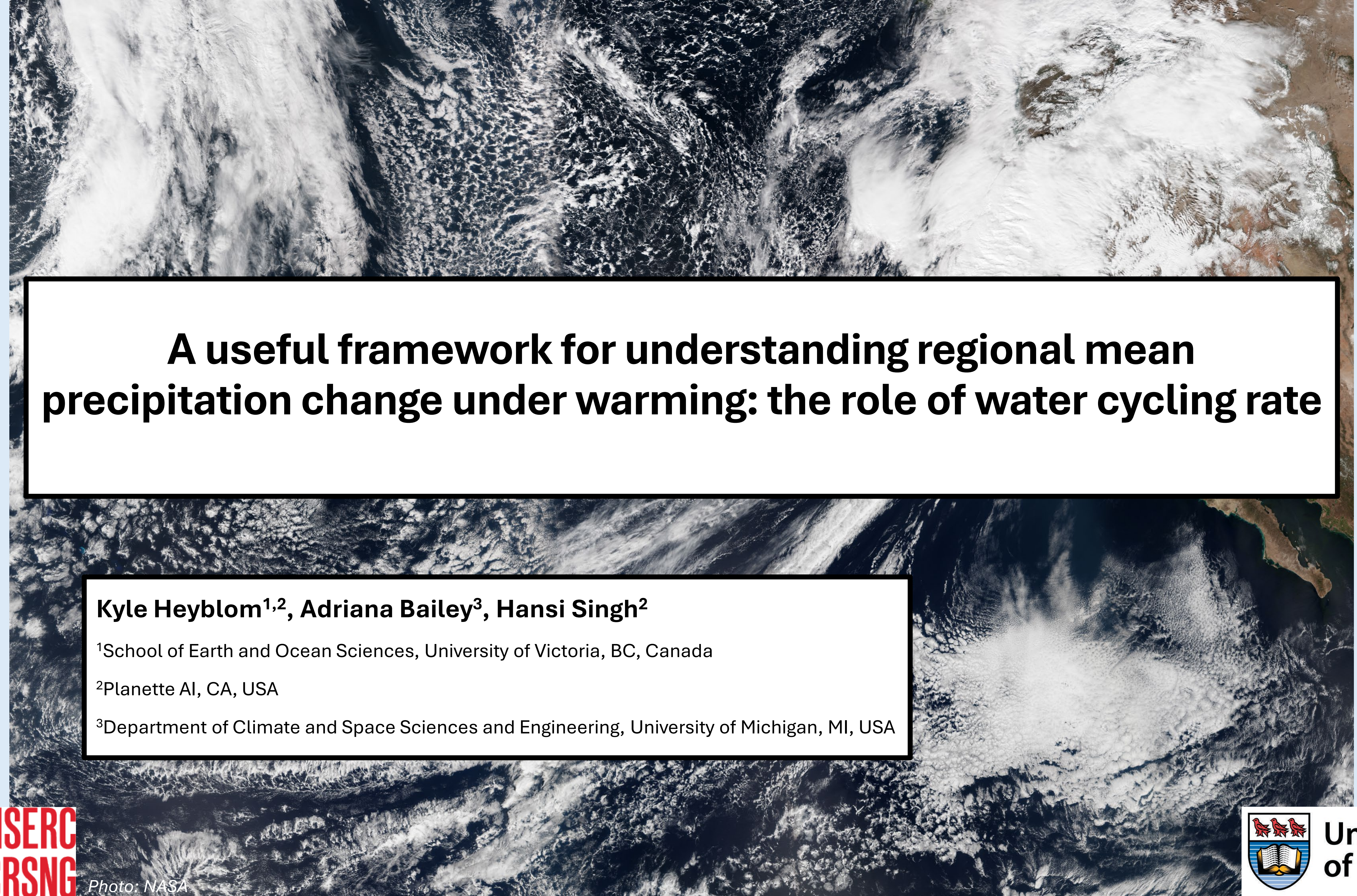

Photo: NASA

A useful framework for understanding regional mean precipitation change under warming: the role of water cycling rate

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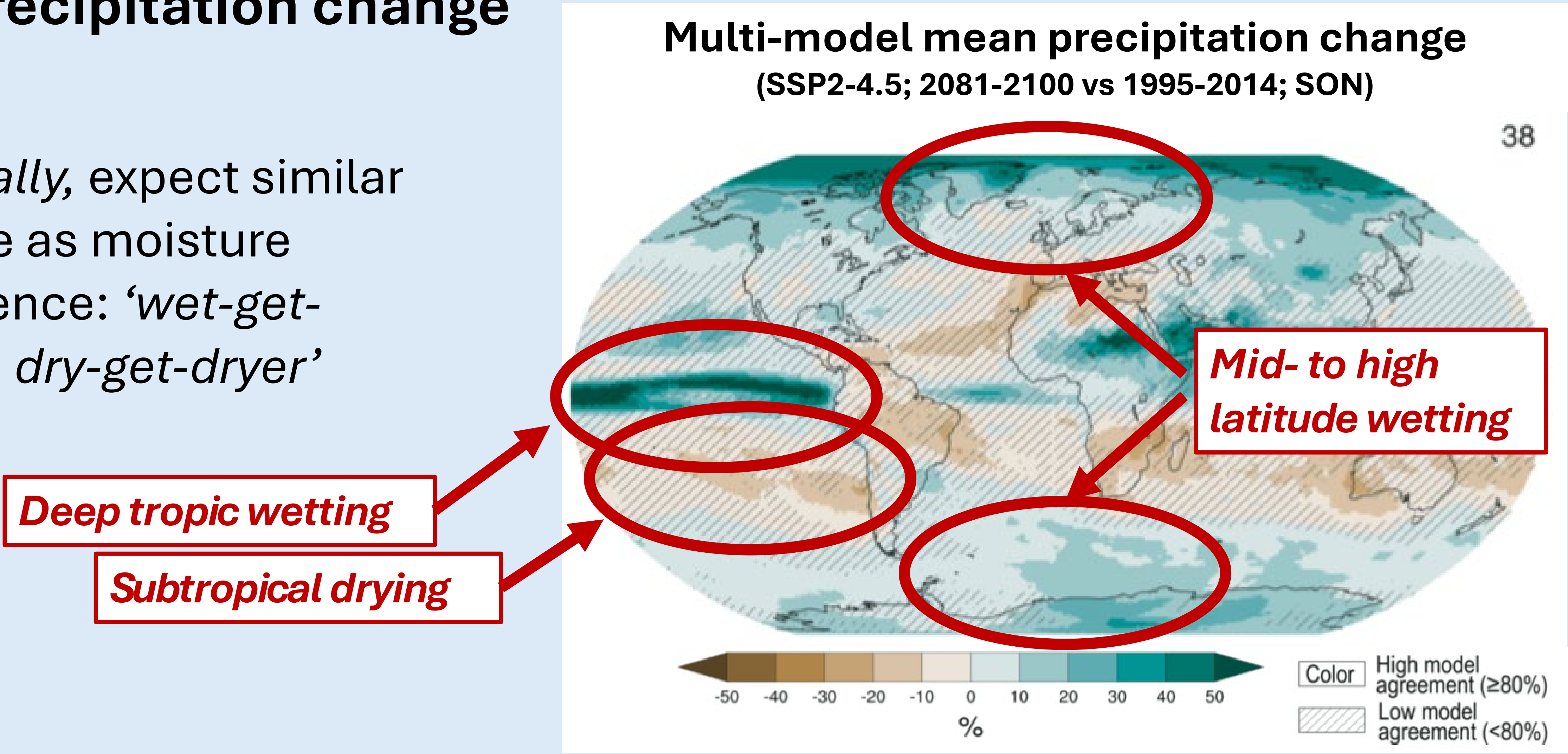
NSERC CRSNG

University of Victoria

ESMs tend to agree on the general spatial pattern of annual mean precipitation change

- *Generally,* expect similar change as moisture divergence: *'wet-get-wetter, dry-get-dryer'*



