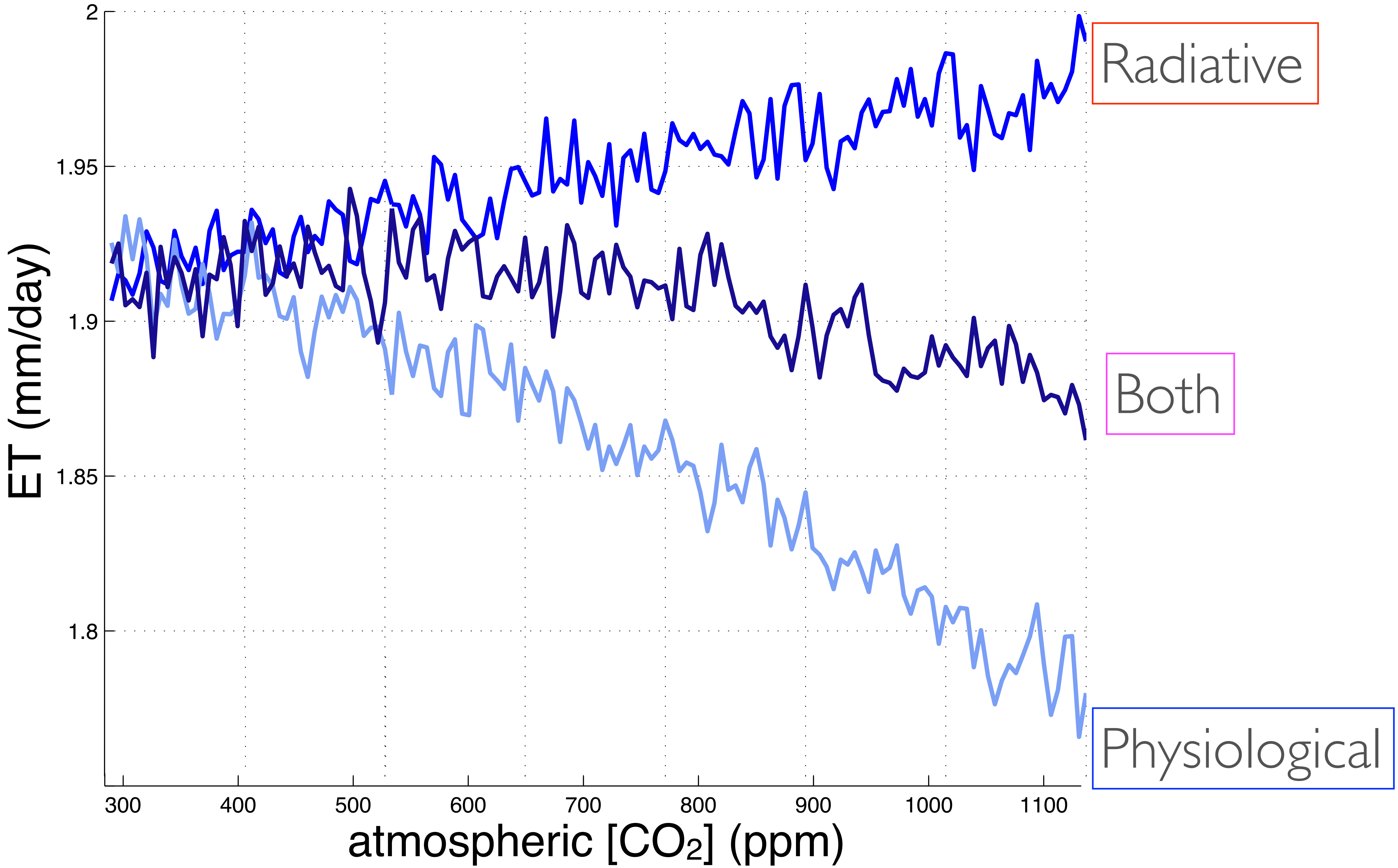
ET goes down from Physiological effects of CO_2



Multimodel mean for land area 45S to 45N

Swann et al. 2016 *PNAS*

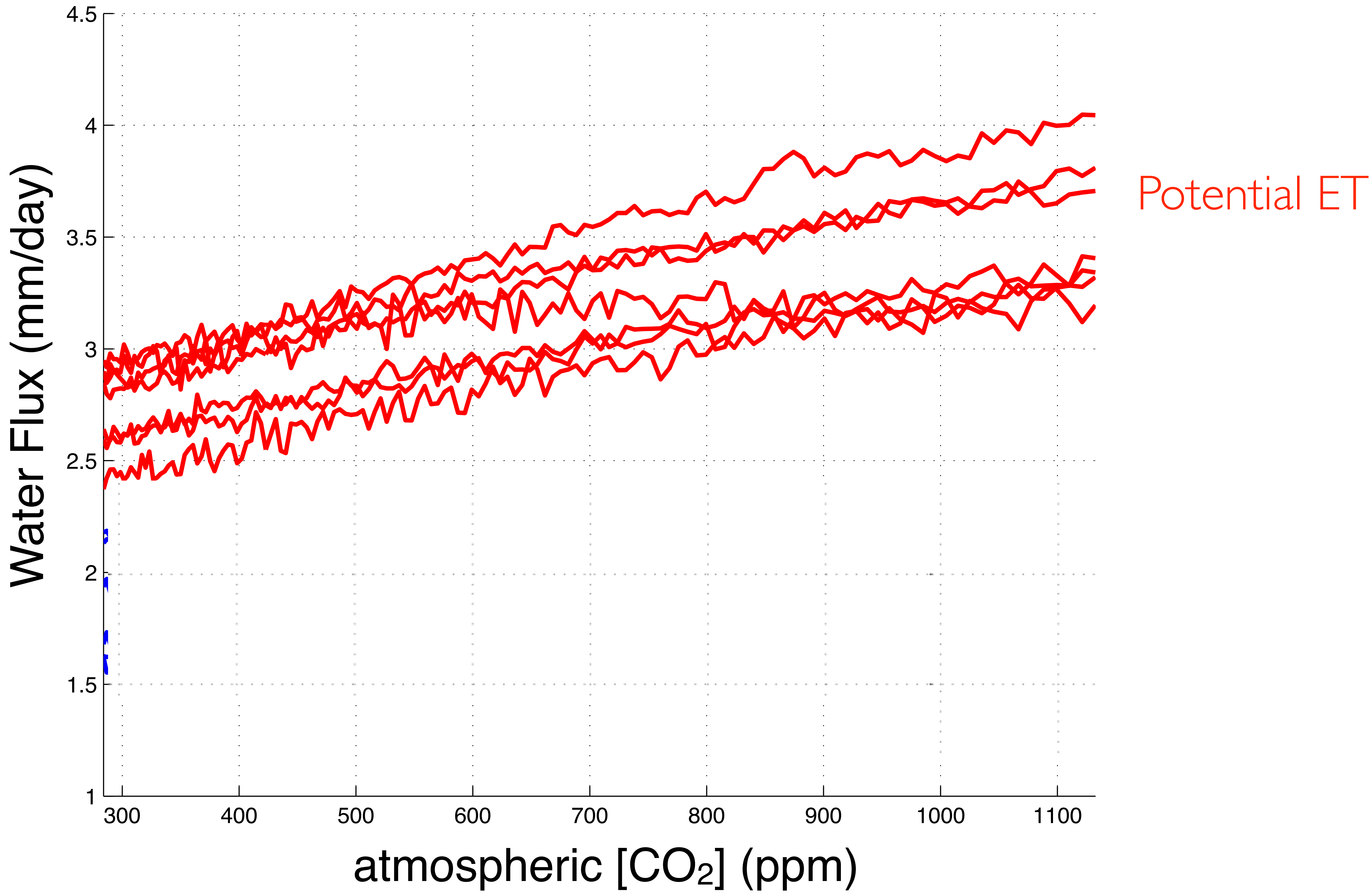
The combination shows small decrease in ET



