Drought: looking to the future

Martin De Kauwe

26th June 2018

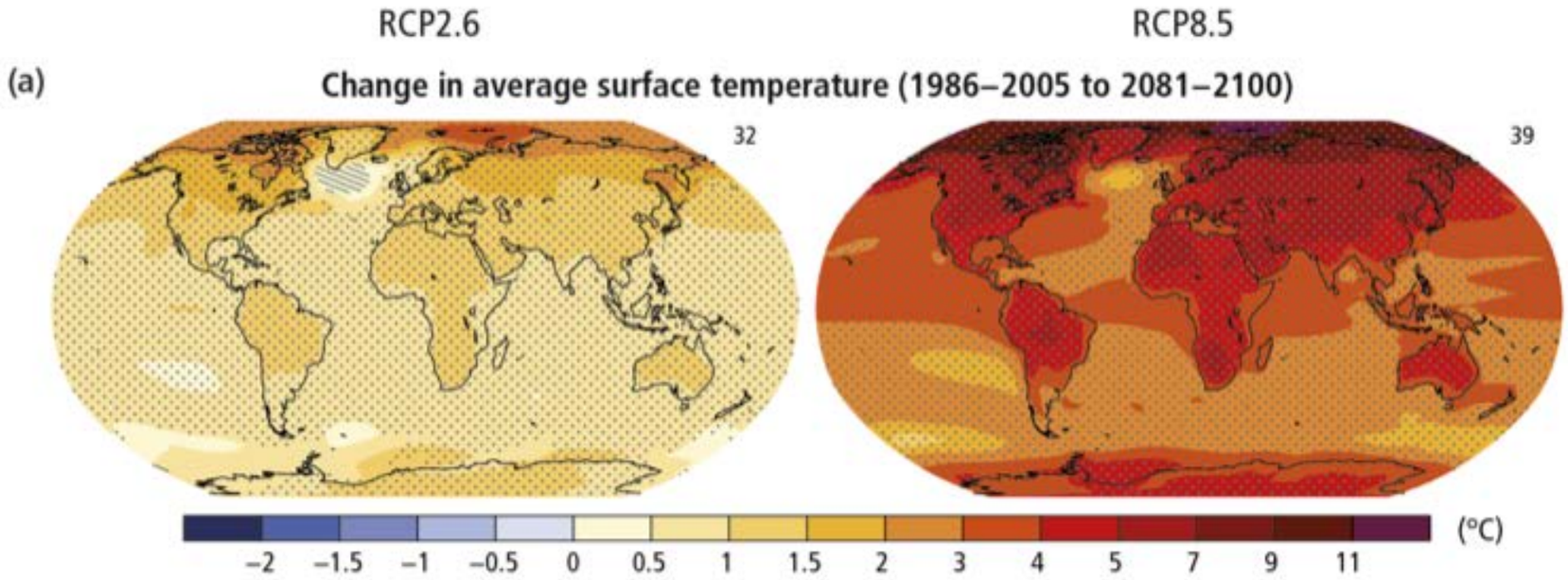
UNSW SYDNEY | Australia's Global University

ARC CENTRE OF EXCELLENCE FOR CLIMATE EXTREMES

Key Questions

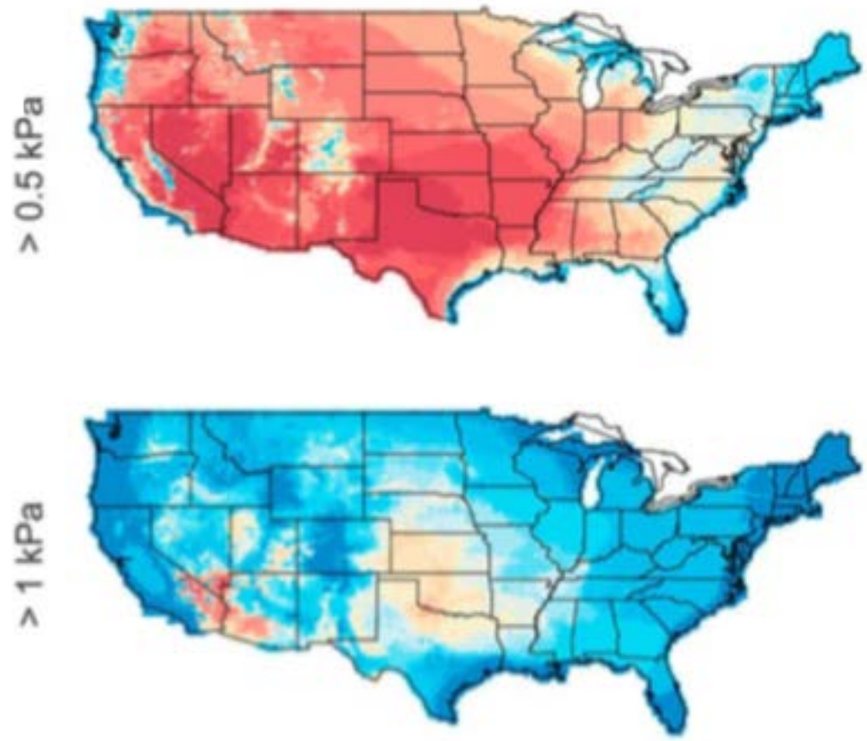
- Will the frequency, intensity and/or duration of droughts increase in the future?
- What role will increasing CO_2, temperature (VPD) and uncertain rainfall play?
- Do our models adequately project drought?

Future: warmer & increased VPD

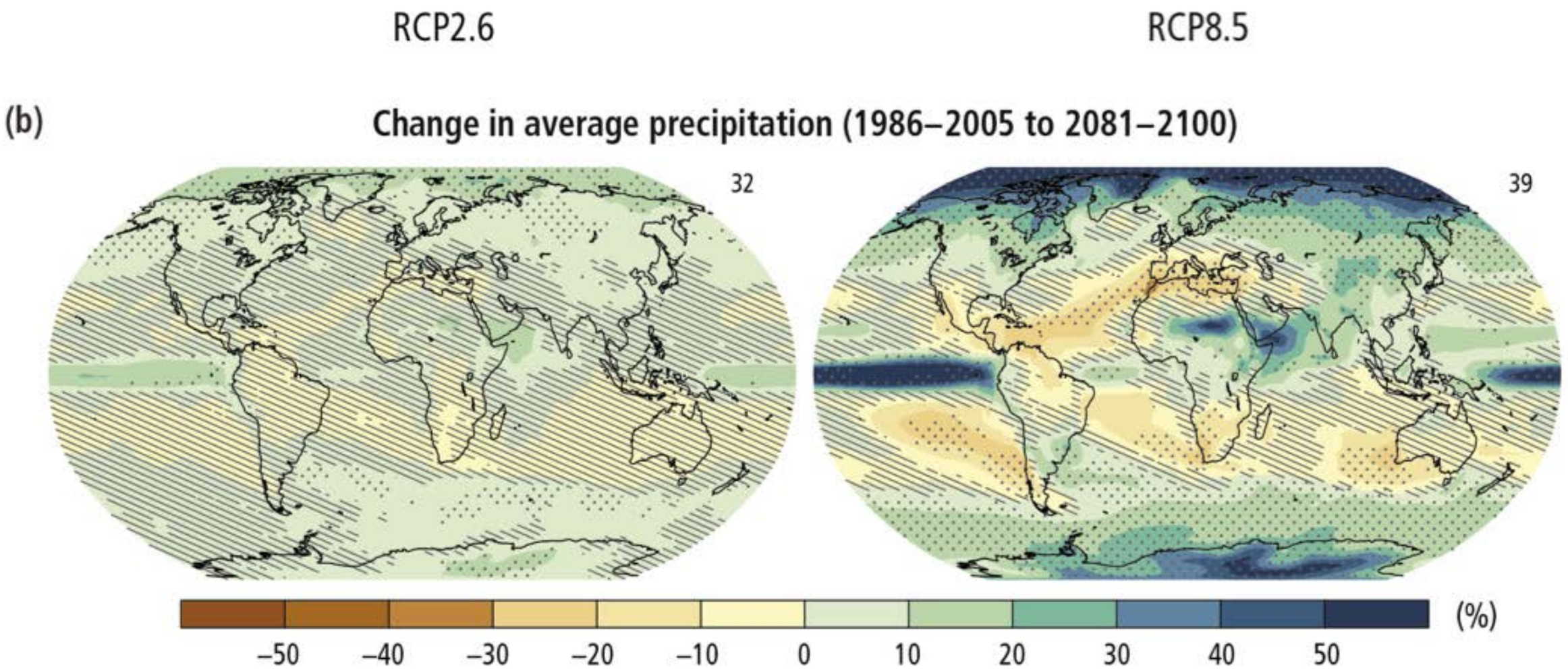


IPCC AR5

Ficklin and Novick (2017) J. Geophys. Res. Atmos

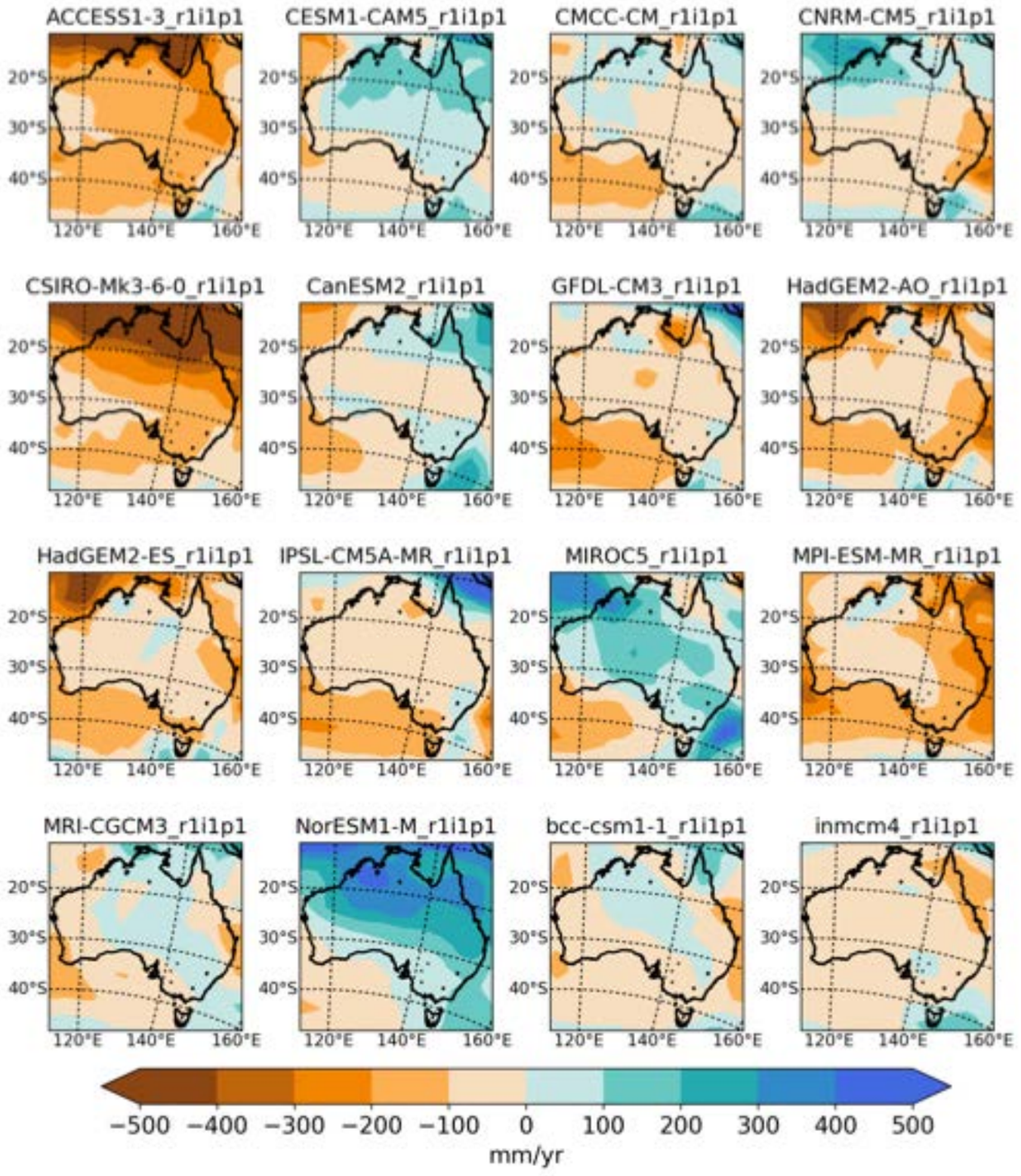


Future: wetter or drier?