(IPCC AR6 WG1, Ch. 8)

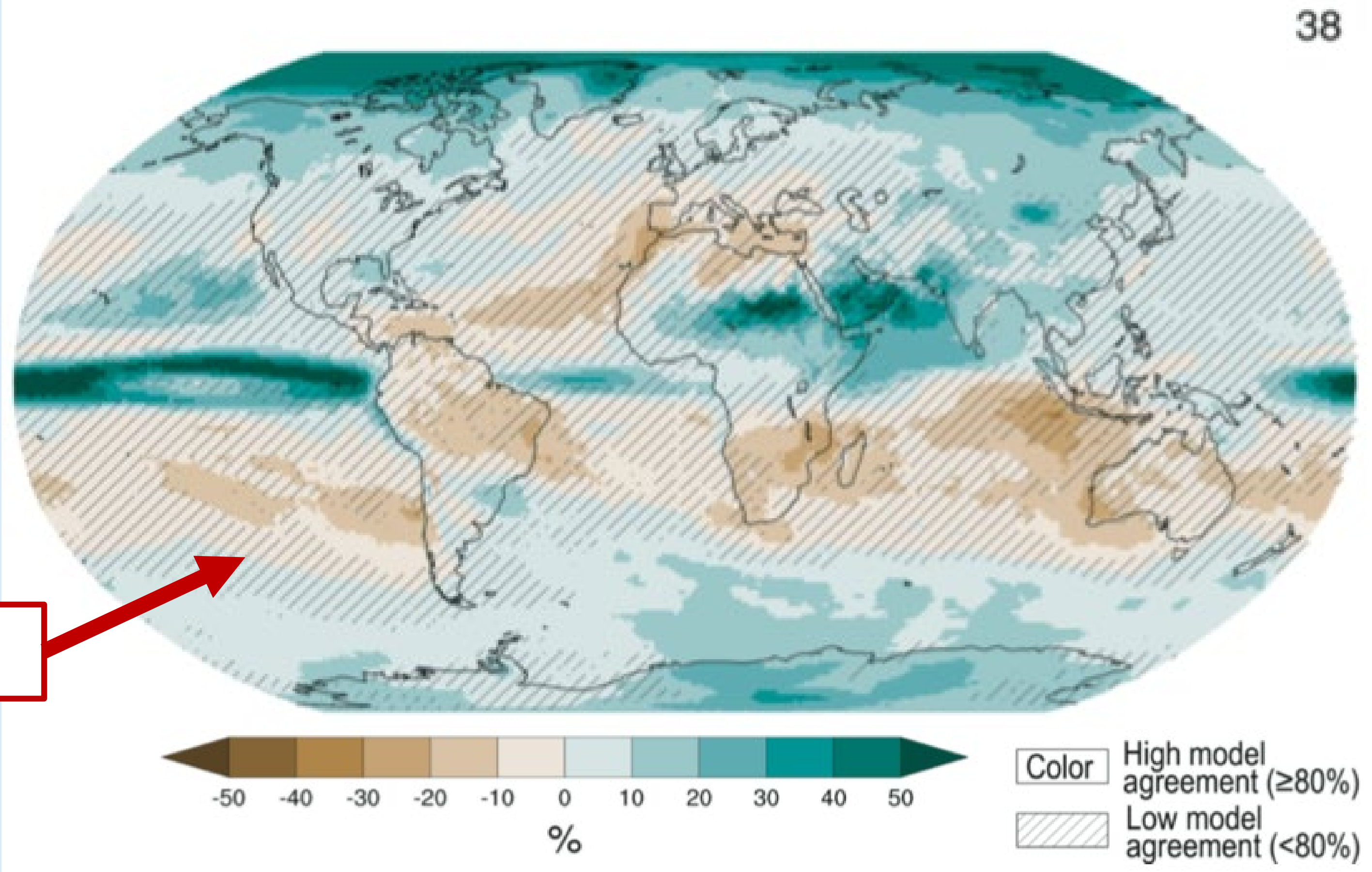
However, little agreement between ESMs on specifics

- ***Little agreement on even direction of change***

Stippling = low model agreement

Multi-model mean precipitation change

(SSP2-4.5; 2081-2100 vs 1995-2014; SON)



(IPCC AR6 WG1, Ch. 8)

- Can we develop a ***comprehensive*** and ***mechanistic*** framework for why the spatial pattern of mean precipitation changes under warming?

- Can we understand these changes as a set of **intuitive physical drivers?**

- Which of these drivers are **well-constrained amongst ESMs and scenarios**?

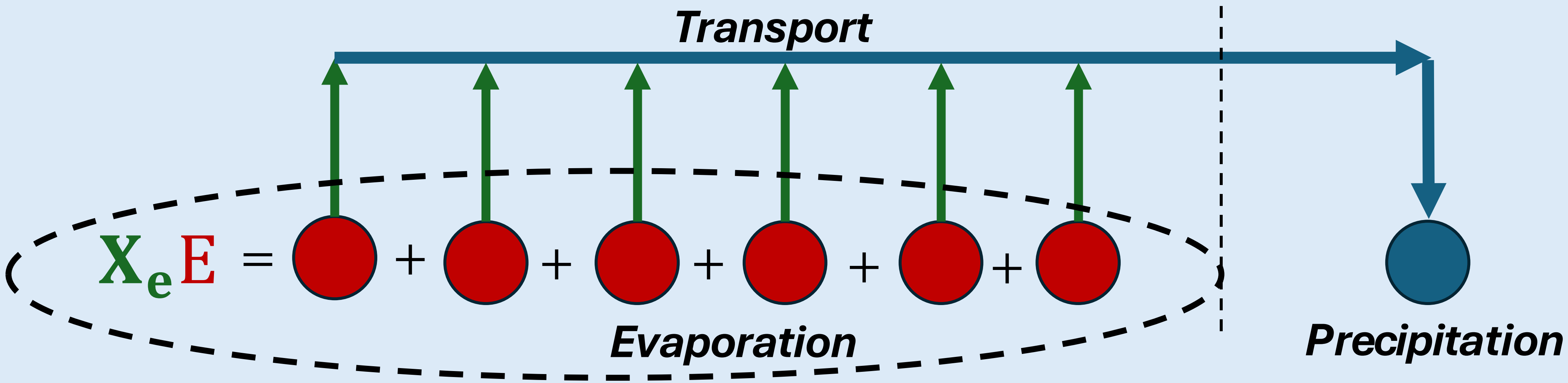
Precipitation as the aggregate of moisture transported from all evaporation sources

Following Singh et al. (2016):

Fraction of moisture evaporated from each source precipitated at each location

$$\underbrace{\overbrace{\mathbf{X_e}}\,E}\ = P$$

Evaporation amount from each source



Precipitation as the aggregate of moisture transported from all evaporation sources

Following Singh et al. (2016):

$$\mathrm{P} = \mathbf{X_e}\mathrm{E}$$

Changes in mean precipitation the result of:

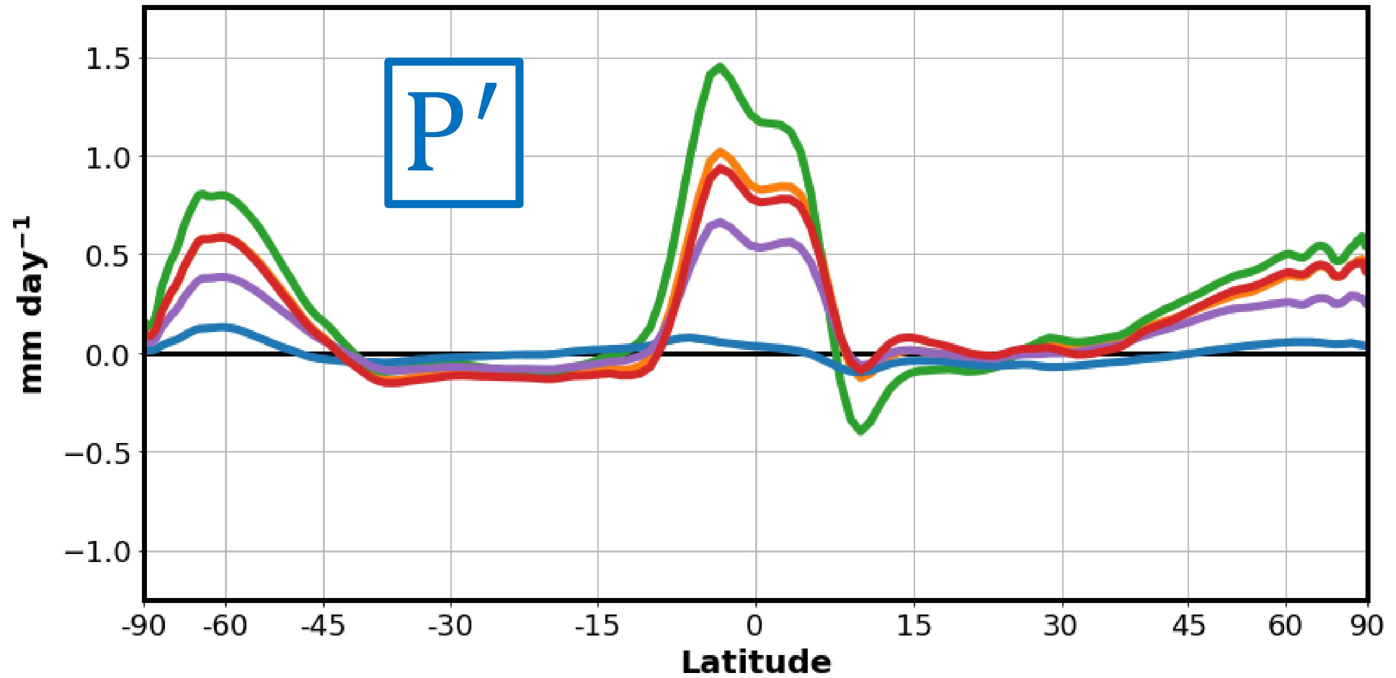
$$\mathrm{P}' = \underbrace{\mathbf{X_e}\mathrm{E}'}_{} + \underbrace{\mathbf{X}'_{\mathbf{e}}\mathrm{E}}_{}$$

Change in source evaporation amount

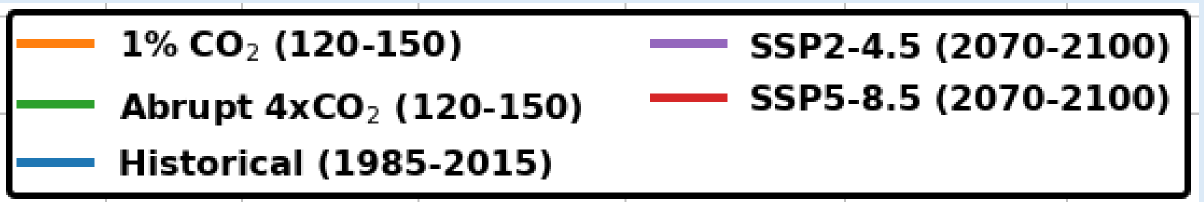
Redistribution of where moisture from each source region precipitates

Spatial pattern of precipitation change dominated by precipitation redistribution ($\mathbf{X}_\mathbf{e}'\mathrm{E}$)

$$\mathrm{P}' \approx \mathbf{X}_\mathbf{e}\mathrm{E}' + \mathbf{X}_\mathbf{e}'\mathrm{E}$$

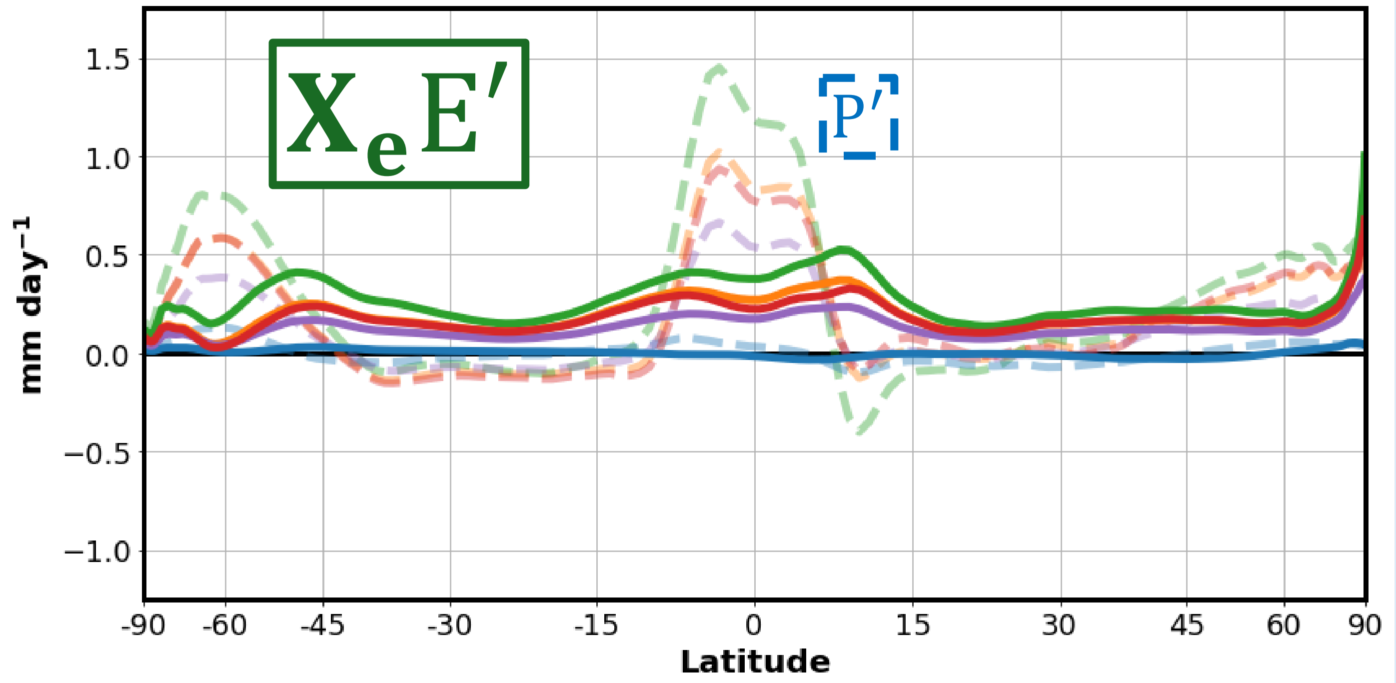


Multi-model mean precipitation response

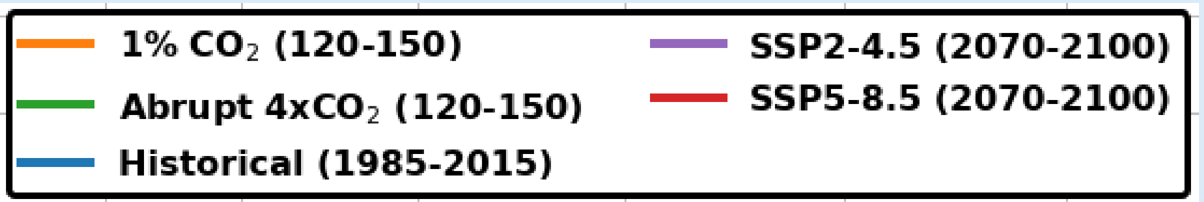


Spatial pattern of precipitation change dominated by precipitation redistribution ($\mathbf{X}_\mathbf{e}'\mathrm{E}$)

$$\mathrm{P}' \approx \mathbf{X}_\mathbf{e}\mathrm{E}' + \mathbf{X}_\mathbf{e}'\mathrm{E}$$