Multimodel mean for land area 45S to 45N

Swann et al. 2016 *PNAS*

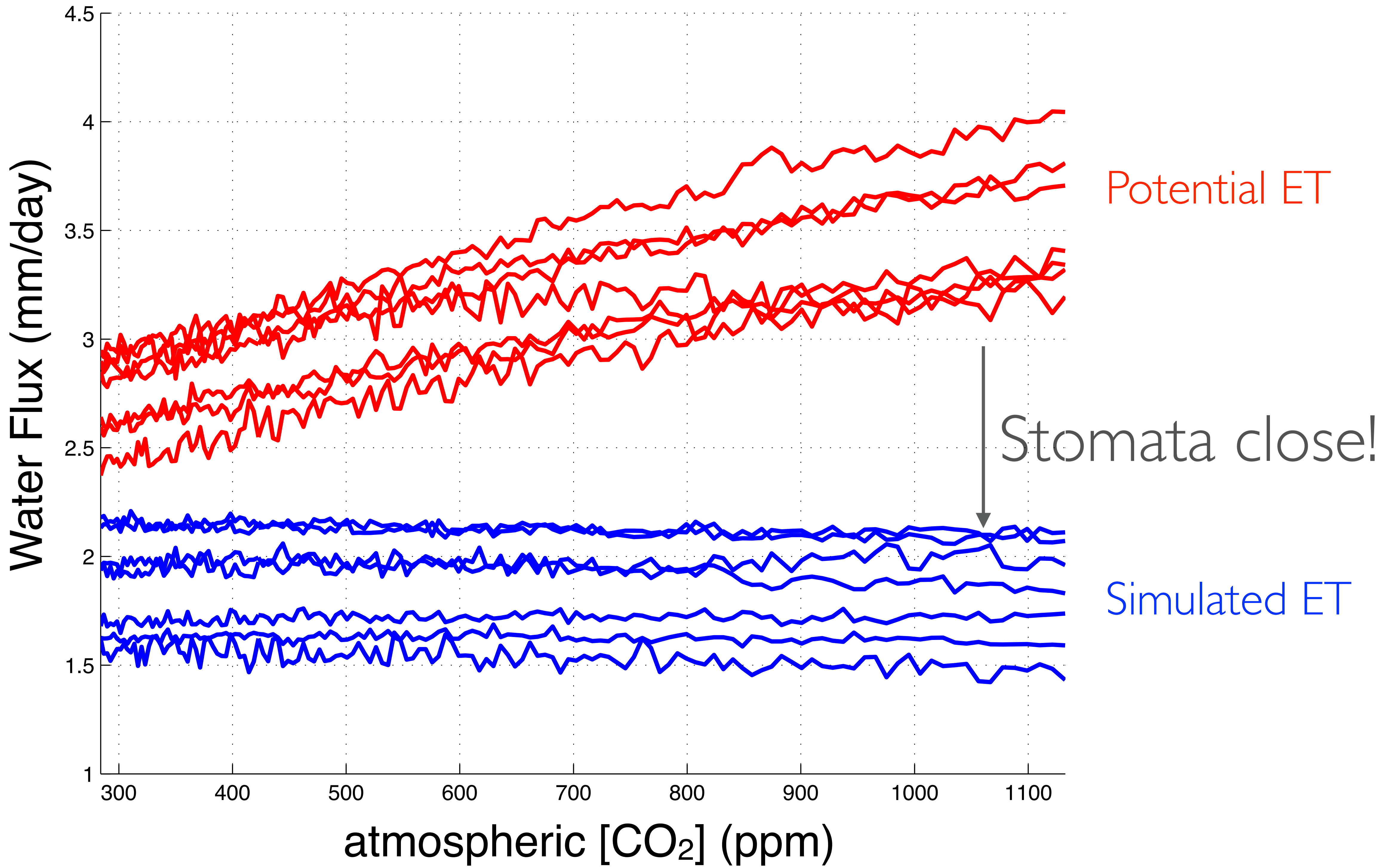
The Potential to evaporate water goes up as CO_2 increases



Mean for land area 45S to 45N

Swann et al. 2016 *PNAS*

But the *actual* ET is stable as CO_2 increases

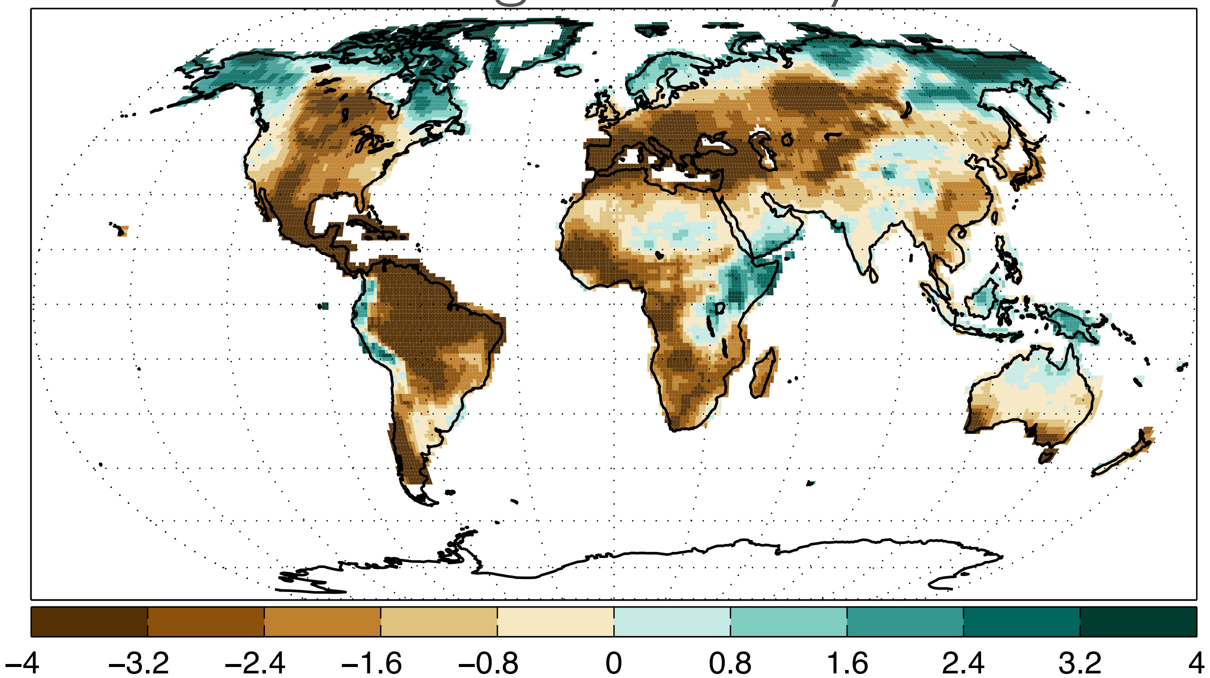


Mean for land area 45S to 45N

Swann et al. 2016 *PNAS*

Widespread drought?

