Diagnosing Drought in a Changing Climate

NOAA George E. Marsh Album

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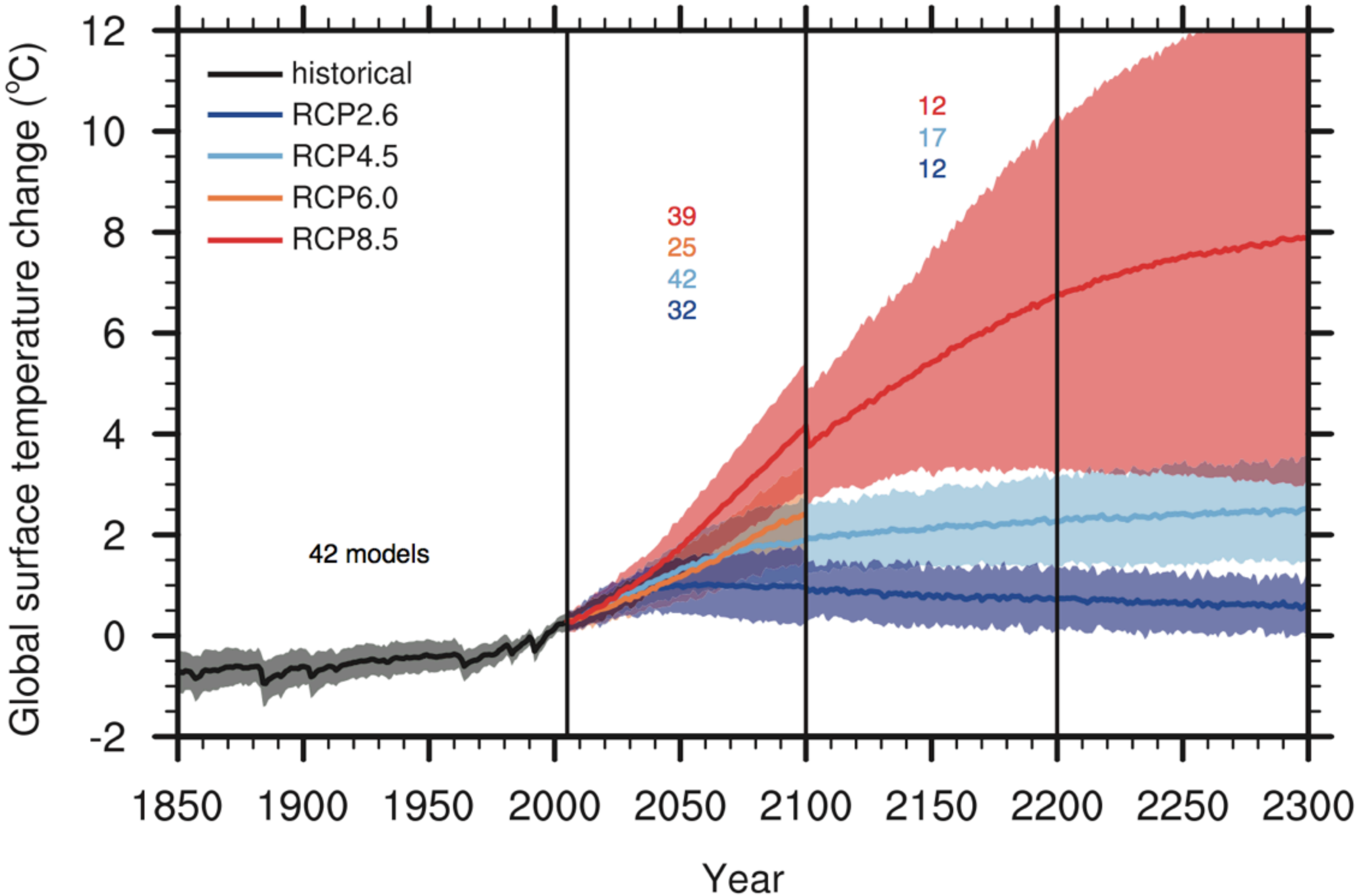
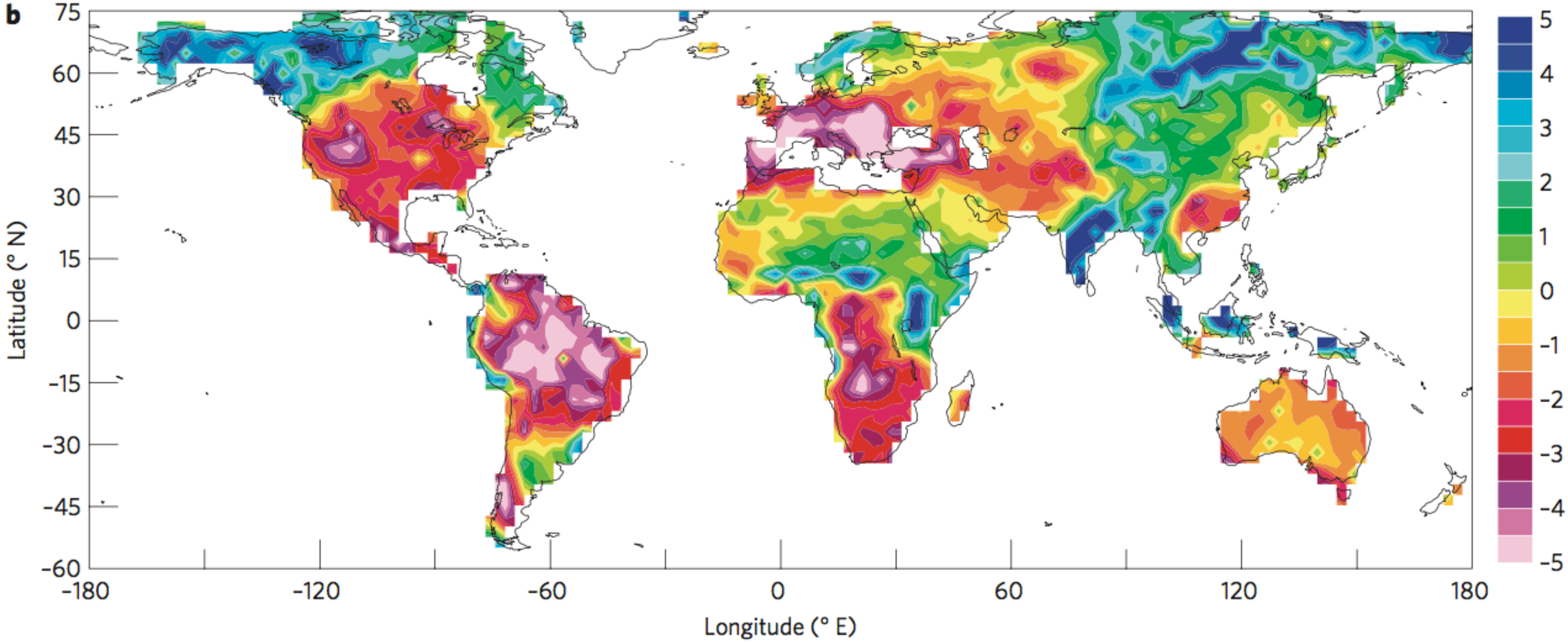
Temperatures are going up due to greenhouse gasses



IPCC AR5 Fig. 12.5

Droughts are predicted to become more severe



PDSI 2080-2100 relative to now

Dai 2013, Nat Clim Change

If rainfall is low compared to "*normal*", but plants and water supplies are not affected...

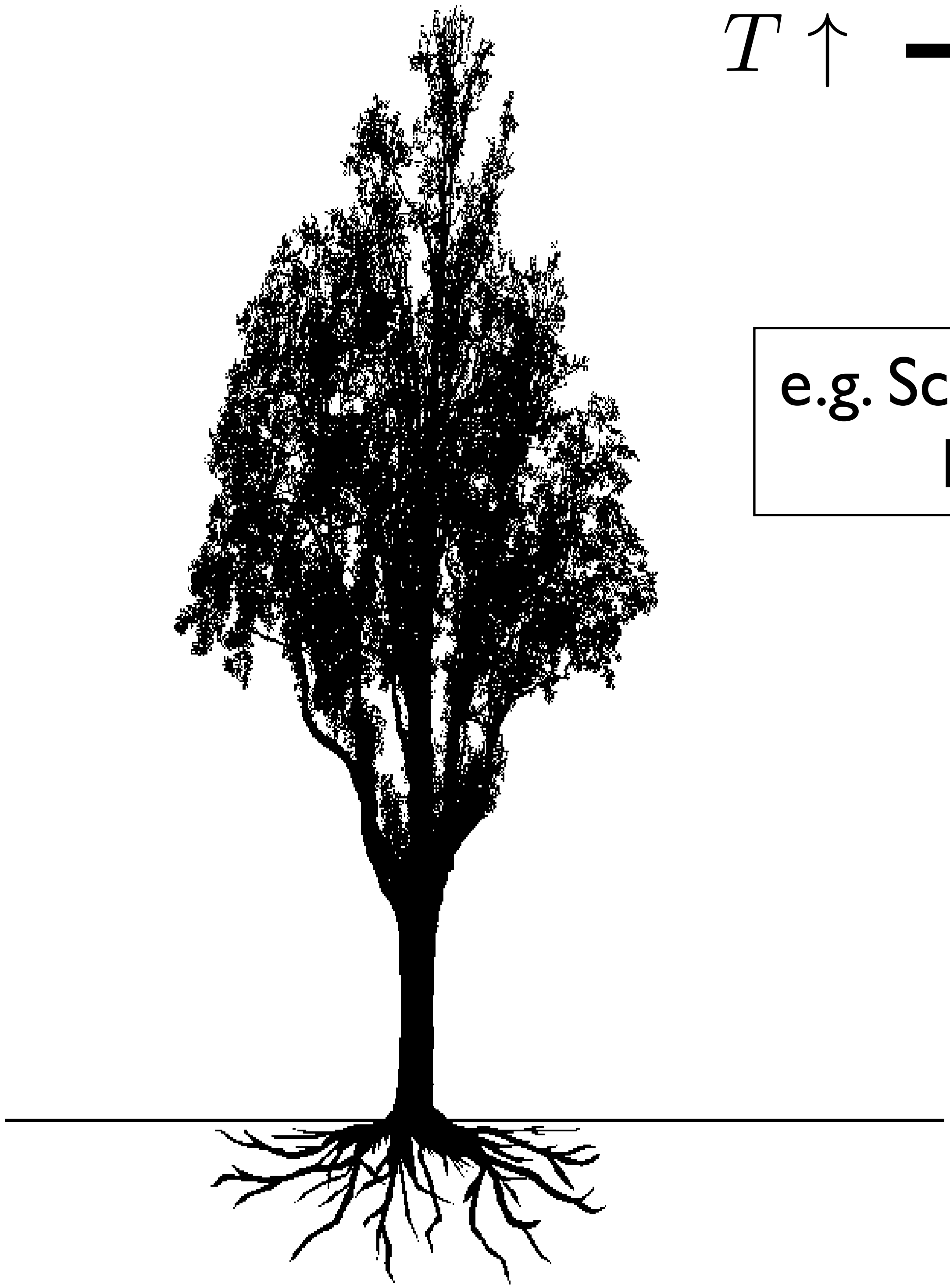
Is it a ***drought***?

If rainfall is low compared to "*normal*", but plants and water supplies are not affected...

Is it a ***drought***?

=> is the plant stressed by water?

Think like a tree



$T \uparrow \longrightarrow$ atmospheric demand is increasing

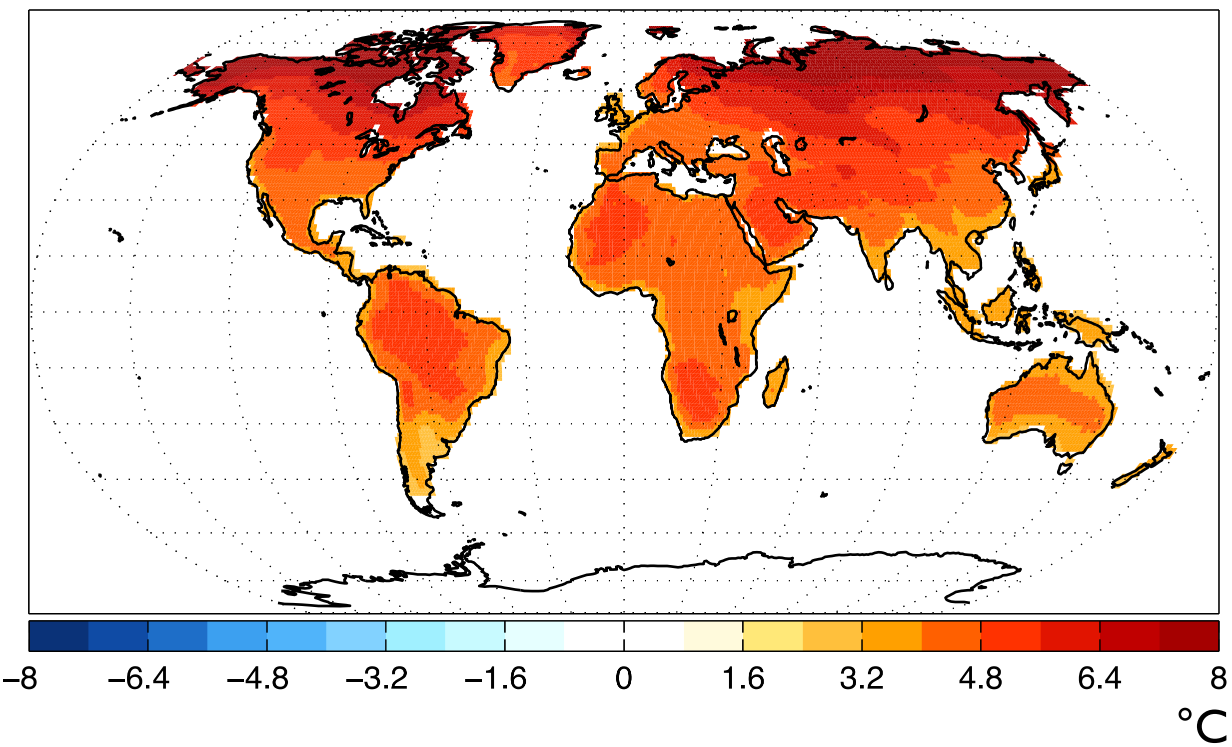
e.g. Scheff and Frierson 2014, Feng and Fu 2013