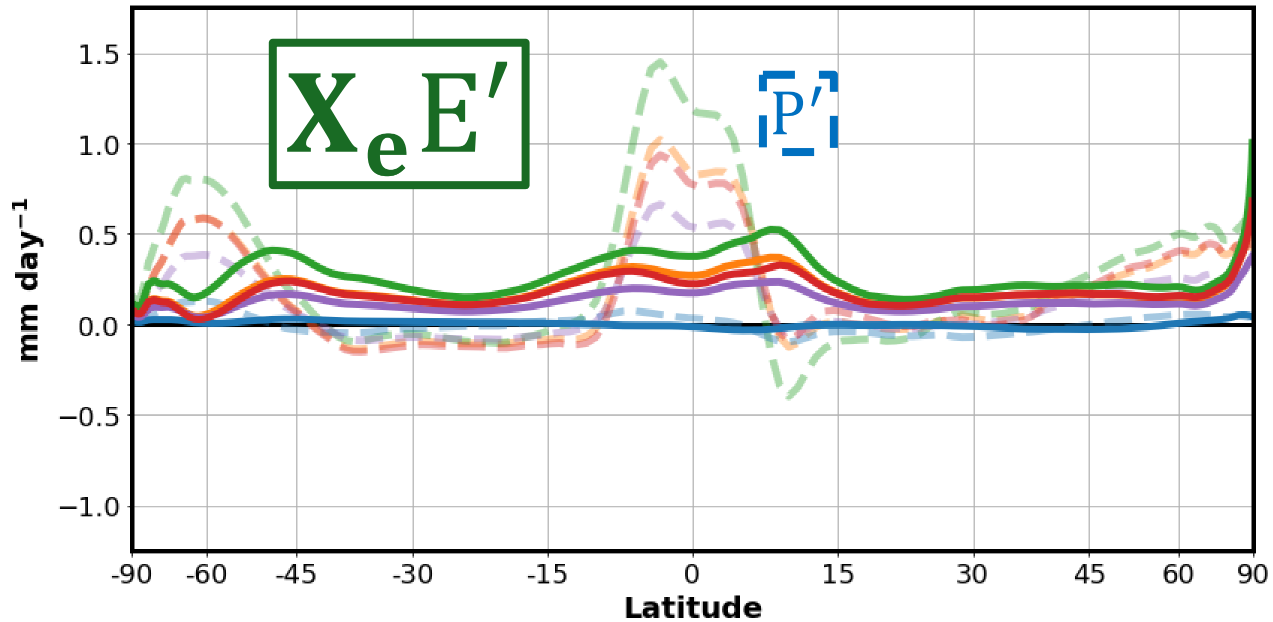


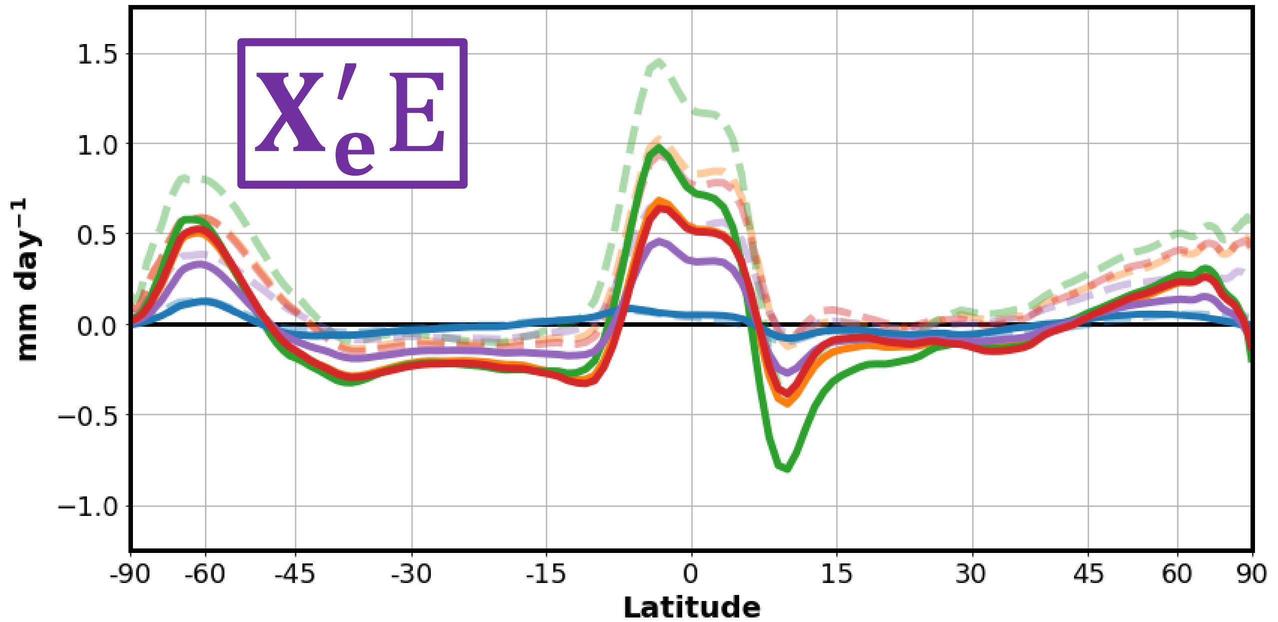
Driven by increased evaporation amount



Spatial pattern of precipitation change dominated by precipitation redistribution ($\mathbf{X}'_{\mathbf{e}}\mathrm{E}$)

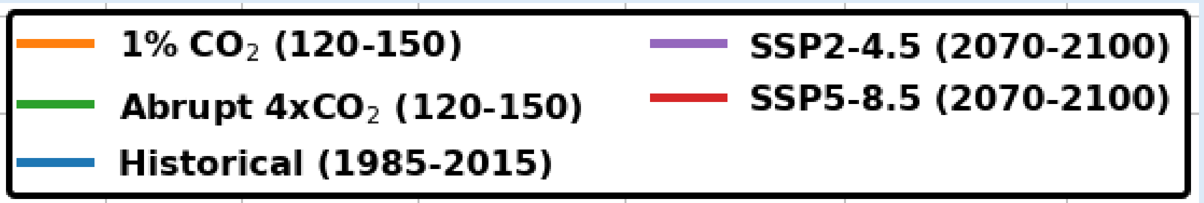
$$\mathrm{P}' \approx \mathbf{X}_{\mathbf{e}}\mathrm{E}' + \mathbf{X}'_{\mathbf{e}}\mathrm{E}$$





