What Drives Projections of Subtropical Precipitation Decline?

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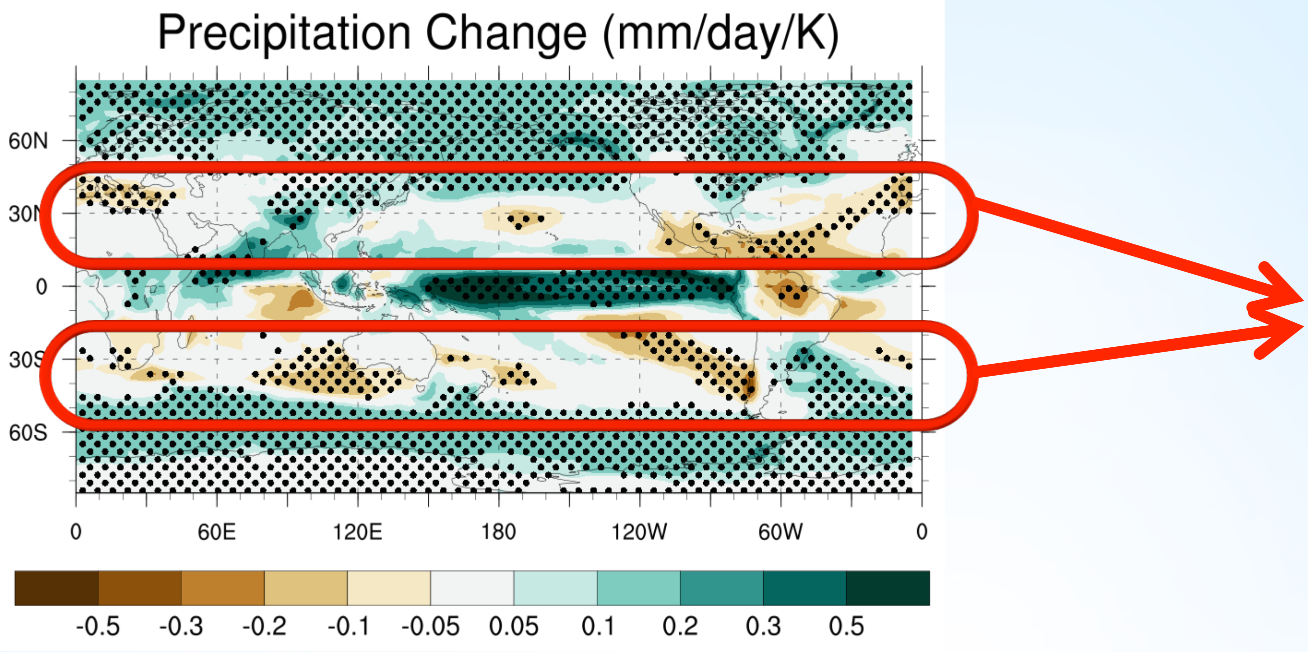
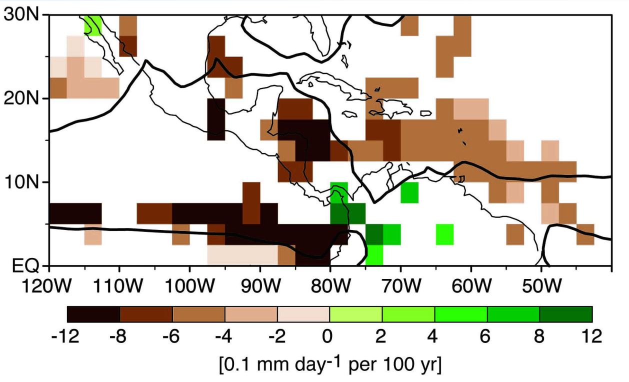
Precipitation declines in the subtropics.