Tree: Charlie Koven

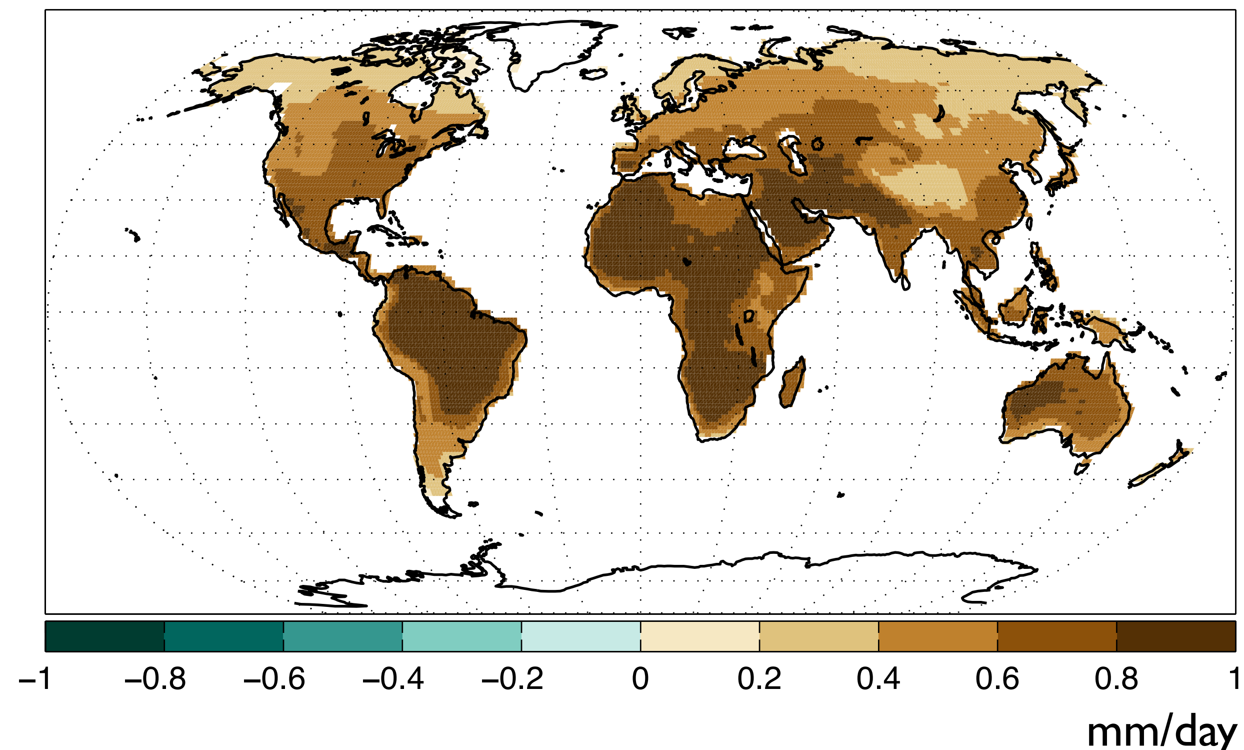
ΔTemperature leads to more atmospheric demand

$$T \uparrow \longrightarrow PET \uparrow$$

ΔTemperature



ΔPotential Evapotranspiration

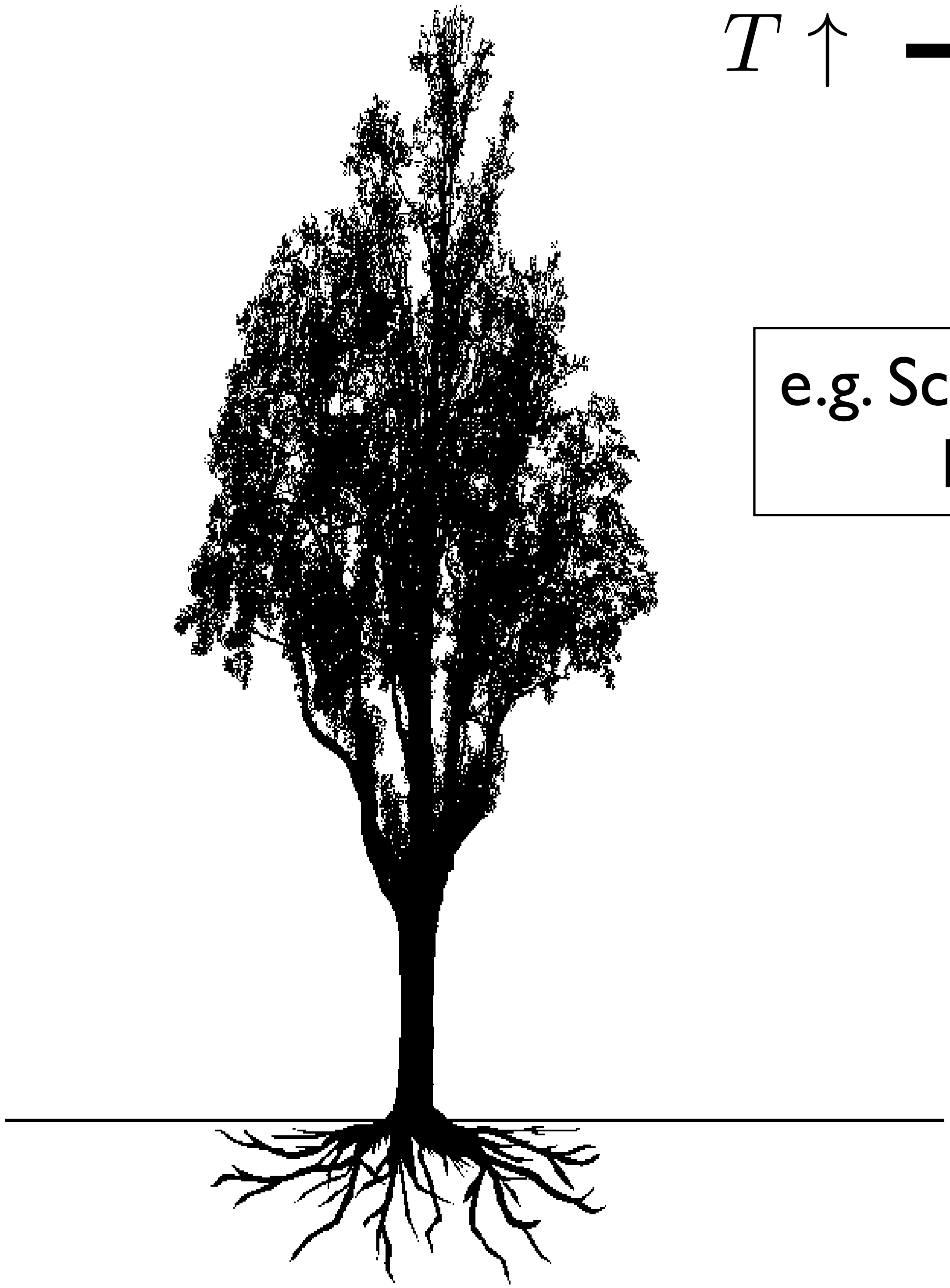


(calculated with Pennman-Monteith)

CMIP5 7 model mean, Change over 4X CO_2

Swann et al. 2016, PNAS

Think like a tree

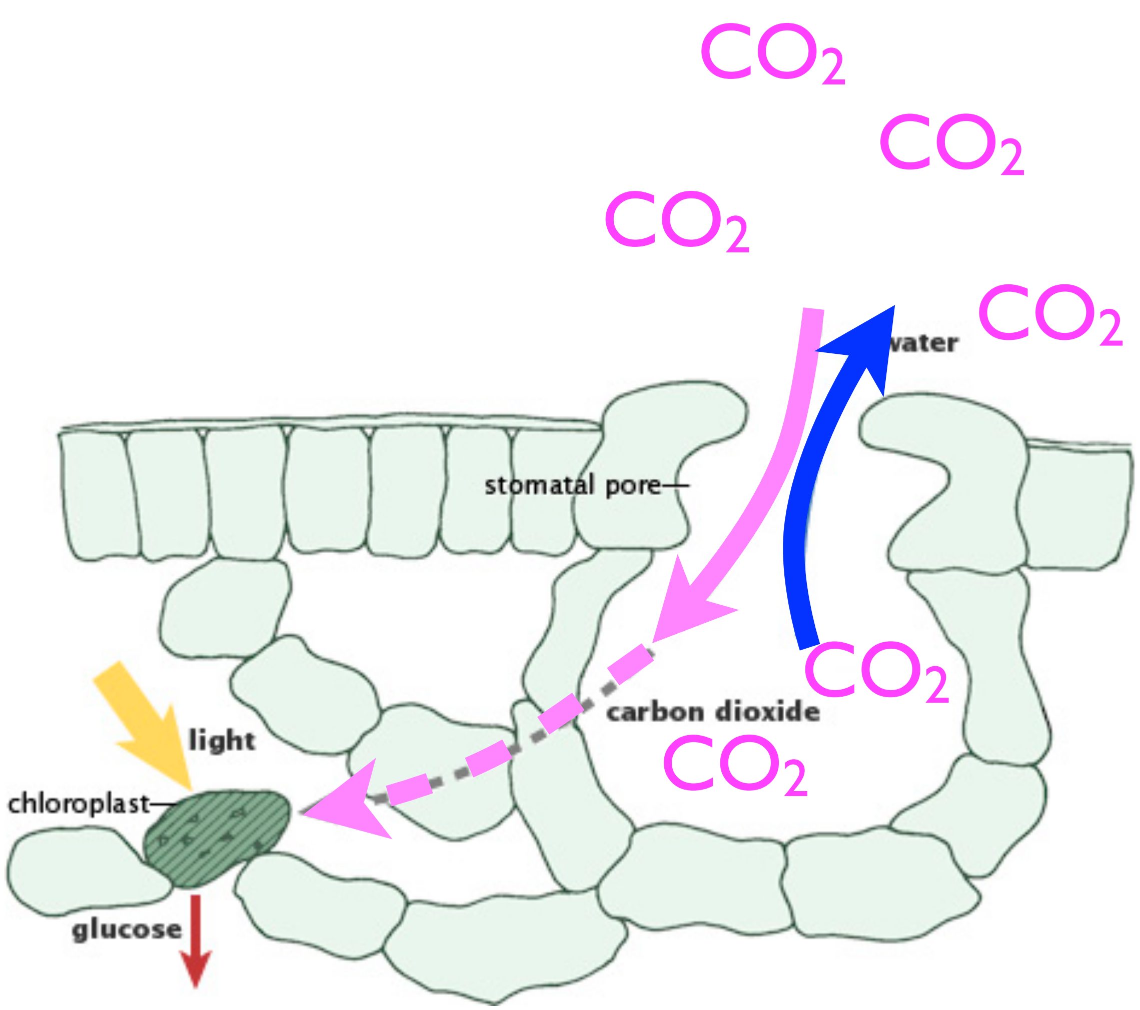


$T \uparrow$ ⟶ atmospheric demand is increasing

e.g. Scheff and Frierson 2014, Feng and Fu 2013

Tree: Charlie Koven

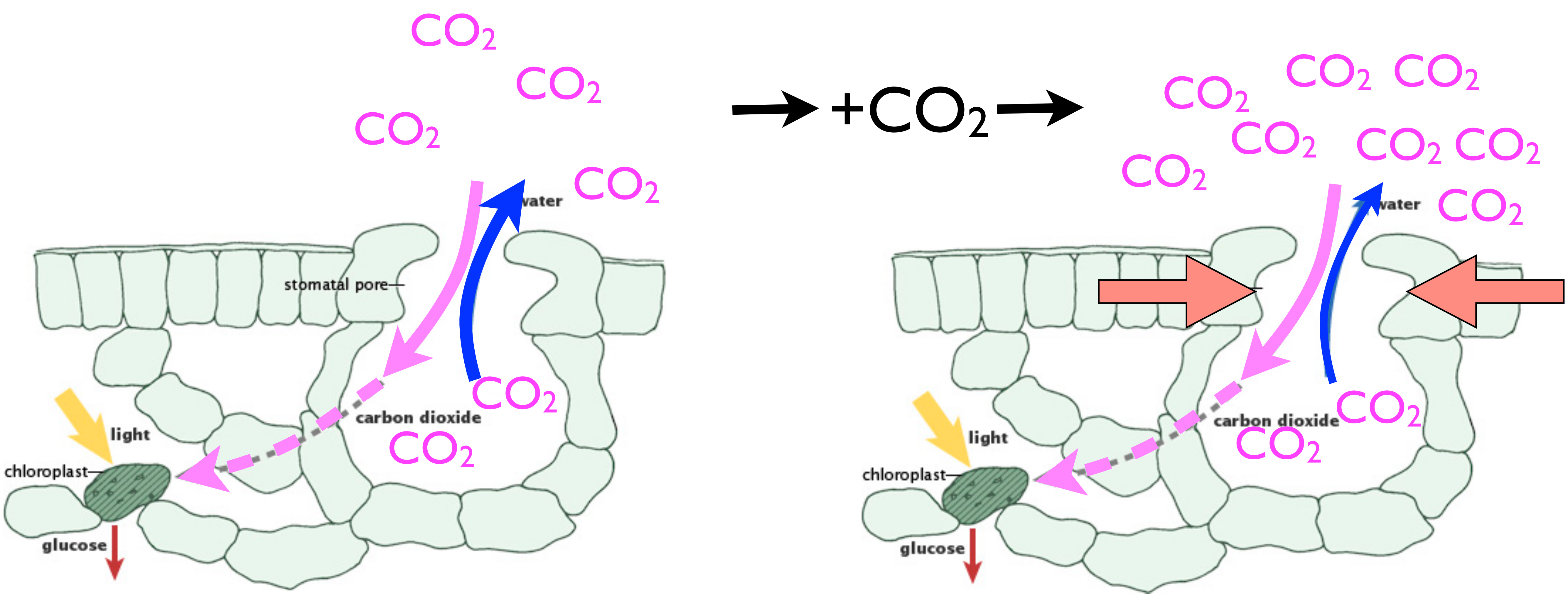
Stomatal conductance depends on CO_2



adapted from Sellers 1992

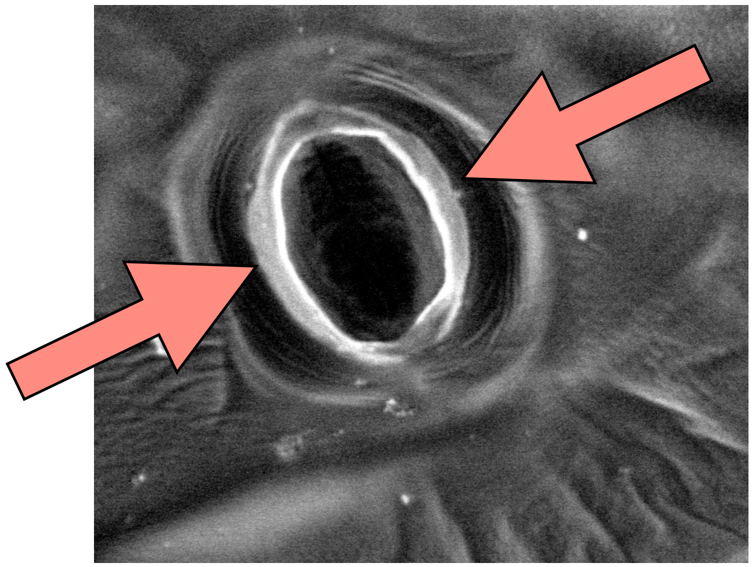
transpiration per CO_2 uptake => decrease under high CO_2