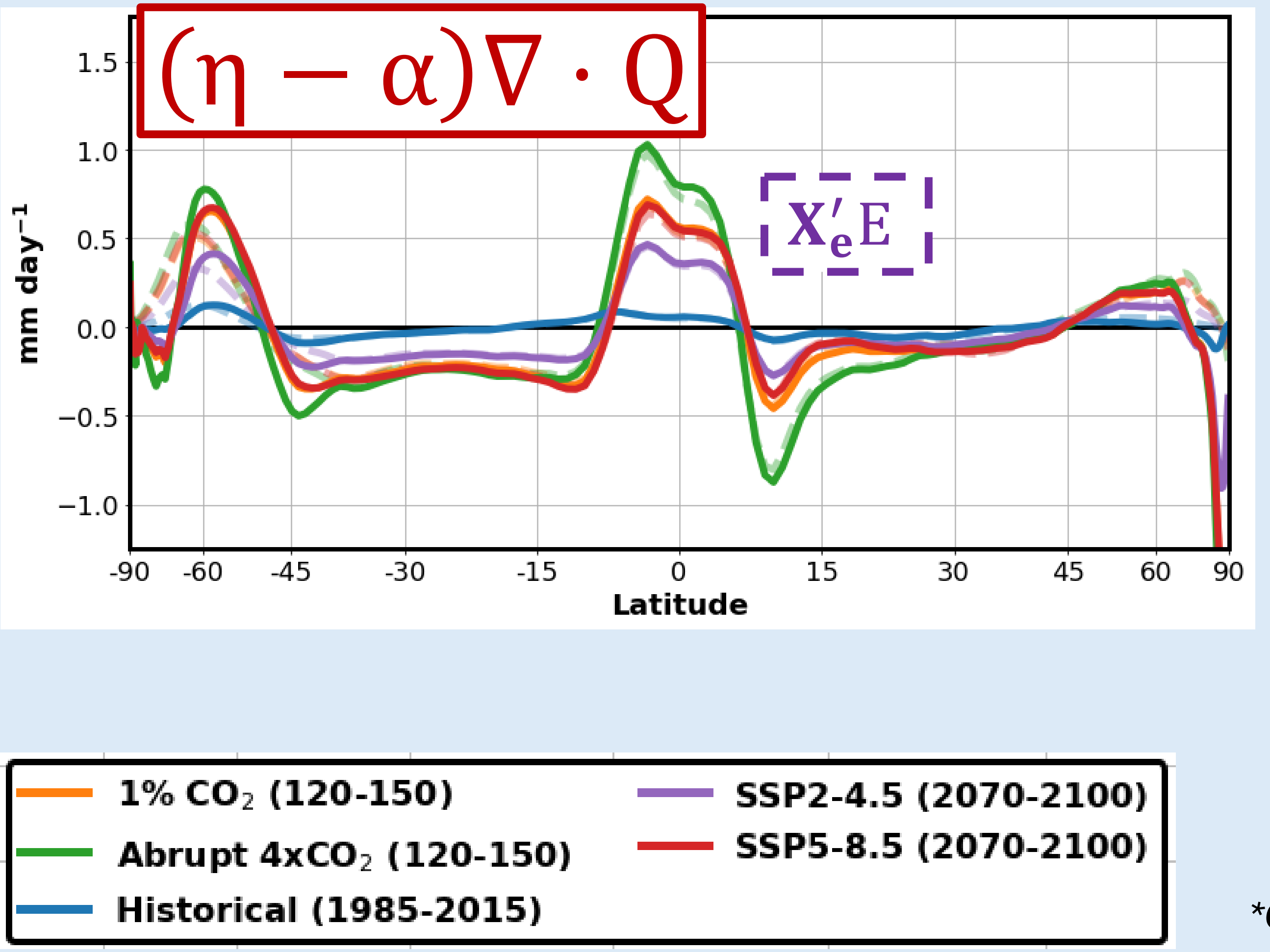
Driven by increased evaporation amount

Driven by redistribution of precipitation location



Precipitation redistribution ($X'_e E$) dominated by locally disparate response in evaporation (η) and moisture divergence (α)

$$X'_e E \approx (\eta - \alpha)\nabla \cdot Q$$



$$\eta \equiv \frac{E'}{E}$$

$$\alpha \equiv \frac{\nabla \cdot Q'}{\nabla \cdot Q}$$

**Check out our upcoming manuscript for full derivation!*

Precipitation redistribution ($X'_e E$) dominated by locally disparate response in evaporation (η) and moisture divergence (α)

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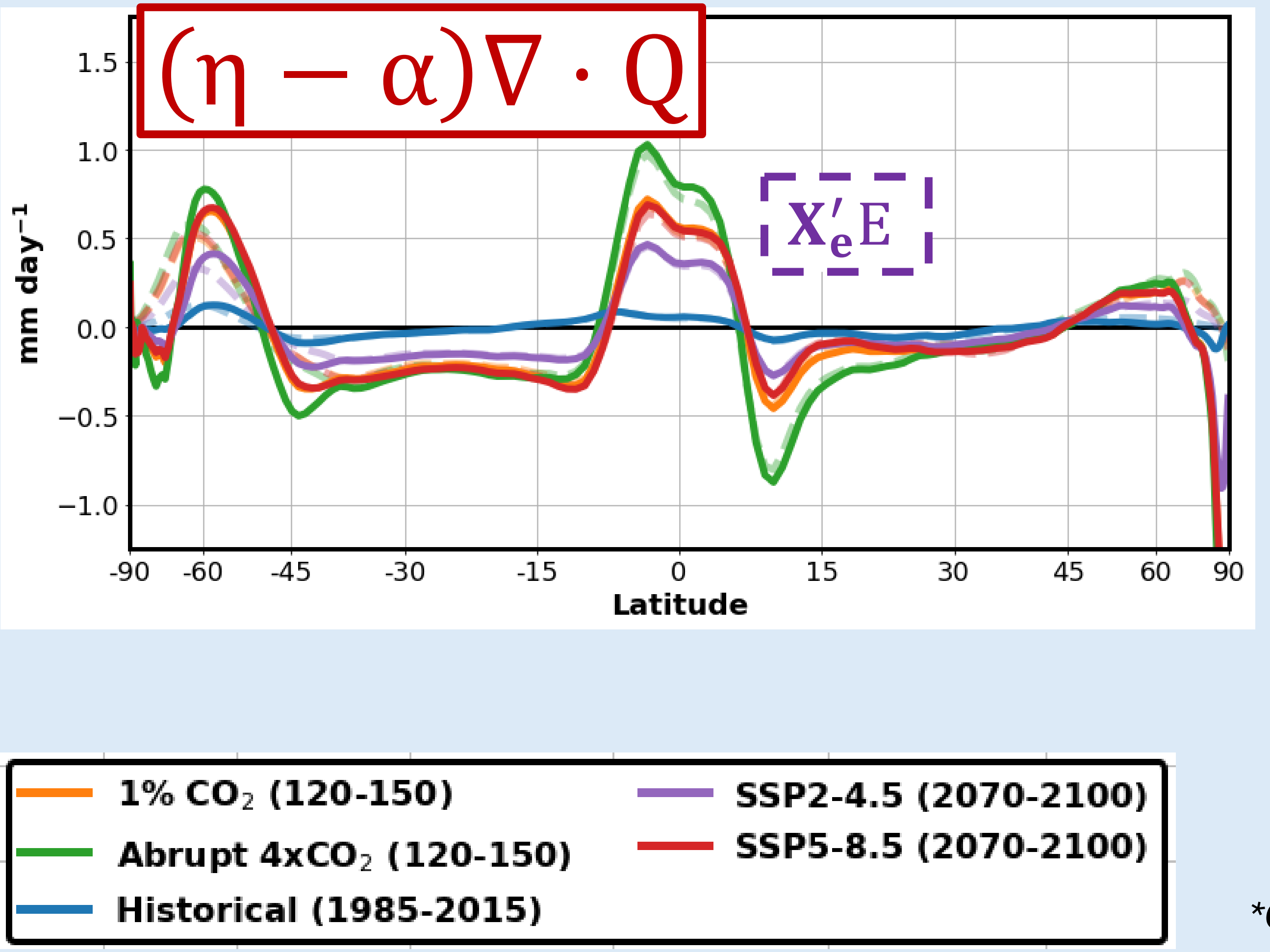


Recognizing:

- *α can be approximated using humidity change*
- *α and η are roughly constant globally*

$$(\eta - \alpha)\nabla \cdot Q \approx \underbrace{\bar{\gamma}'/\bar{\gamma}}\,\nabla \cdot Q$$