- Model evidence (1pctCO2)

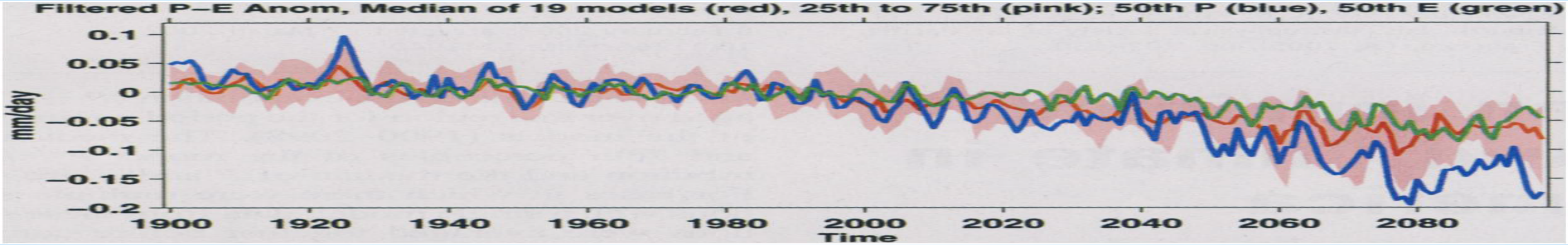


"Dry get Drier"

- Observation (Neelin et al. 2006, *PNAS*)



Dry getting drier?

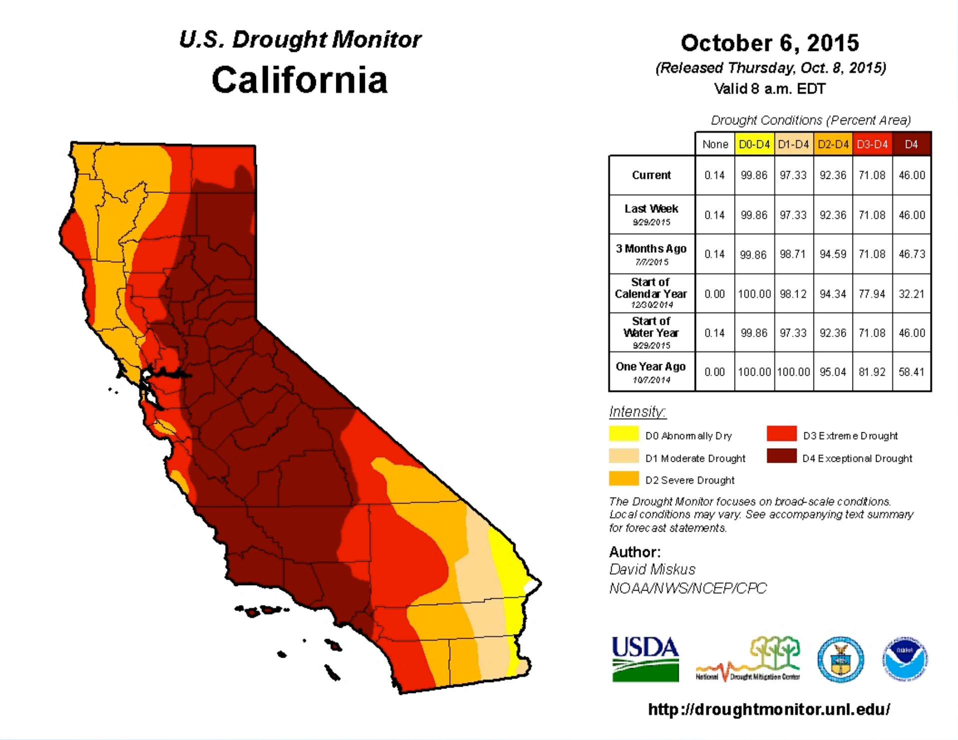


"If these models are correct, the levels of aridity of the recent multi-year drought or the Dust Bowl and the 1950s droughts will become the new climatology of the American Southwest within a time frame of years to decades."

-- Seager et al. 2007, *Science*

Dry getting drier?