called *Water Use Efficiency (WUE)*



adapted from Sellers 1992

Think like a tree



$CO_2 \uparrow \longrightarrow WUE \uparrow$

$stomata \downarrow \quad transp \downarrow$

plants need
less water

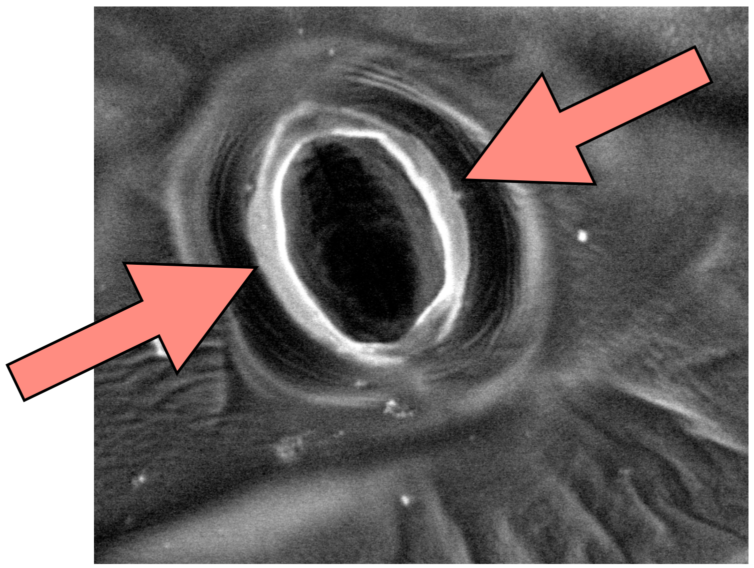
observations
support this
(tree rings, FACE)
climate models
show this

$T \uparrow \longrightarrow PET \uparrow$

demand
increasing

Tree: Charlie Koven

Think like a tree



$CO_2 \uparrow \longrightarrow WUE \uparrow$

$stomata \downarrow \quad transp \downarrow$

plants need *less* water

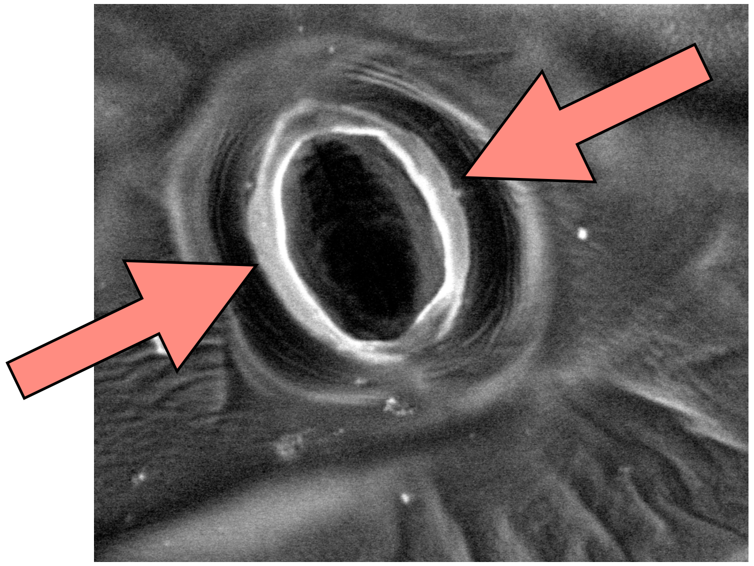
$T \uparrow \longrightarrow PET \uparrow$

demand increasing

which effect is larger?

Tree: Charlie Koven

Think like a tree



$CO_2 \uparrow \longrightarrow WUE \uparrow$

$stomata \downarrow \quad transp \downarrow$

plants need
less water

$T \uparrow \longrightarrow PET \uparrow$

demand
increasing

which effect
is larger?

Use the models to
figure this out

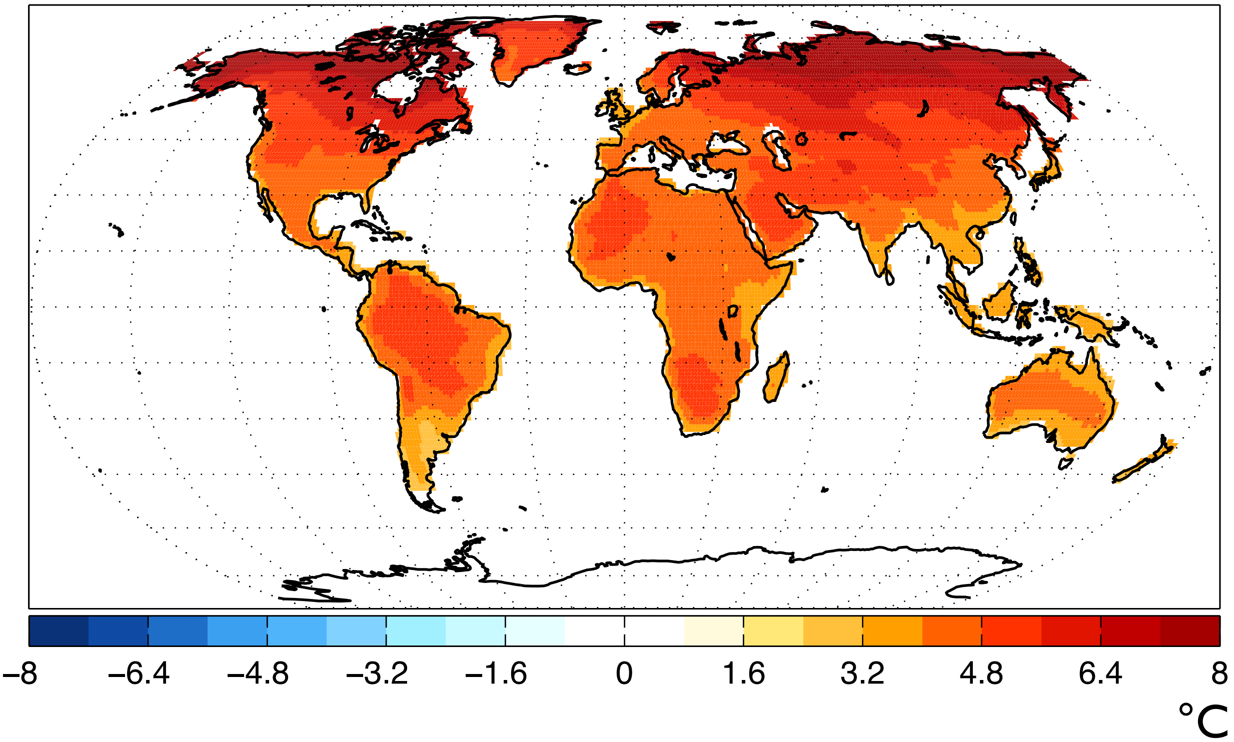
Use CMIP5 archive: how does water on land change in the future?

Tree: Charlie Koven

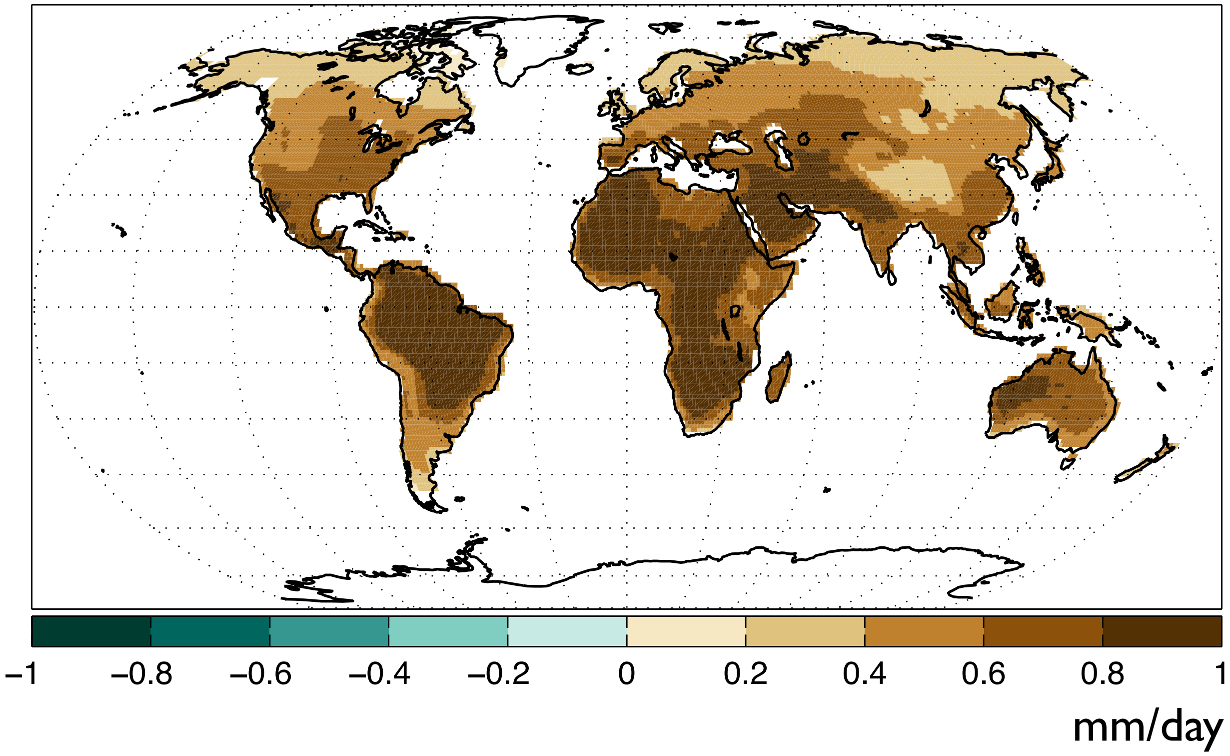
ΔTemperature leads to more atmospheric demand

$T \uparrow \longrightarrow PET \uparrow$

ΔTemperature



ΔPotential Evapotranspiration



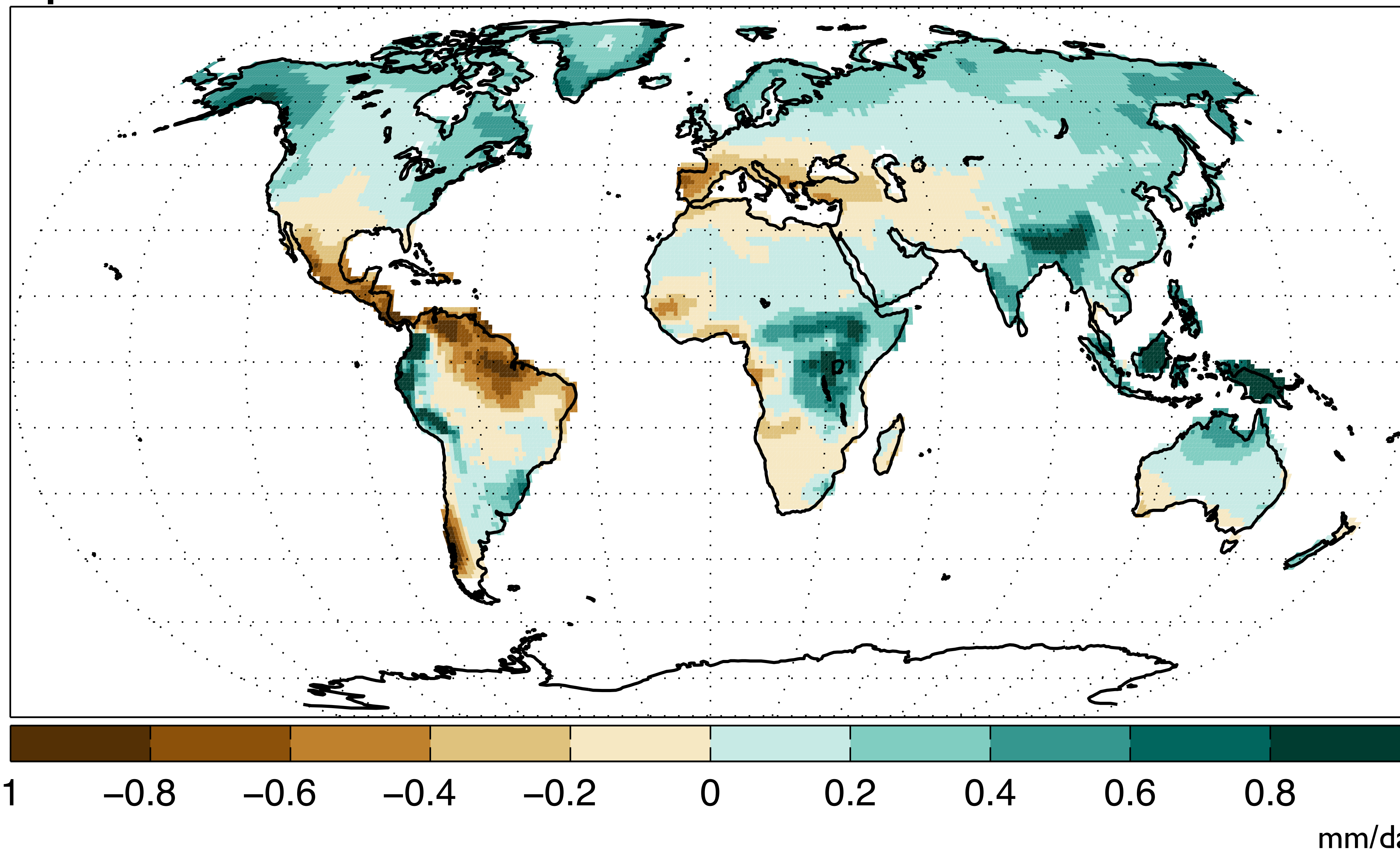
(calculated with Pennman-Monteith)