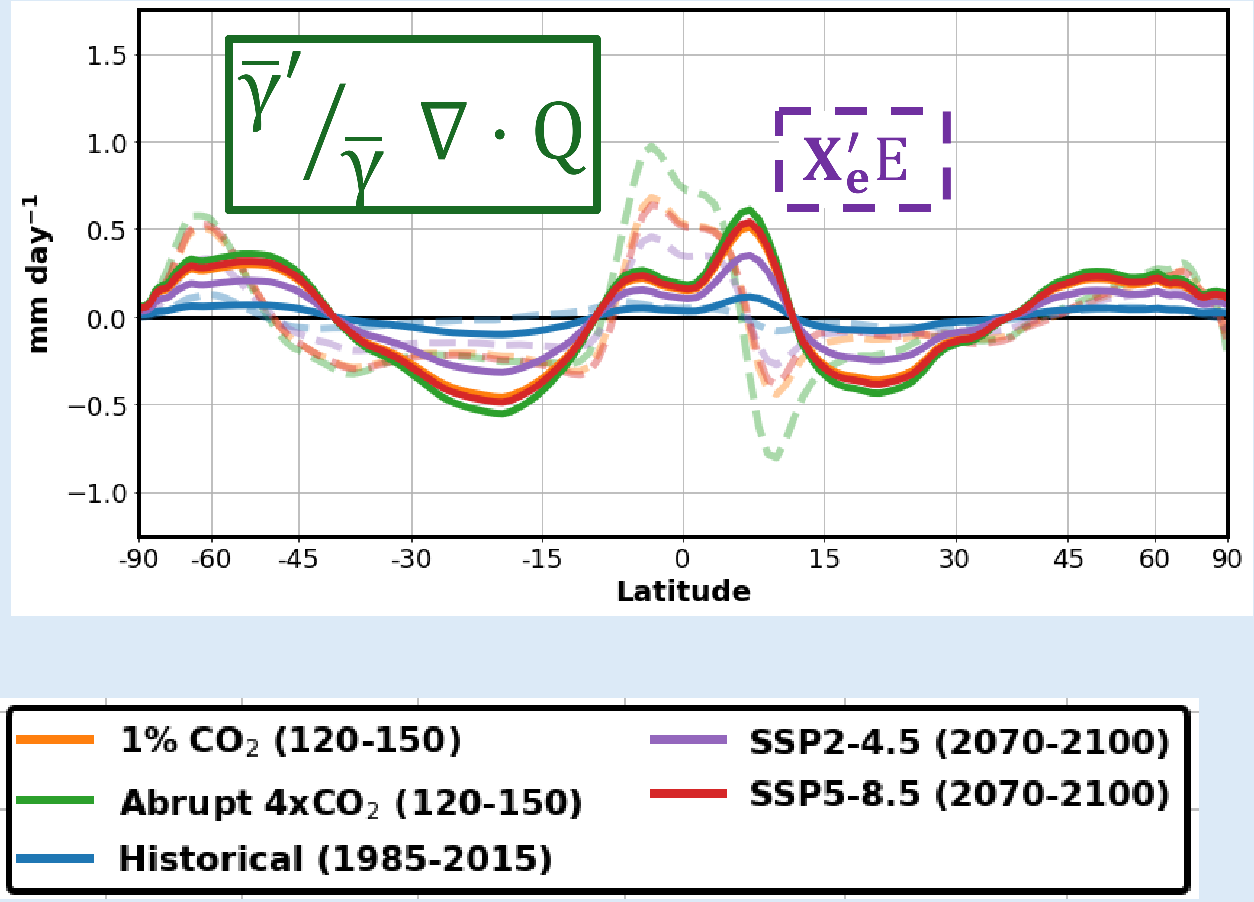
GLOBAL WATER CYCLING RATE

**Check out our upcoming manuscript for full derivation!*

Global water cycling rate adjustment ($\bar{\gamma}'$) explains important aspects of precipitation redistribution ($X_e'E$)

$$X_e'E \approx \bar{\gamma}'/_{\bar{\gamma}}\, \nabla \cdot Q$$

$$\eta \equiv \frac{E'}{E} \qquad \alpha \equiv \frac{\nabla \cdot Q'}{\nabla \cdot Q}$$



Recognizing:

- *α can be approximated using humidity change*
- *α and η are roughly constant globally*

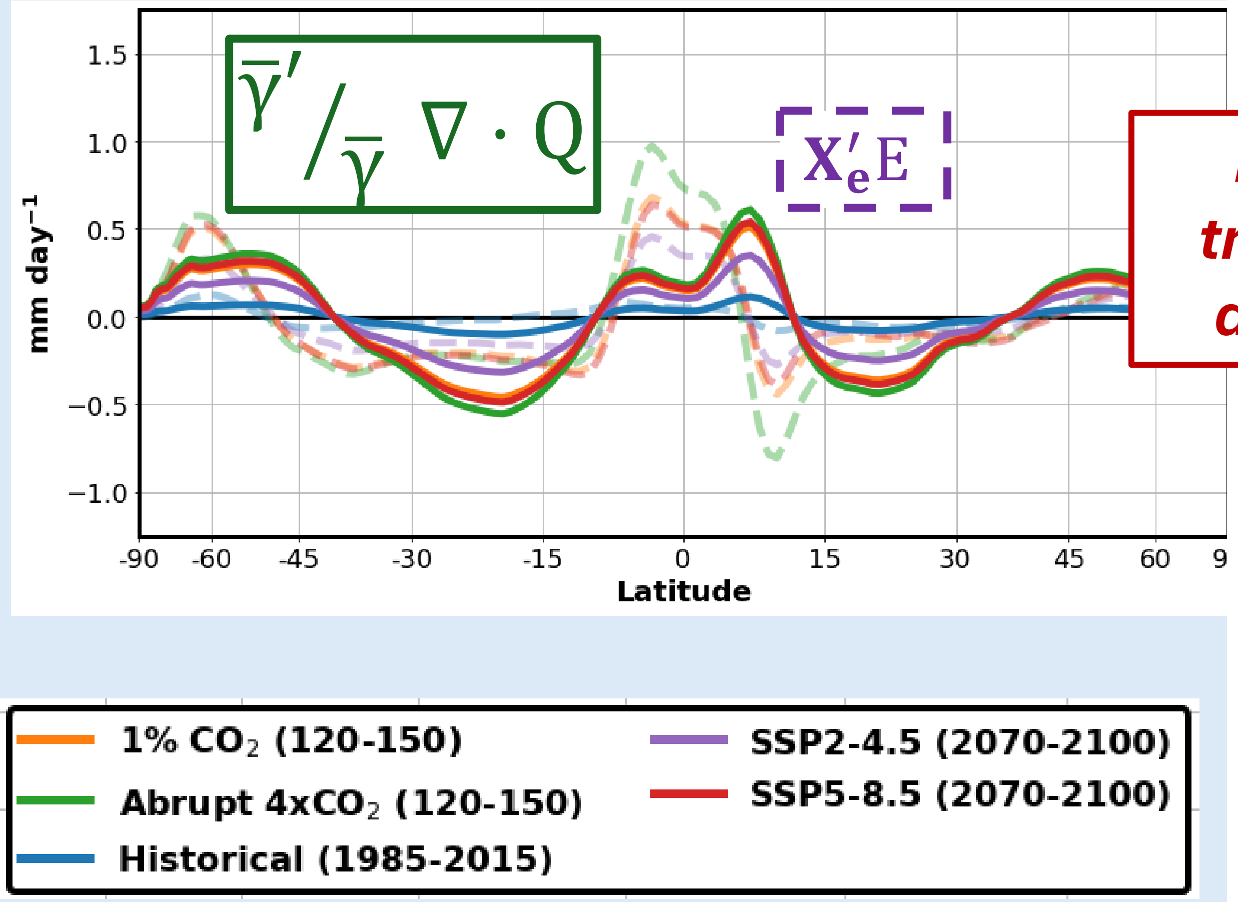
$$(\eta - \alpha)\nabla \cdot Q \approx \underbrace{\bar{\gamma}'/_{\bar{\gamma}}}\, \nabla \cdot Q$$