IPCC AR5

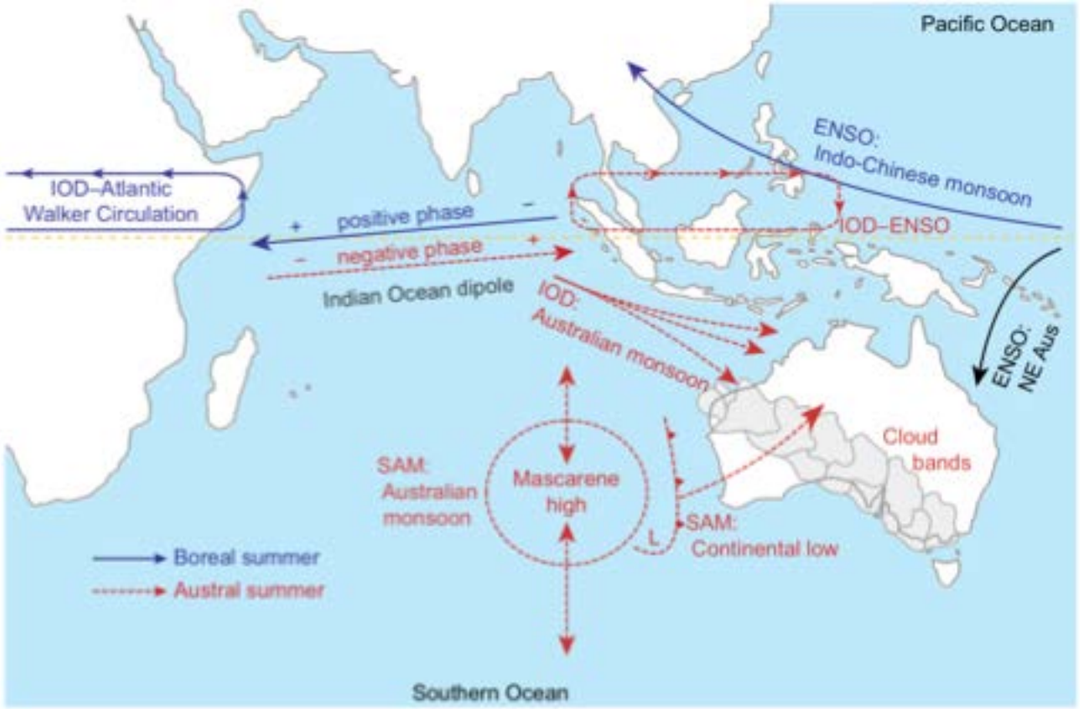
Australia future precipitation

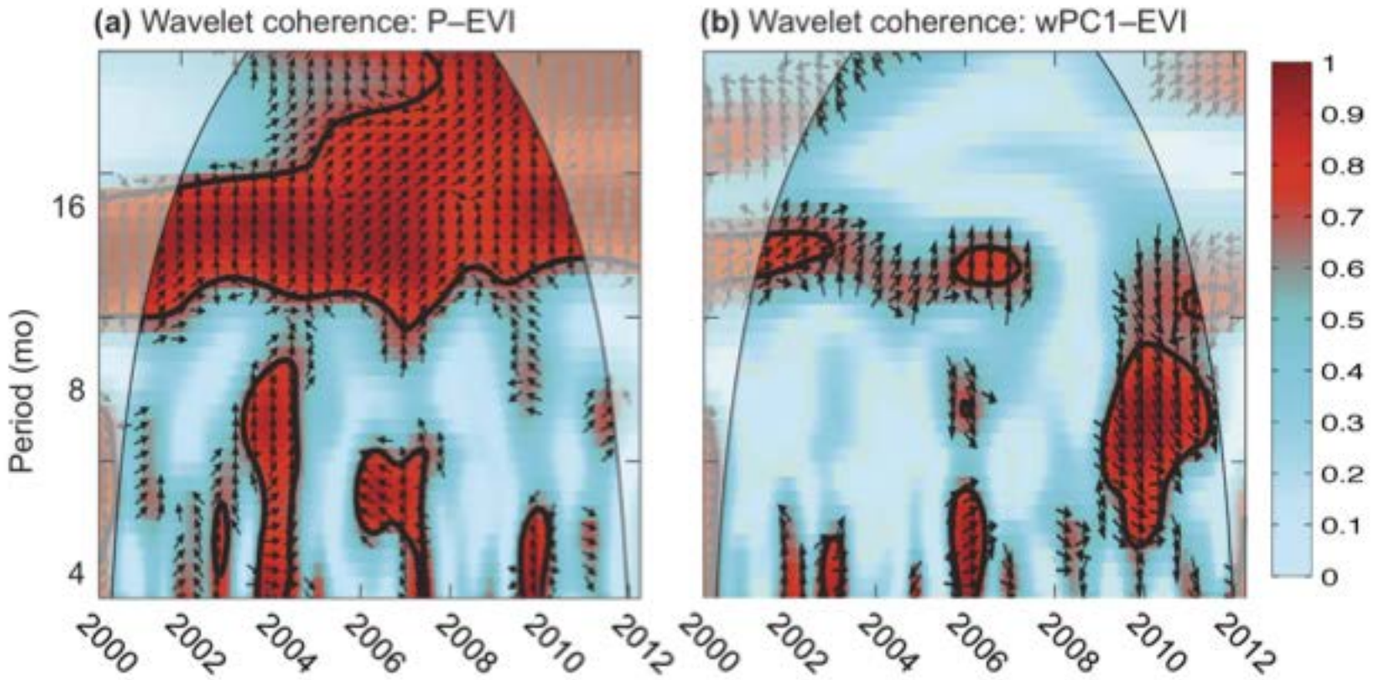


From Nadja Herger

Need to better understand the role of climate modes

El Niño, the Indian Ocean dipole, and the Southern Annular Mode

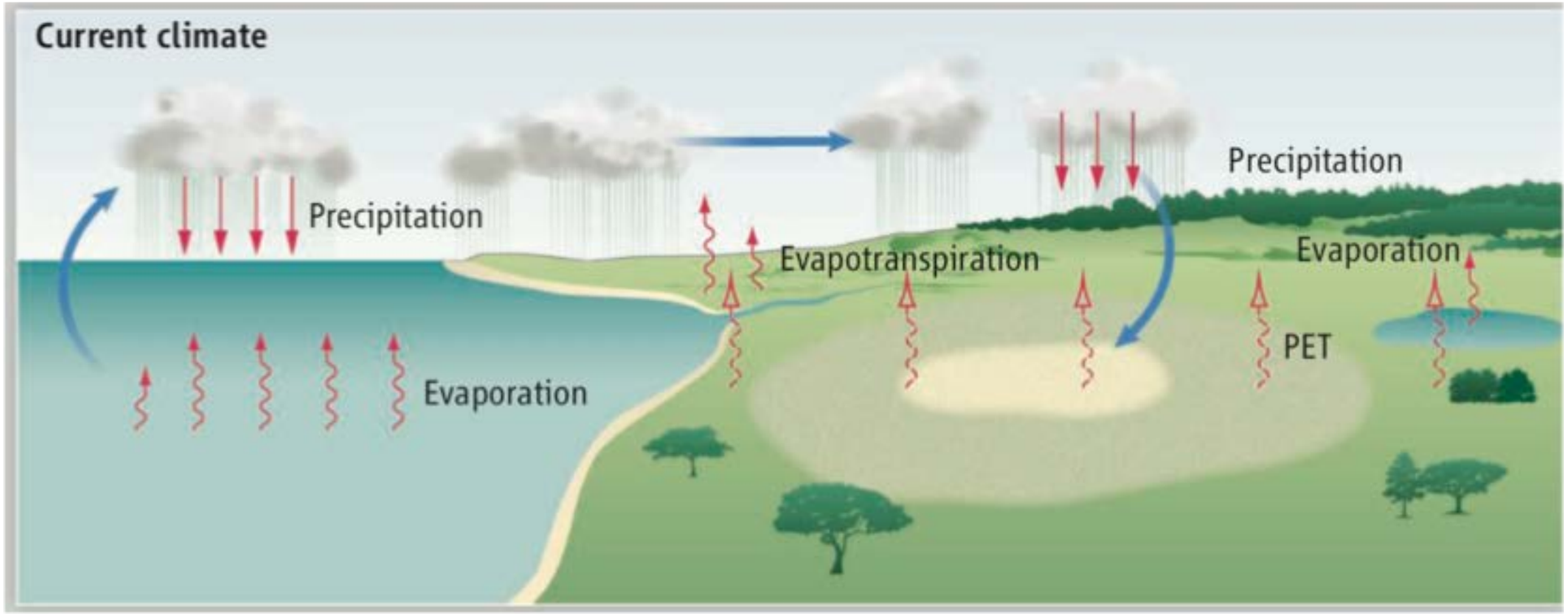




Cleverley et al. (2016) Sci. Reports

Drought metrics

- Three of the most commonly used drought metrics: PDSI, aridity (P/PET) and SPI/E

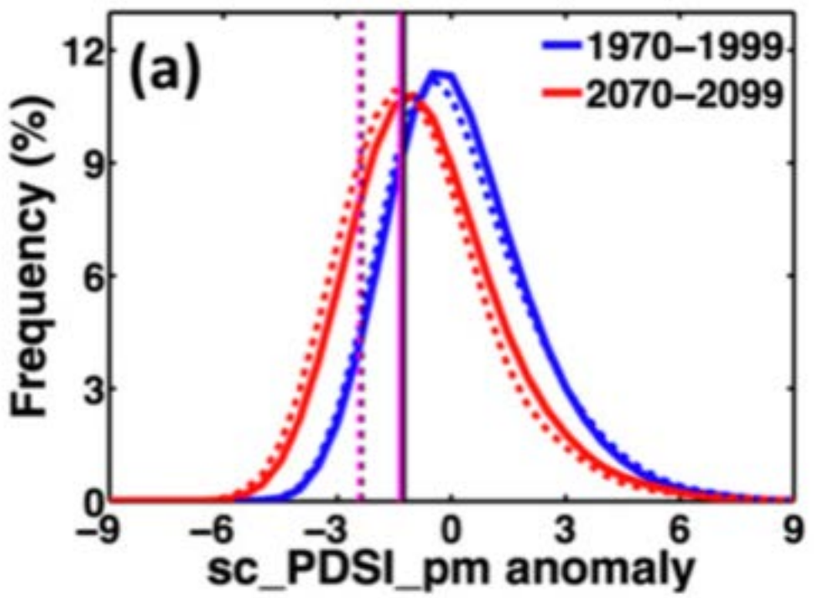


Sherwood and Feng (2014) Science

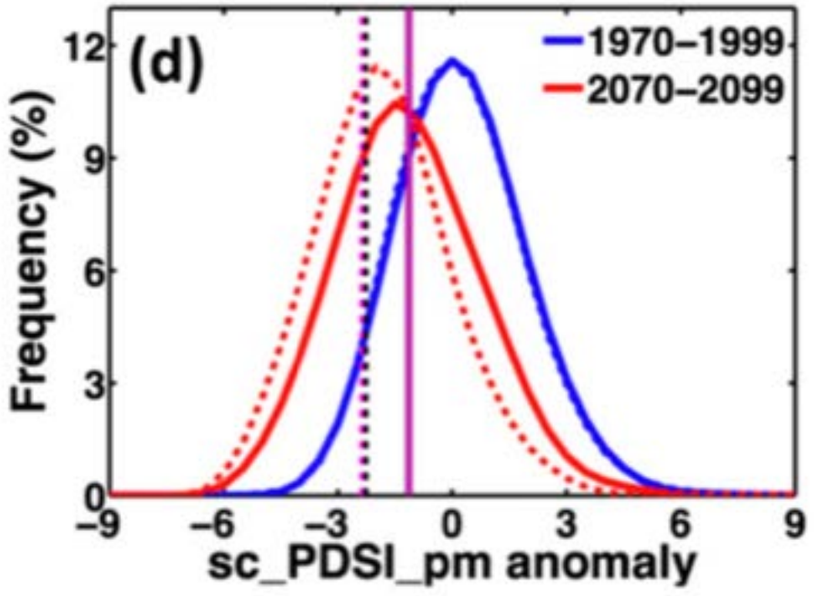
- What do they project?

PDSI projections

Western US

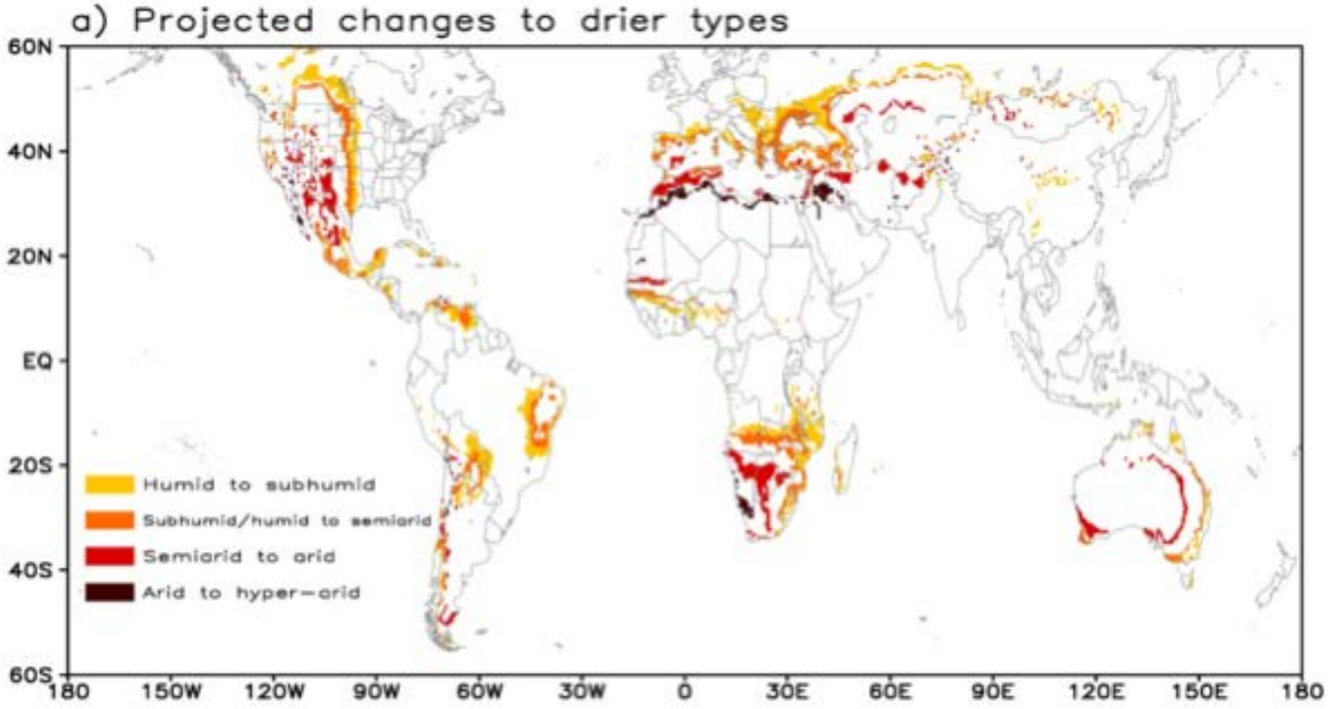


Southern Europe



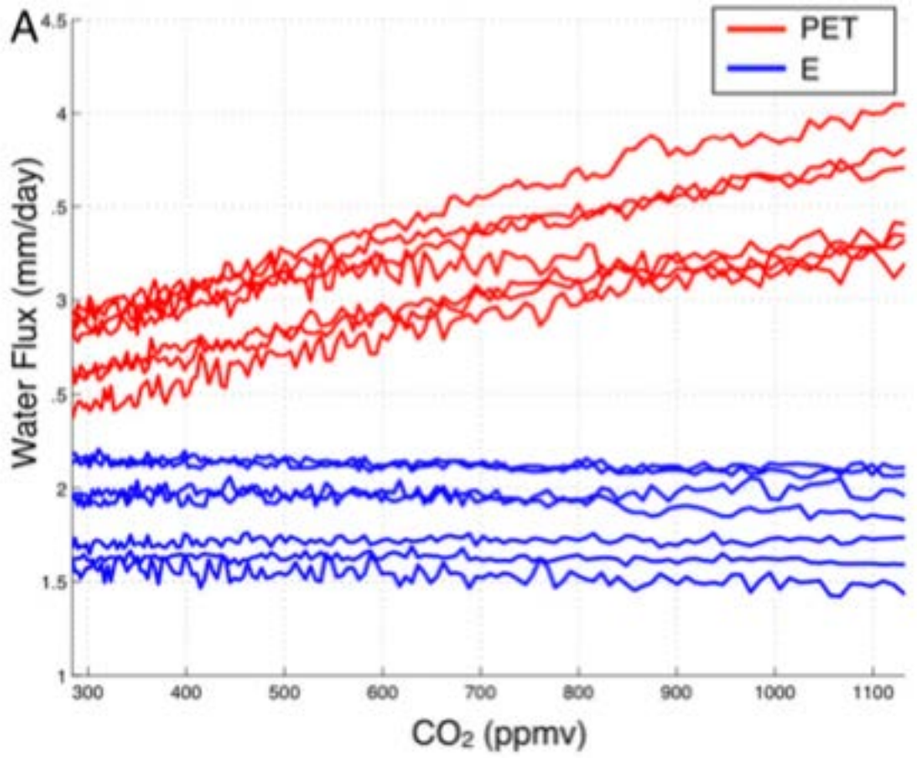
Zhao and Dai (2015) J. Clim.

Expansion of global drylands?



Feng and Fu (2013) Atmos. Chem. Phys.

$$AI = \frac{PET\ (\uparrow)}{P}$$

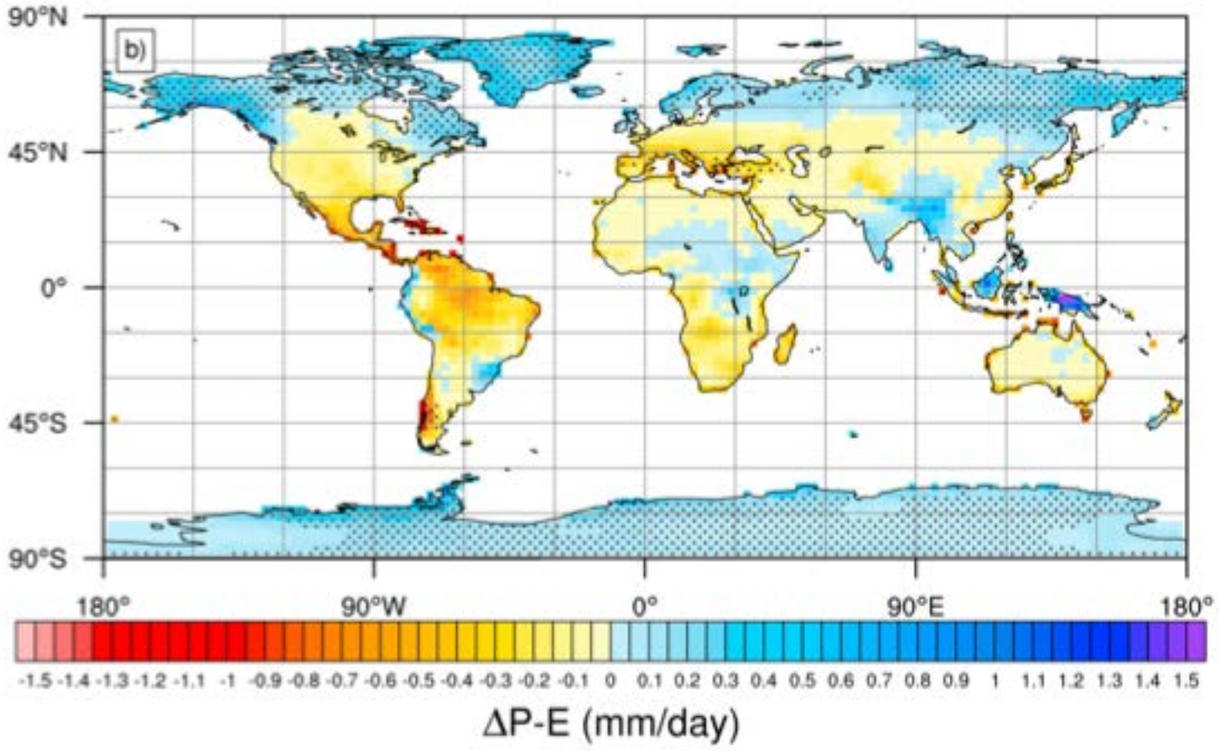


Swann et al. (2016) PNAS

Is this what climate models project?