CMIP5 7 model mean, Change over 4X CO_2

Swann et al. 2016, PNAS

ΔPrecipitation (*supply*) more variable across space

ΔPrecipitation



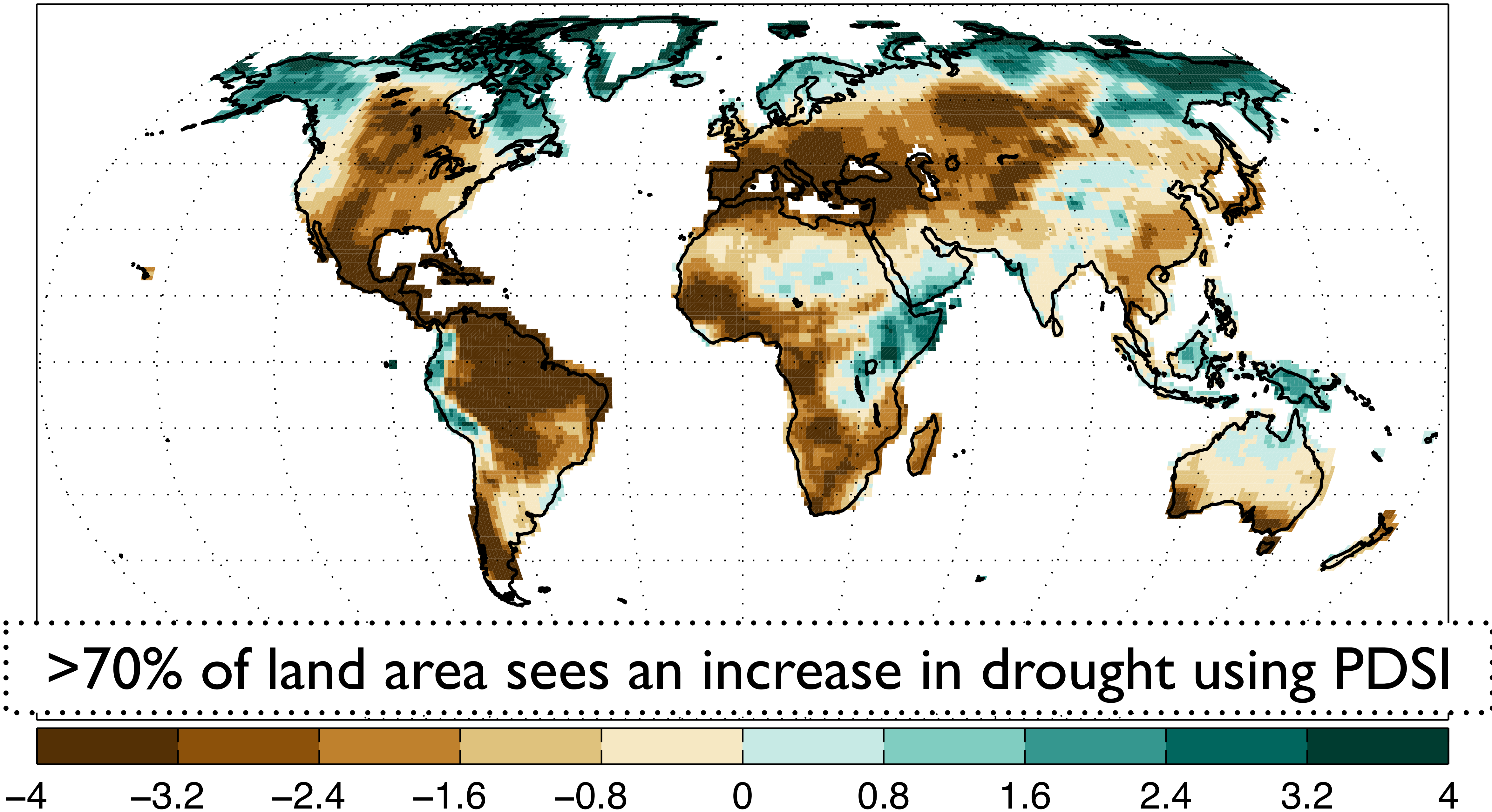
CMIP5 7 model mean, Change over 4X CO_2

Swann et al. 2016, PNAS

Palmer Drought Severity => Widespread drought

ΔPDSI

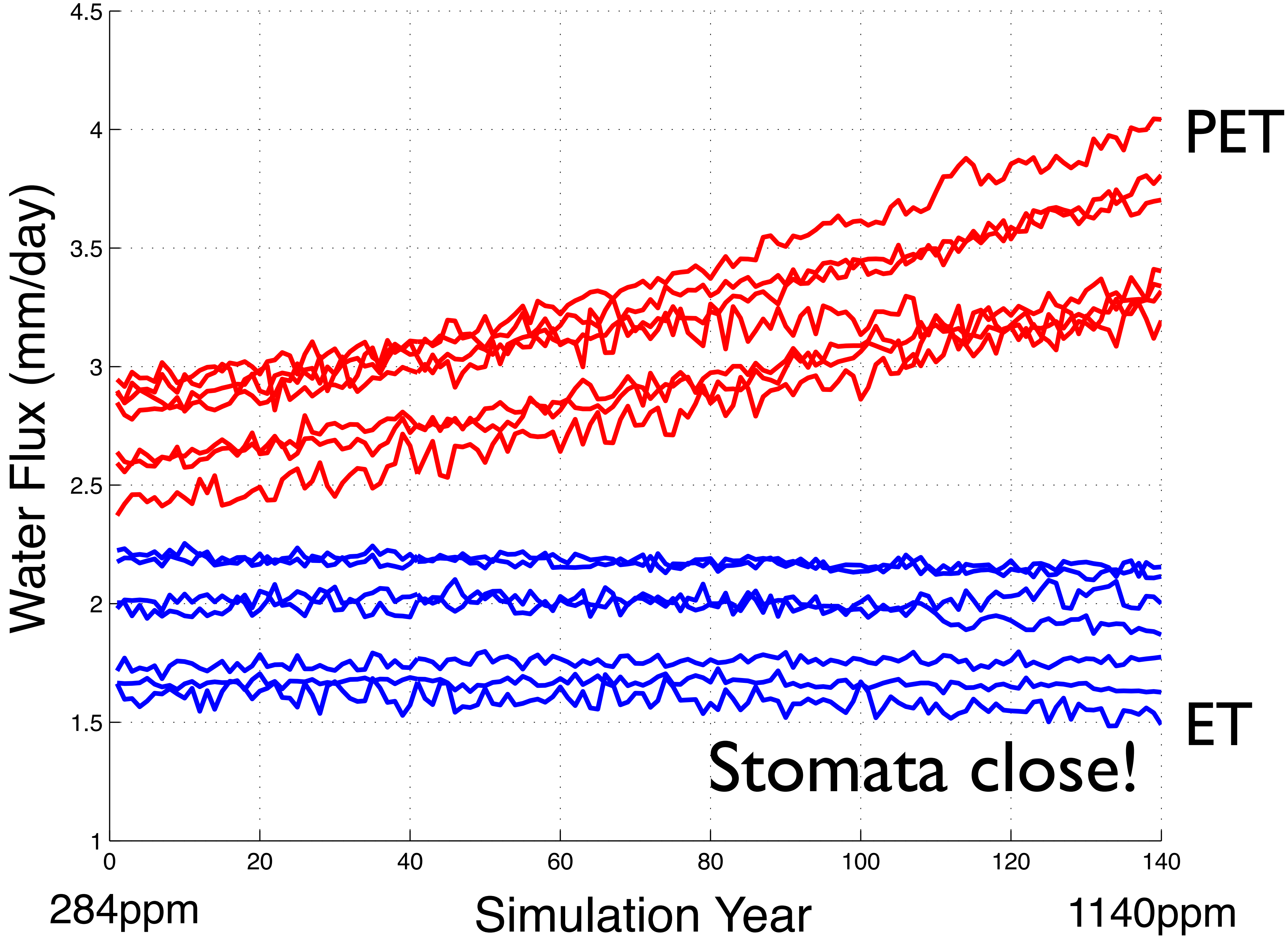
$$PDSI_i \sim PDSI_{i-1} + (P - PET)$$



CMIP5 7 model mean, Change over 4X CO_2

Swann et al. 2016, PNAS

PET *diverges* from actual ET as CO_2 increases



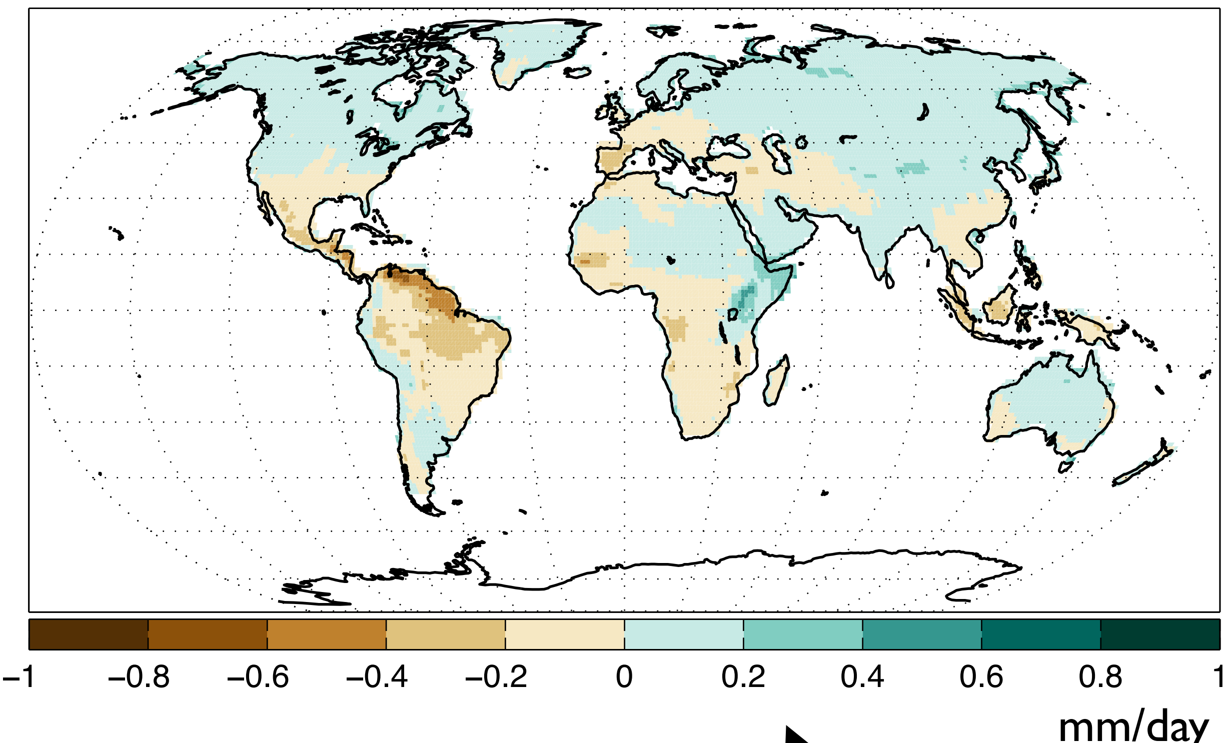
CMIP5 7 model mean, Change over 4X CO_2

Swann et al. 2016, PNAS

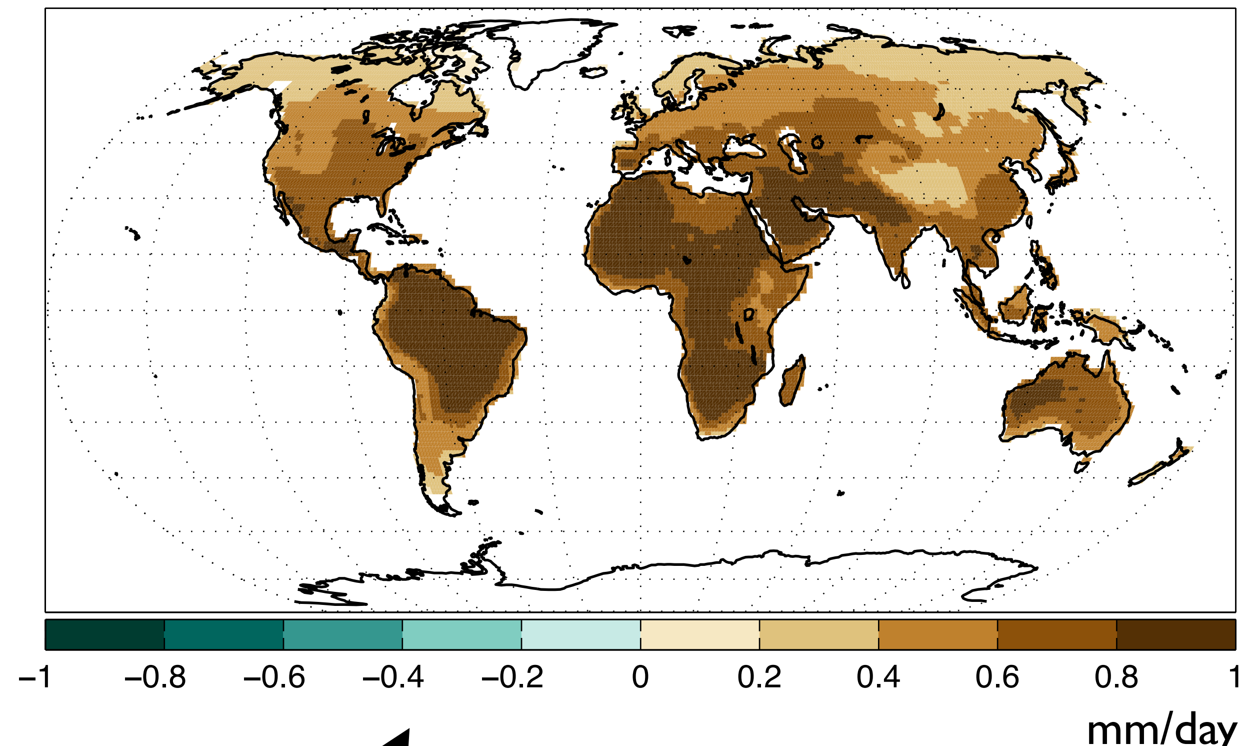
PET *diverges* from actual ET as CO_2 increases