- California Drought (2011-)



U.S. Drought Monitor

California

October 6, 2015

(Released Thursday, Oct. 8, 2015)

Valid 8 a.m. EDT

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.14	99.86	97.33	92.36	71.08	46.00
Last Week *9/29/2015*	0.14	99.86	97.33	92.36	71.08	46.00
3 Months Ago *7/7/2015*	0.14	99.86	98.71	94.59	71.08	46.73
Start of Calendar Year *12/30/2014*	0.00	100.00	98.12	94.34	77.94	32.21
Start of Water Year *9/29/2015*	0.14	99.86	97.33	92.36	71.08	46.00
One Year Ago *10/7/2014*	0.00	100.00	100.00	95.04	81.92	58.41

Intensity:

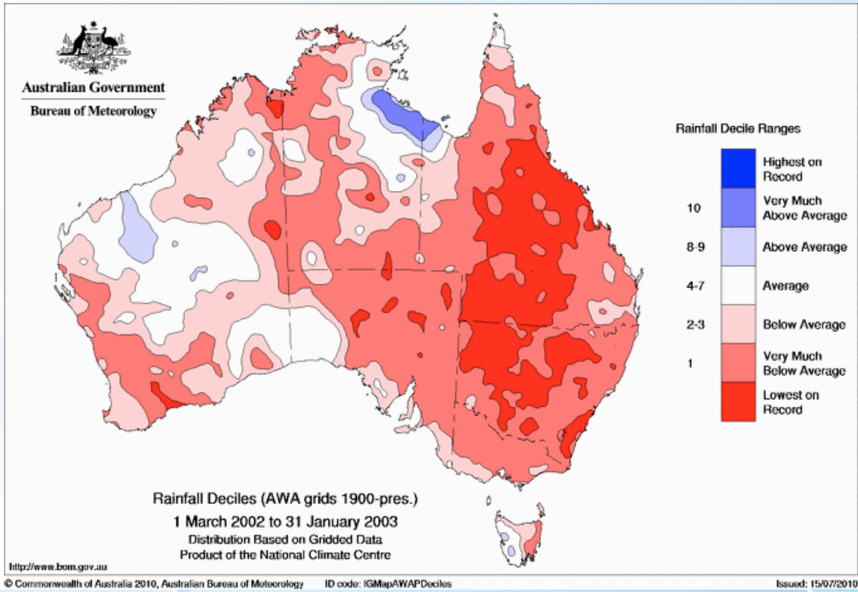
D0 Abnormally Dry	D3 Extreme Drought
D1 Moderate Drought	D4 Exceptional Drought
D2 Severe Drought	

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
David Miskus
NOAA/NWS/NCEP/CPC

http://droughtmonitor.unl.edu/

- Australia Drought (1997-2009)

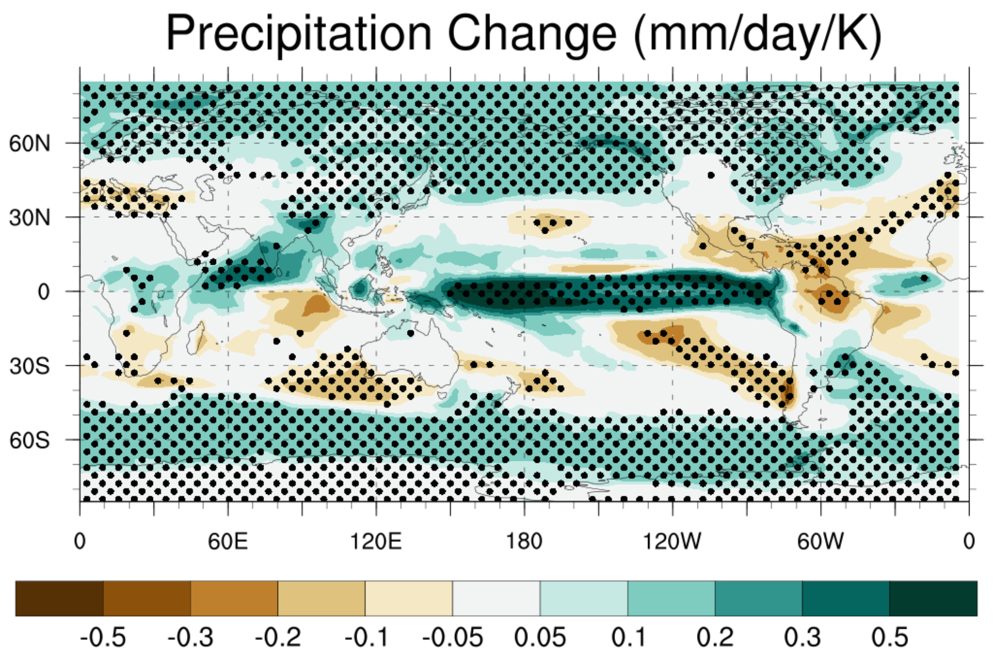


Rainfall Deciles (AWA grids 1900-pres.)
1 March 2002 to 31 January 2003
Distribution Based on Gridded Data
Product of the National Climate Centre

http://www.bom.gov.au

ID code: IGMapAWAPDeciles Issued: 15/07/2010

Dry getting drier?