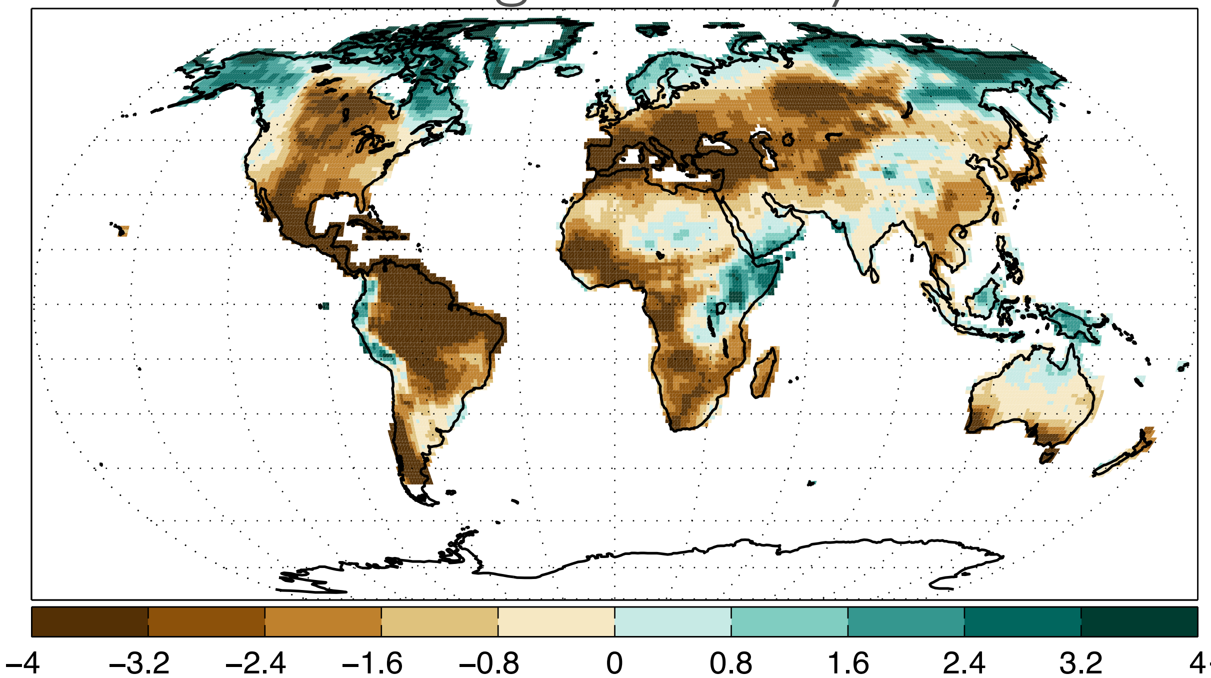
ΔPalmer Drought Severity Index



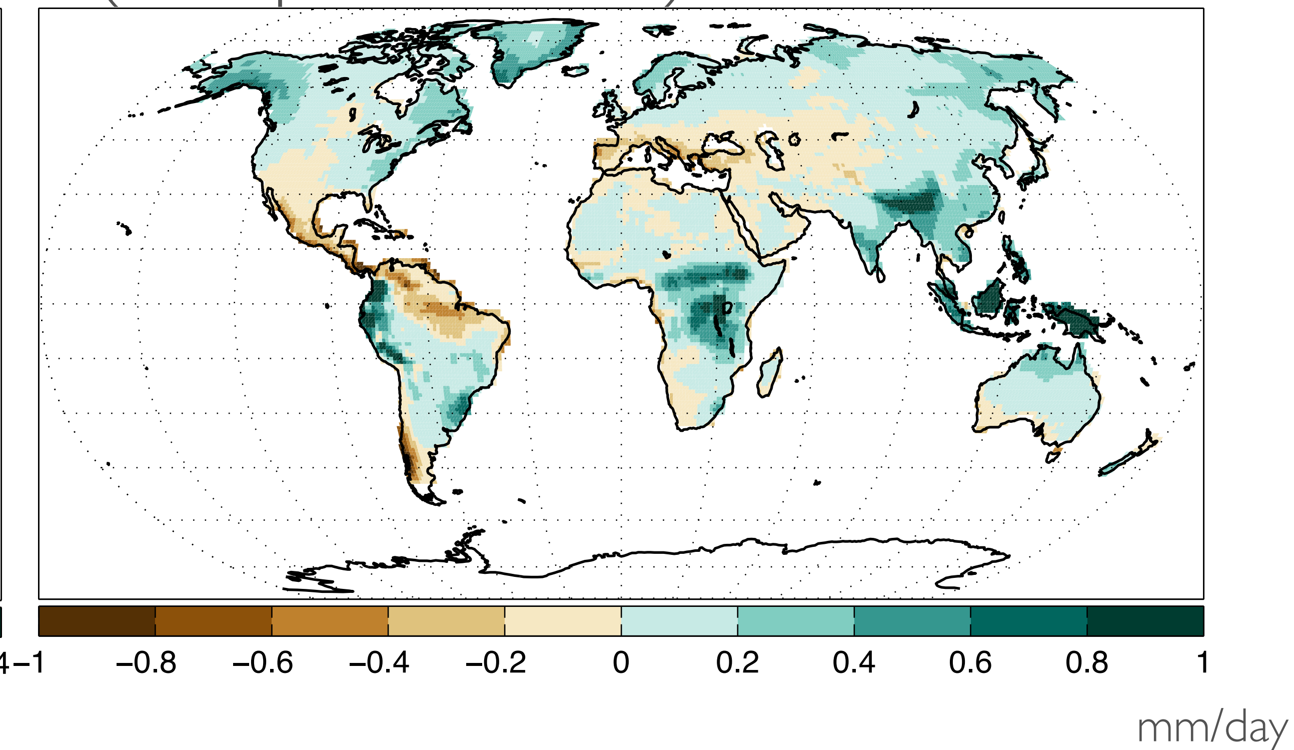
>70% of land area sees an increase in drought

Widespread drought?

ΔPalmer Drought Severity Index



Δ(Precipitation - ET)



>70% of land area sees an increase in drought

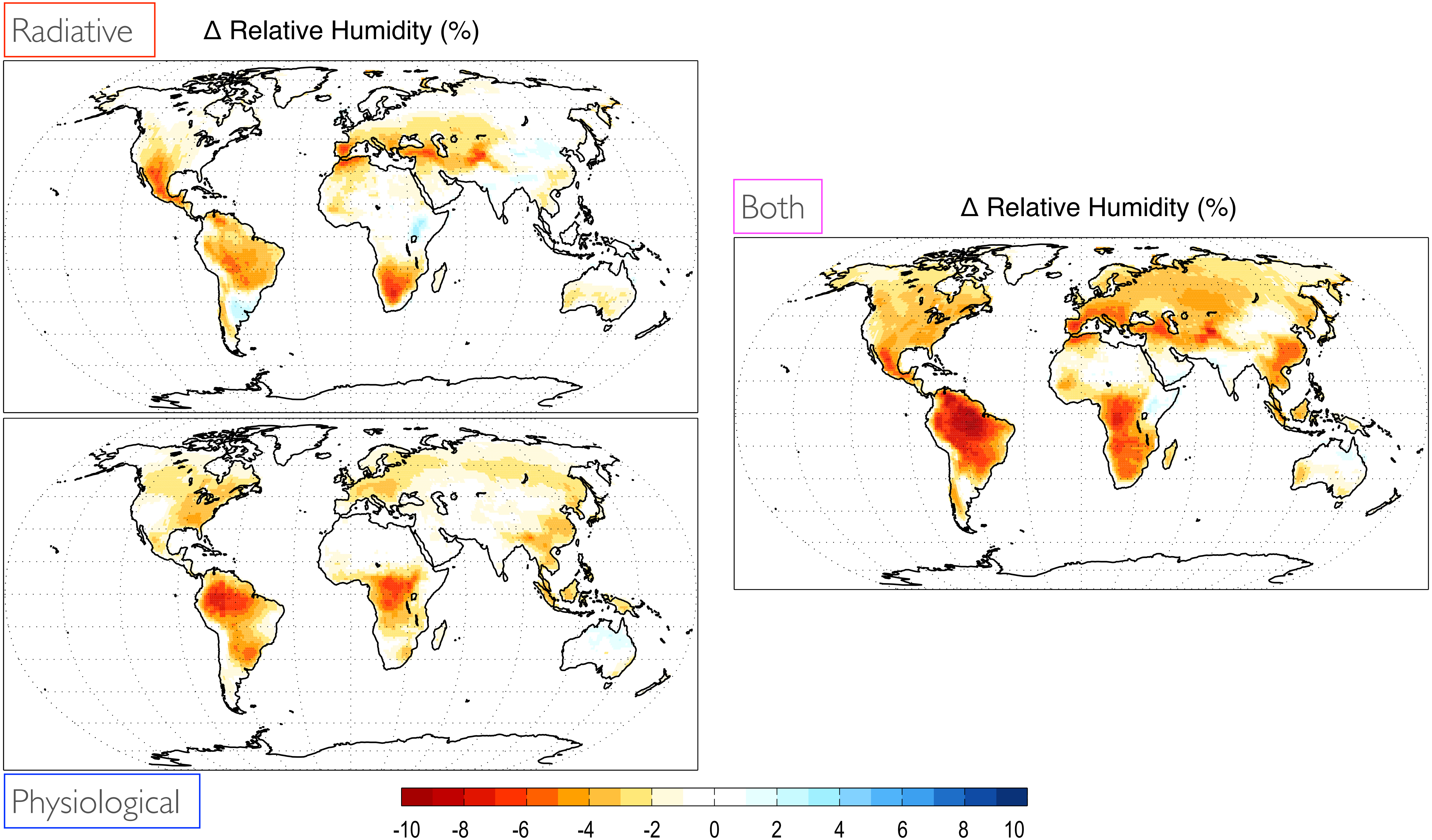
36% of land area sees drier conditions

Based on 7 models from CMIP5 at 4X CO_2

Swann et al. 2016 *PNAS*

Some atmospheric variables respond strongly to plants:

About *half* of RH change is from plants closing stomata

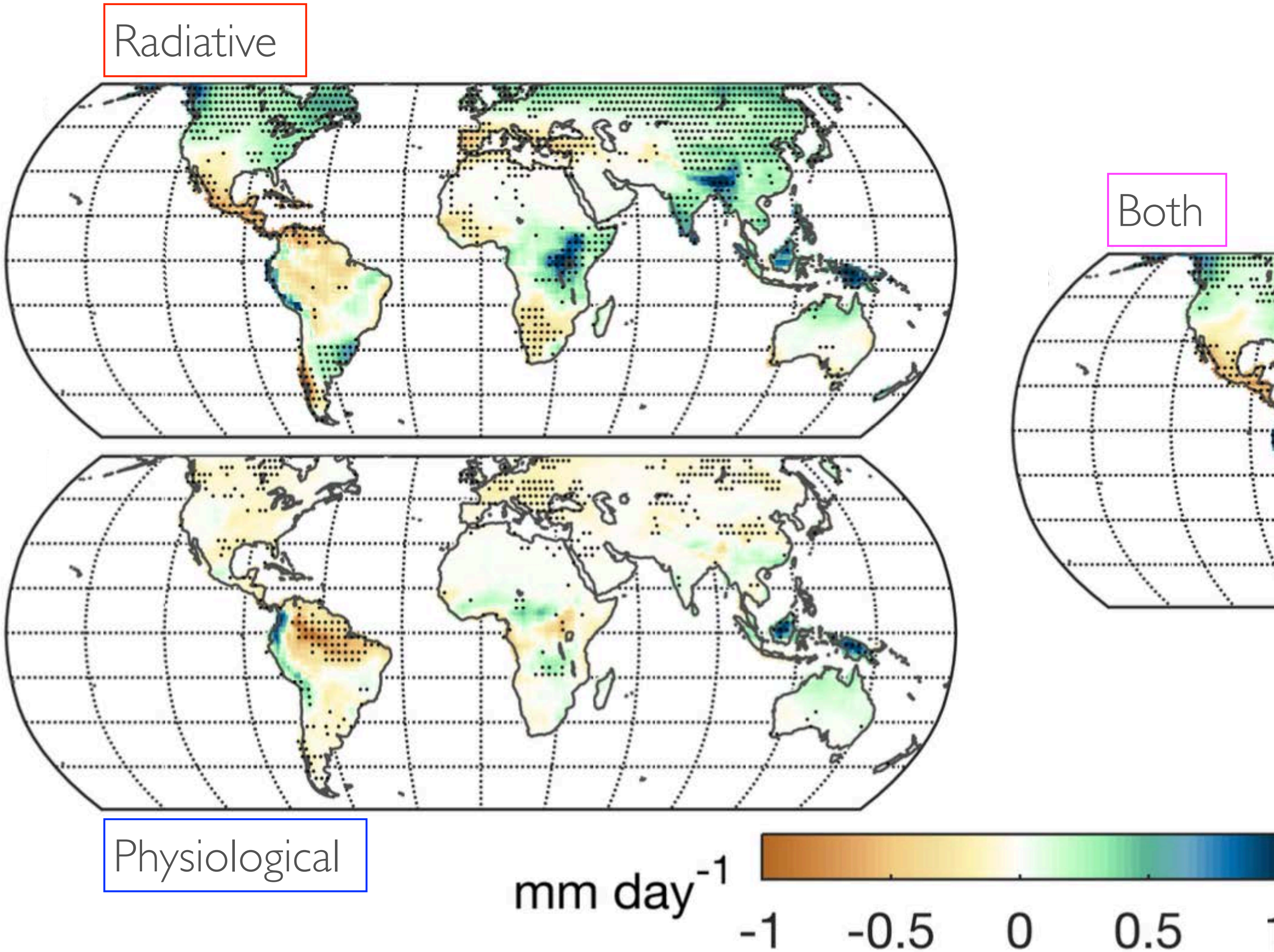


Based on 7 models from CMIP5 at 4X CO_2

Swann et al. 2016 *PNAS*

Tropical Precipitation has a big signal from plants!