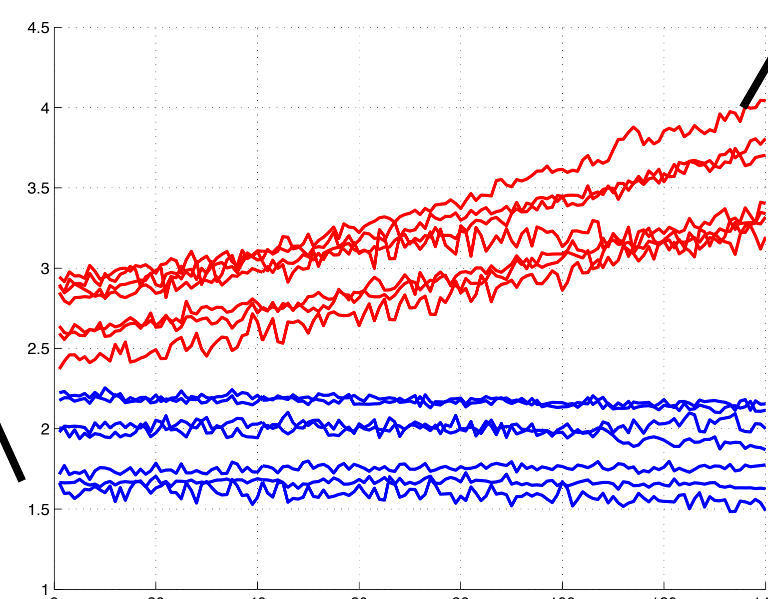
$ET \simeq$ $PET \uparrow$

ΔET



ΔPET



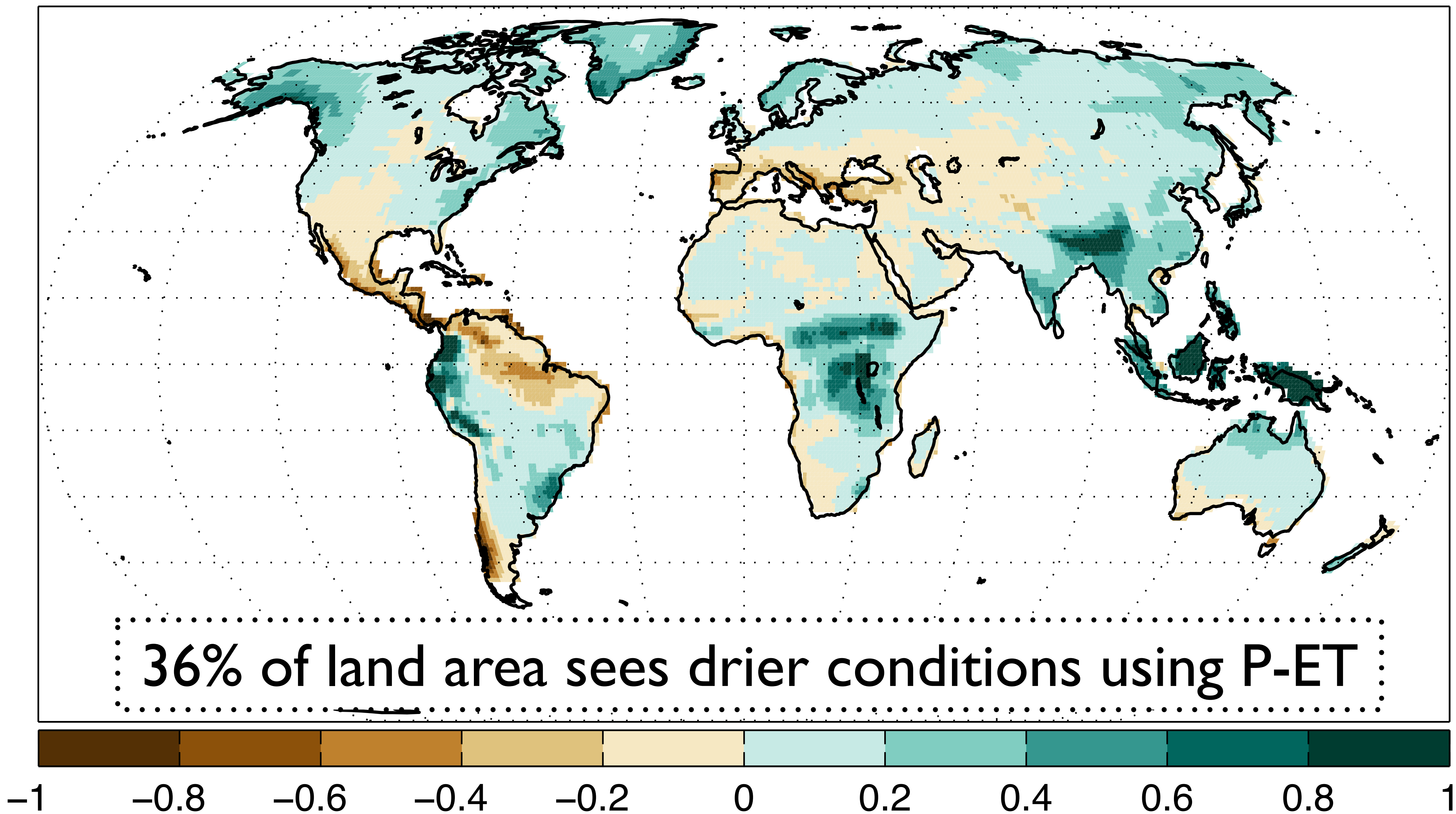


Swann et al. 2016, PNAS

Actual Water Deficit (P-ET) gets *smaller*

=> Widespread drought?

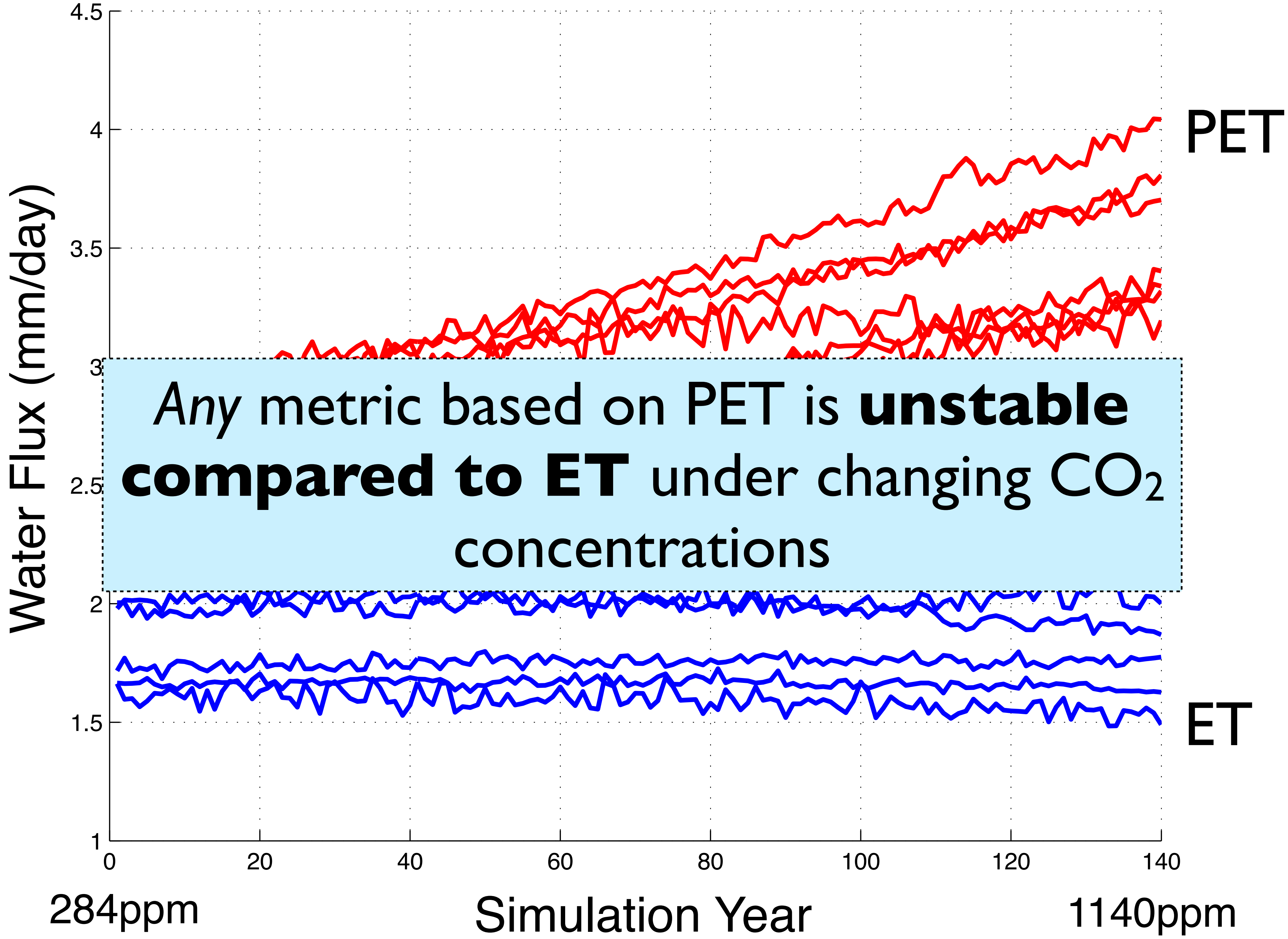
Δ(P-ET)



(compare to >70% for PDSI)

Swann et al. 2016, PNAS

PET *diverges* from actual ET as CO_2 increases



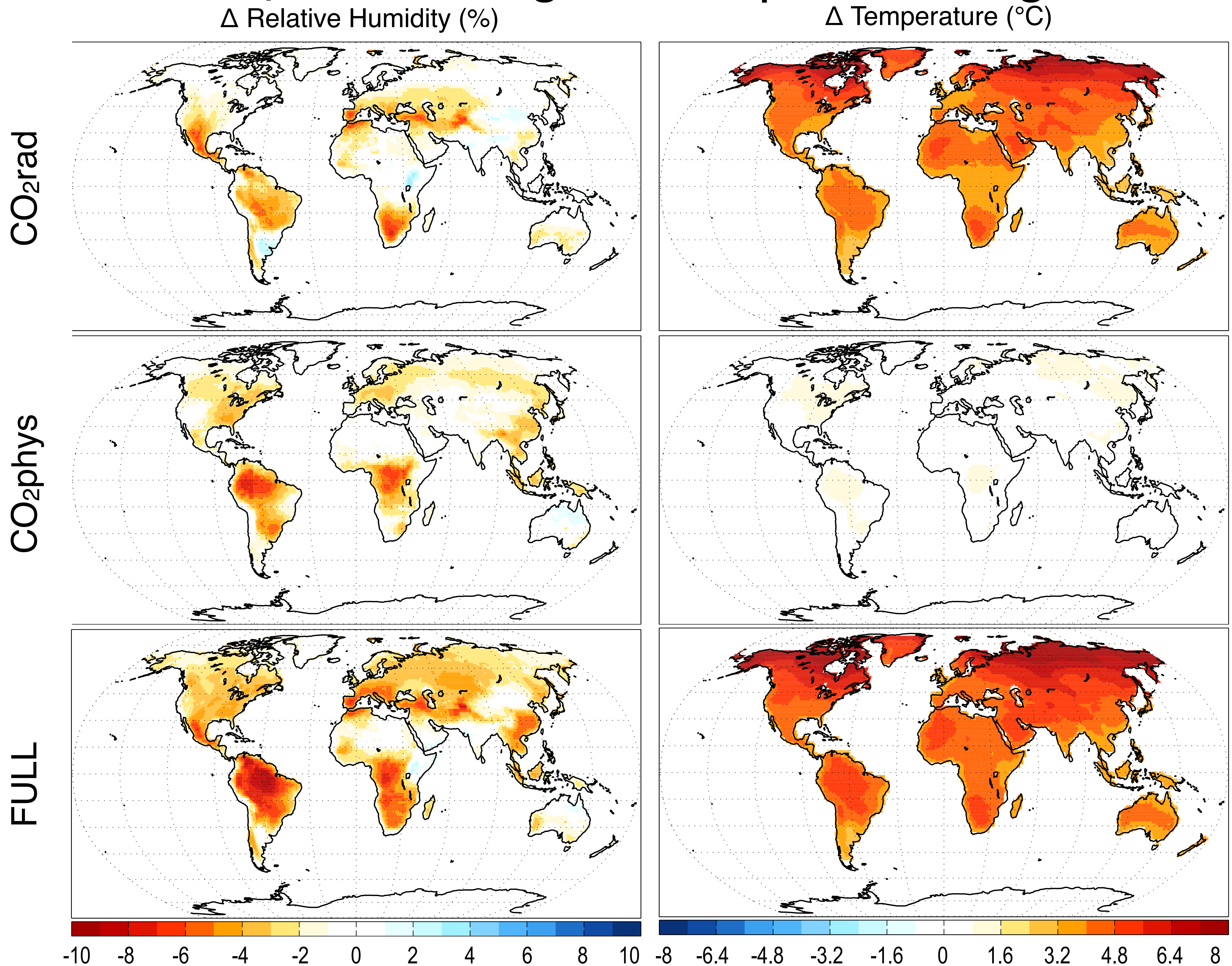
Any metric based on PET is **unstable compared to ET** under changing CO_2 concentrations