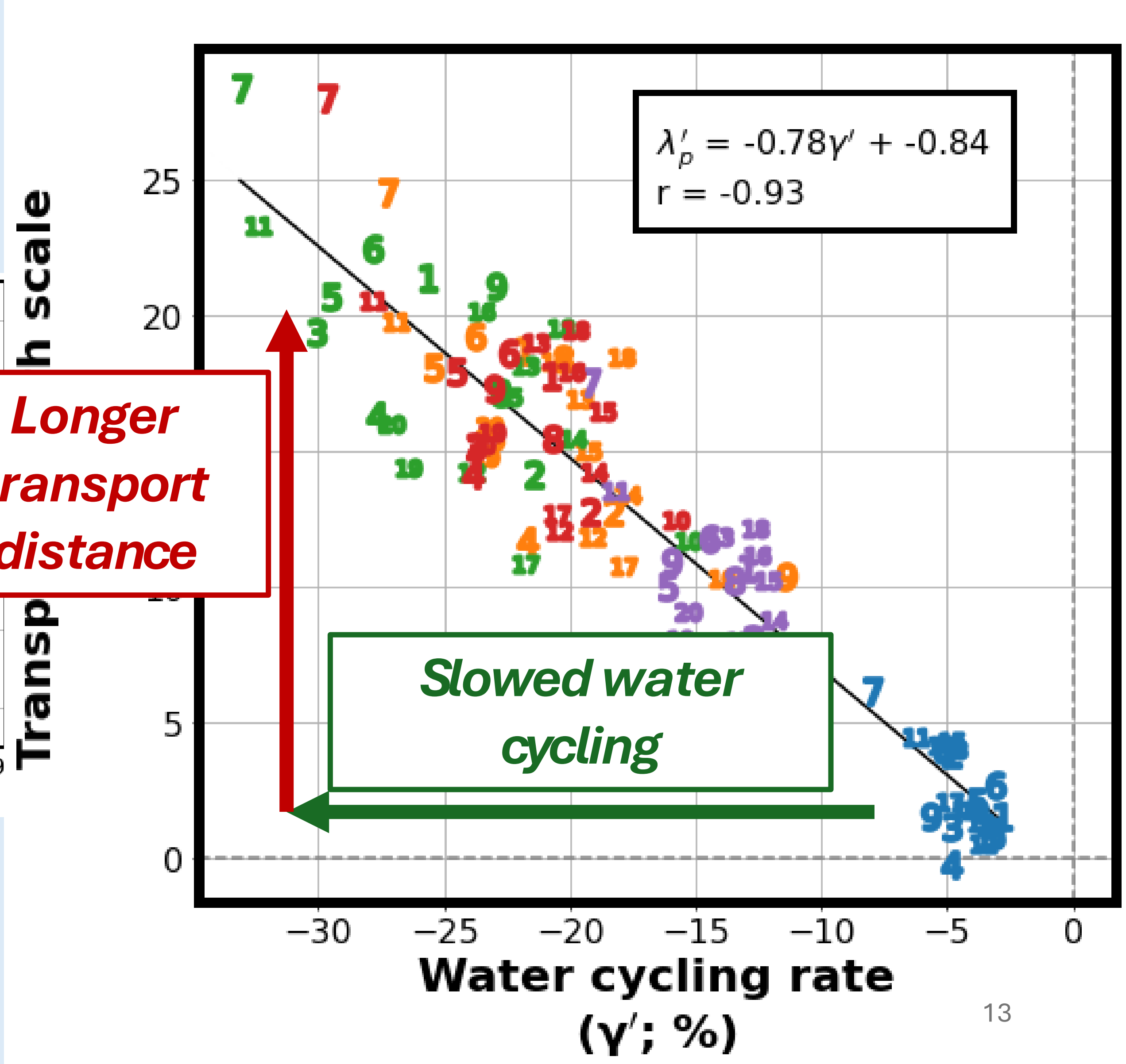
GLOBAL WATER CYCLING RATE

**Check out our upcoming manuscript for full derivation!*

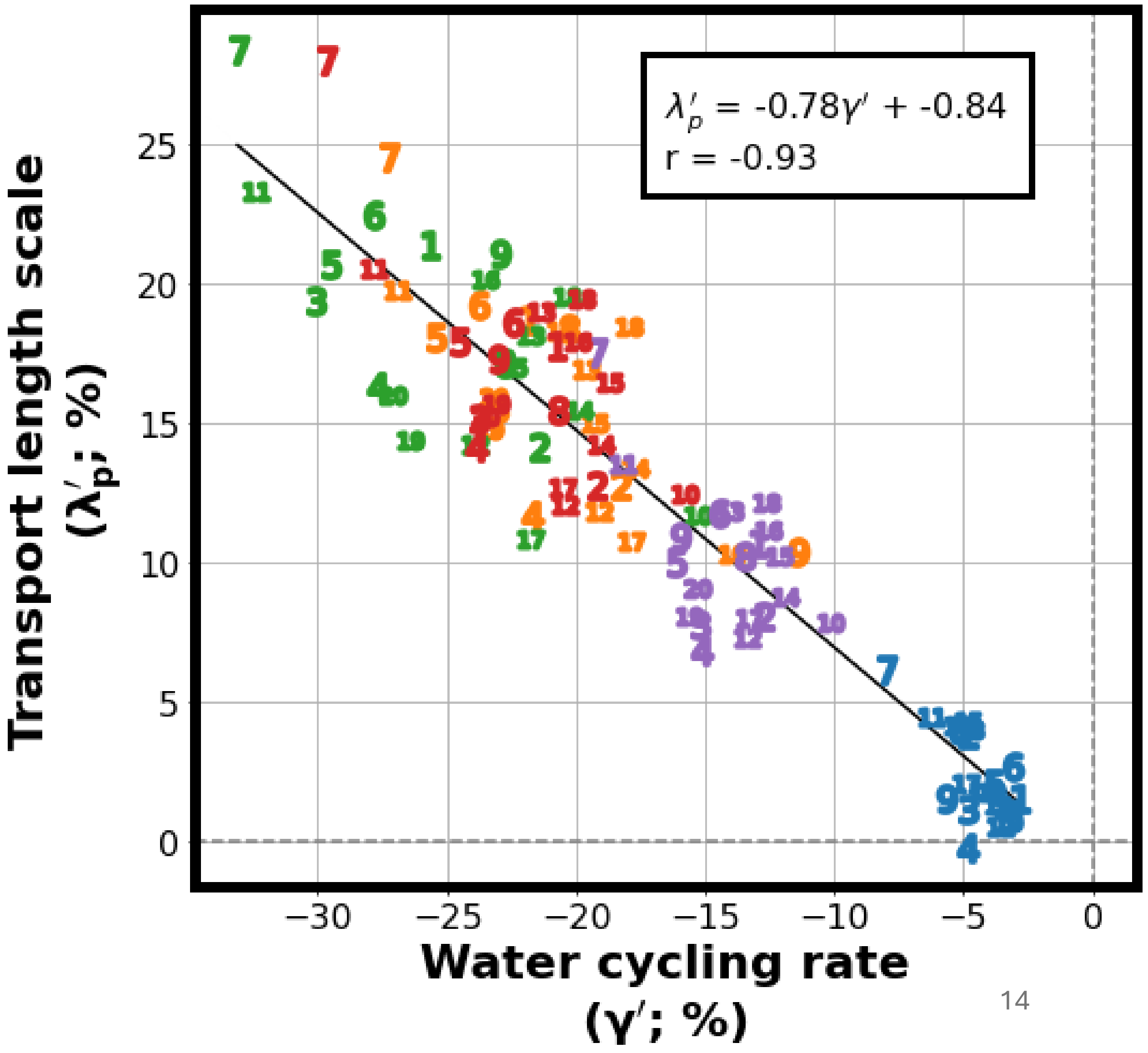
Slowed water cycling rate results in a *lengthened moisture transport* through atmosphere under warming

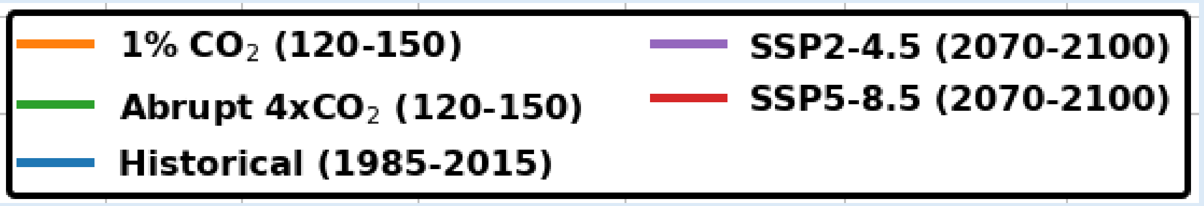
$$X'_e E \approx \bar{\gamma}' / \bar{\gamma} \, \nabla \cdot Q$$