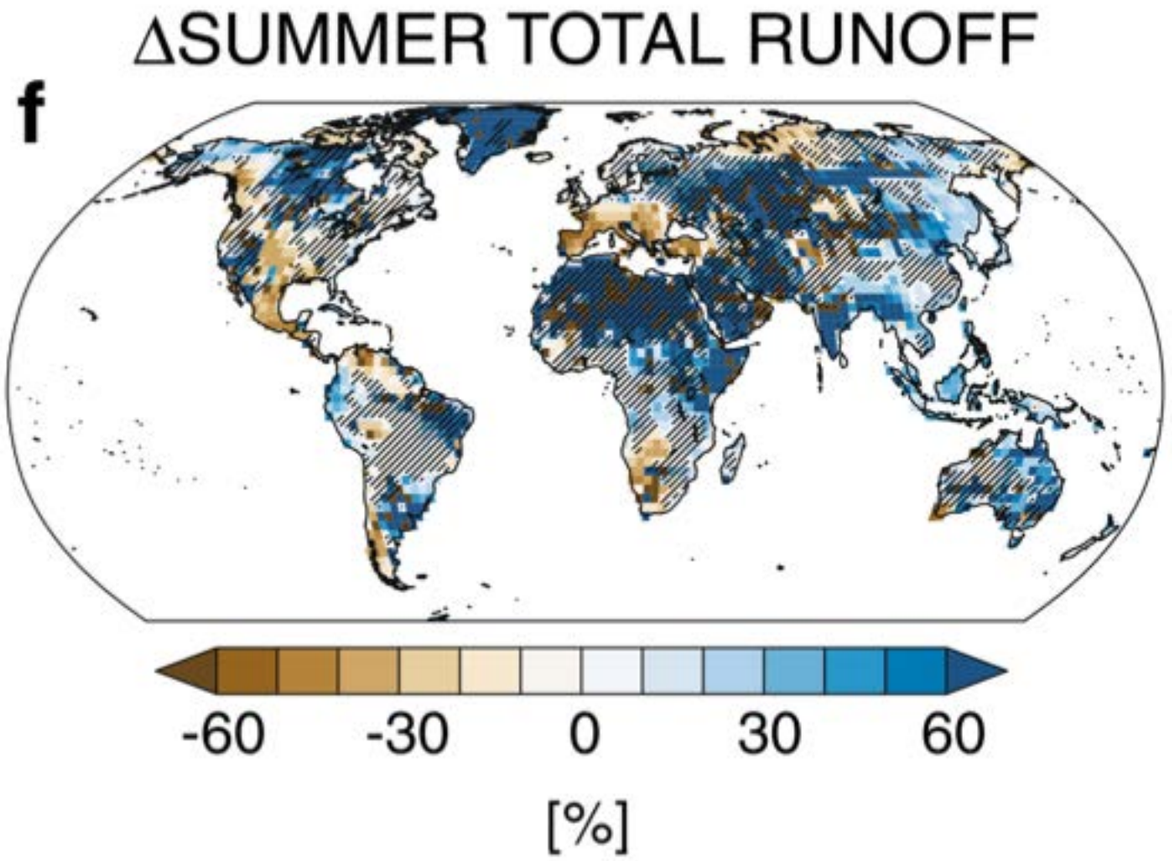
CMIP5 hydrological drought (P-E; 2080-2100)

P-E 2080-2100



Greve et al. (2015) Geophys. Res. Lett.

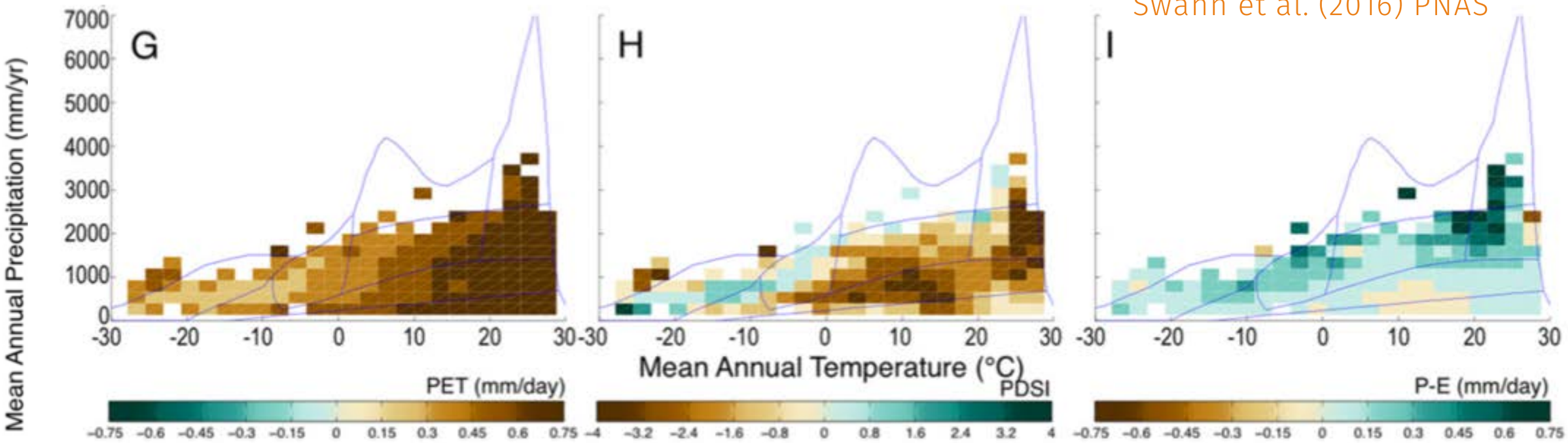
2070–2099 minus 1976–2005



Cook et al. (2018) Clim. Change

Mid- & low-latitude P-E increases in CMIP5

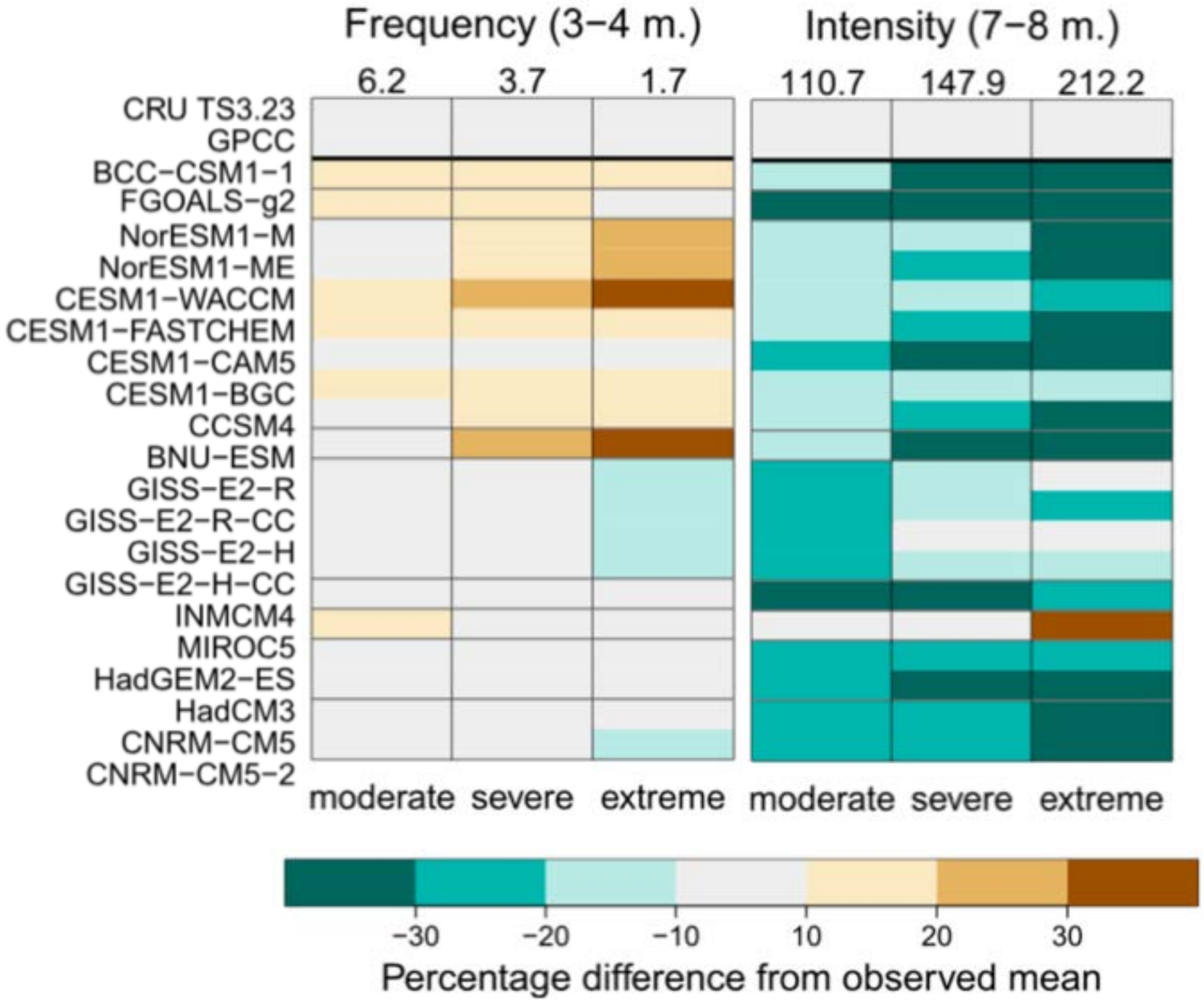
Swann et al. (2016) PNAS



- Using climate model **outputs** as **inputs** →over-estimate drought

- Ignores the response of the vegetation to CO_2 + double counting (already include feedback on temp, VPD)

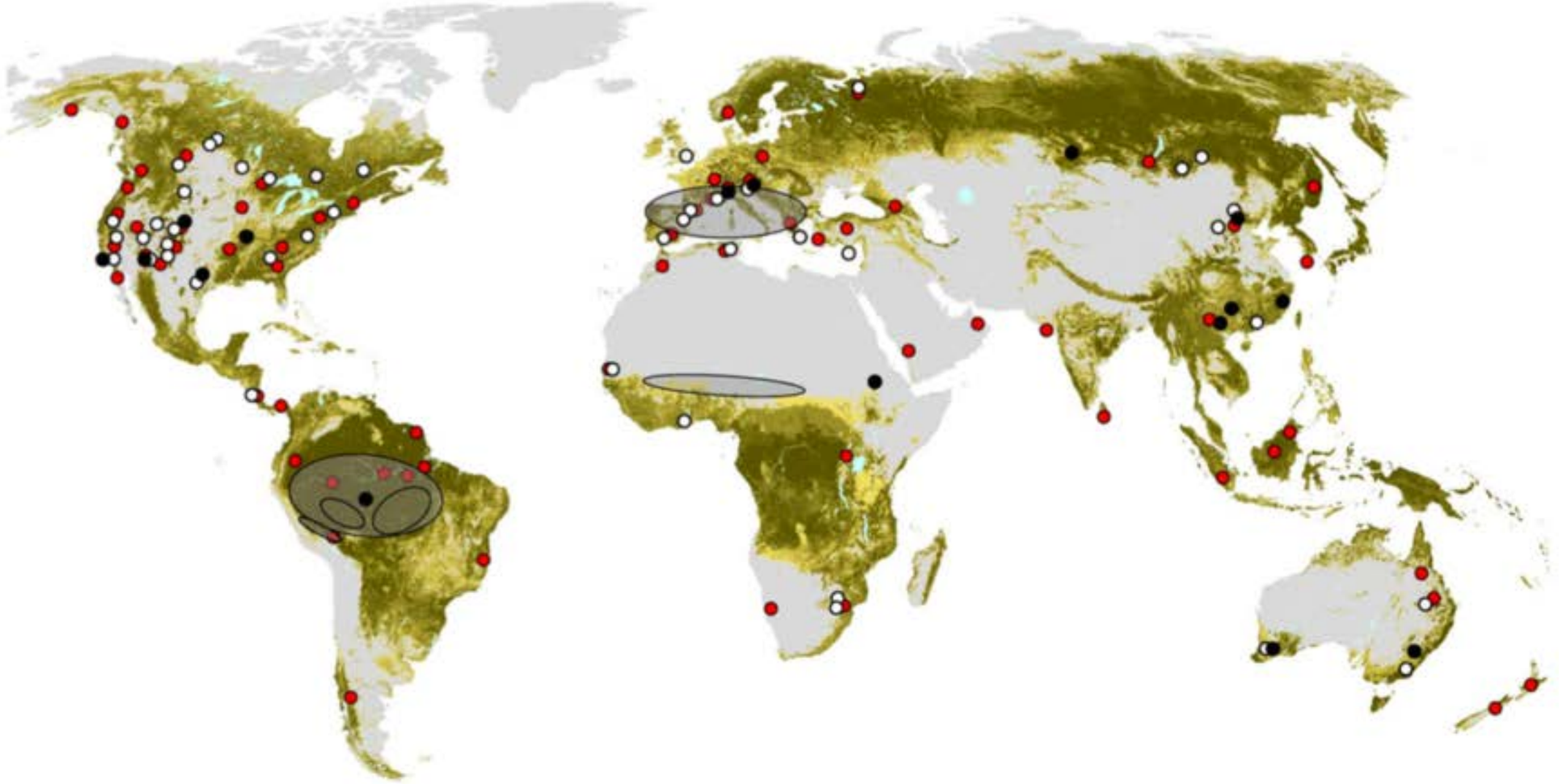
But CMIP5 models have their issues too!



Ukkola et al. (2018) J. Hydromet.

Can we look at the last 30 years as an analogue for future drought?

Perception: drought-induced mortality since 1970



But what is our **baseline**?

Allen et al. (2015) Ecosphere

Widespread future mortality?

nature climate change

LETTERS

PUBLISHED ONLINE: 18 MAY 2015 | DOI: 10.1038/NCLIMATE2641

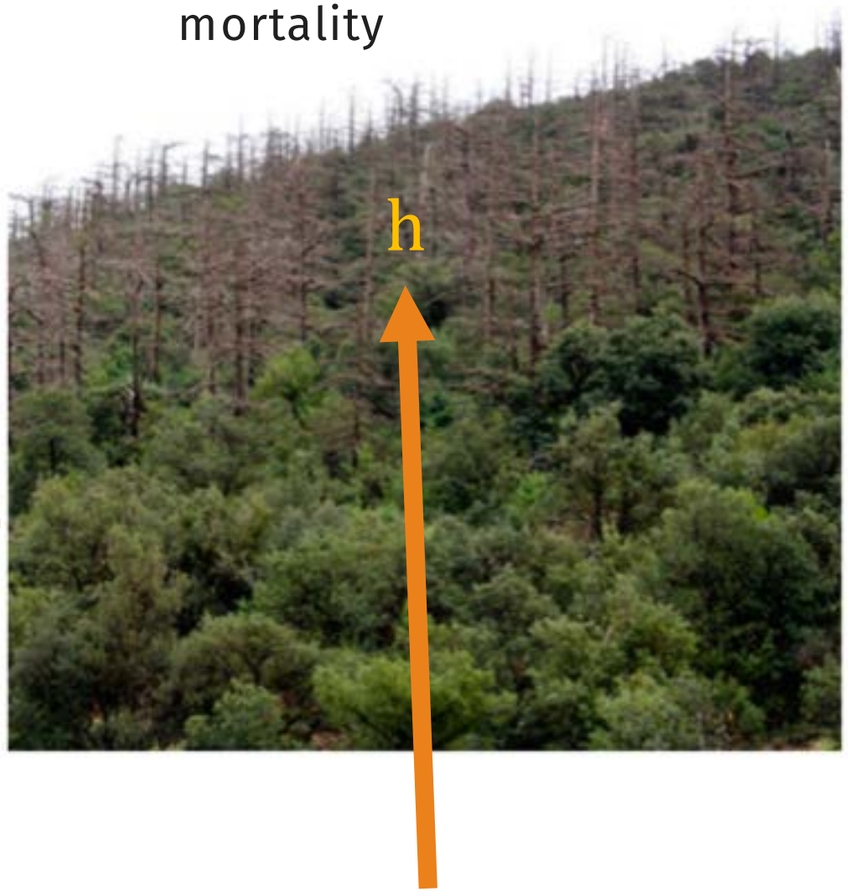
Darcy's law predicts widespread forest mortality under climate warming

Nathan G. McDowell[1]* and Craig D. Allen[2]

Canopy conductance

$$G = \frac{A_s k_s(\psi_s - \psi_l)}{h\eta A_l D}$$

Cedrus atlantica mortality



- Predicts future decline in G due to increasing D
- Most vulnerable plants have a high leaf area (A_l) and/or are tall (h).
- **What is missing from this equation?**

But tall tress have deep roots!