What drives the decline?

2 prominent mechanisms:

- **"Dry-get-drier"**
- **Poleward expansion**

What drives the decline?

- **“Dry-get-drier”** (Held and Soden 2006, *J. Climate*)

$$P-E=-\int\nabla\cdot(q\cdot V)$$

$$\delta(P-E)=-\int\nabla\cdot\delta(q\cdot V)$$

$$\Big\downarrow$$

$$\delta(P-E)=-\int\nabla\cdot(\delta q\cdot V)-\int\nabla\cdot(q\cdot\delta V)-\int\cancel{\nabla\cdot(\delta q\cdot\delta V)}$$

$$\Big\downarrow\quad \delta V\approx 0$$

$$\delta(P-E)=-\int\nabla\cdot(\delta q\cdot V)$$

$$\Big\downarrow\quad \delta q\approx q\times 7\%/K$$

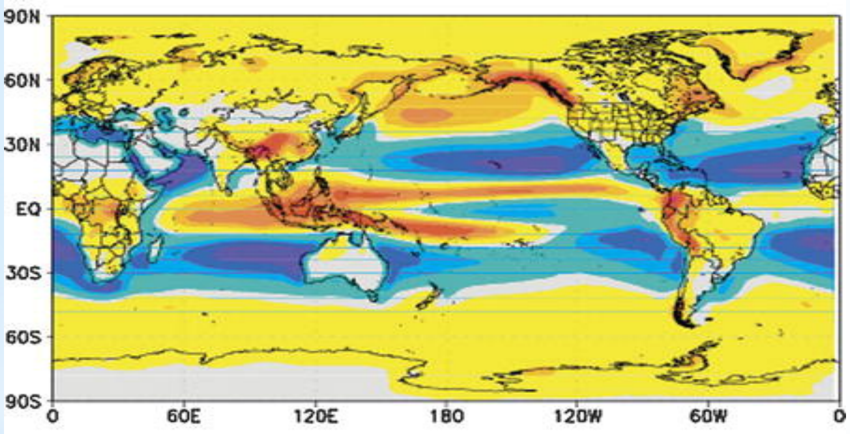
$$\boxed{\delta(P-E)}=-\int\nabla\cdot(q\cdot V)\times 7\%/K=\boxed{(P-E)\times 7\%/K}$$

What drives the decline?

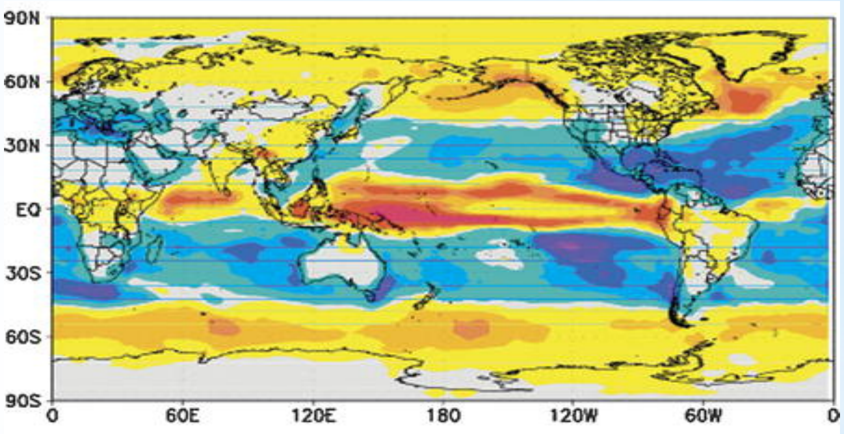
- **“Dry-get-drier”** (Held and Soden 2006, *J. Climate*)

$$\delta(P-E)=(P-E)\times 7\%/K$$

Climatological (P-E)x7%/K



Change in P-E



> “Since the changes in precipitation have considerably more structure than the changes in evaporation, this simple picture helps us understand the zonally averaged pattern of precipitation change.”

$$\longrightarrow \quad \delta P \propto (P-E)$$

What drives the decline?