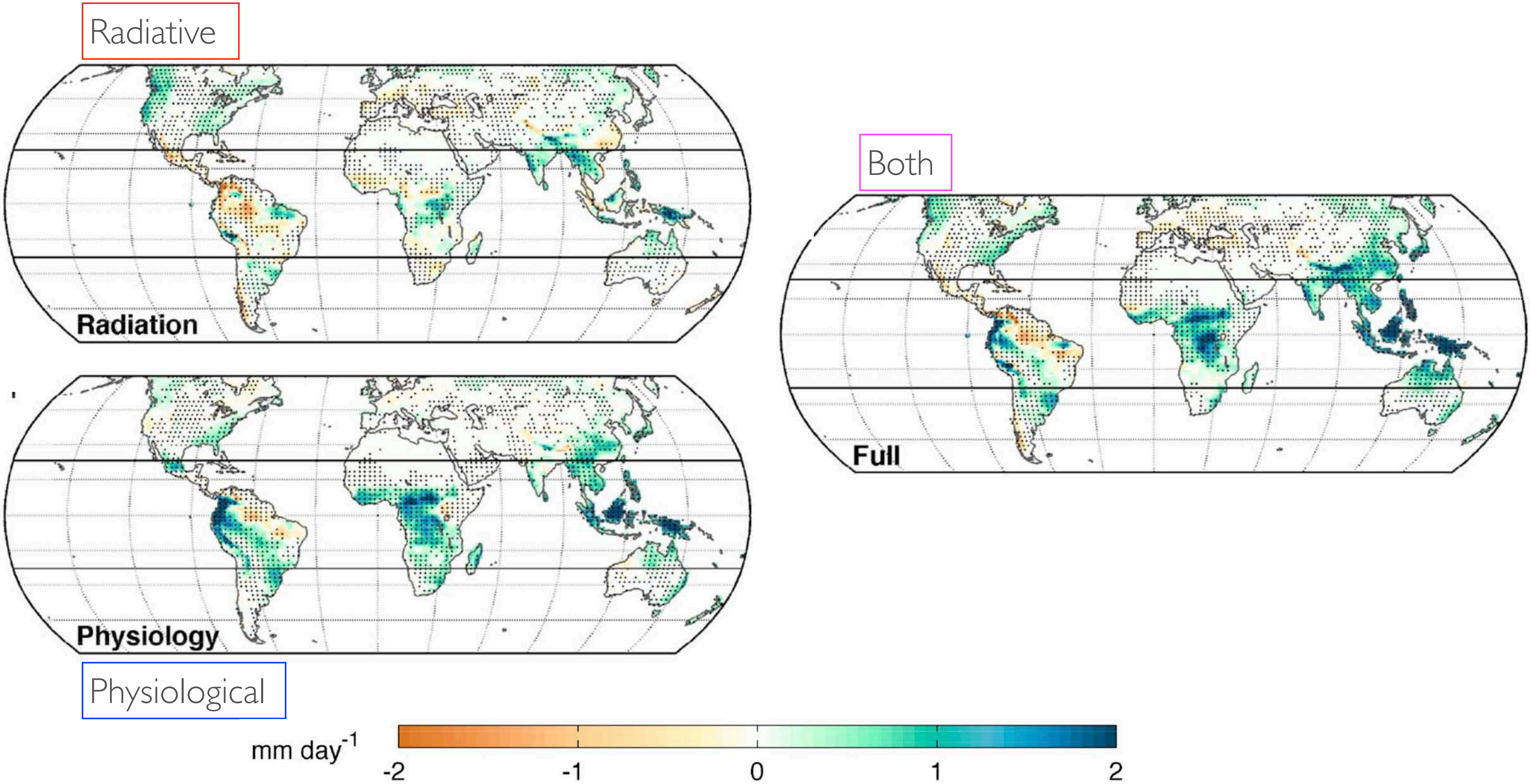
And it's all local to each continent, not due to circulation



Based on 7 models from CMIP5 at 4X CO_2

Kooperman et al. *Nat. Climate Change, 2018*

Runoff also has a big signal from plants!

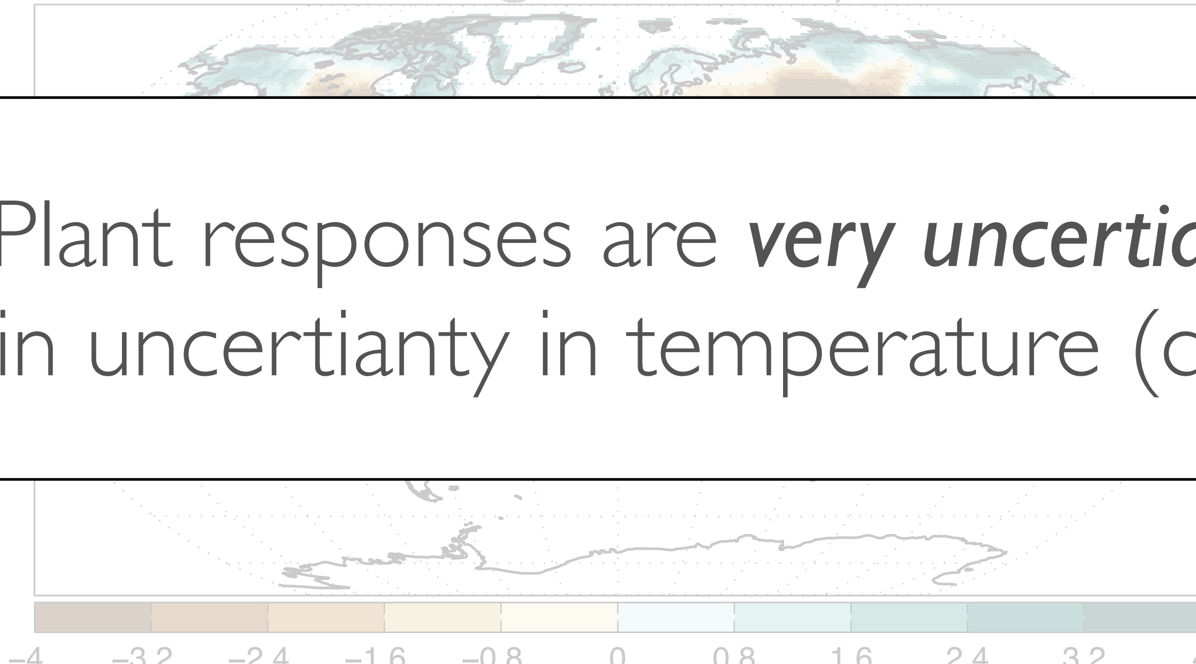


Based on CESM at 4X CO_2

Kooperman et al. *GRL, 2018*

Widespread drought?

ΔPalmer Drought Severity Index



Δ(Precipitation - ET)

mm/day

Plant responses are ***very uncertian*** => typically not accounted for in uncertianty in temperature (drought, etc) under future climate