nature geoscience

ARTICLES

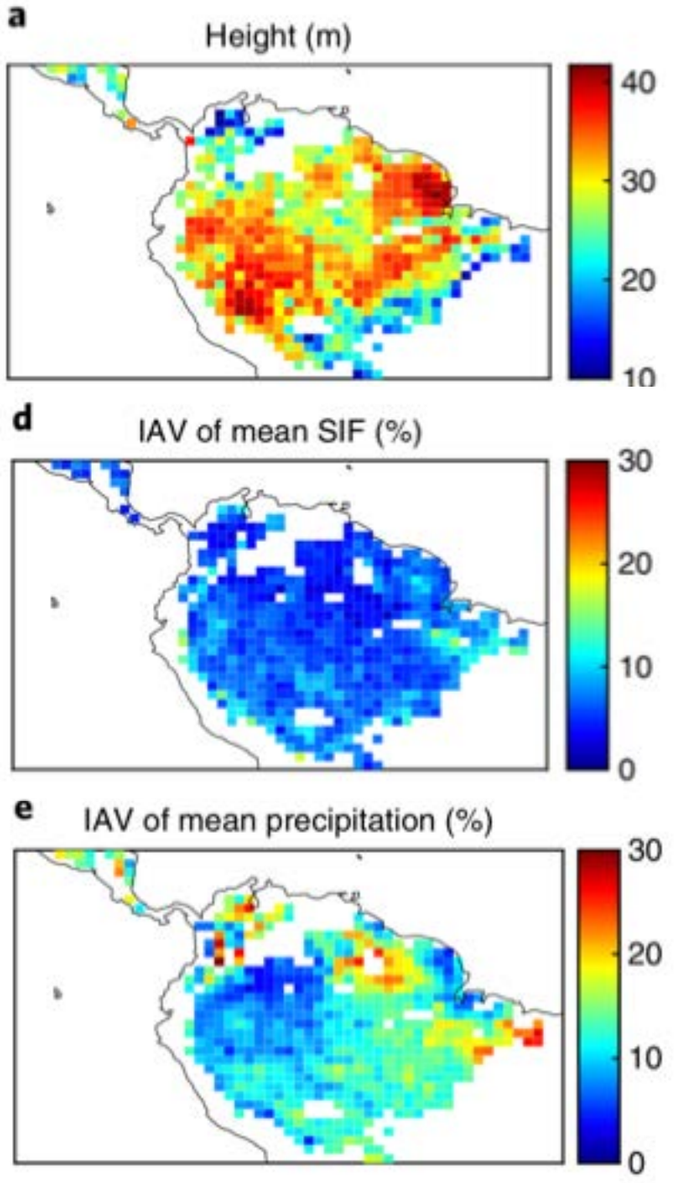
https://doi.org/10.1038/s41561-018-0133-5

Tall Amazonian forests are less sensitive to precipitation variability

Francesco Giardina[1,2], Alexandra G. Konings[3], Daniel Kennedy[4], Seyed Hamed Alemohammad[4], Rafael S. Oliveira[5,6], Maria Uriarte[7] and Pierre Gentine[4,8]*

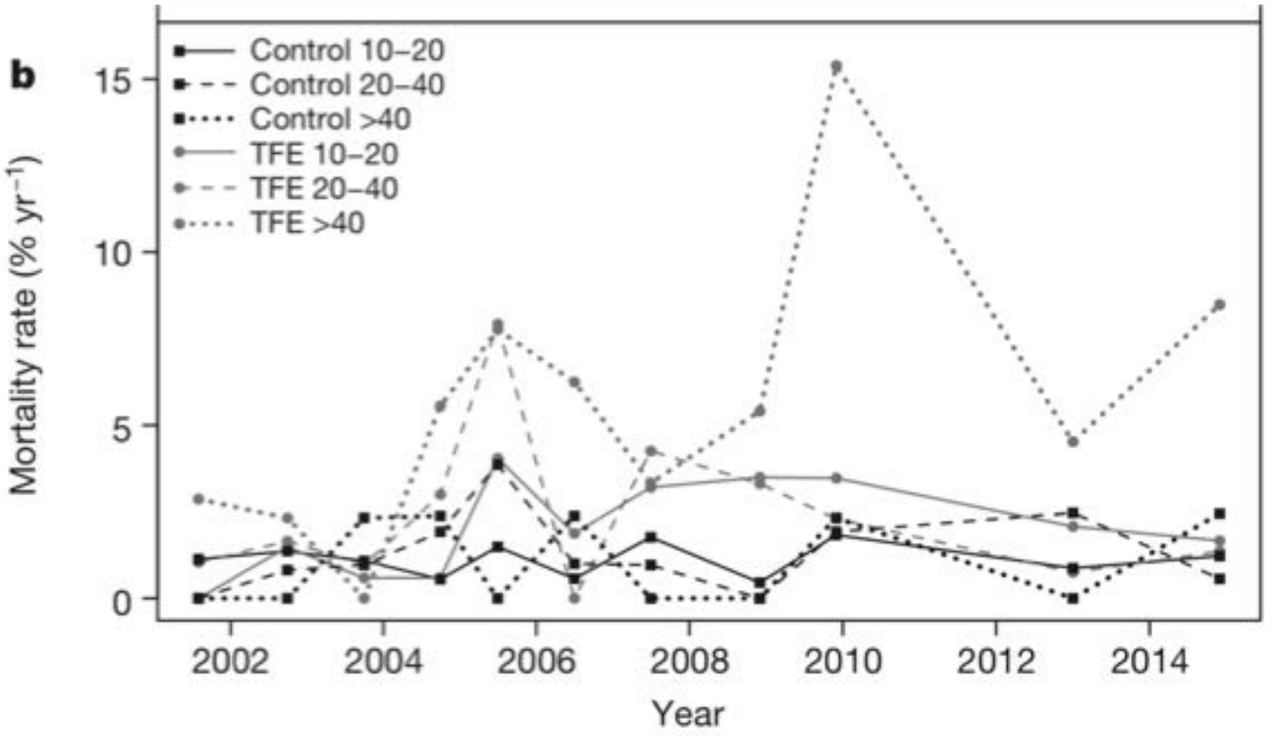
- Photosynthesis in > 30m trees 3X less sensitive to precipitation variability than shorter trees

- But does this tell us anything about vulnerability to drought?



Longest-running rain exclusion experiment

- Mortality signal dominated by the large tress - greater risk of hydraulic failure.

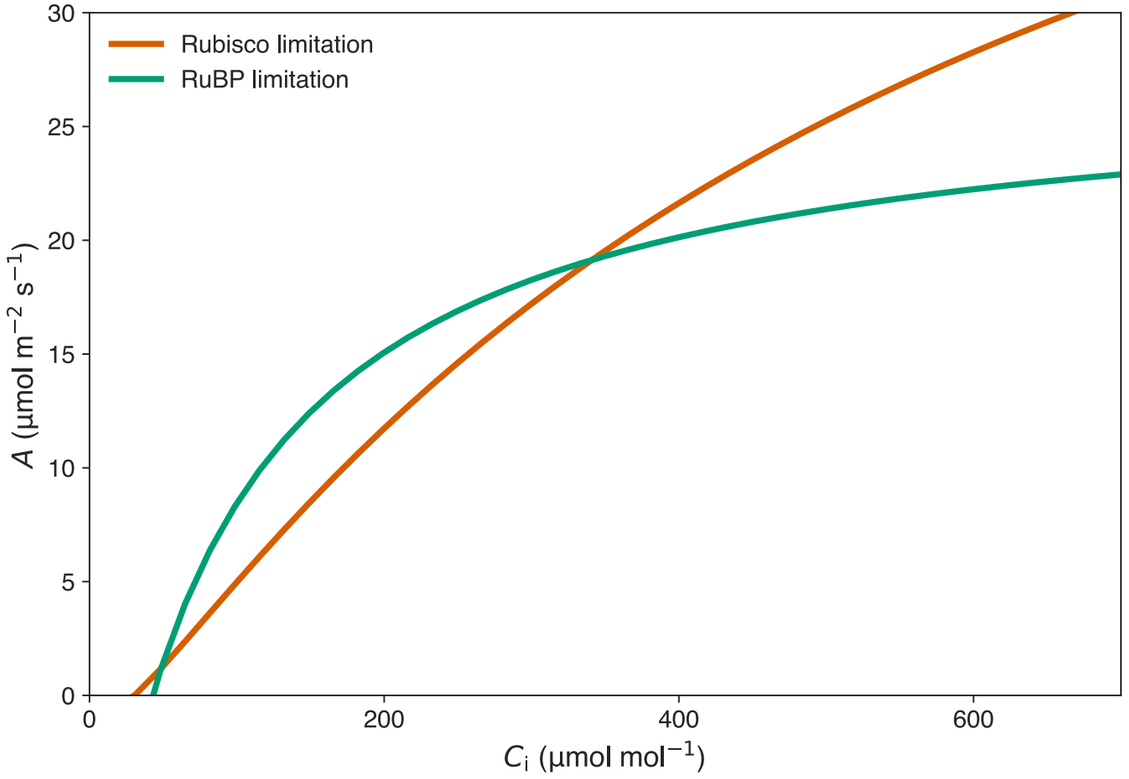


Rowland et al. (2015) Nature

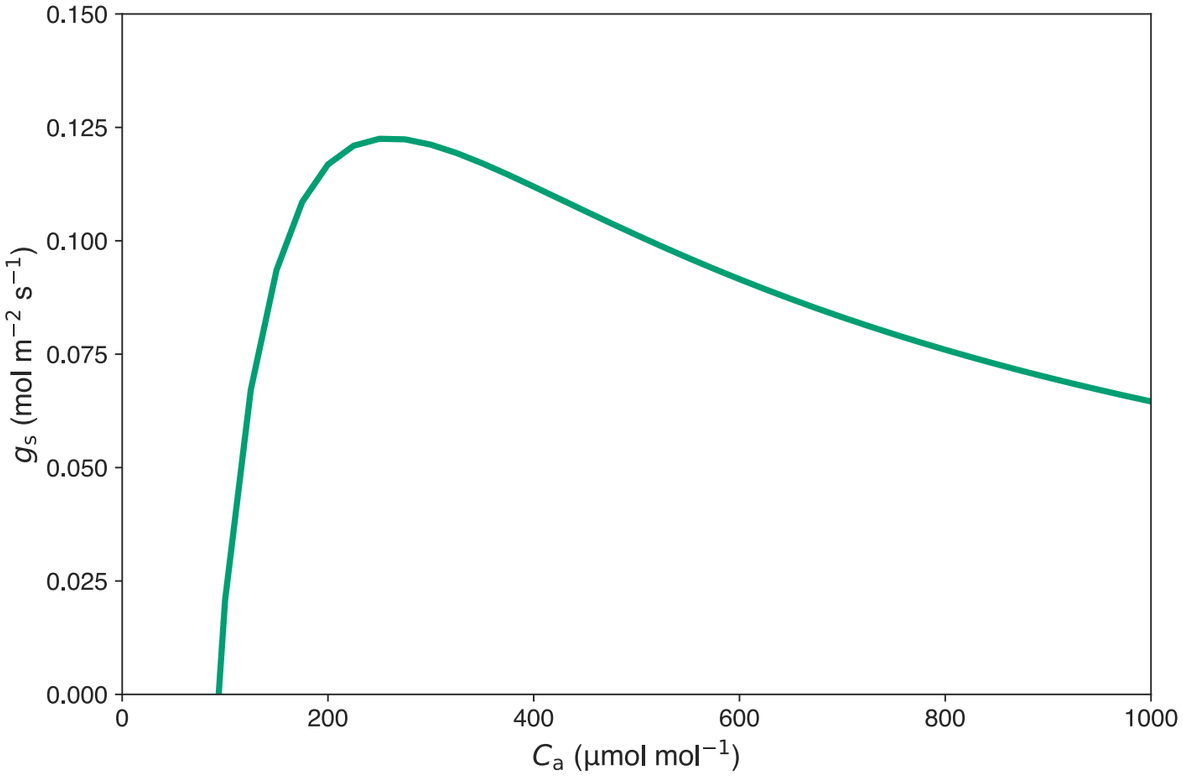
What about the response to CO_2?

At the leaf scale …

Photosynthesis (A)

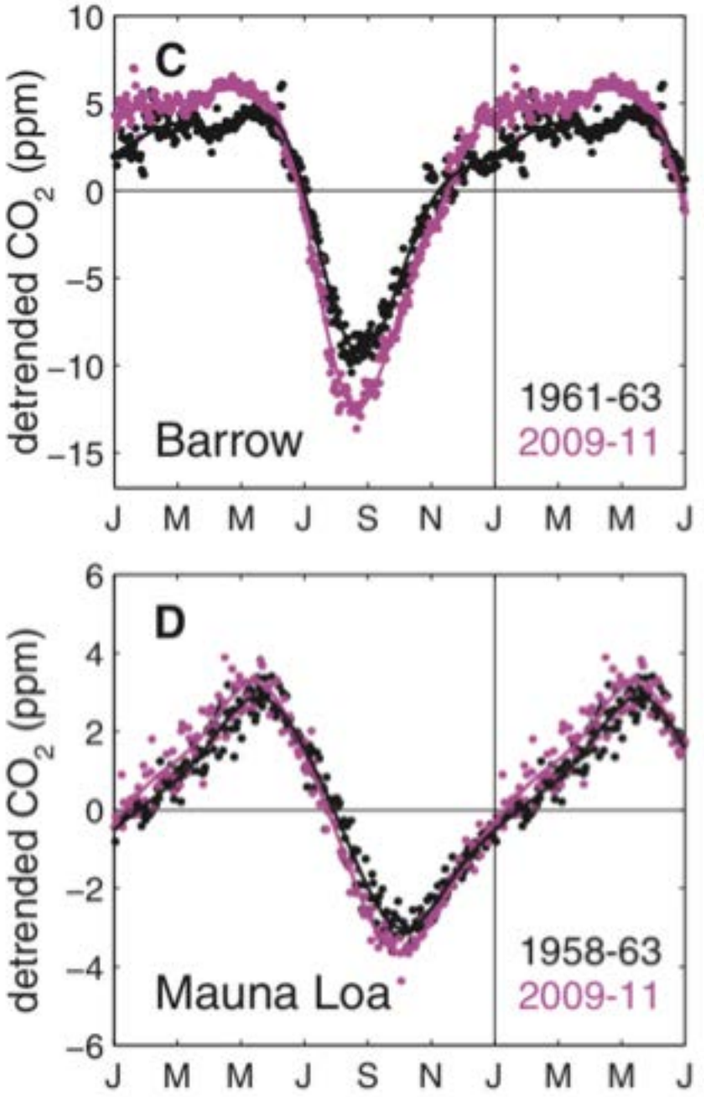


Stomatal Conductance (g_s)

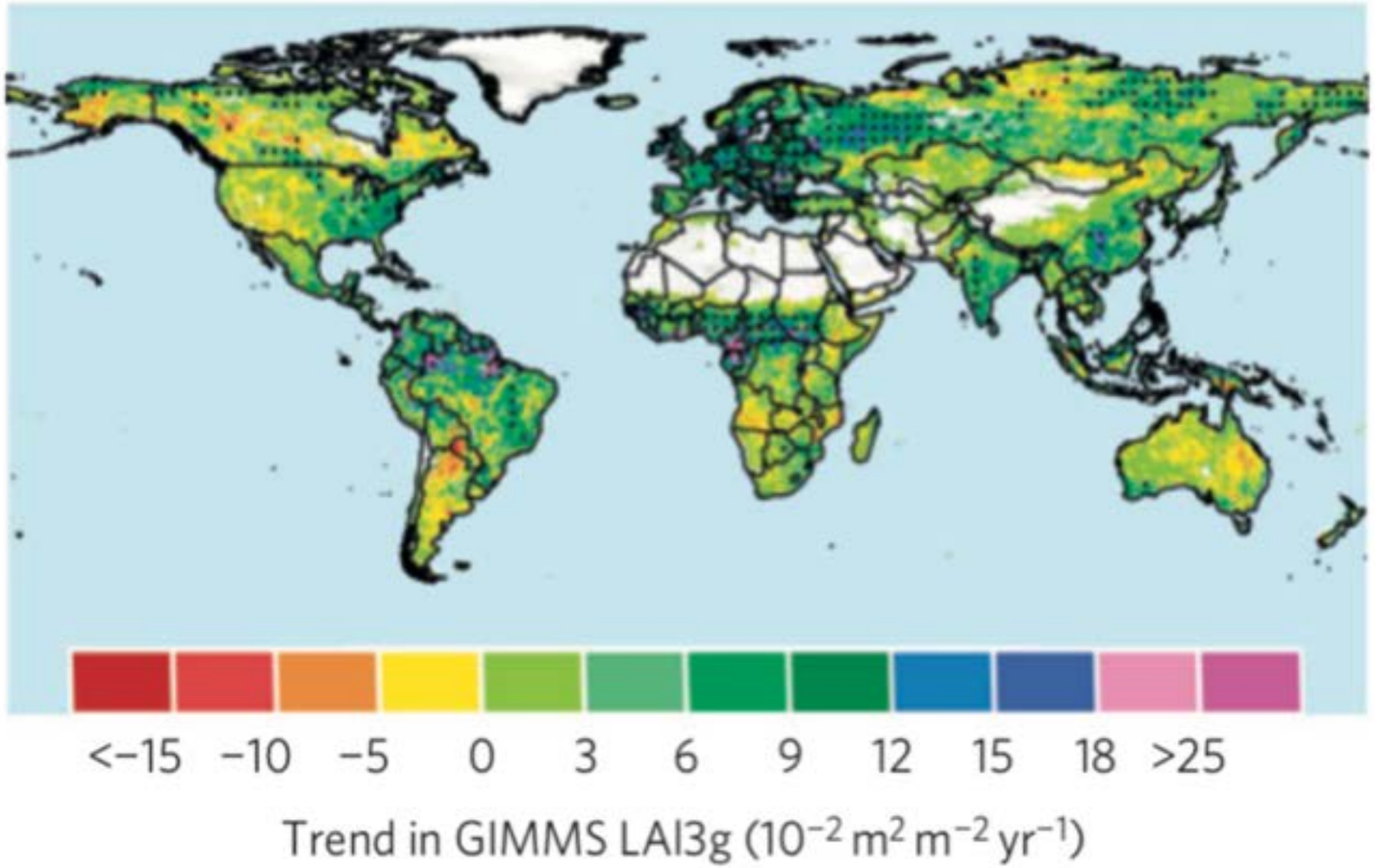


Increasing CO_2

Enhanced carbon uptake



Graven et al. (2013) Science



Zhu et al. (2016) Nature Clim. Chg.