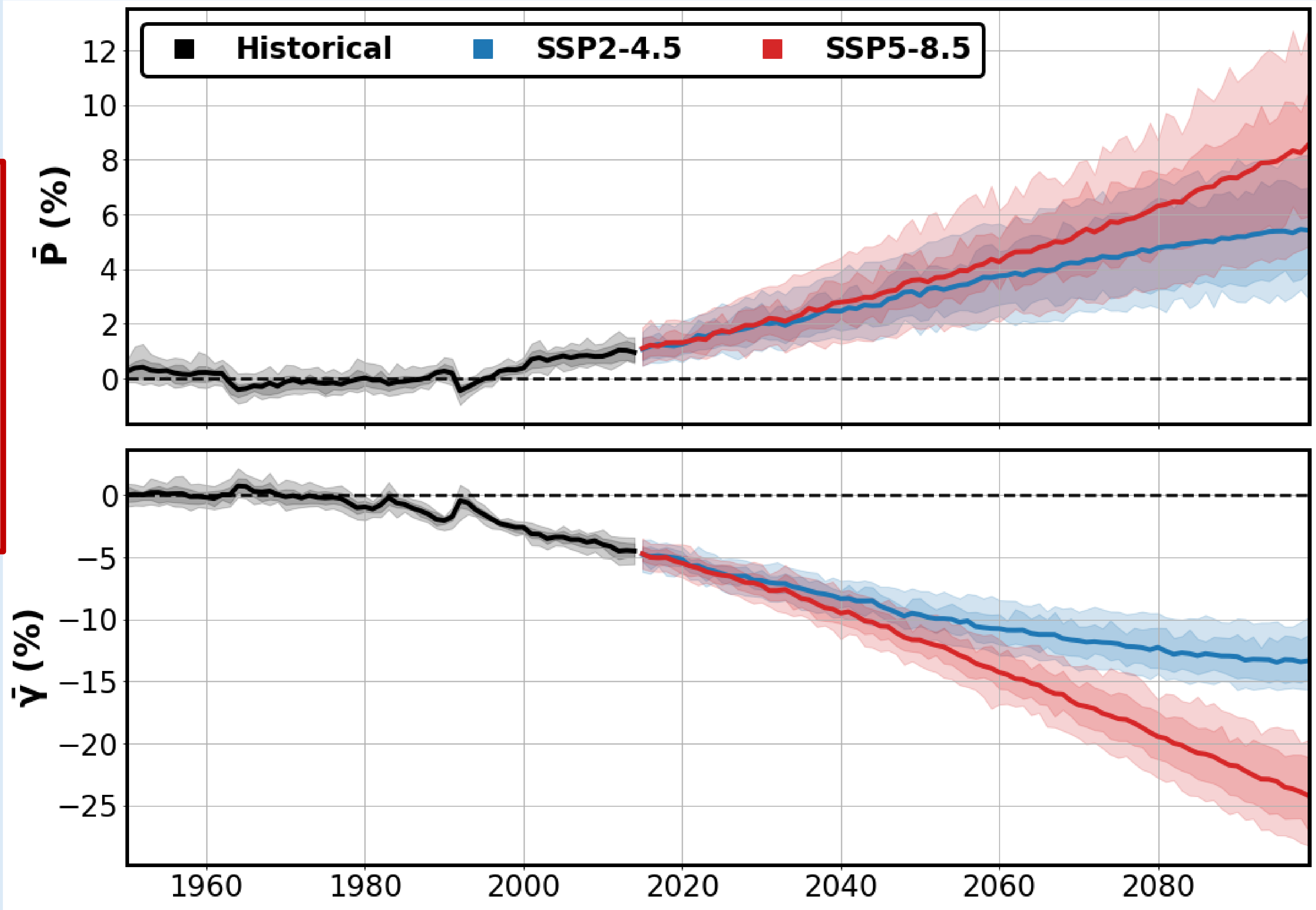


Reduced water cycling rate and corresponding transport distance increase ***robust across all models and scenarios***





*Global water cycling rate has **large simulated S/N***



An opportunity:

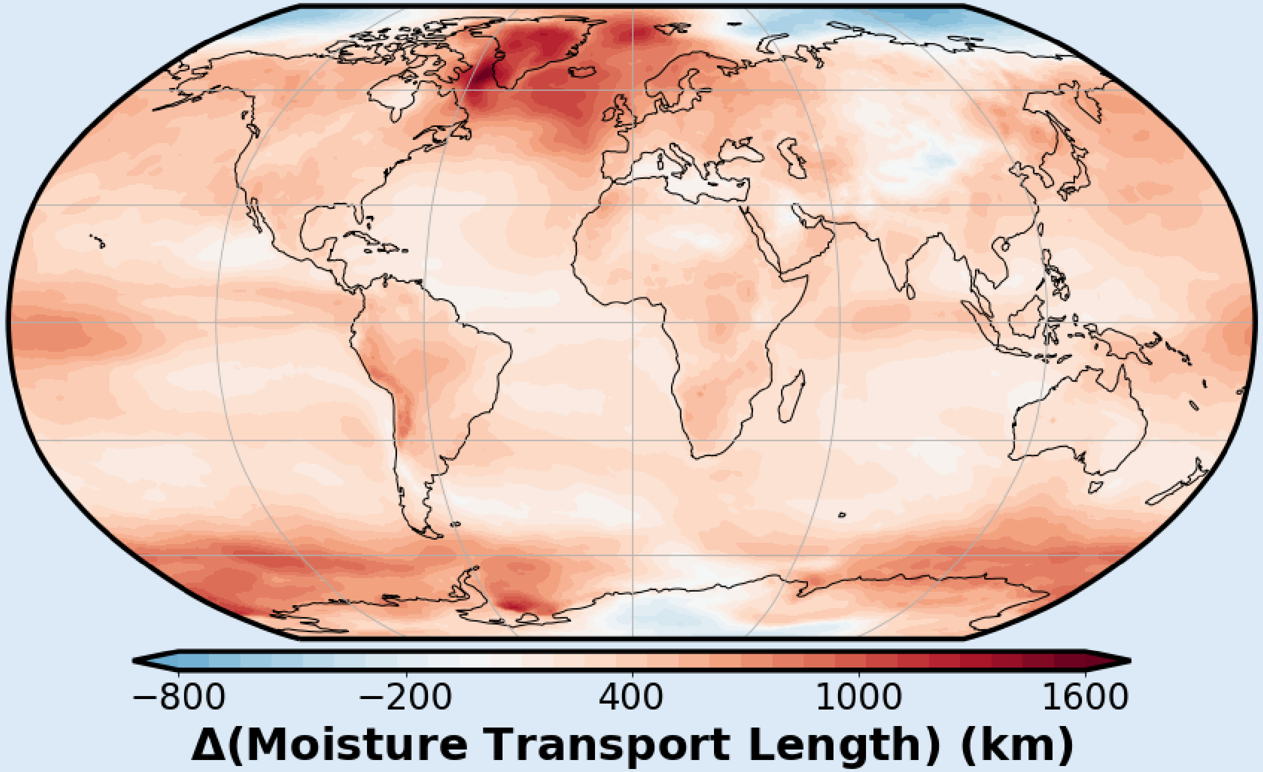
- We can directly compute water cycling rates and transport distances in CESM

- iCESM1 (isotope-enabled version) allows for the simulation of source tracers – can investigate changes in moisture transport distance

- Recent developments have allowed for direct computation of residence times (or cycling rates) in CAM6 *(Fiorella et al., 2021)*

iCESM1.2:

2070-2100 vs. 1950-1980



If you would like to discuss further

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Also watch for our upcoming manuscript submissions