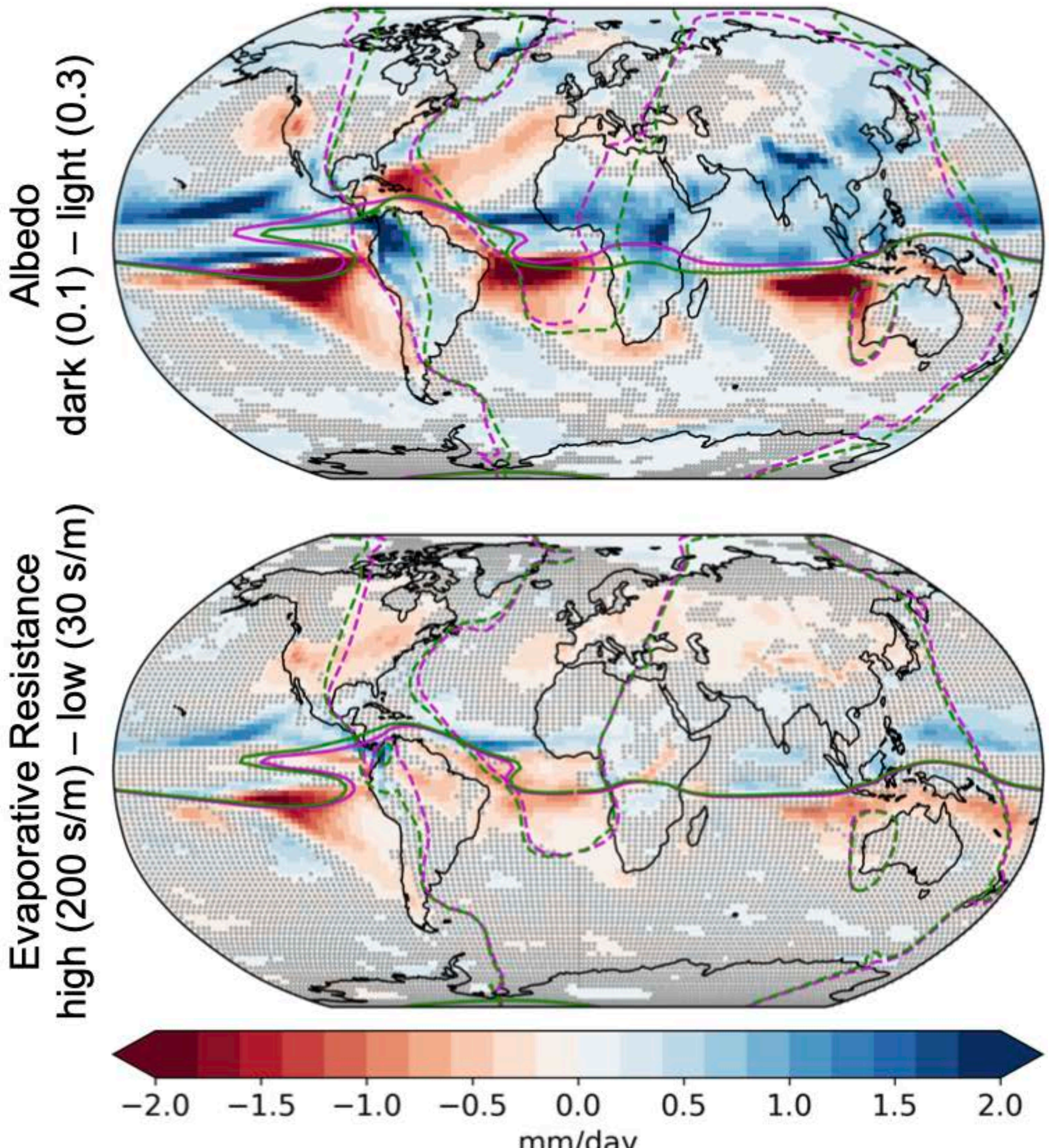
>70% of land area sees an increase in drought

36% of land area sees drier conditions

Based on 7 models from CMIP5 at 4X CO_2

Swann et al. 2016 *PNAS*

Sensitivity of Precipitation to land surface properties

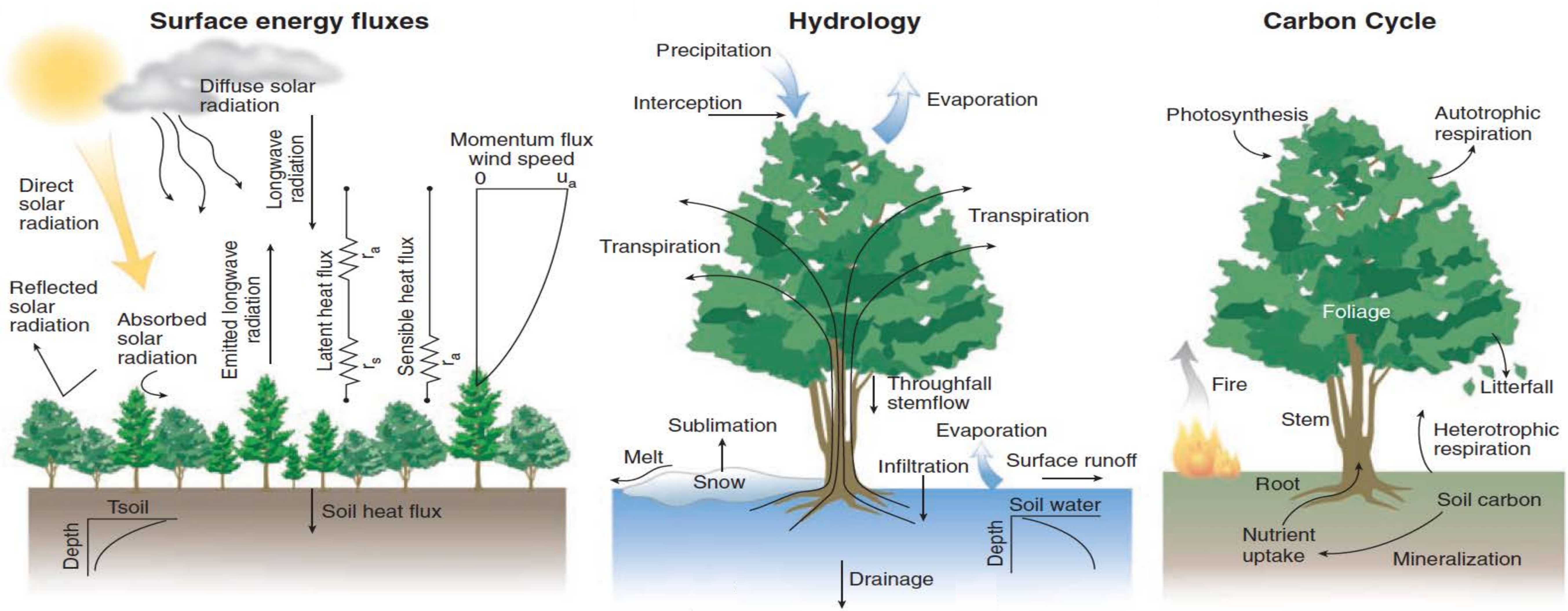


Darker surface

Harder to evaporate water

Marysa Laguë PhD dissertation, 2019

Find the climate impact of plant assumptions



There are ~200 parameters in the land component of CESM

Community Earth System Model (CESM)

Bonan 2008

Find the climate impact of plant assumptions

Vary 18 plant parameters with biggest impact on surface energy fluxes

Plant functioning & plant traits

- Albedo of stems
- Interception
- Stomatal conductance
- Photosynthesis
- Plant Hydraulics
- Biomass heat storage
- Canopy interception

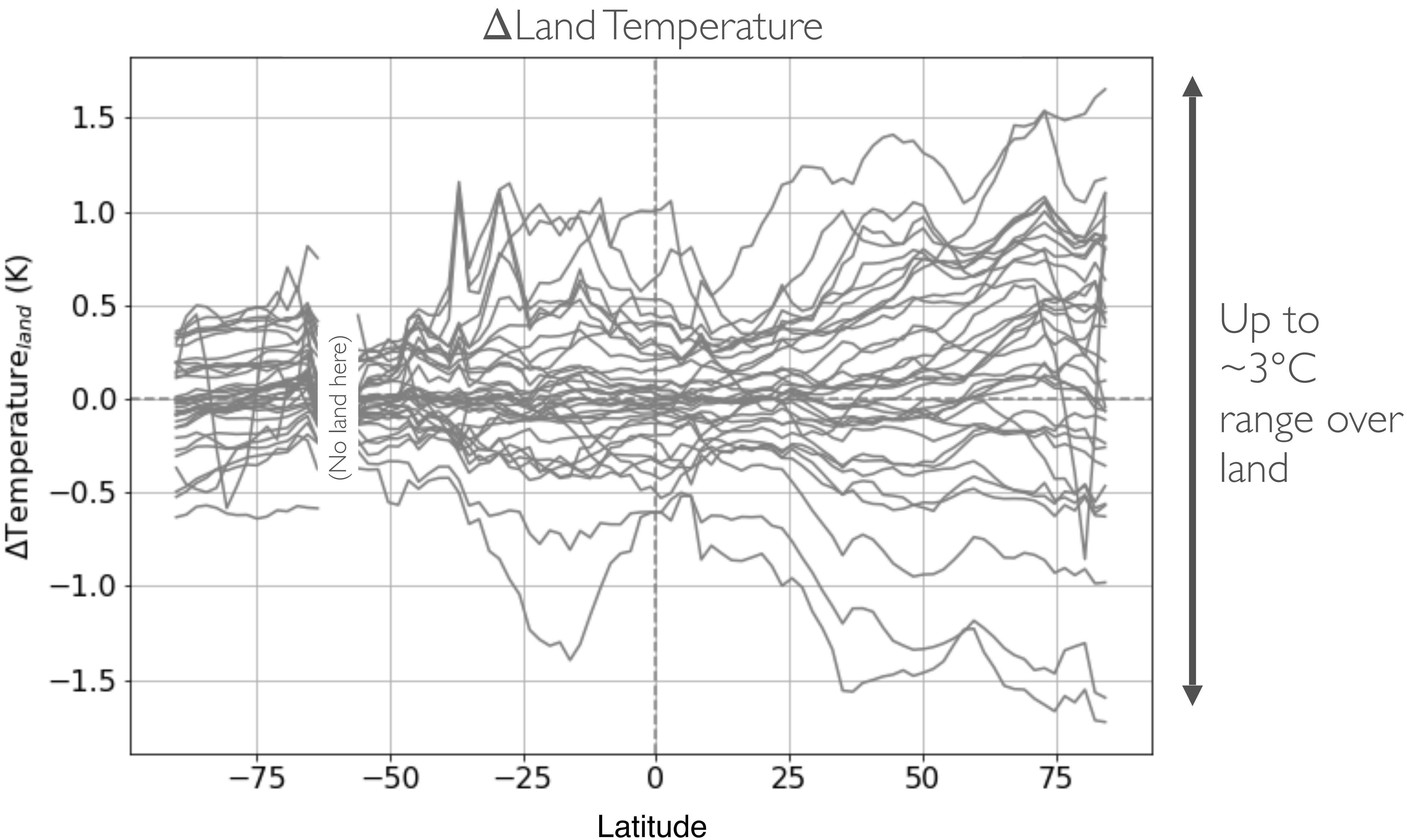
Other land uncertianty

- Dry soil layer at top of soil
- Snow
- Sand percentage in soil
- Roughness of snow