[CO_2 ?] Woody thickening, S.Africa

1925

1993

2011

Bond and Midgley (2012) Phil. Trans. R. Soc. B

Increasing WUE

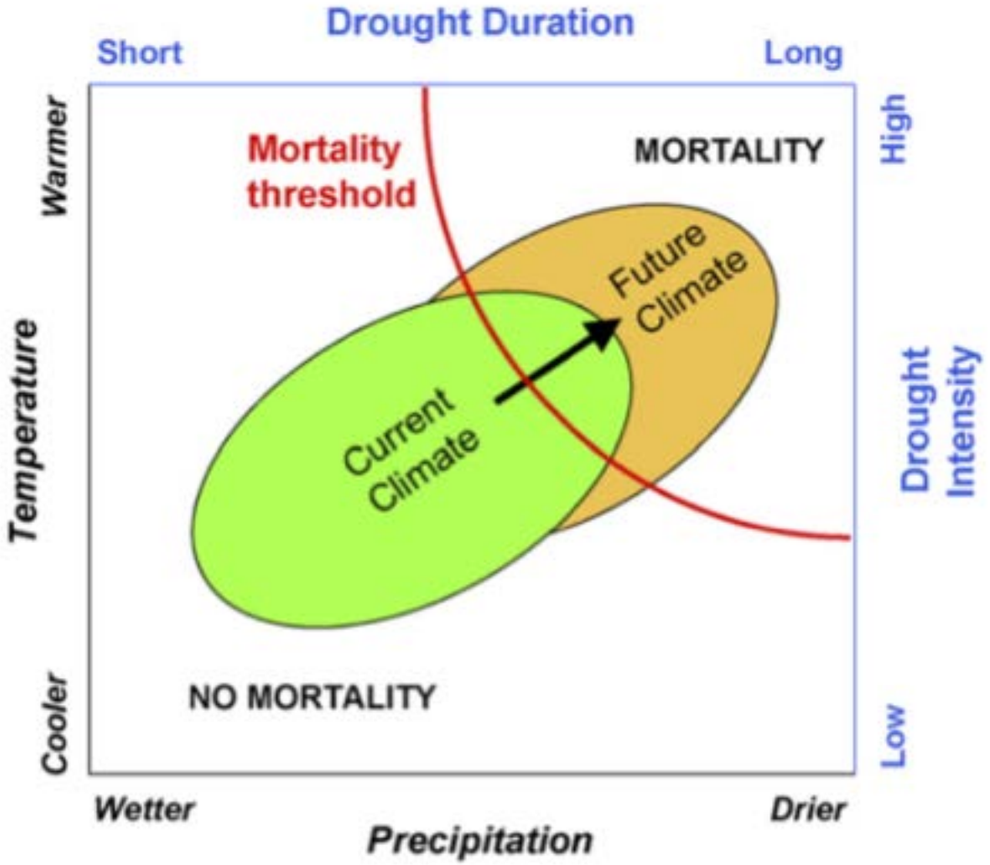
Theory embedded in models …

$$C_a \propto \frac{A}{E\left(gs\frac{D}{P}\right)} = WUE = \frac{C_a P}{1.6\left(D + g_1\sqrt{D}\right)}$$

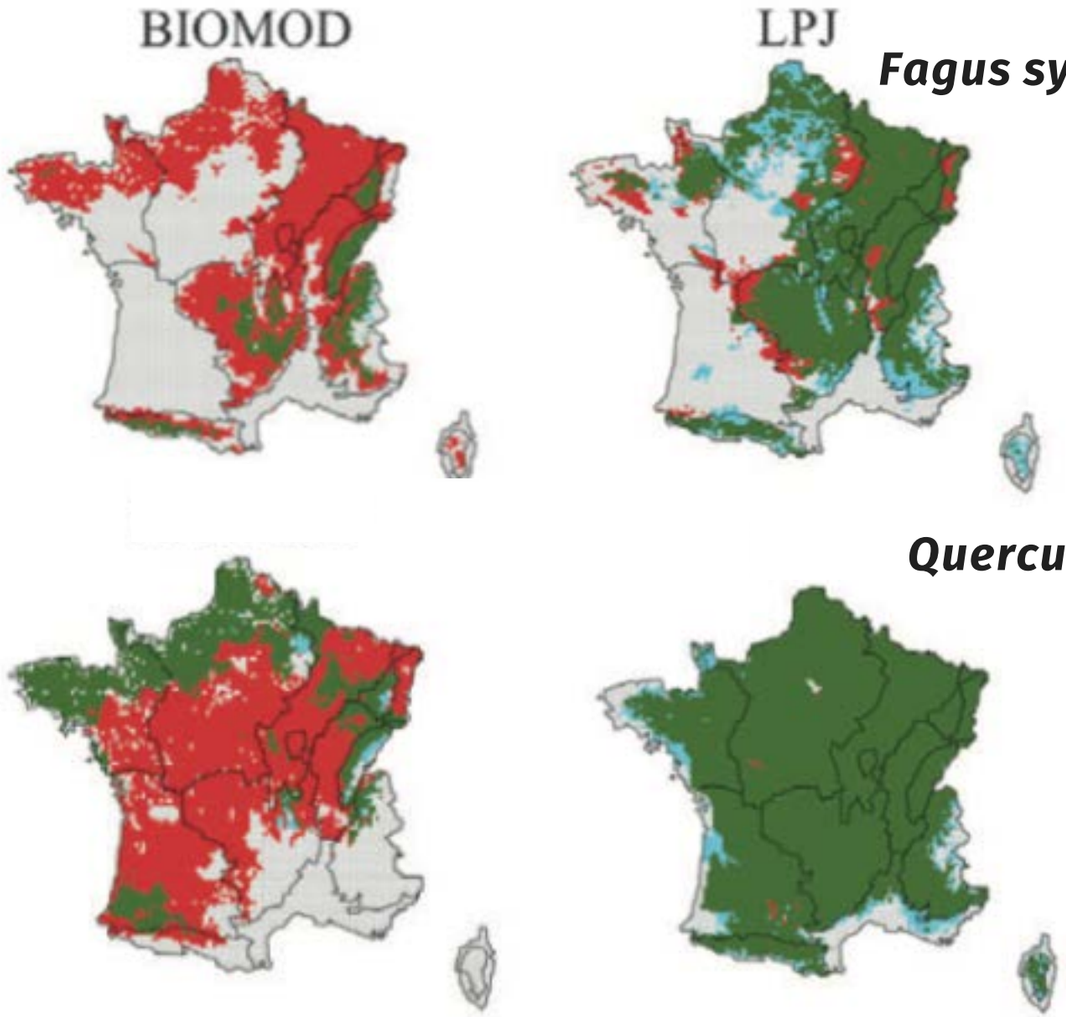
- By 2070 (RCP 8.5), **even** if *D* increased by 40%, plants would still be more WUE than they are currently due to increase in CO_2 (g_1=3; *D*=2)

- Is ignoring the role of CO_2 a warranted assumption by McDowell and Allen?

Projected changes in species ranges



Allen et al. (2015) Ecosphere



Cheaib et al. (2012) Ecol. Lett.

Will eCO_2 alleviate water stress?

- Models predict a CO_2 x drought interaction
  - reduced g_s = ↑SW

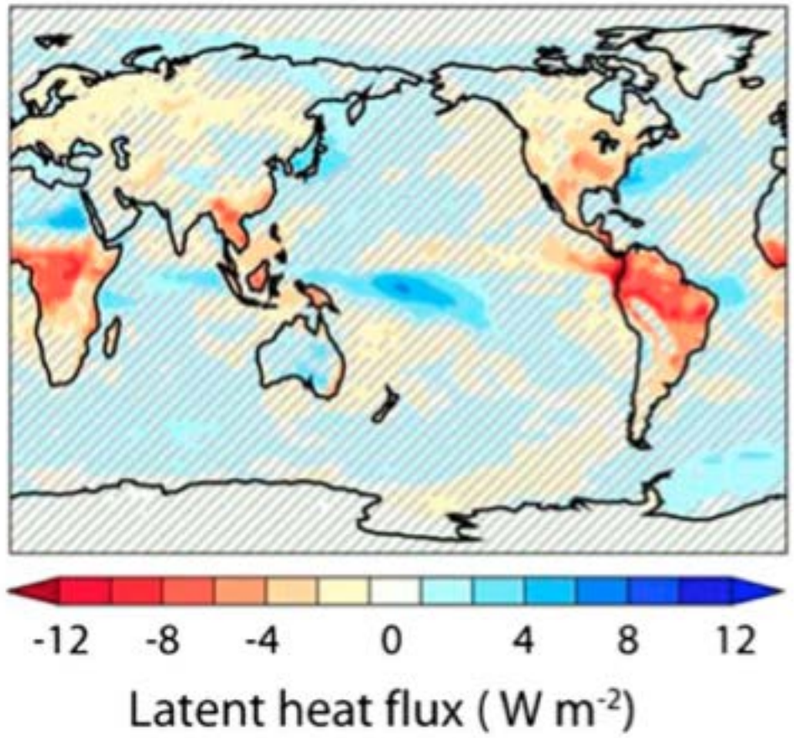
- eCO_2 may also increase carbon reserves, delaying impact of drought

- But support for ↓g_s = ↑SW is mixed (although data is usually < 10 cm in depth!)

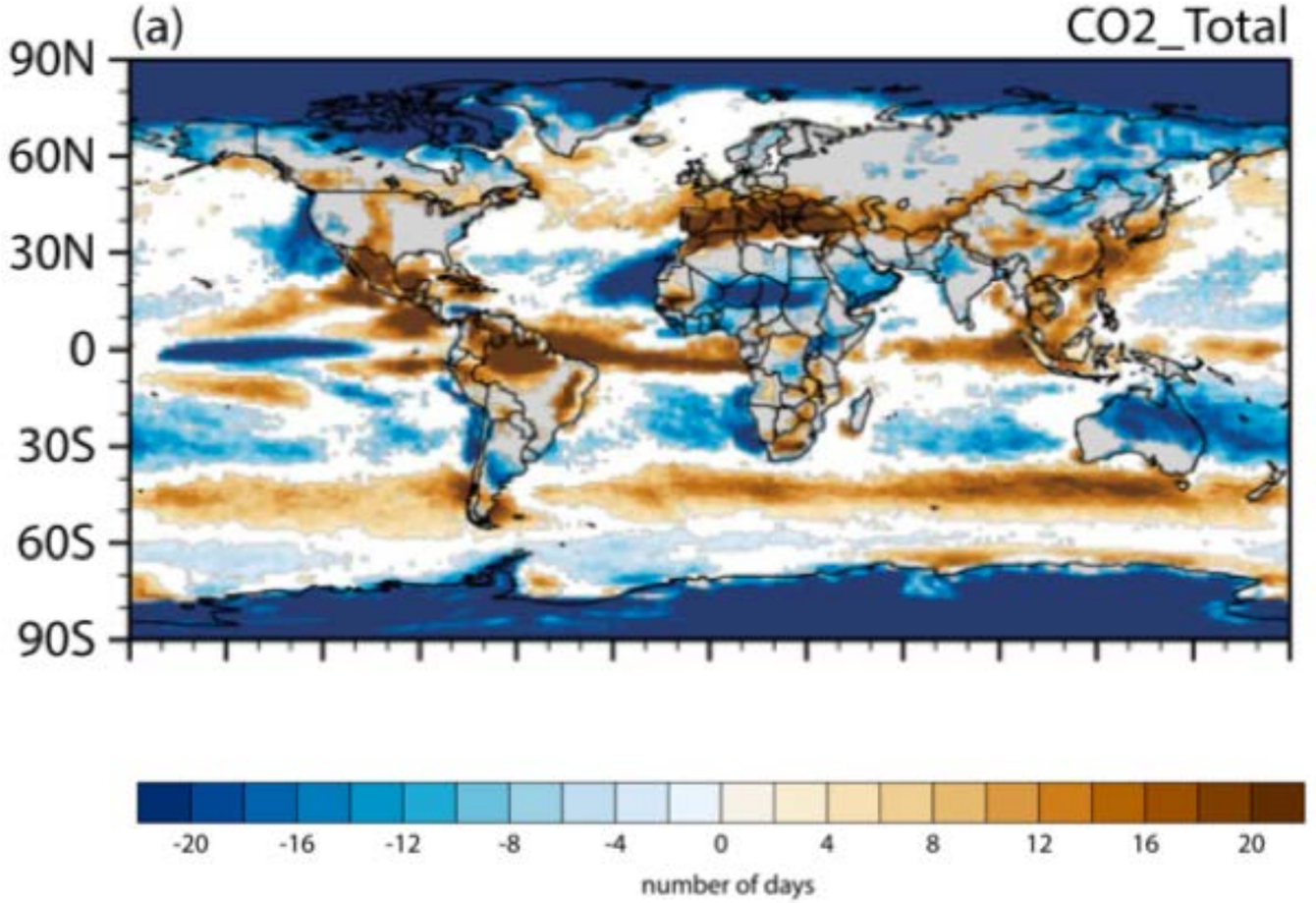
- And increased LAI can use “saved” water

Impact on the water cycle

Physiological



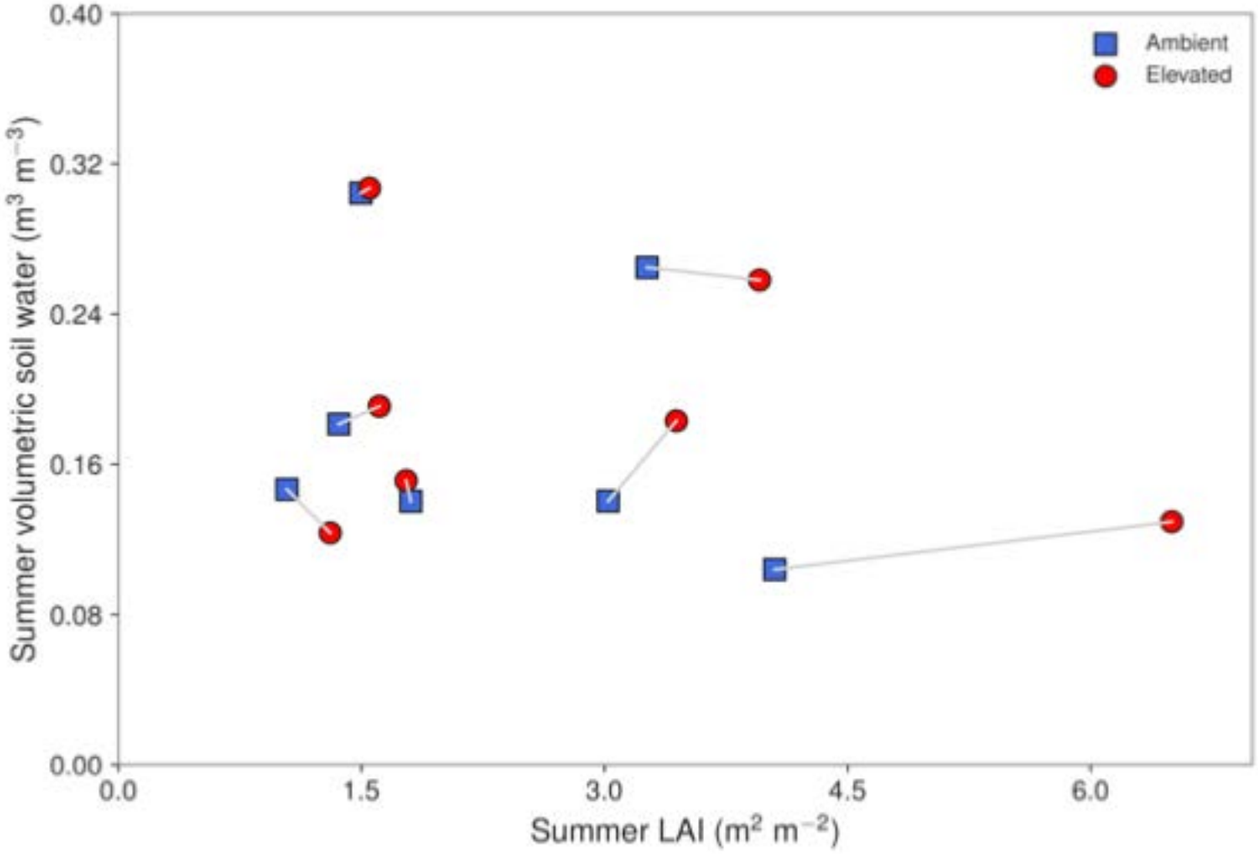
Cao et al. (2010) PNAS



Skinner et al. (2016) J. of Clim.