- **“Dry-get-drier”** (Held and Soden 2006, *J. Climate*)

Subtropical precipitation decline

↑

Increased moisture export

↑

Increase in moisture

↑

Global mean warming

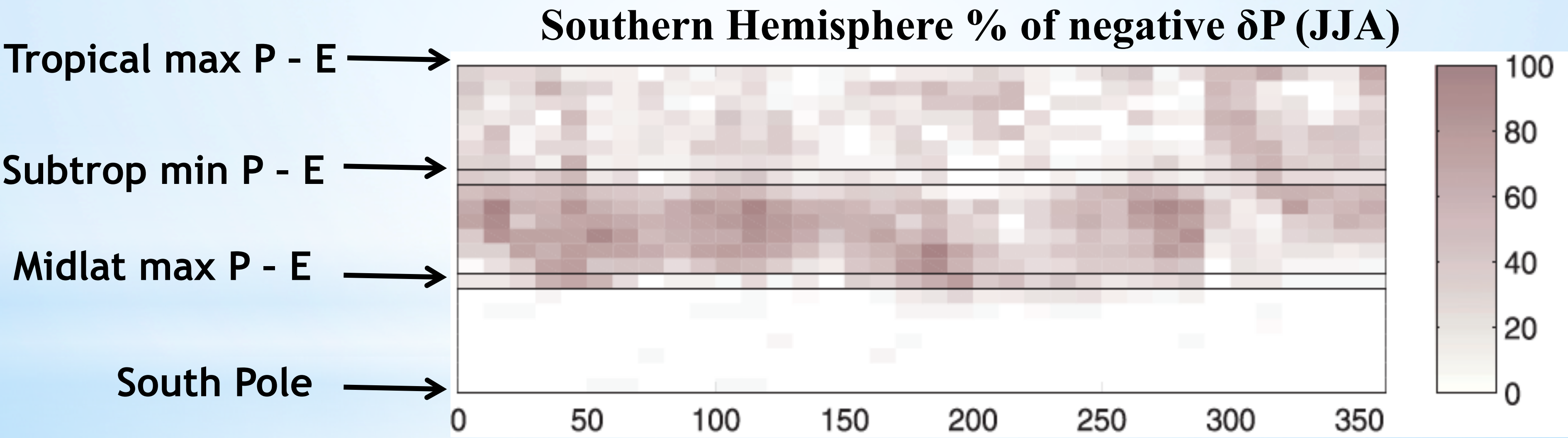
(a thermodynamic response)

What drives the decline?

- **Poleward expansion** (Scheff and Frierson 2012, *J. Climate*, *GRL*)