Leveraging work by Daniel Kennedy, Katie Dagon, David Lawrence et al.
to run ~200 parameters in the land-only version of CESM

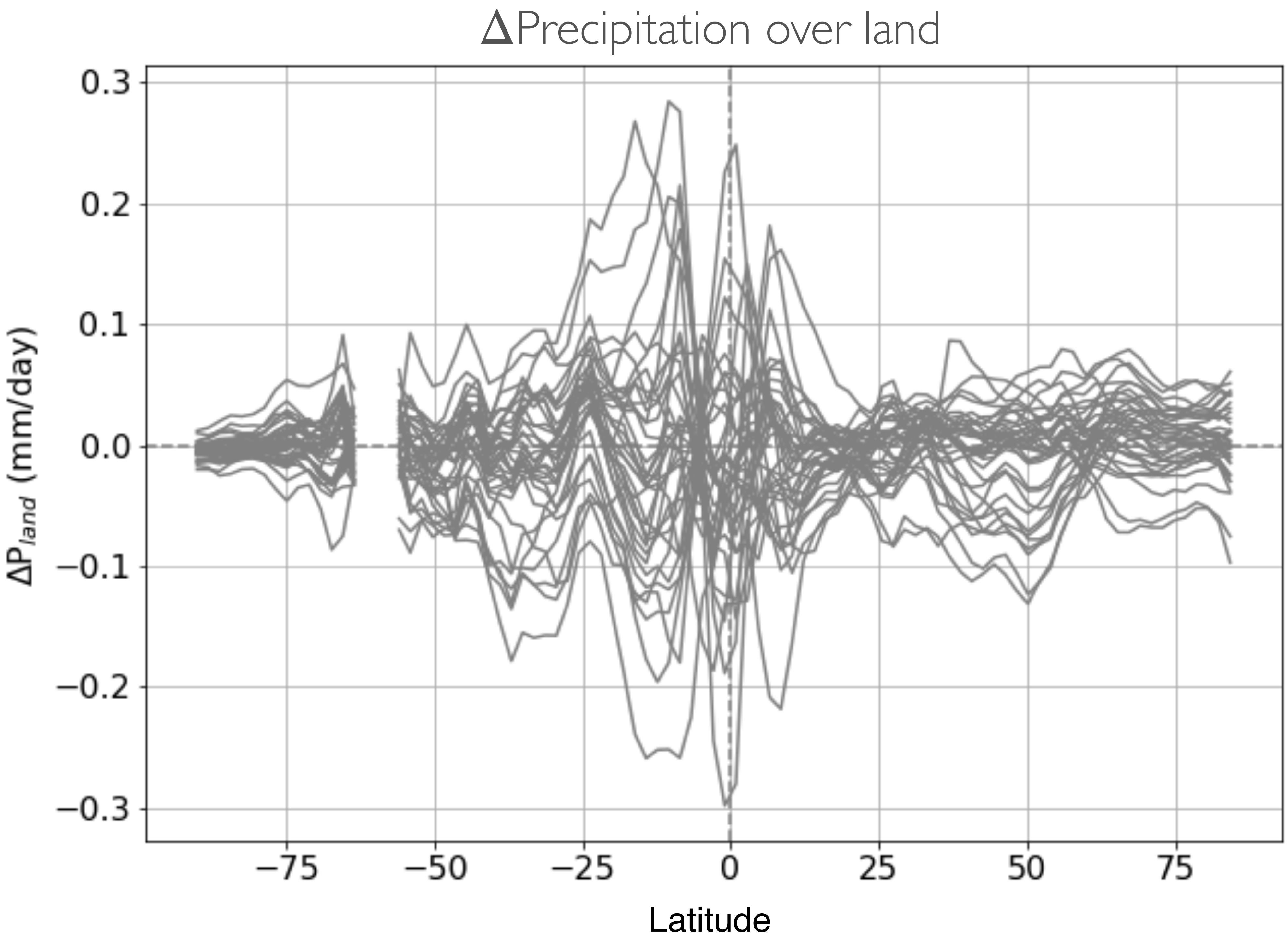
Claire Zarakas et al. *in prep*

Uncertianty in land parameters has *big impact* on temperature!



Claire Zarakas et al. *in prep*

Change in Precipitation over land for different land assumptions



Up to ~200 mm/yr in tropics

Up to ~70 mm/yr in mid-latitudes

Claire Zarakas et al. *in prep*

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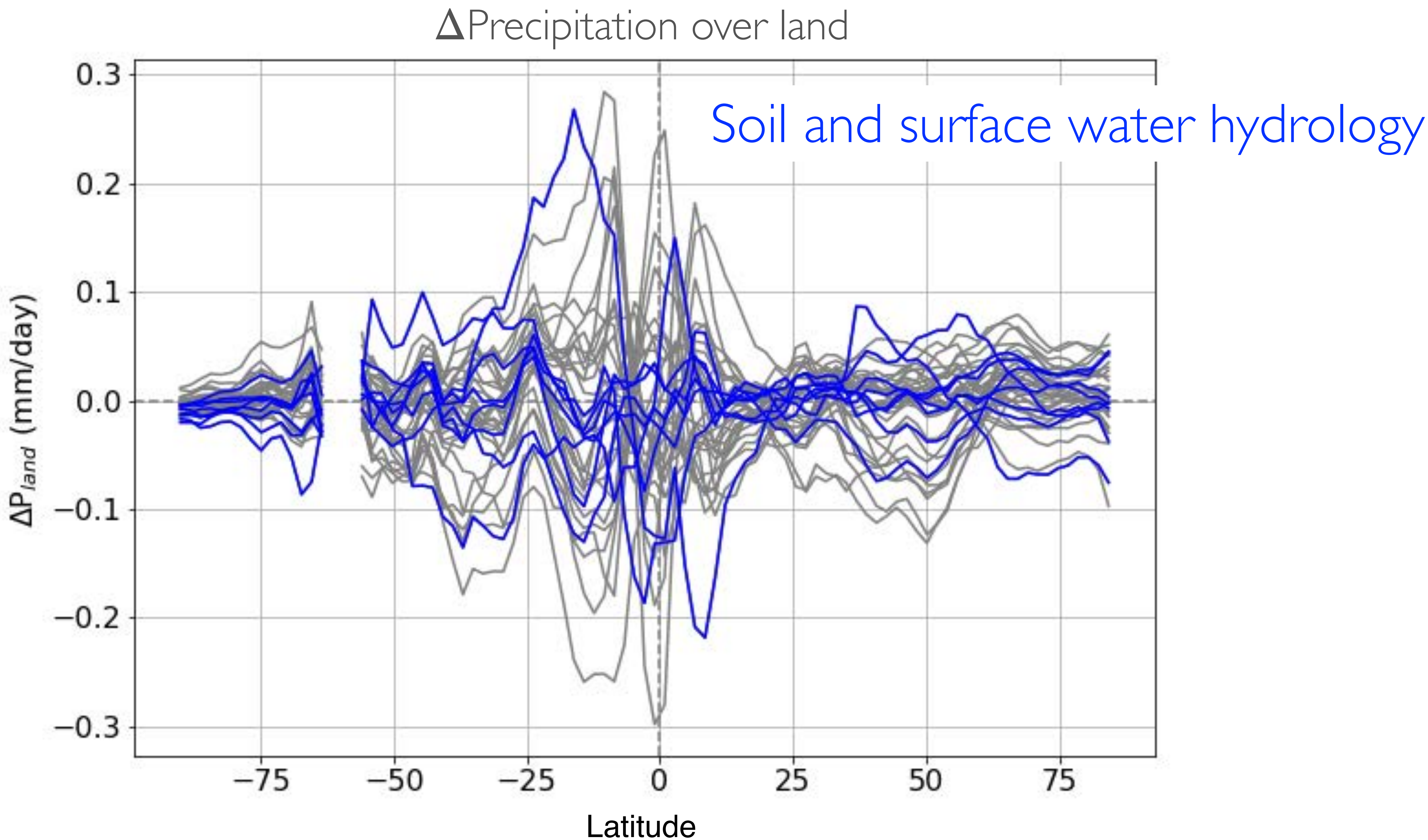