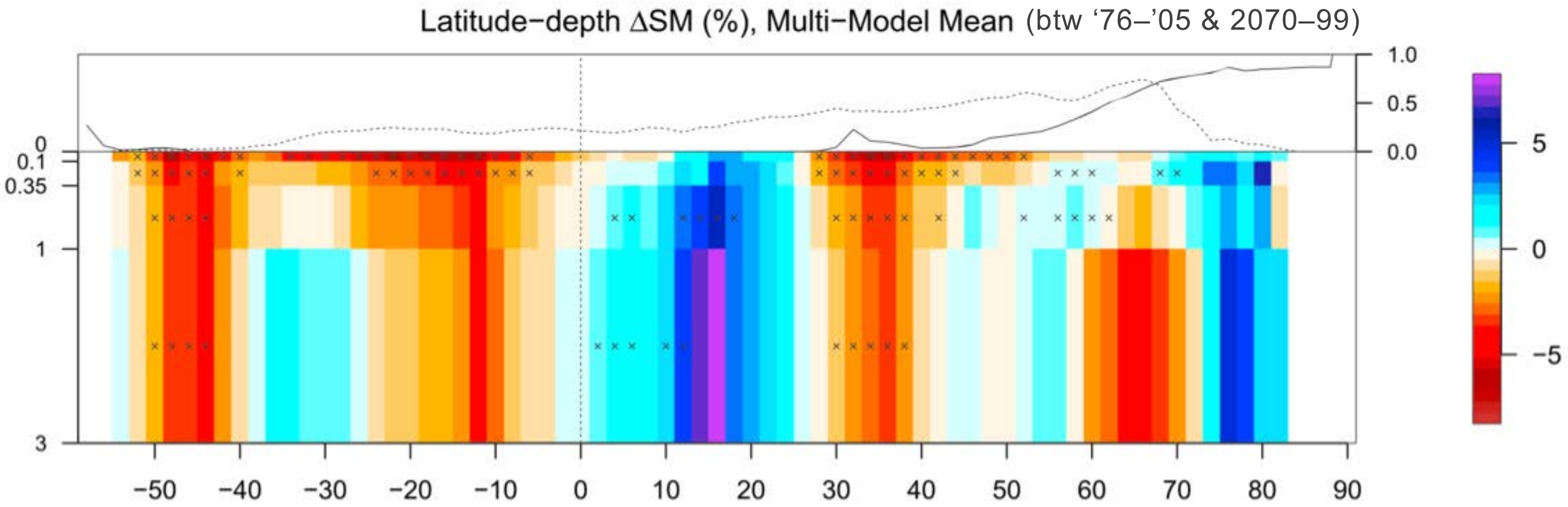
Uncertain response to CO_2

- Response to CO_2 is highly uncertain, which has major implications for the water cycle.
- Will plants save water?
- Will LAI increase?



Medlyn et al. (2016) Global Change Biol.

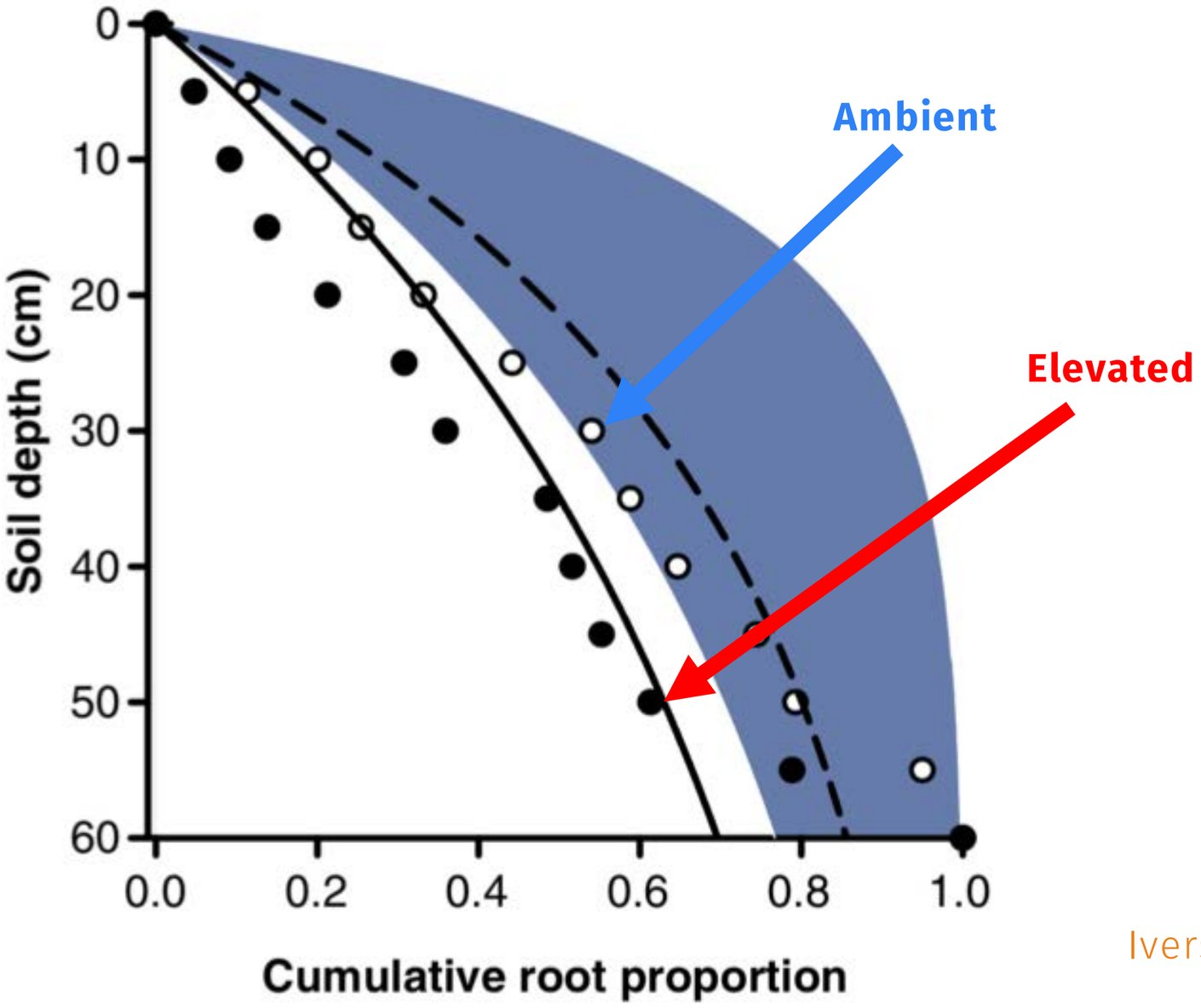
CMIP5 projected changes in SW



Berg et al. (2016) Geophys. Res. Lett.

What key **assumption** is missing in these models?

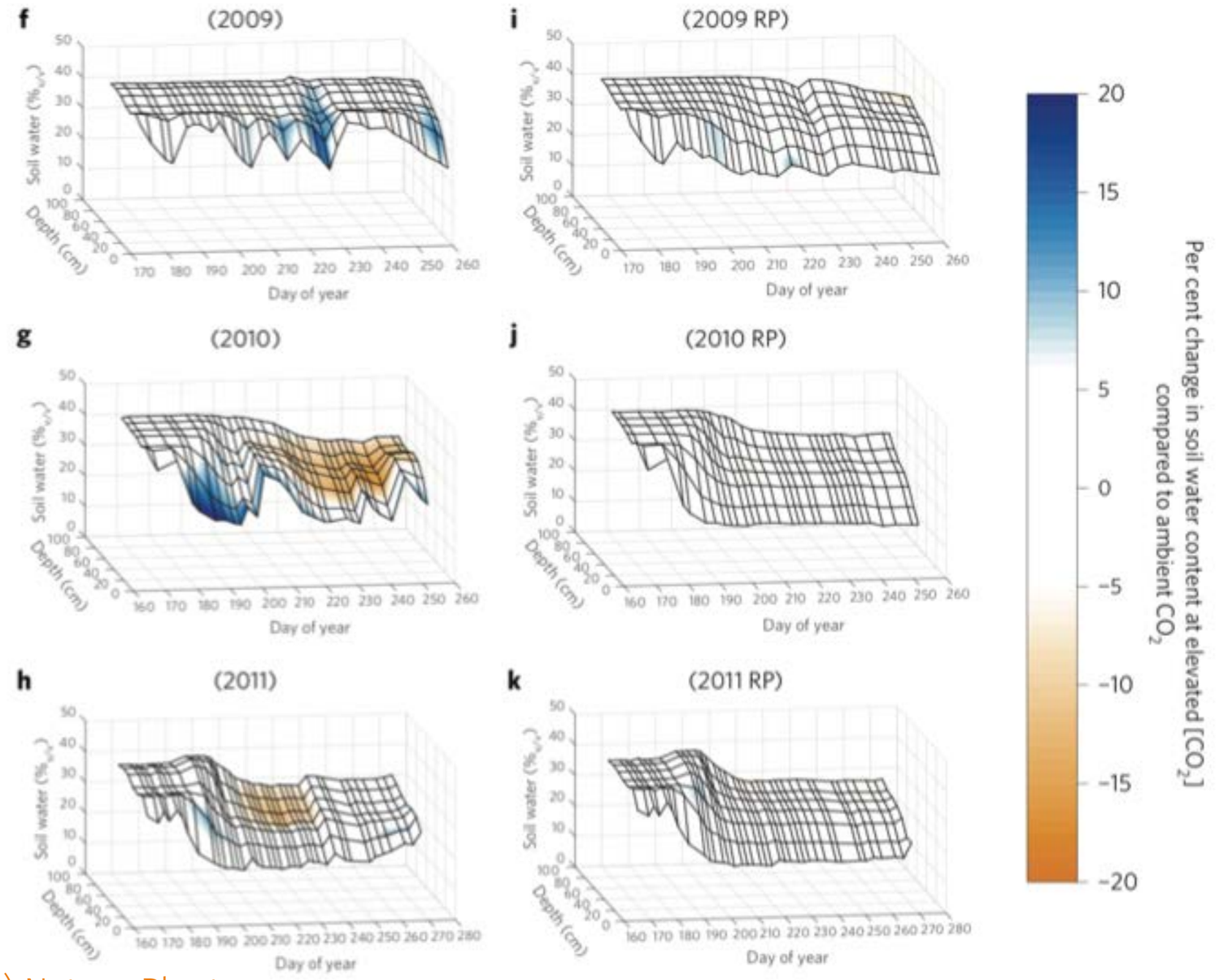
eCO_2 may alter rooting profile



Iversen (2009) New Phyt.

eCO_2 does not always conserve SW

Soybean



CO_2 ↑ ~44%

PPT ↓ 35-64%

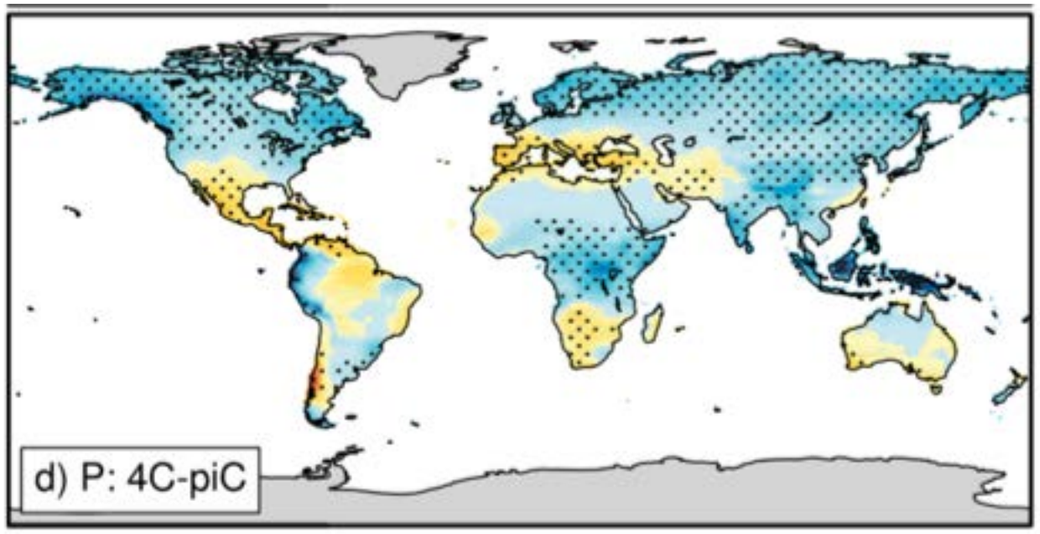
...in a water limited system!

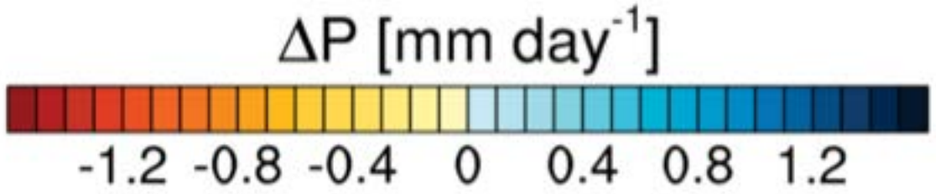
What does this tell us?

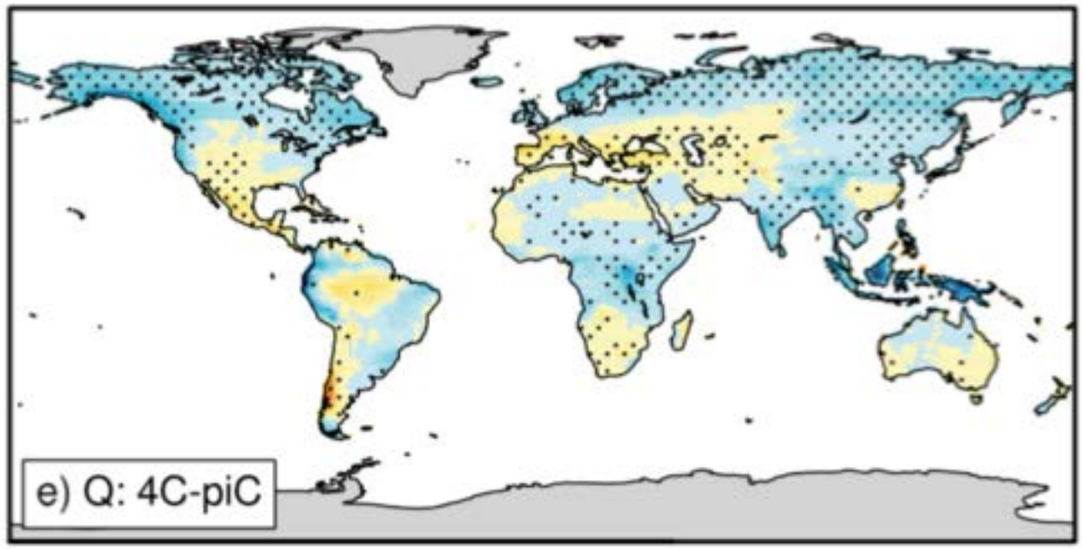
Gray et al. (2016) Nature Plants

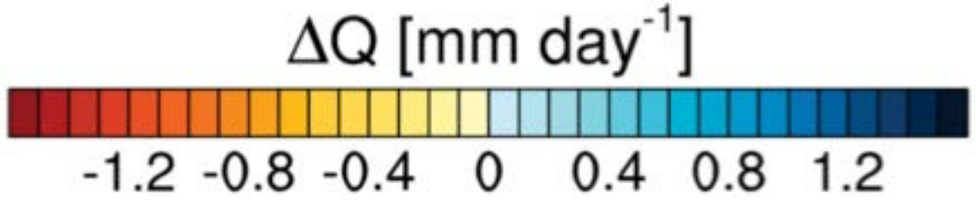
Future runoff

- Increased PPT intensity but reduced frequency → increased runoff?
- Reduced transpiration (g_s) → increased runoff?
- Reduced transpiration → increased LAI and reduced runoff?