$$\delta P \propto (P - E) \;\; ??$$

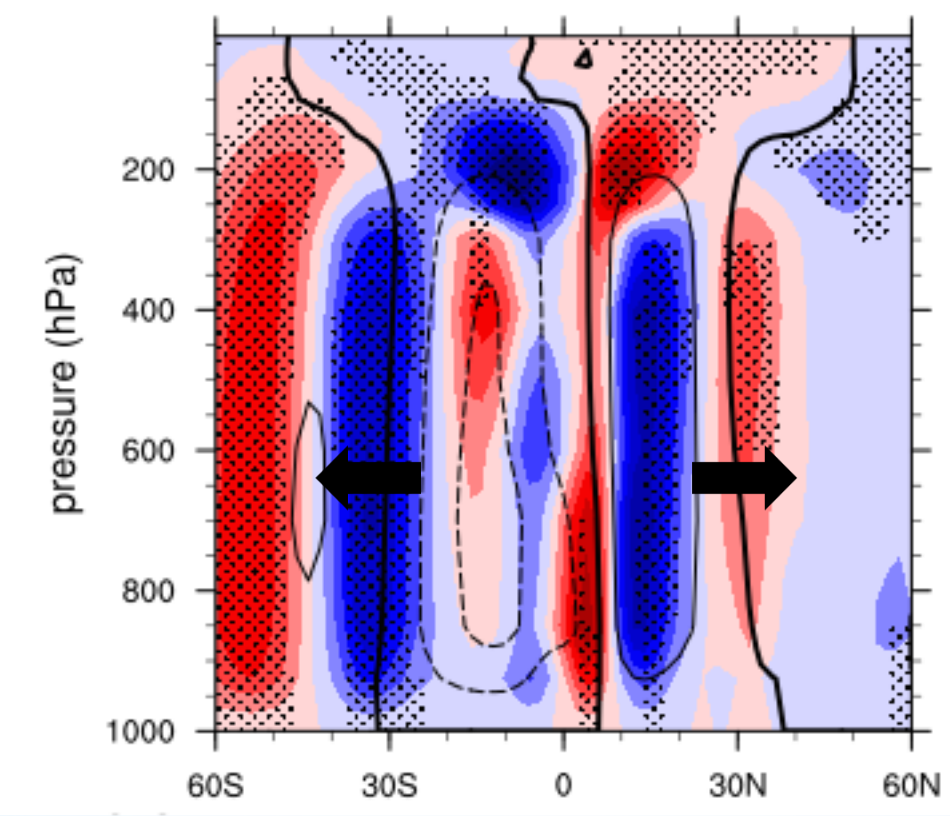
Most of the decline happens poleward of P-E minima.



What drives the decline?

- **Poleward expansion** (Scheff and Frierson 2012, *J. Climate*, *GRL*)

Change in zonal mean stream function



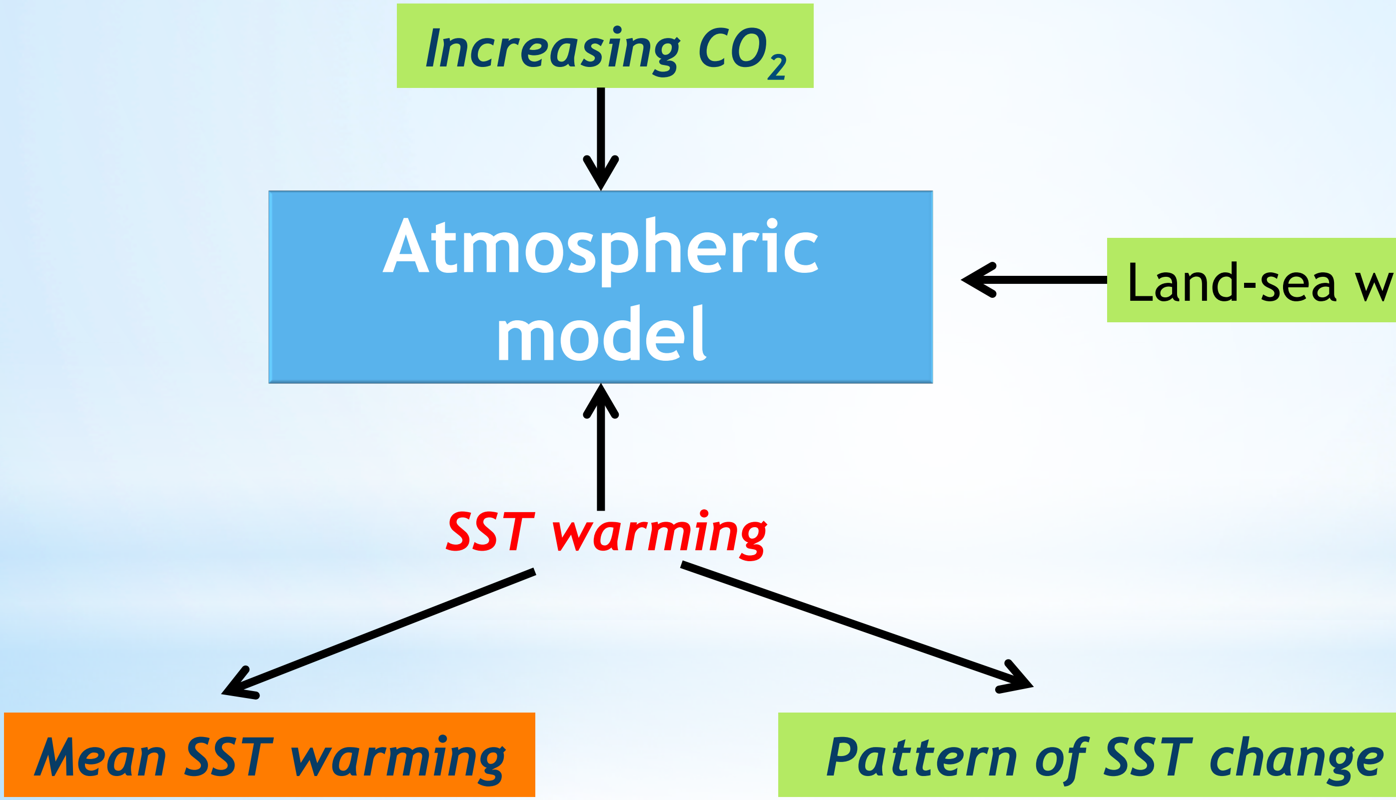
(He and Soden 2015, *J. Climate*)