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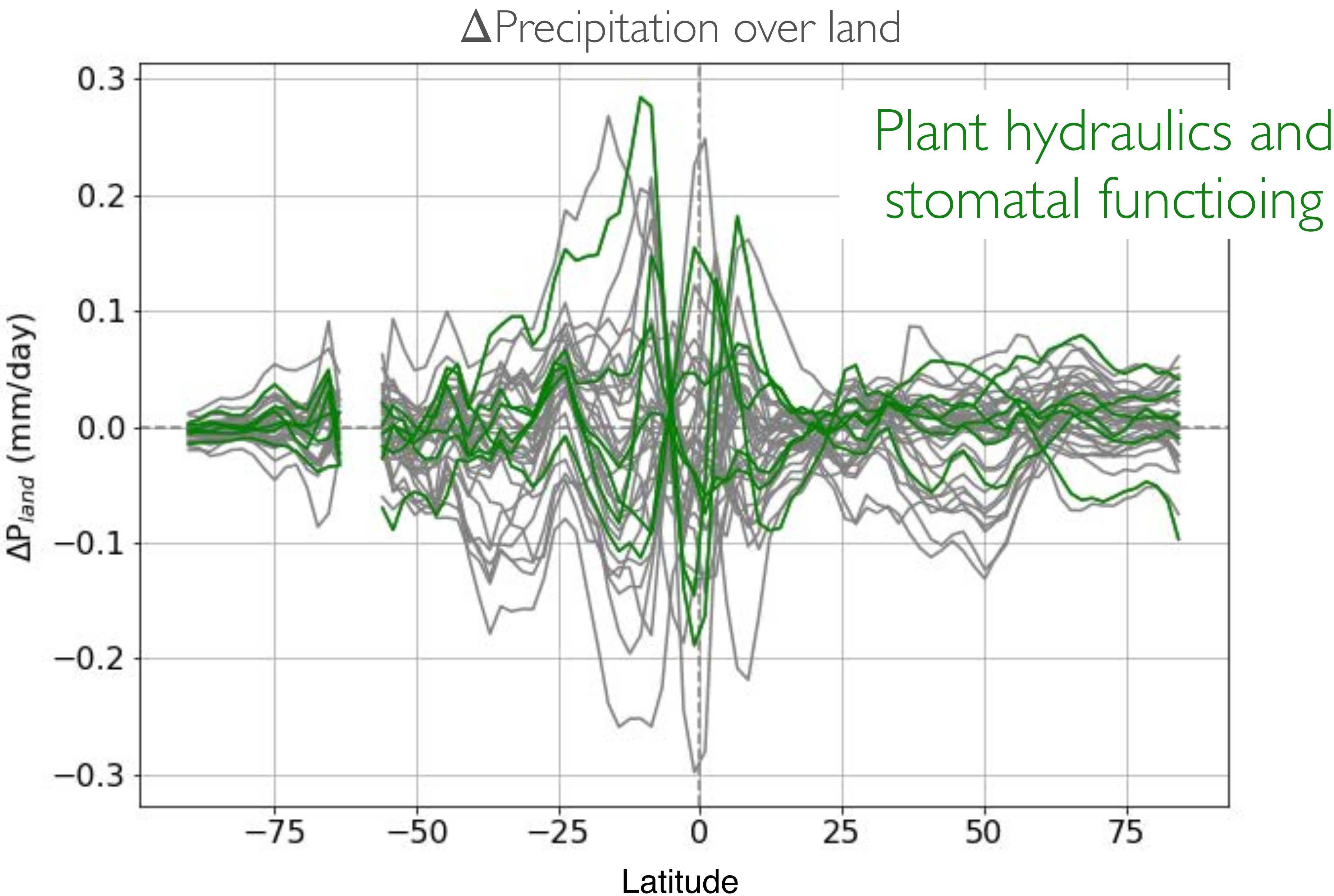

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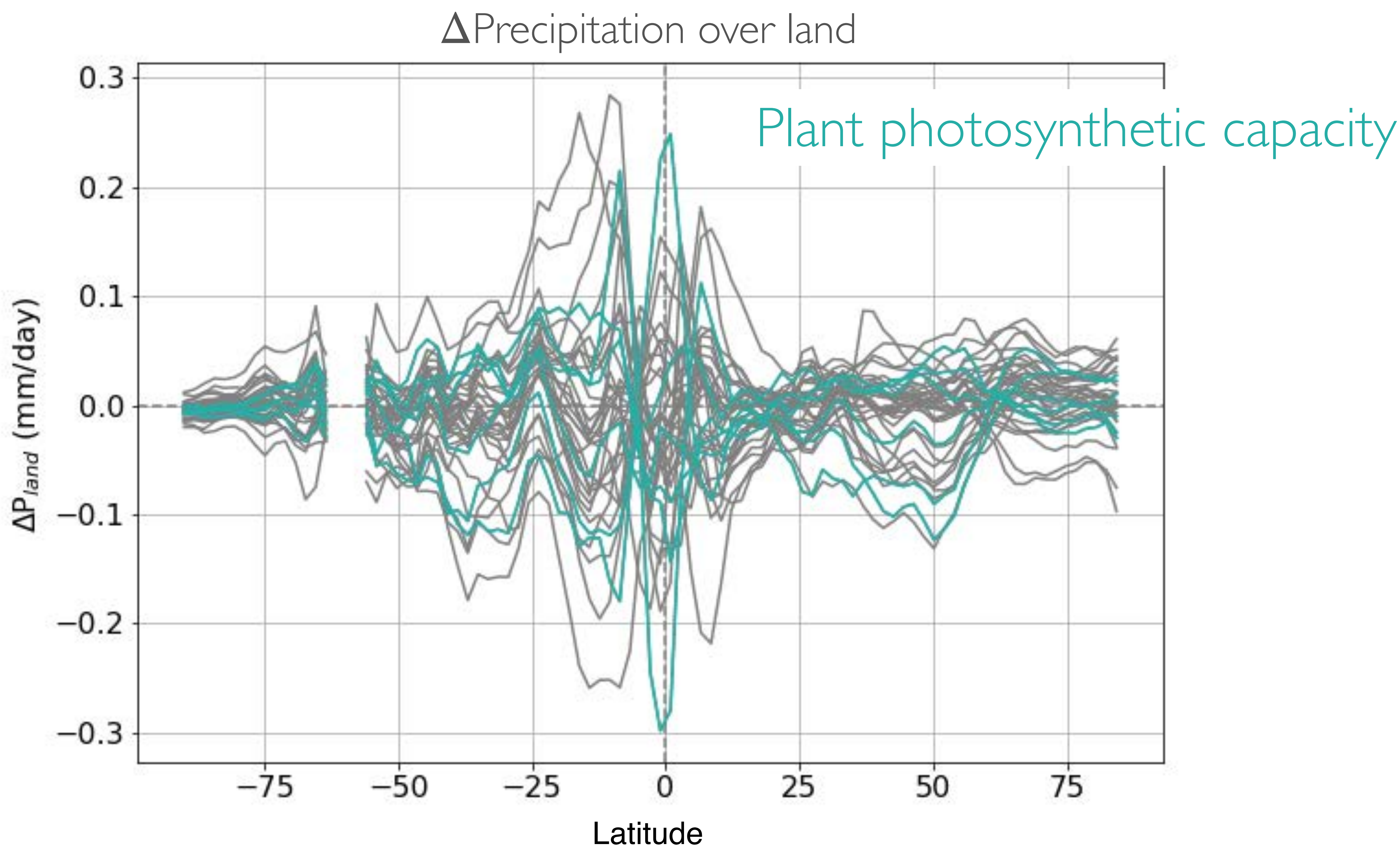
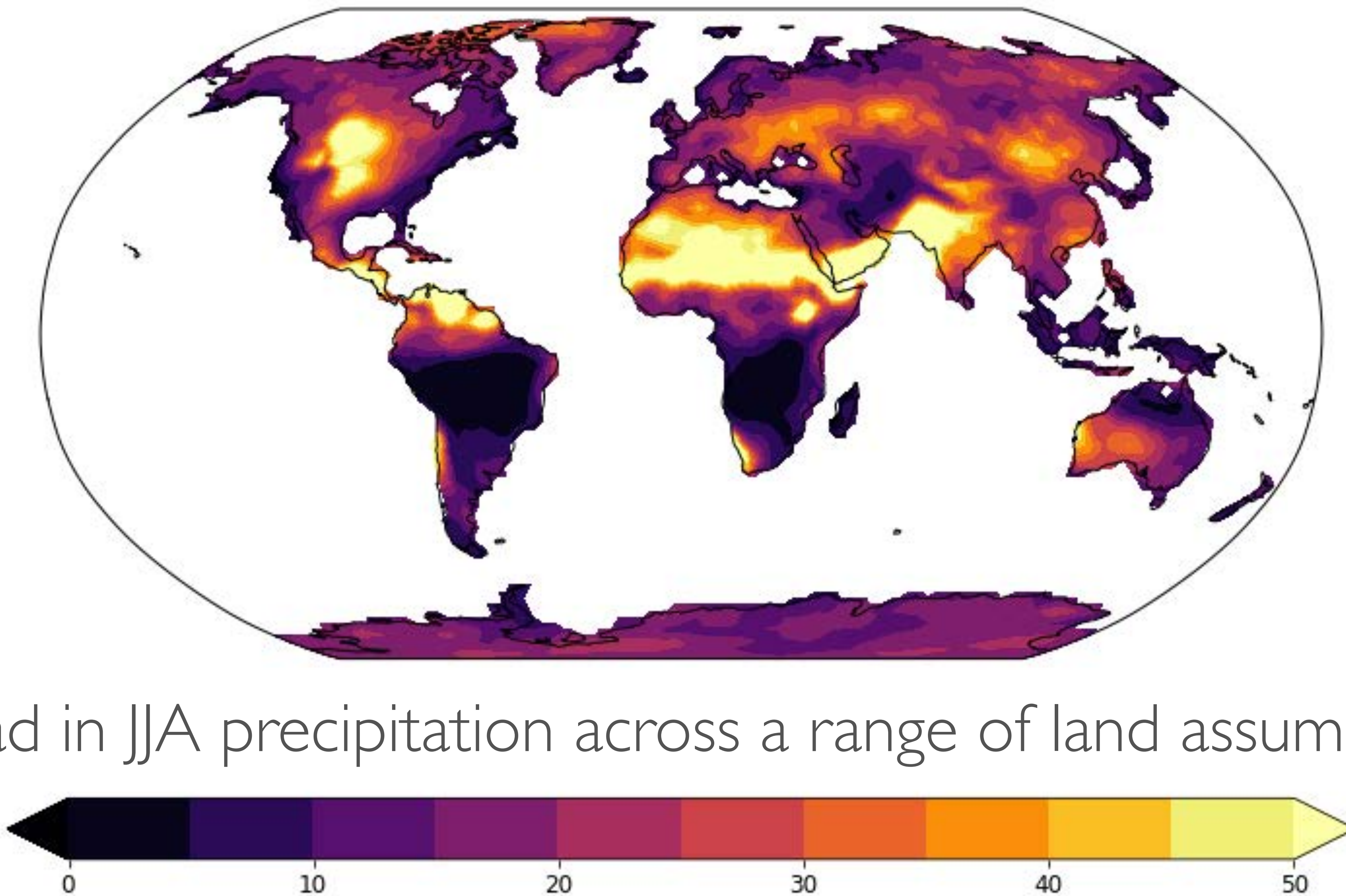