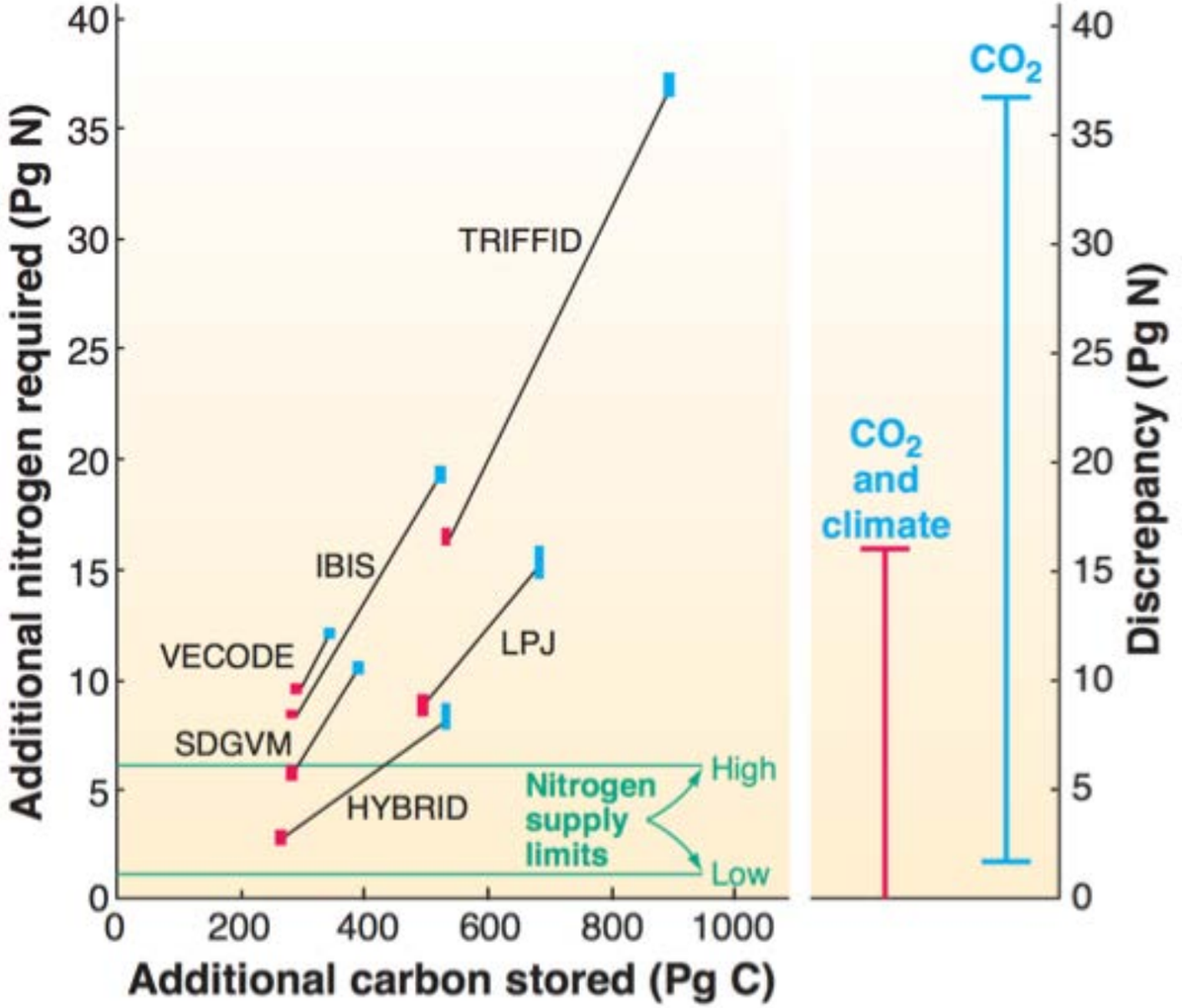






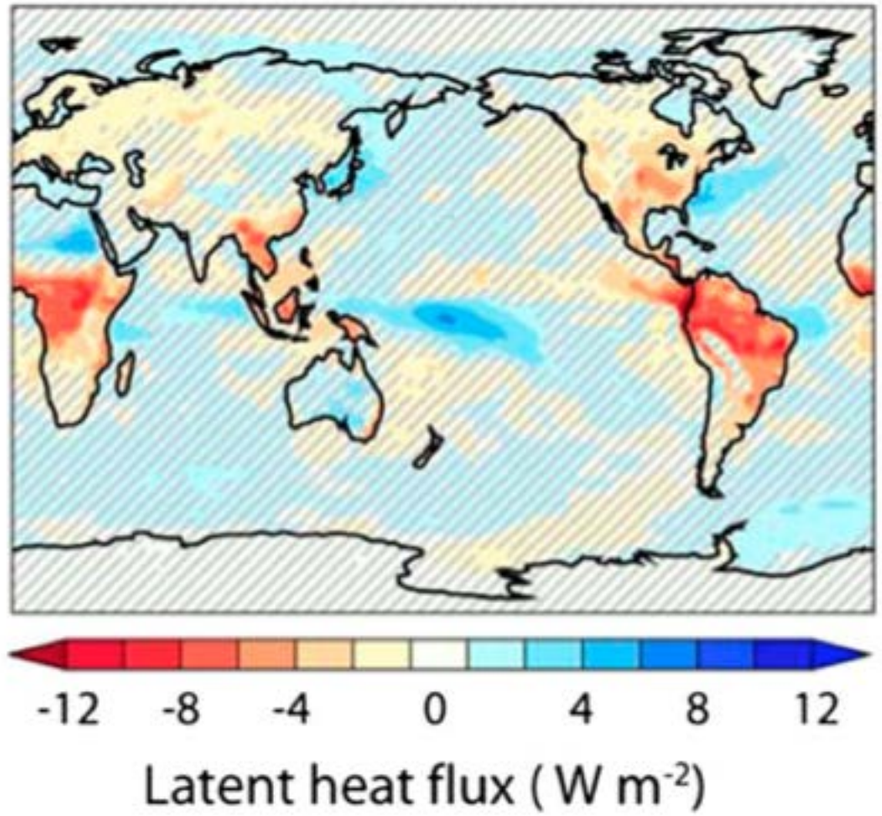
Greve et al. (2017) Environ. Res. Lett.

But what about nutrients?



Hungate et al. (2003) Science

Cao et al. (2010) PNAS

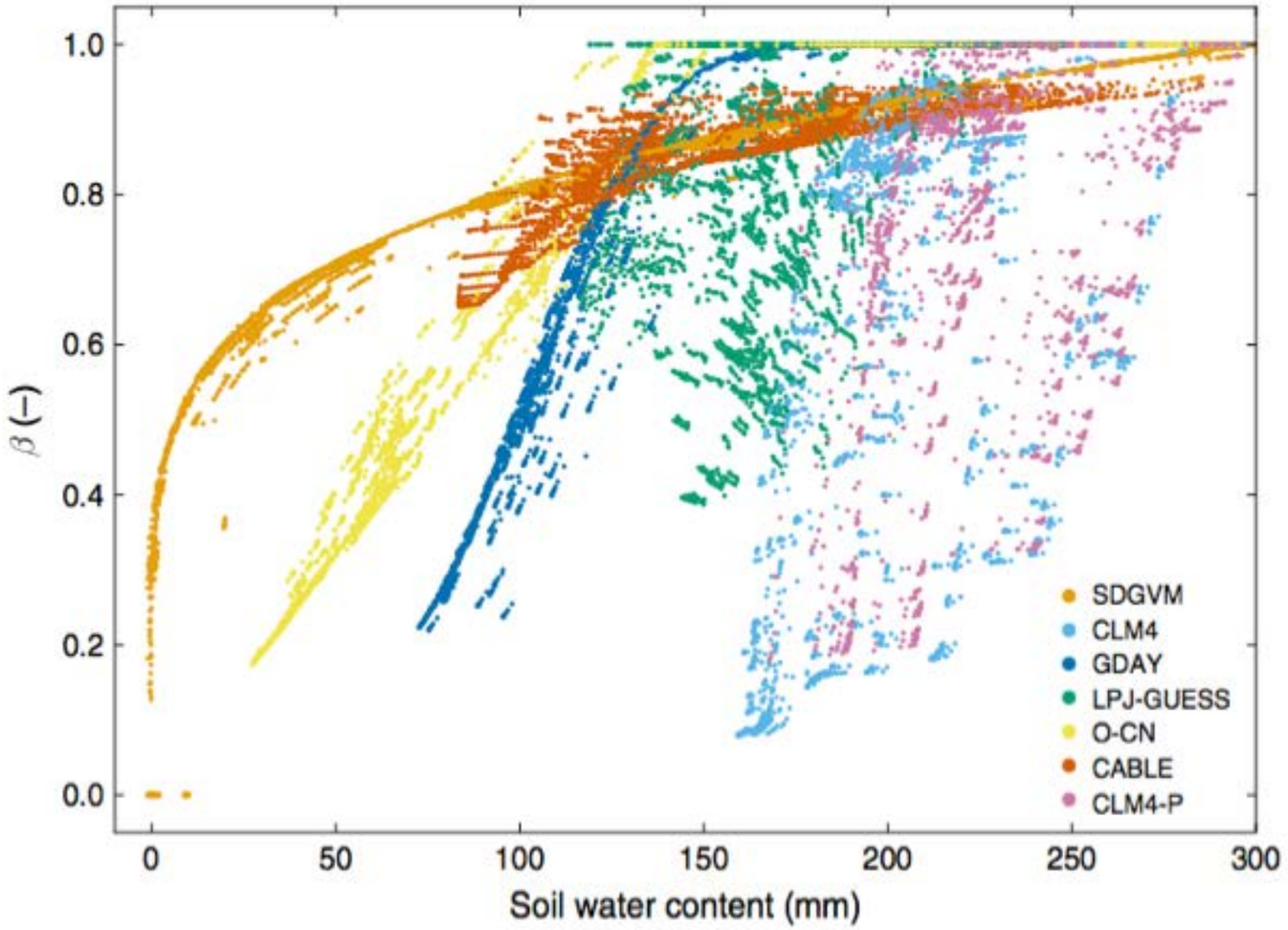


How will this affect **precipitation**?

$$\frac{A}{g_s} \propto C_a$$

What processes are currently missing (or poorly represented) in models?

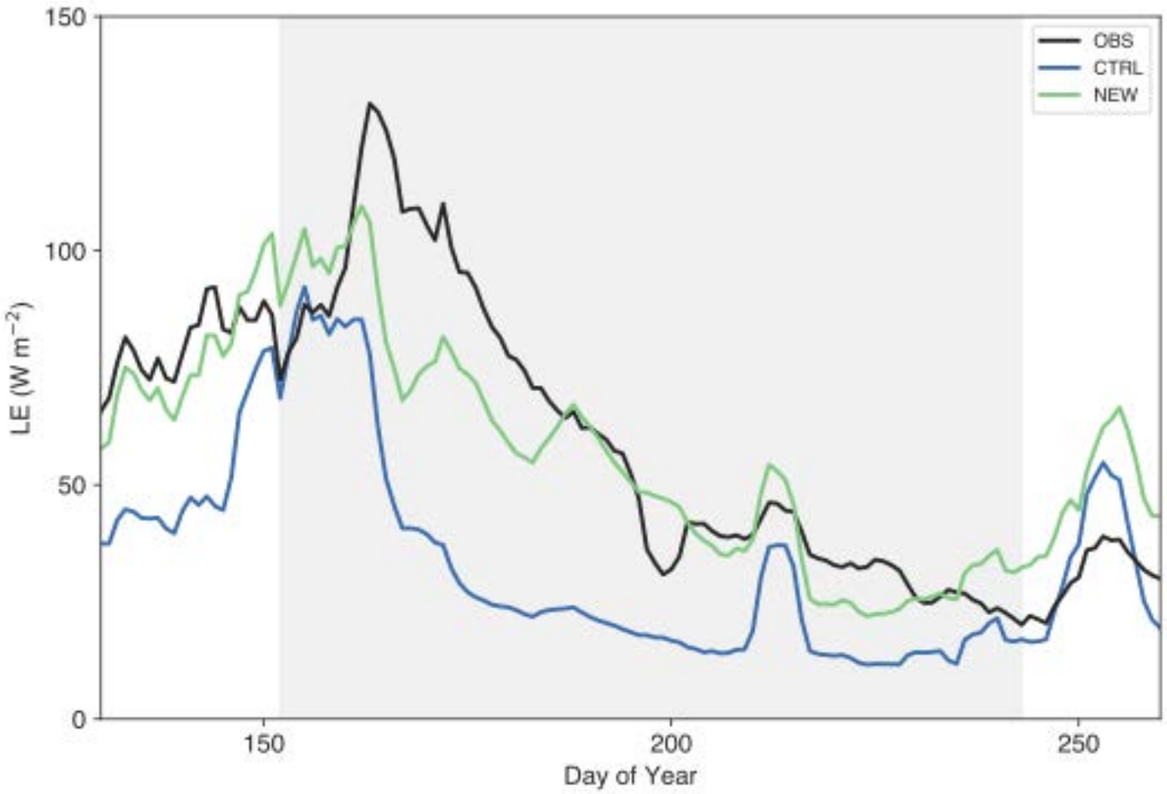
Models represent water stress differently



Increasing water stress

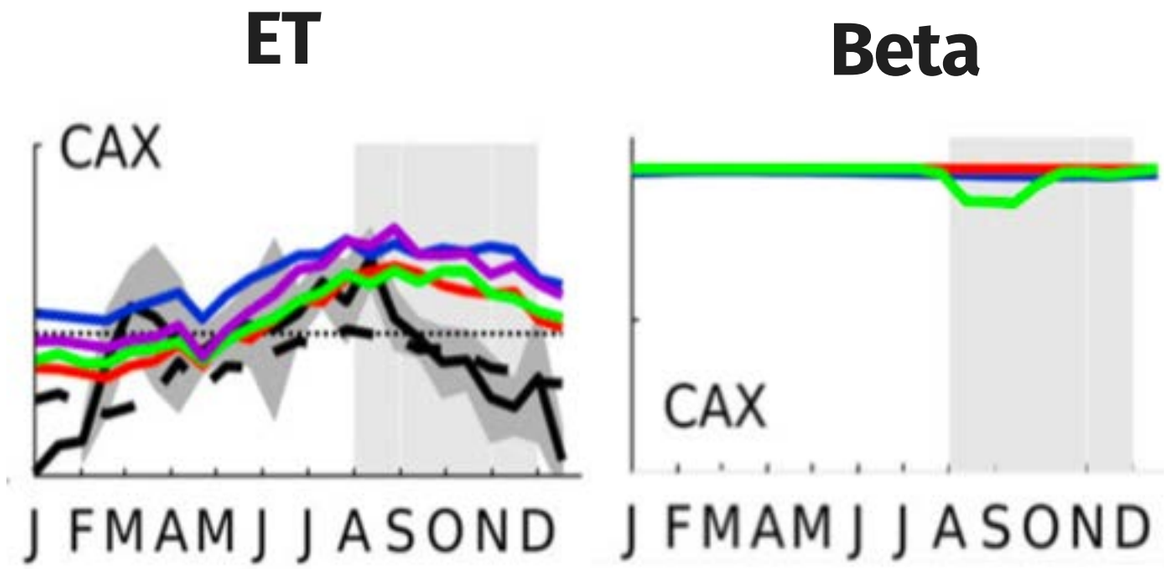
Sensitivity to water stress isn’t well represented

“Dry”



De Kauwe et al. (2015) Biogeosci.