CMIP5 7 model mean, Change over 4X CO_2

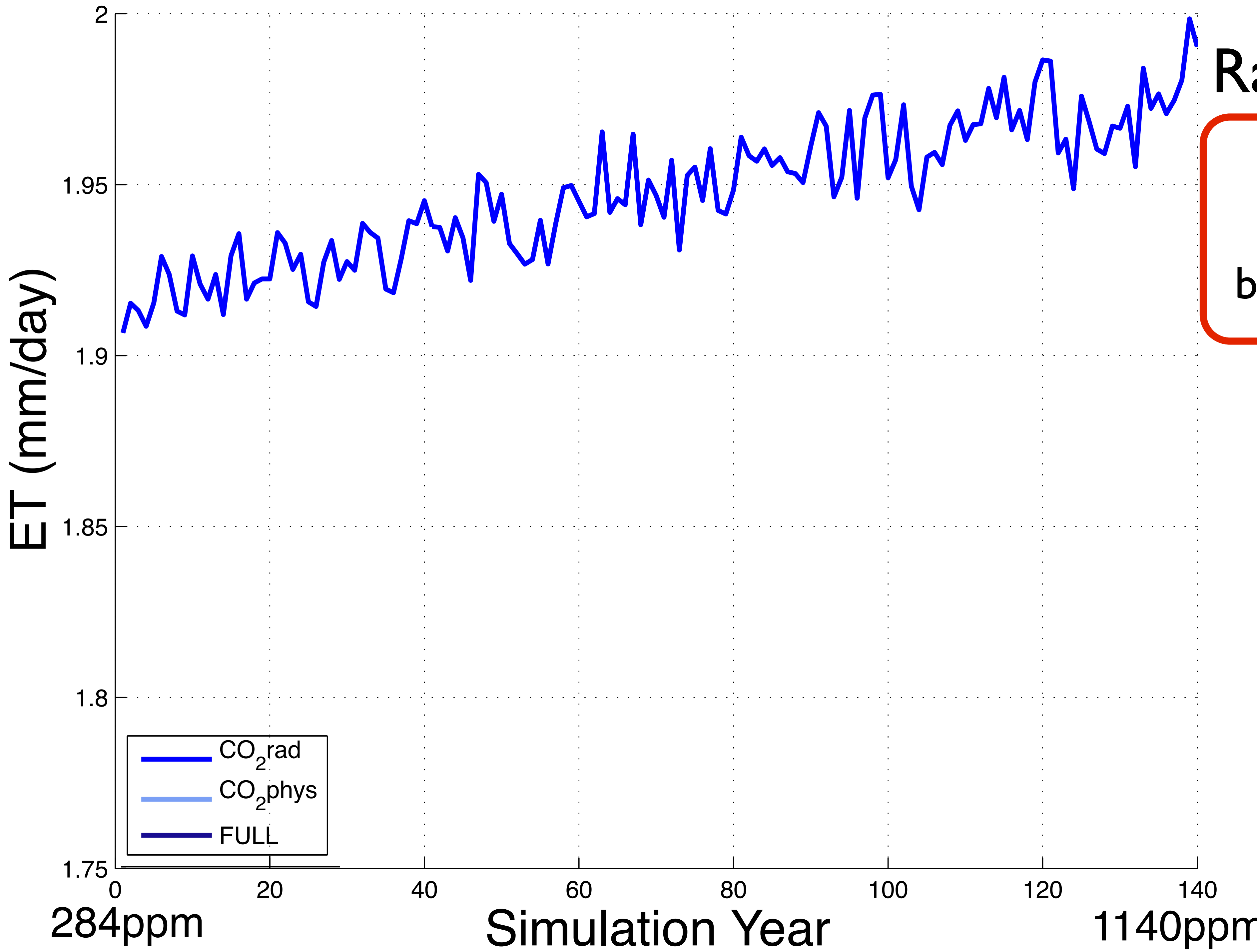
Swann et al. 2016, PNAS

Some atm variables respond strongly to plants:

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



ET goes up from Radiative effects of CO_2



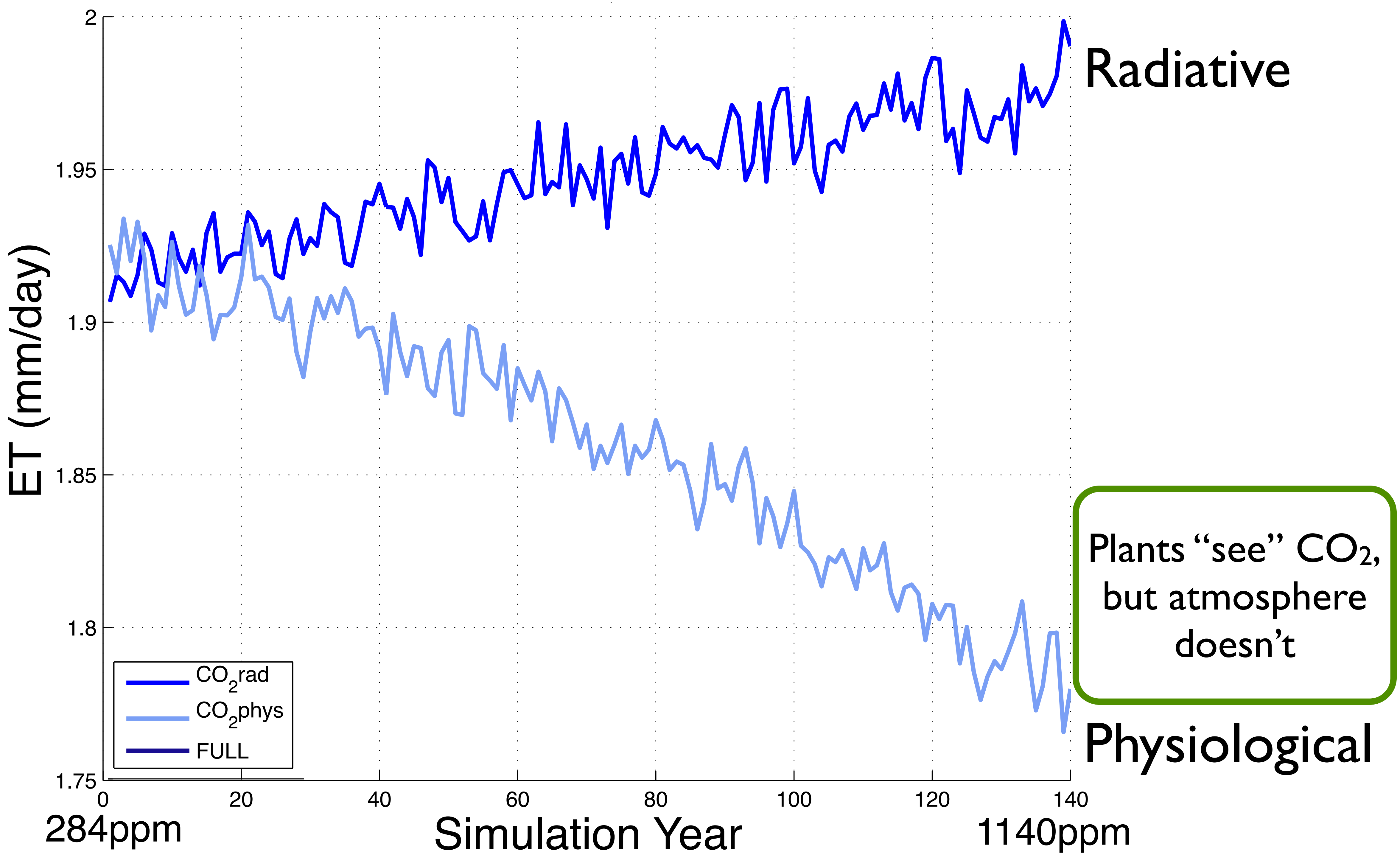
Radiative

Atmosphere "sees" CO_2, but plants don't

Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

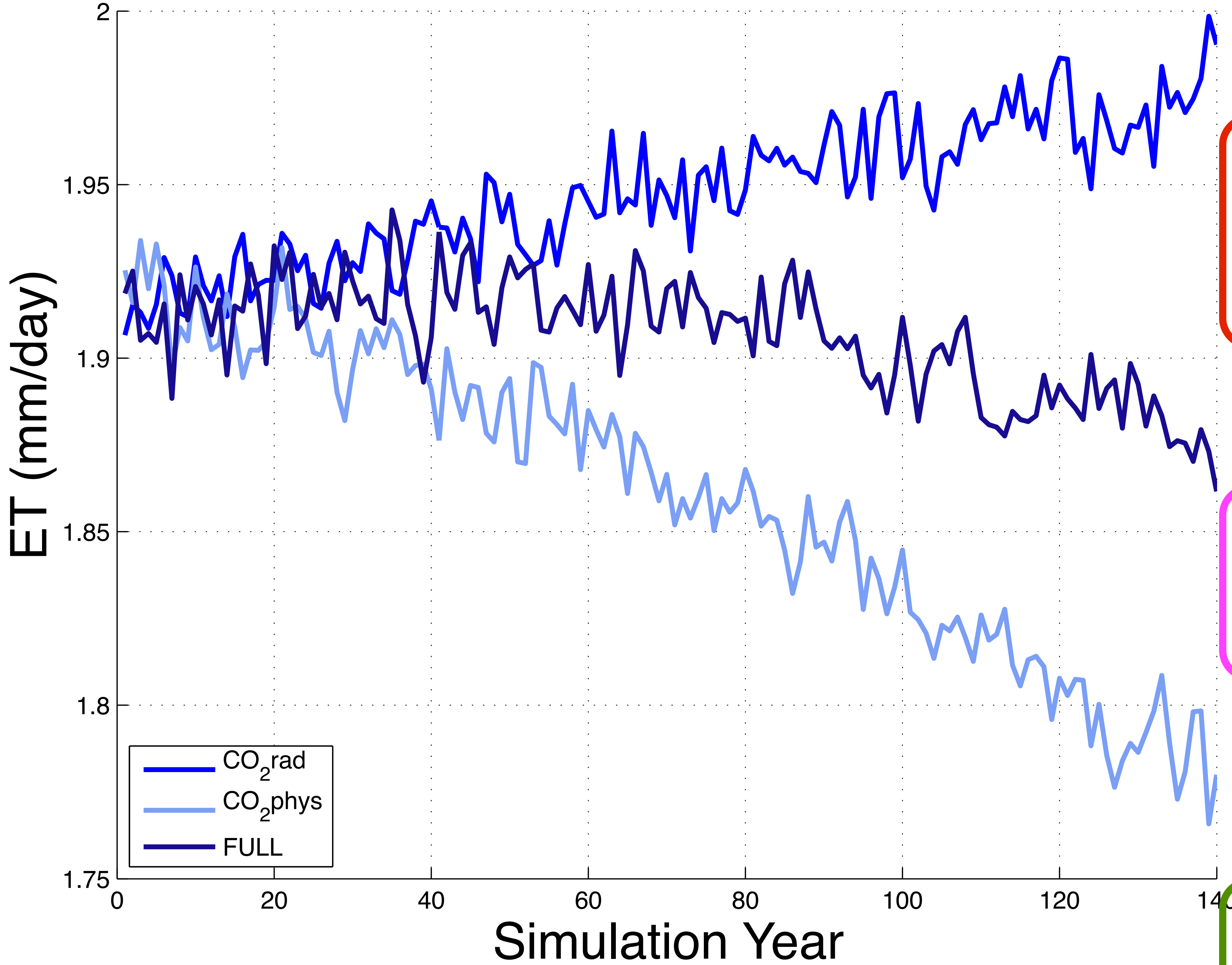
ET goes down from Physiological effects of CO_2



Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

The combination shows small decrease in ET



Radiative

Atmosphere "sees" CO_2, but plants don't

Both

Both Atmosphere and Plants "see" CO_2

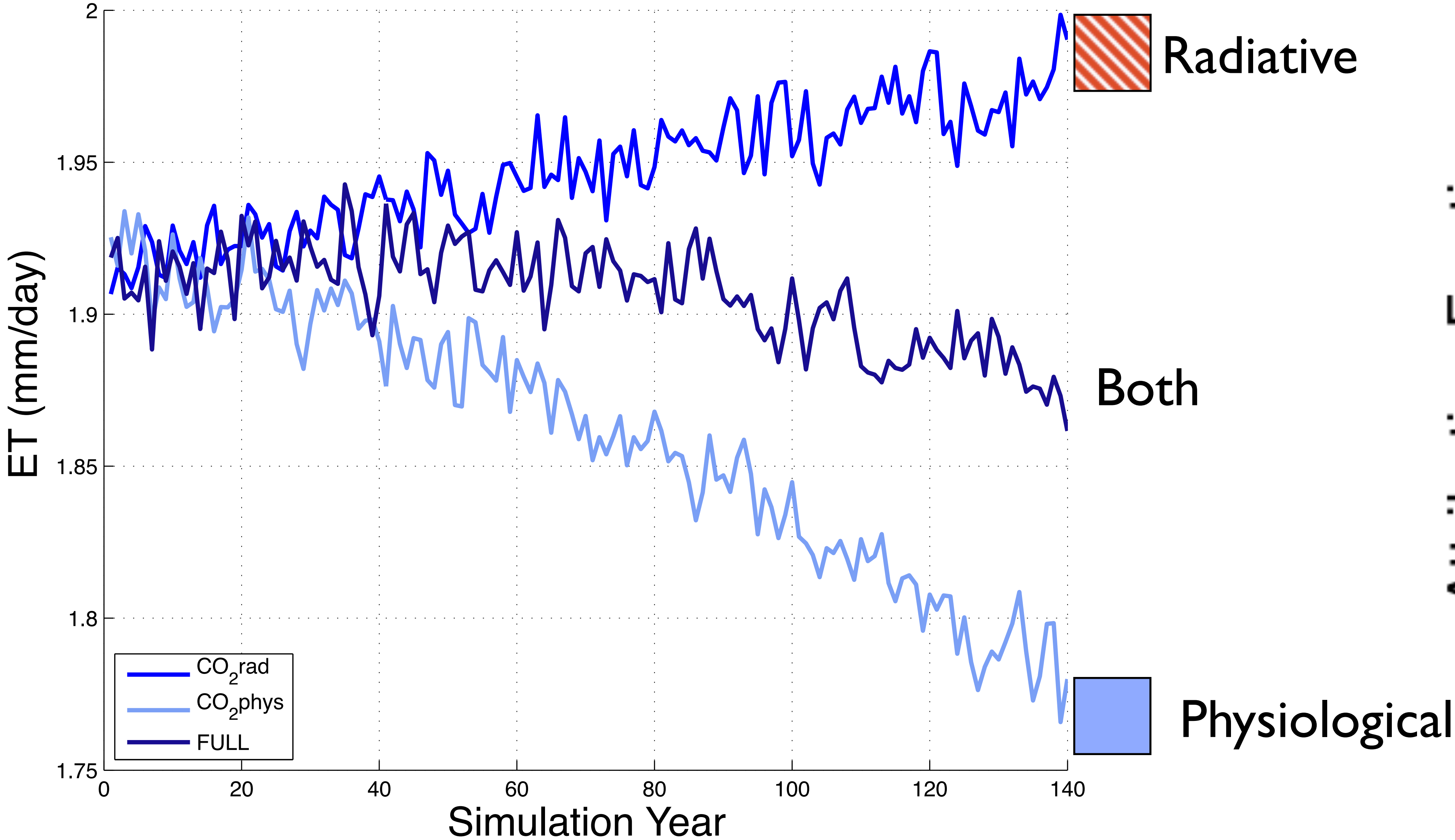
Physiological

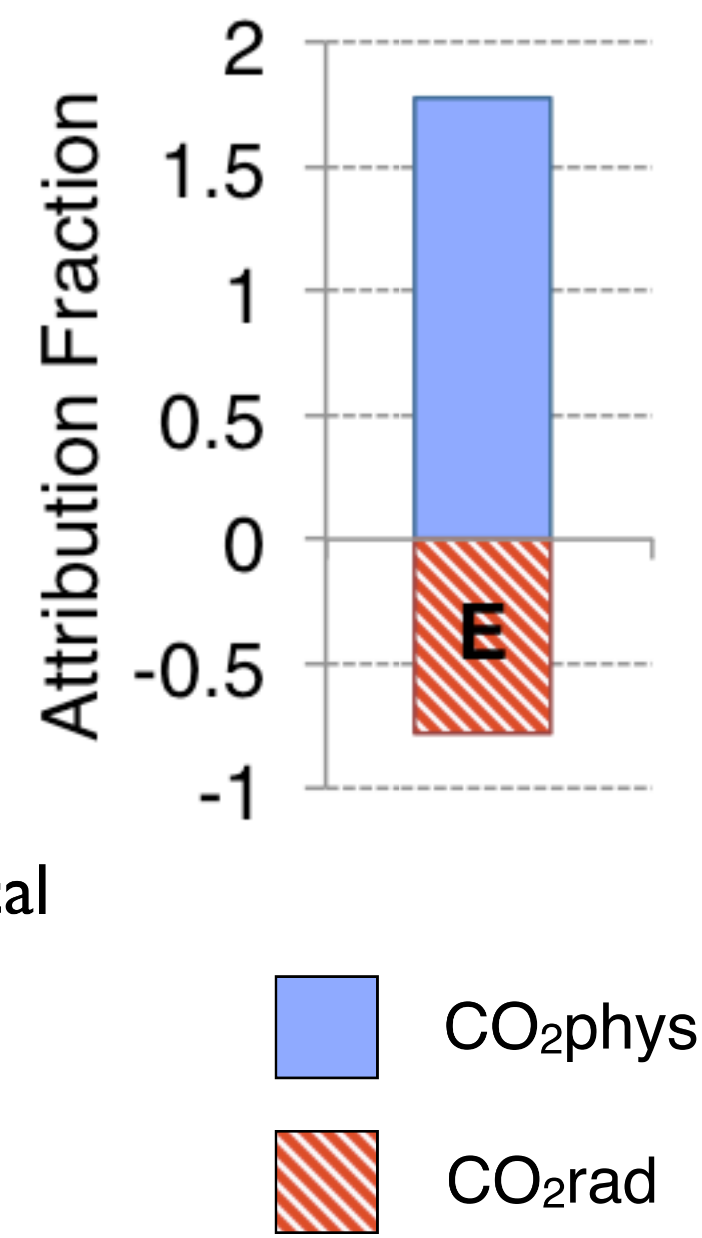
Plants "see" CO_2, but atmosphere doesn't

Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

Linear attribution of contributions of Rad vs Phys

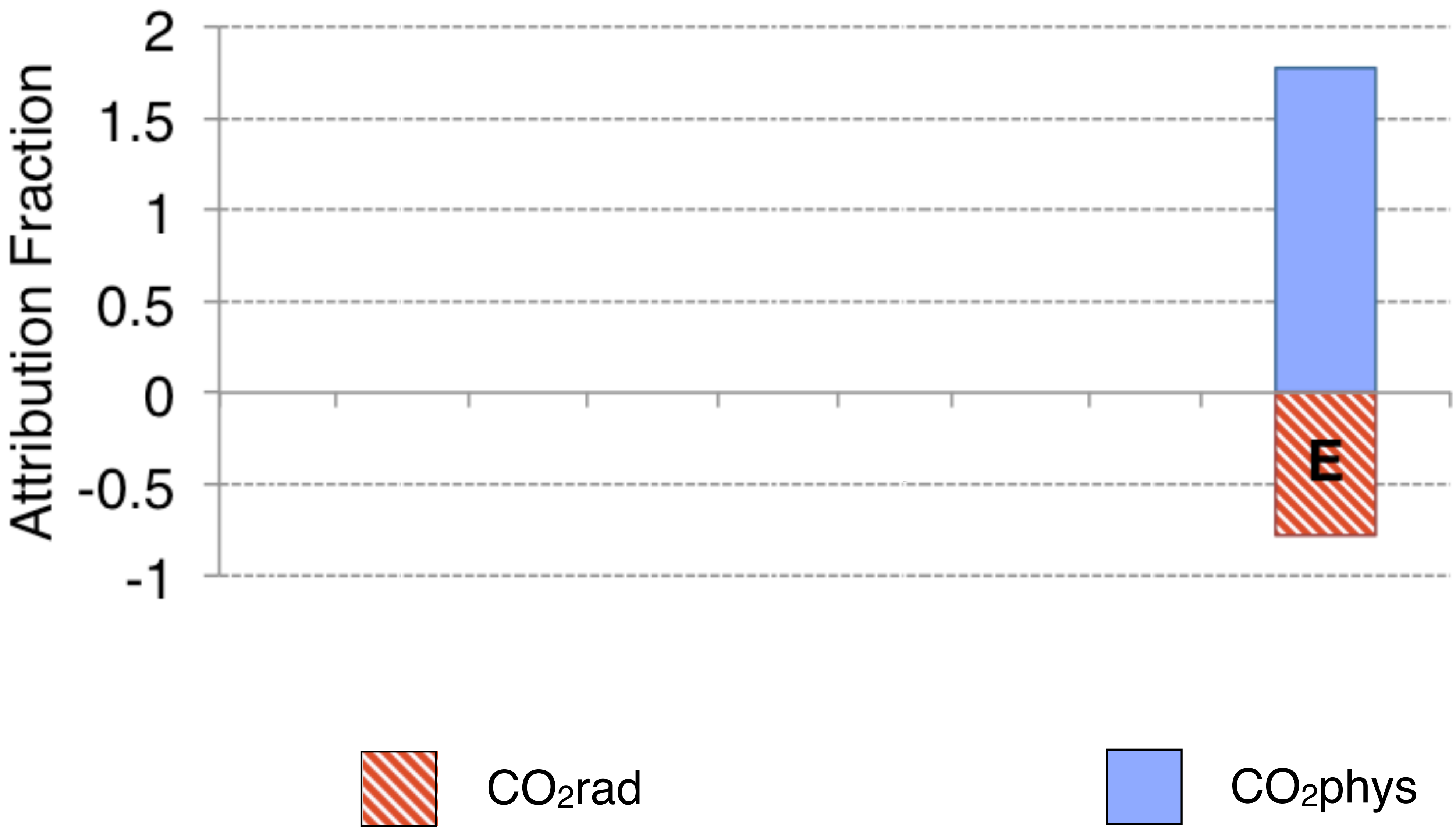




Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

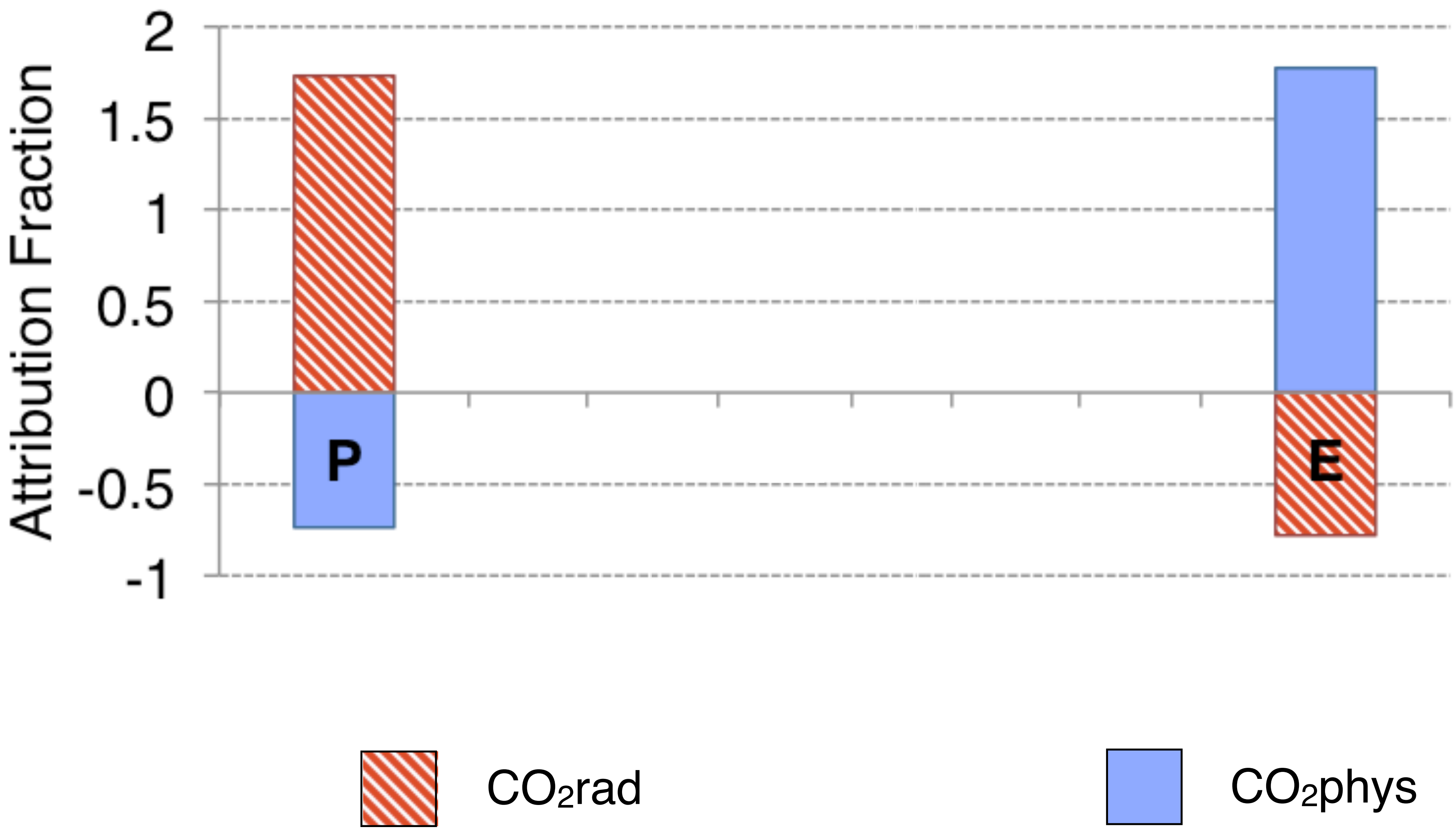
ET is dominated by Physiological effects



Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

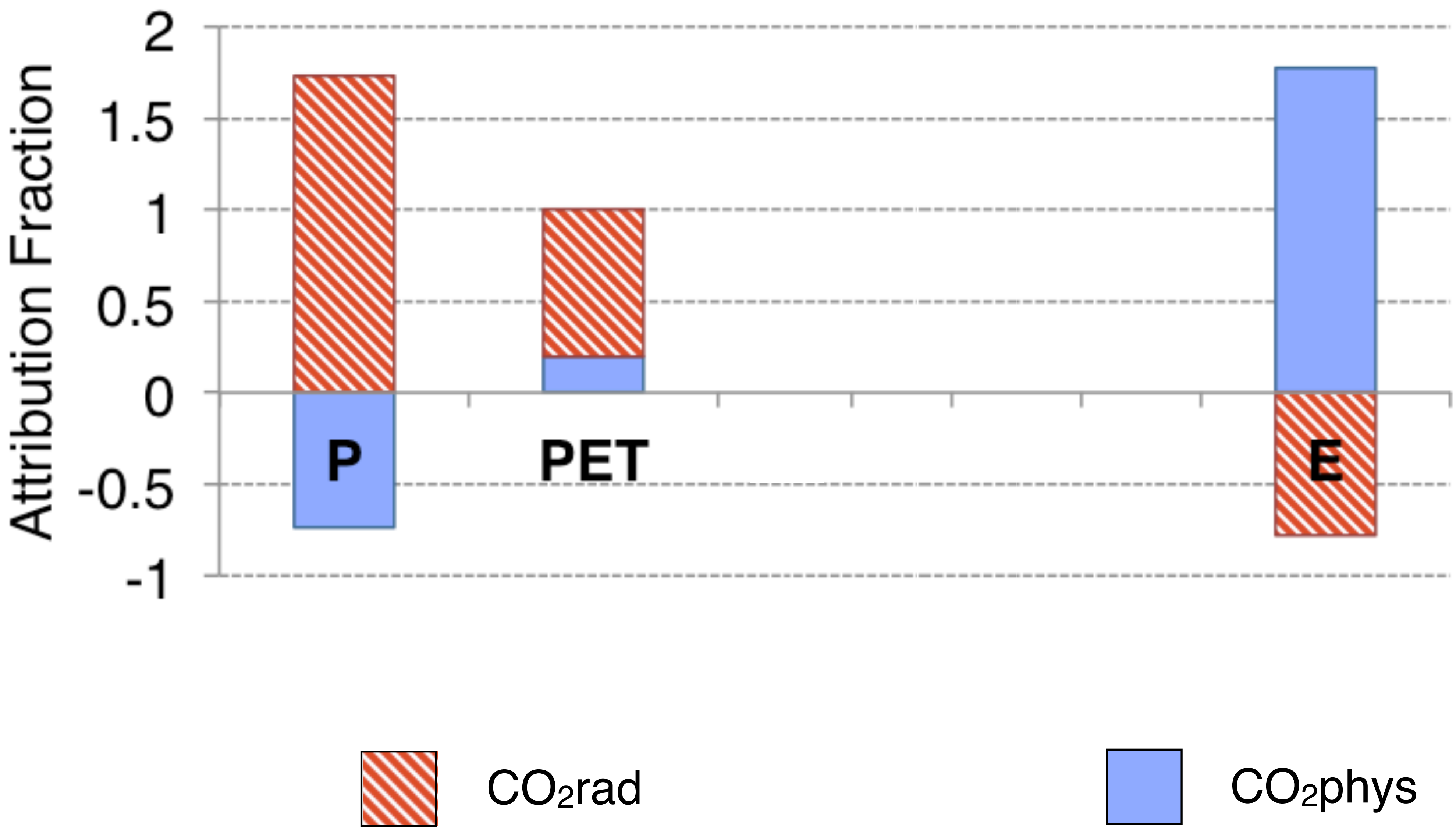
Precip is dominated by Radiative effects



Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

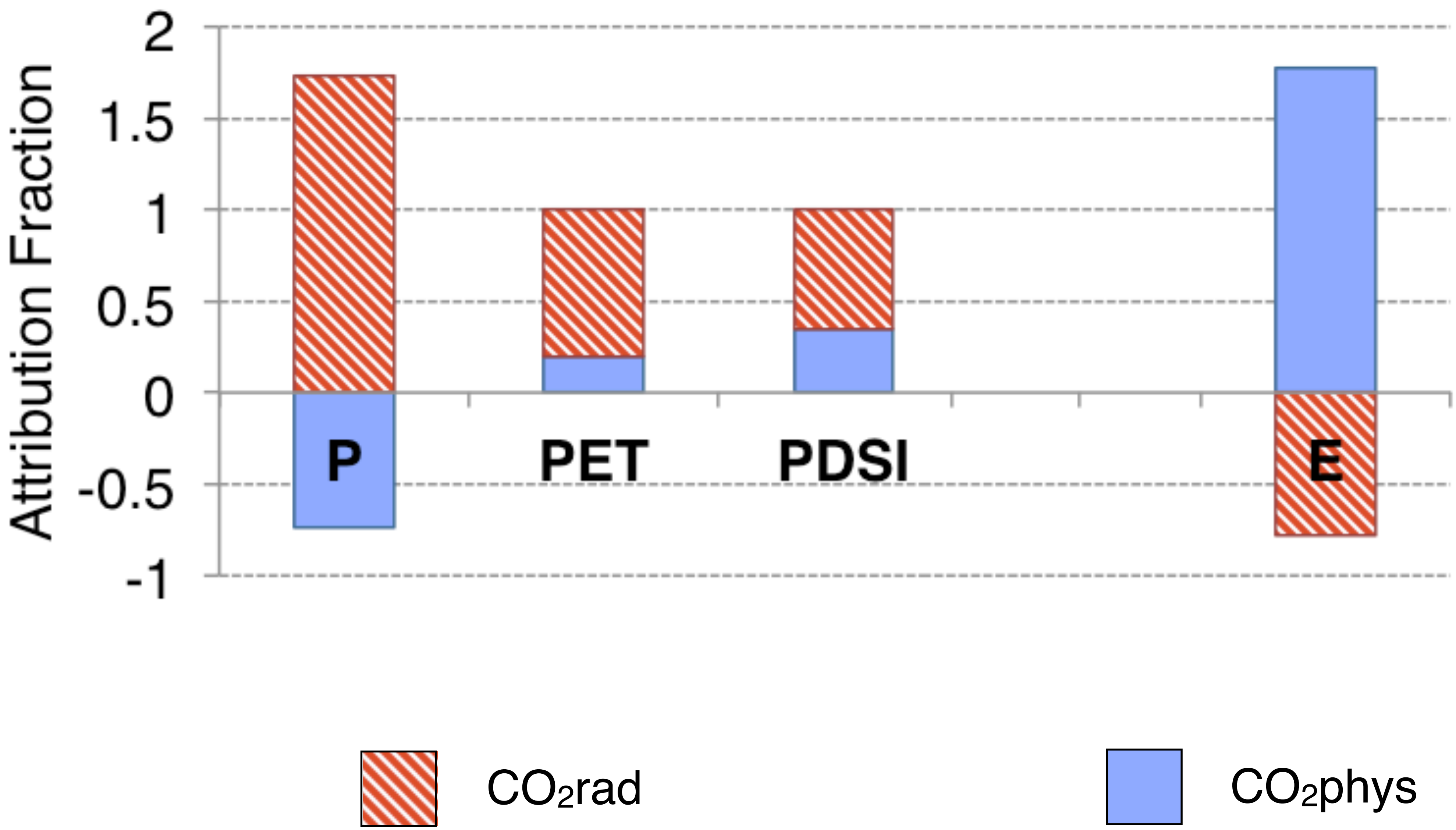
PET is 80% explained by Radiative effects



Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

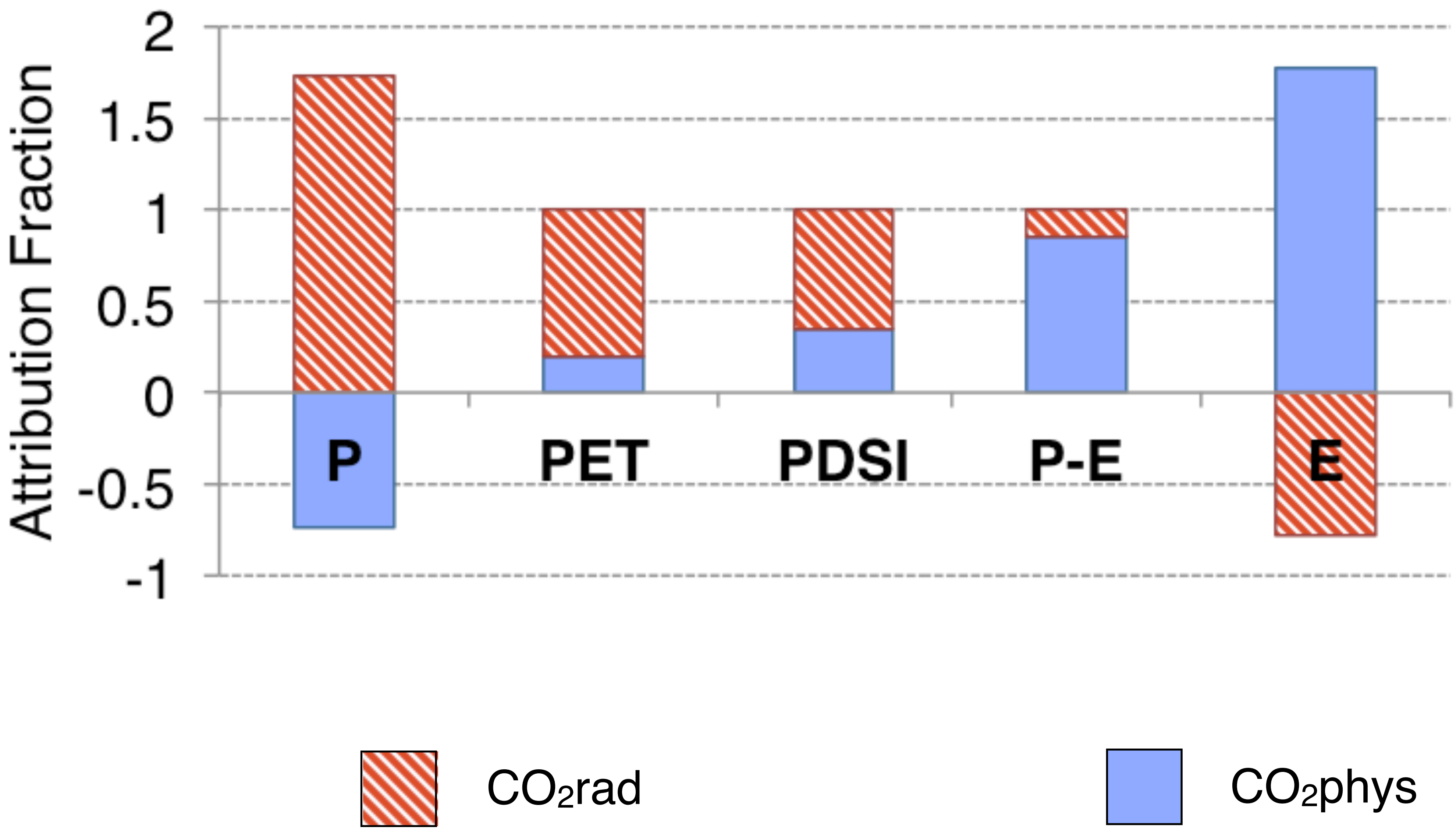
PDSI is 65% explained by Radiative effects



Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

P-ET is 84% explained by Physiological effects

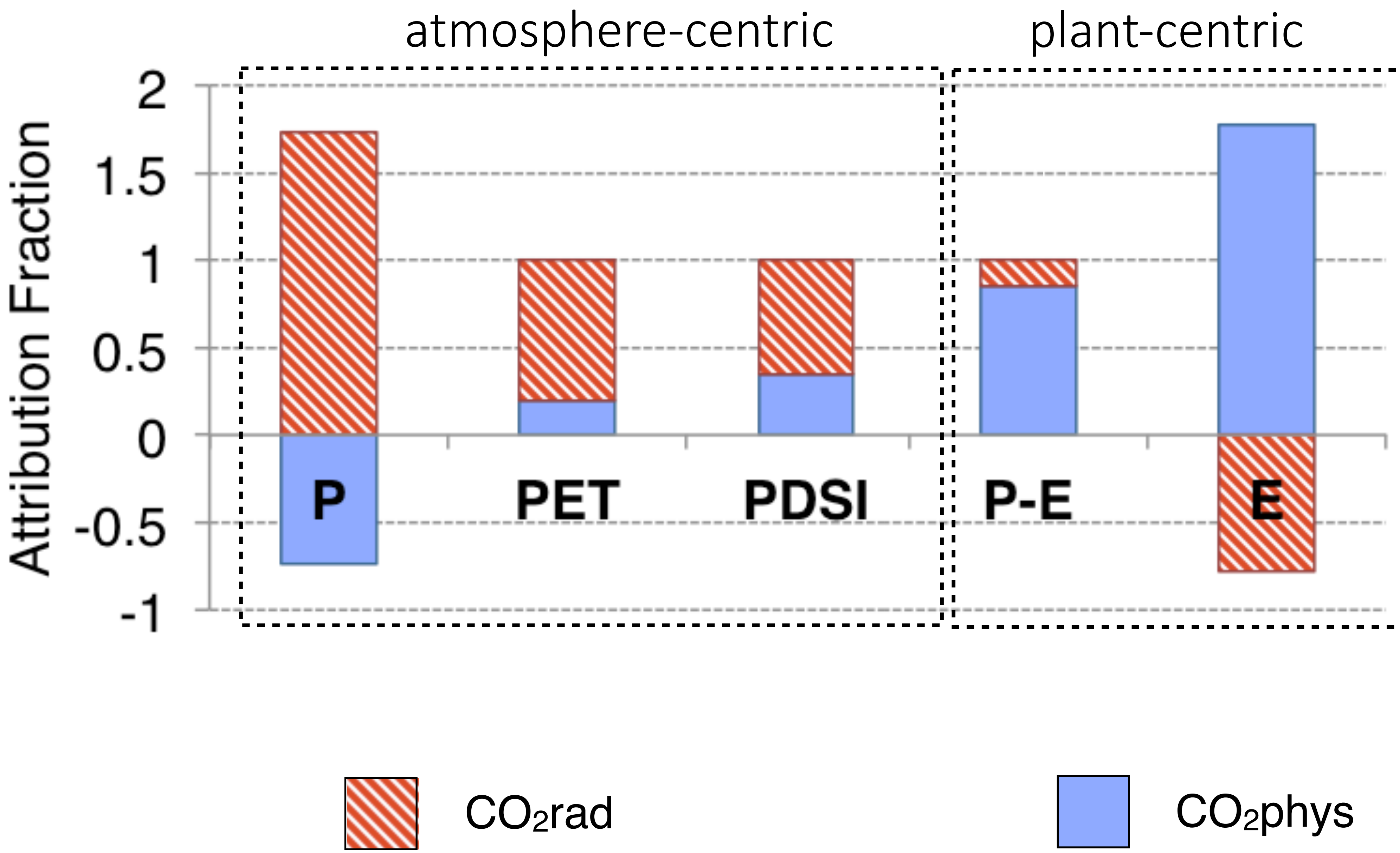


Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

We can define variables as atmosphere or plant centric:

does a variable account for changing plant conductance?



Multimodel mean land area 45S to 45N

Swann et al. 2016, PNAS

under high CO_2:

Atmosphere-centric => drier soils

Plant-centric => moderate Δ or wetter soils

Take home point

under high CO_2:

Atmosphere-centric => drier soils

Plant-centric => moderate Δ or wetter soils

Plant-centric metrics are ***more appropriate*** for predicting impacts like drought

Because they relate to ***plant stress***

So what should we do instead?

Plant-centric metrics are ***more appropriate*** for predicting impacts like drought

Because they relate to ***plant stress***

ESMs already account for our best guess for plant responses to CO_2

=> we should use output from ESMs directly (e.g. P-E, soil moisture)

=> choose offline models thoughtfully

Summary

Impact metrics based on *PET* (including PDSI) make ***opposite predictions*** to *actual* ET under high CO_2

Any metric based on PET is **unstable compared to ET** under changing CO_2 concentrations

predicting impacts using metrics that ***ignore*** some fields in Earth System Models is *internally inconsistent*


Questions?
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