Claire Zarakas et al. *in prep*

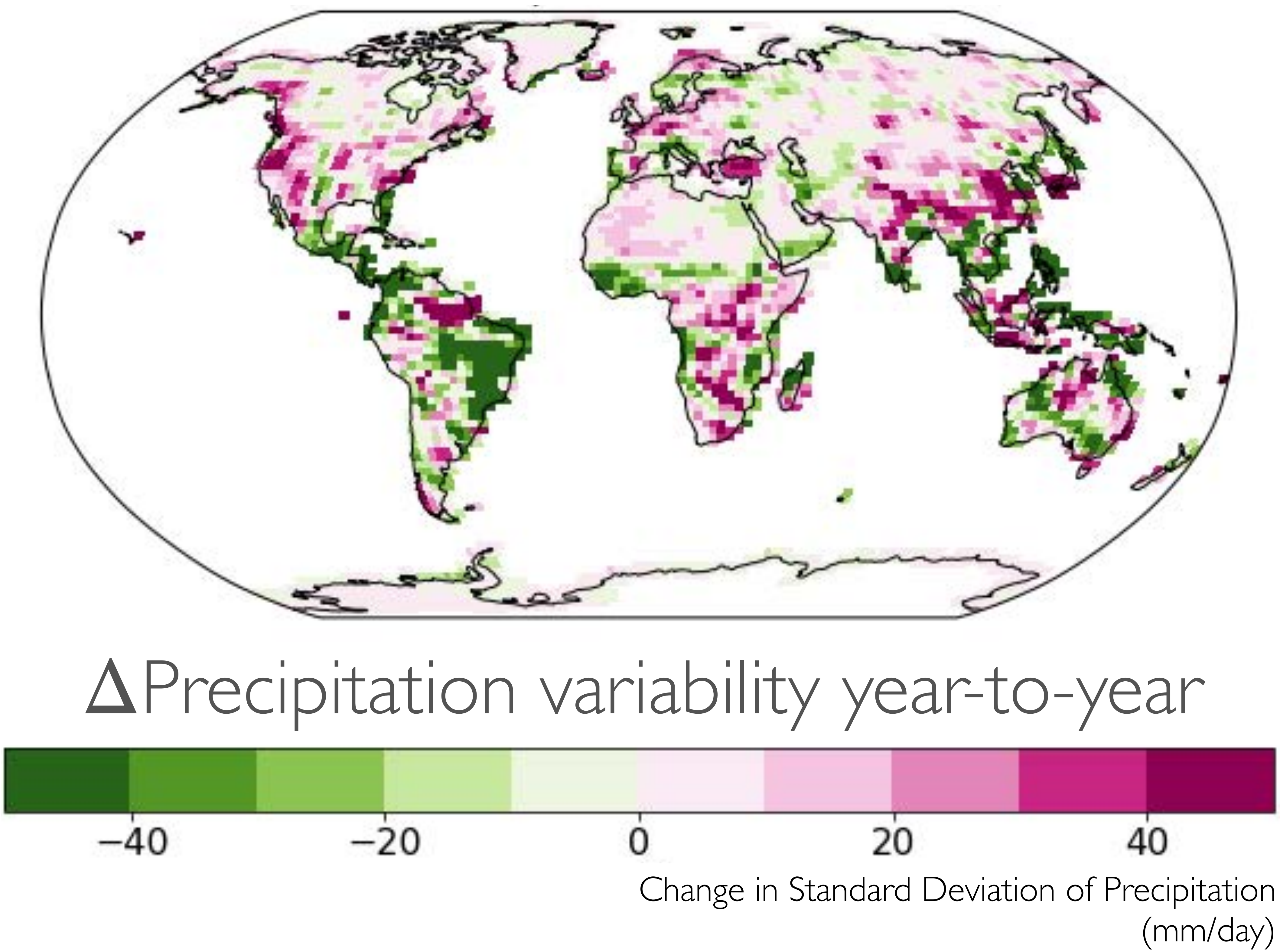
Where land uncertianty matters for total Precipitation



% Change in JJA Precipitation
(5th – 95th percentile range across ensemble)

Claire Zarakas et al. *in prep*

Where land uncertianty matters for volatility of Precipitation



Claire Zarakas et al. *in prep*

Biological uncertianty has a large impact on *hydroclimate*

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Changes in plant distributions and functioning impact hydroclimate

- Local impacts
- Remote impacts

Biological uncertianty has a large impact on *hydroclimate*

Changes in plant distributions and functioning impact hydroclimate

Local impacts

Remote impacts

We need to be very careful *predicting impacts* using metrics that ***ignore*** plant responses to climate even if they are *uncertain*

Biological uncertianty has a large impact on *hydroclimate*

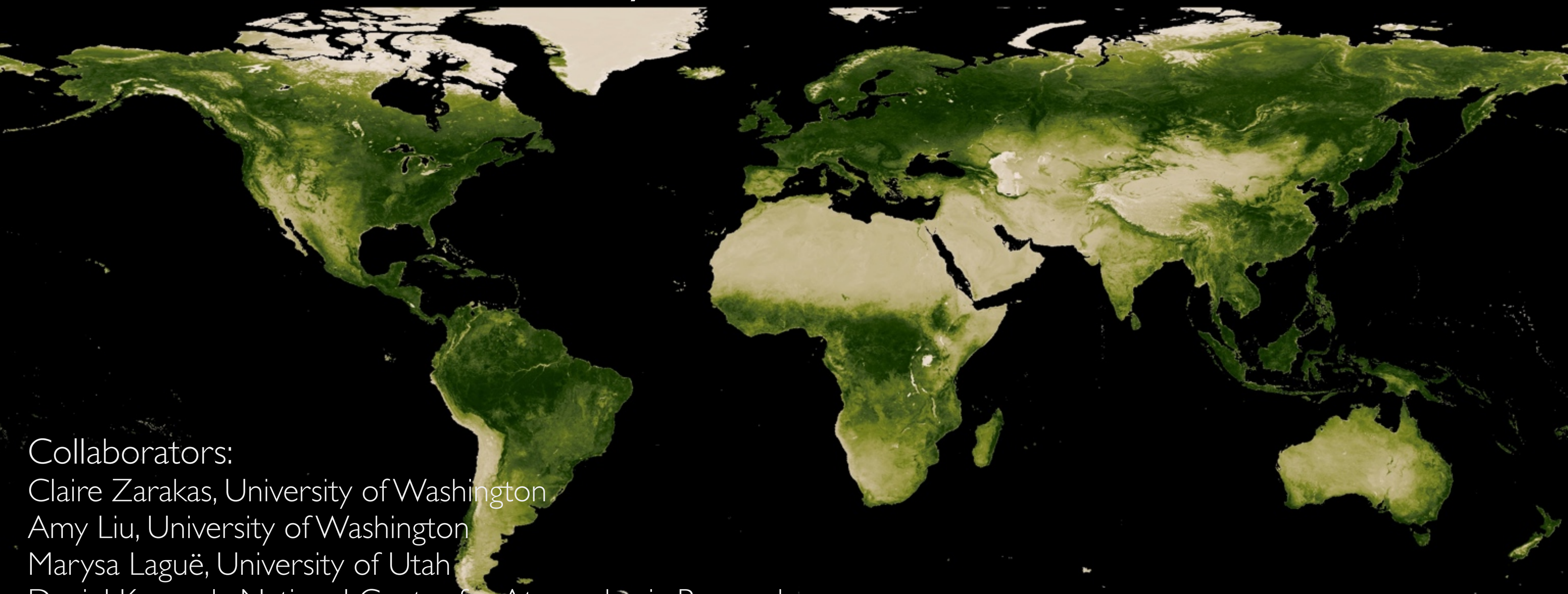
Changes in plant distributions and functioning impact hydroclimate

- Local impacts
- Remote impacts

We need to be very careful *predicting impacts* using metrics that ***ignore*** plant responses to climate even if they are *uncertain*

Even physical climate variables can have a large influence from assumptions about plants

Quantifying the Role of Vegetation on Hydroclimate



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