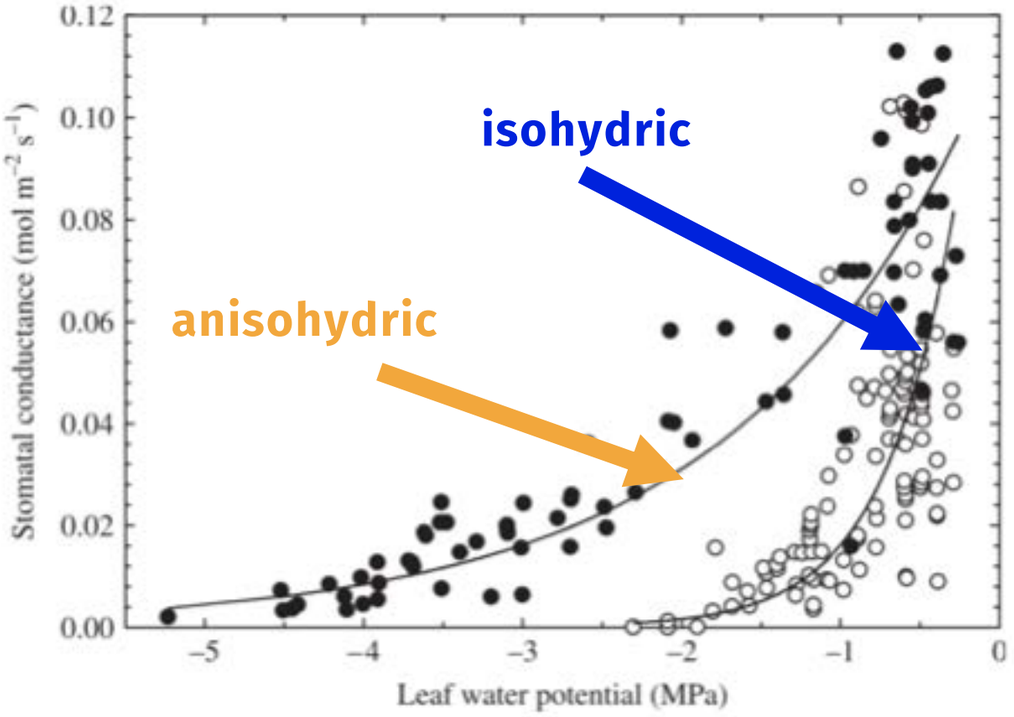
“Wet”



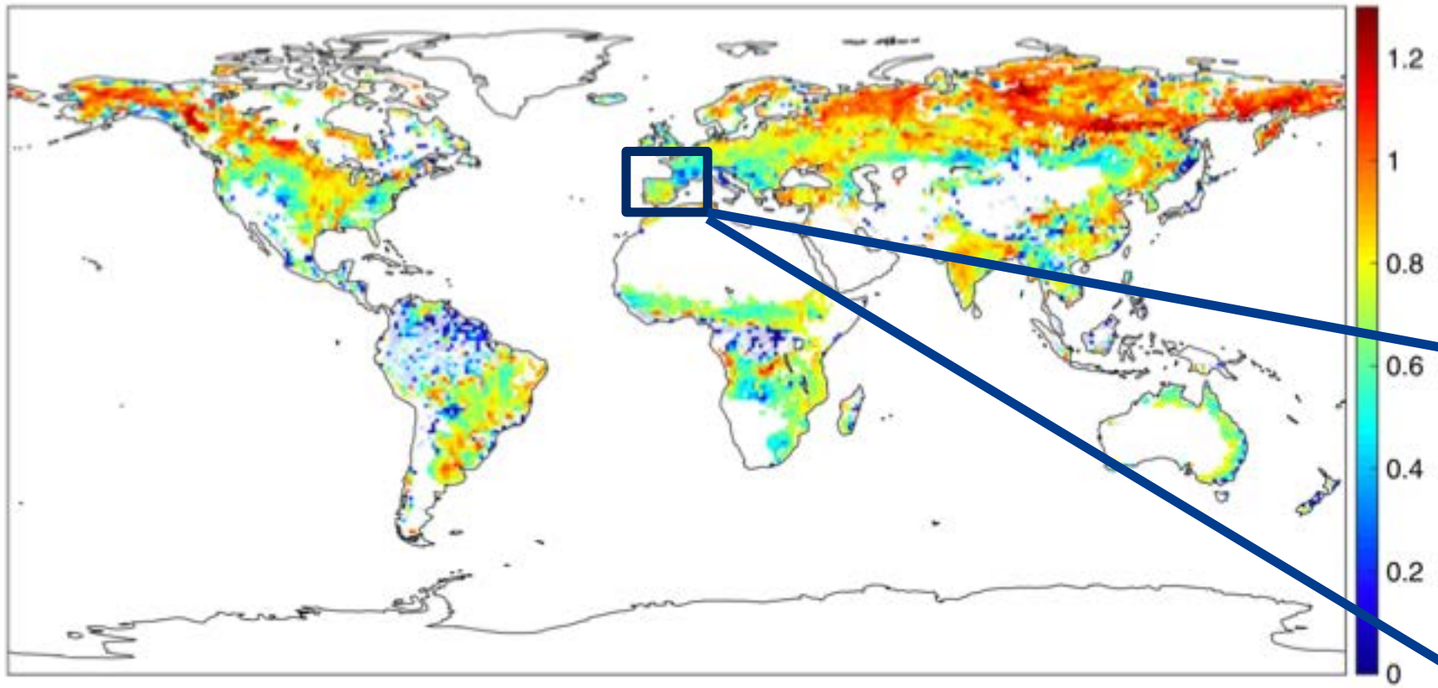
Restrepo-Coupe et al. (2017) Global Change Biol.

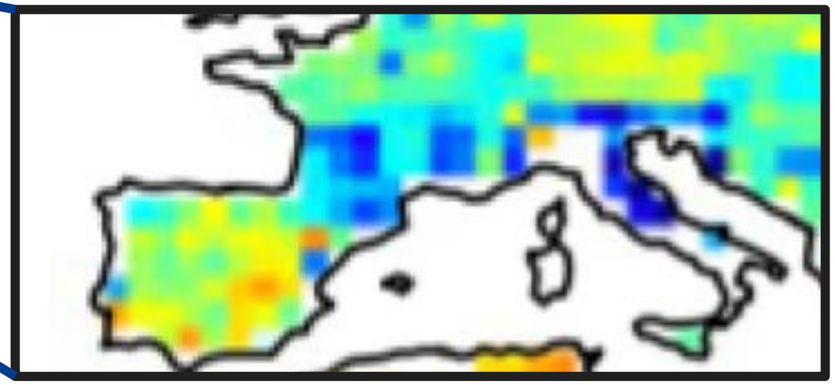
Models need more biology

Need to capture the **sensitivity** of plants to water stress



(apparent) Variations in isohydricity

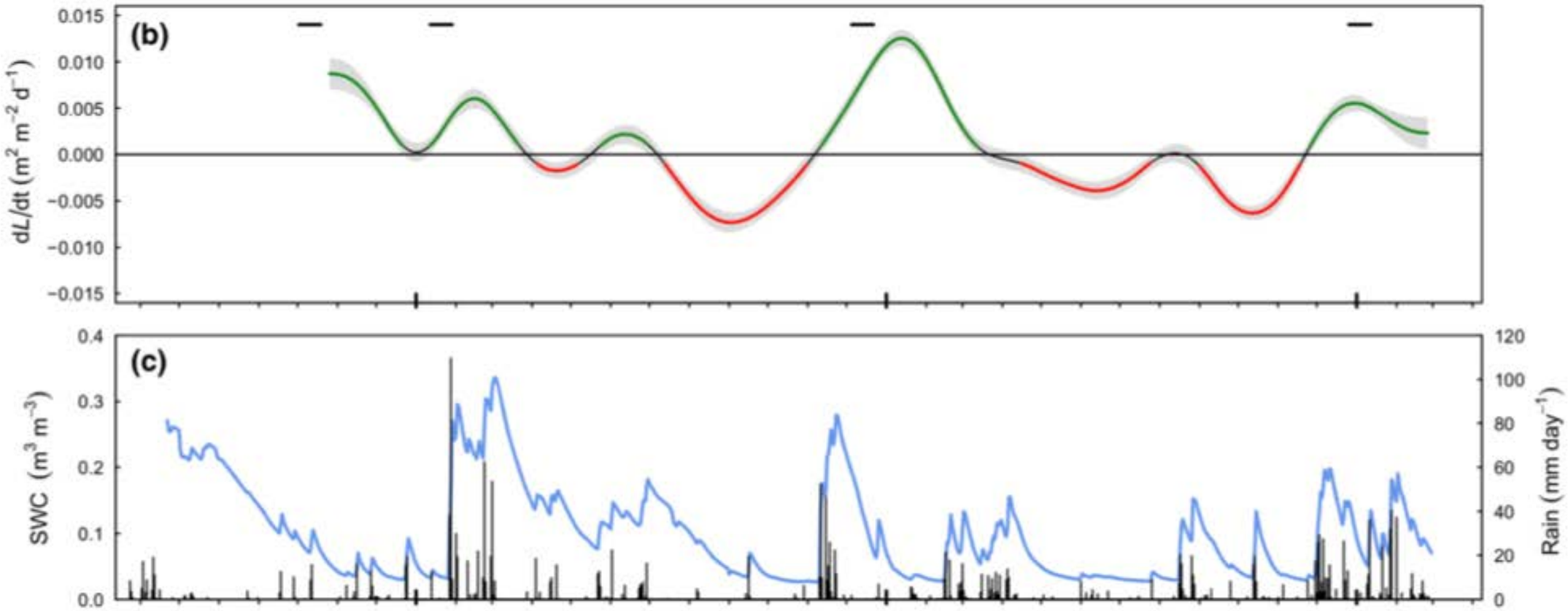




Konings & Gentine (2016) Global Change Biol.

Missing dynamics

- Dynamic vegetation responses to water availability (roots/leaves)

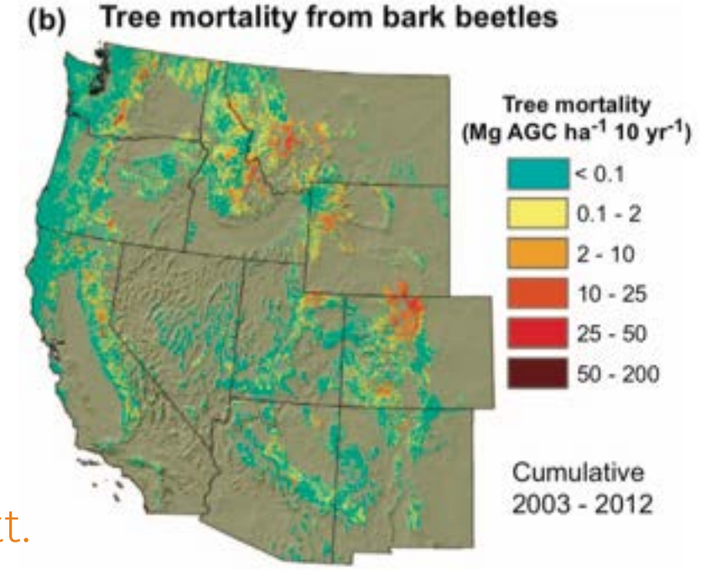


Duursma et al. (2016) Global Change Biol.

Legacy effects

- Vegetation can’t die! Missing feedback to climate …

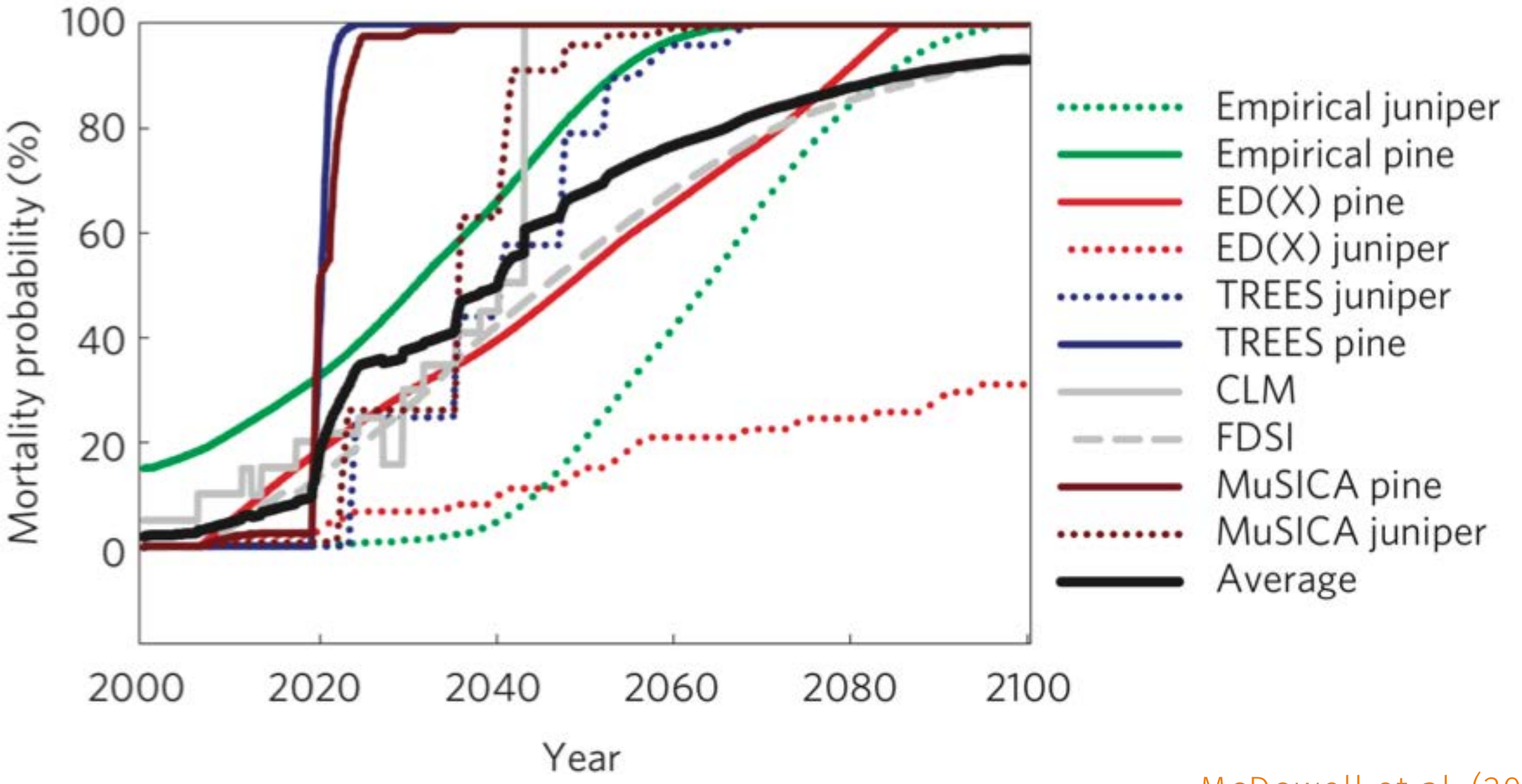
- Insect-associated mortality – linked to drought (low PPT)



Berner et al. (2017) Environ. Res. Lett.

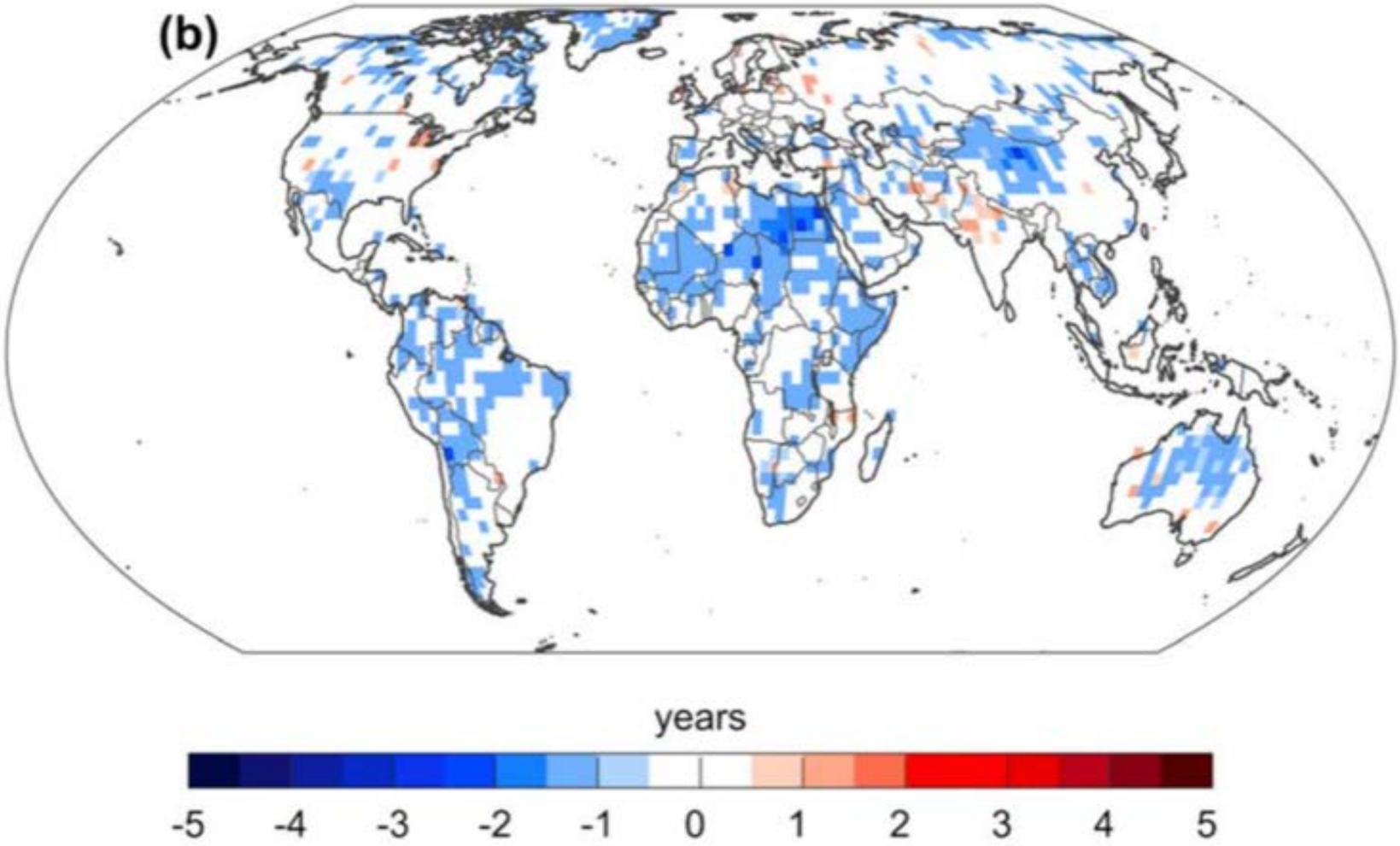
Long way from predicting drought mortality

Conifer mortality predictions



McDowell et al. (2015) Nature Clim Chg.

Underestimate drought persistence



Moon et al. (2018) JGR: Atmospheres

Conclusions

- Projecting changes in drought is a complicated business
- Important to consider the assumptions behind the projections
- Metrics that ignore changes in the vegetation in response to global change are problematic
- But changes in the vegetation response to global change are uncertain