A new perspective…

- “Dry-get-drier”
- Poleward expansion

→ Mean SST warming

(Compo & Sardeshmukh 2009, *C Dyn*; Grise & Polvani 2014, *GRL*; He & Soden 2015, *J Climate*)



Increasing CO_2

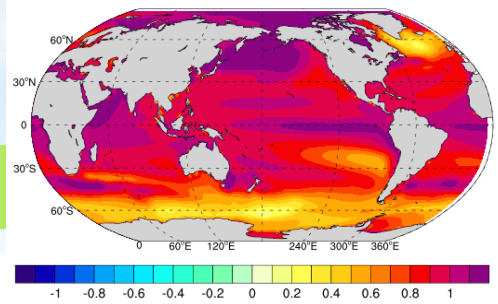
Atmospheric model

Land-sea warming contrast

SST warming

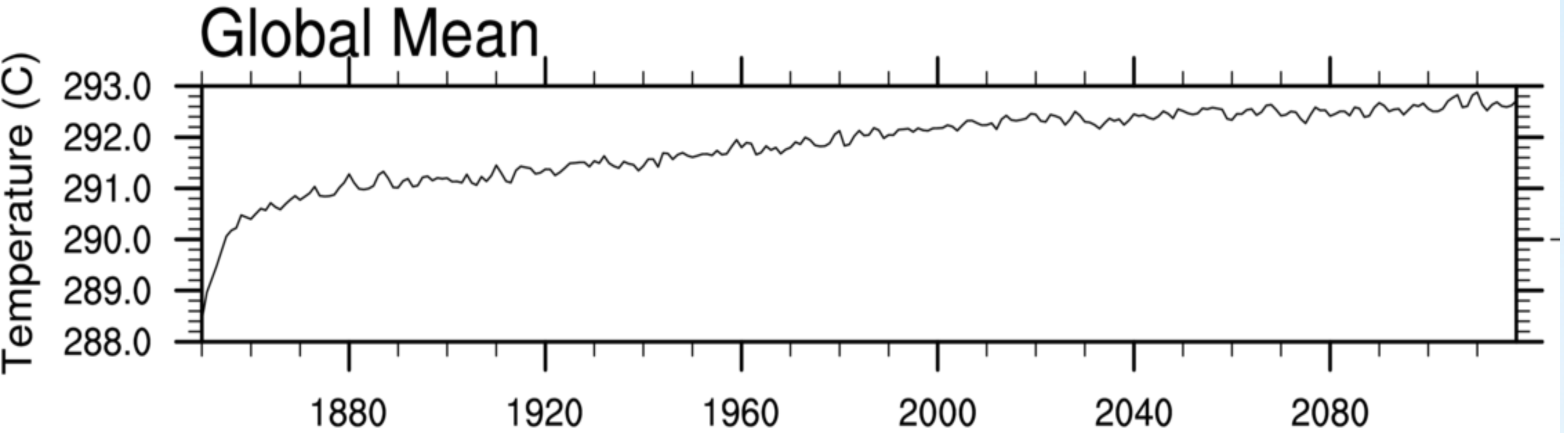
Mean SST warming

Pattern of SST change



A new perspective…

Abrupt4xCO2 (13 CGCMs, CMIP5)

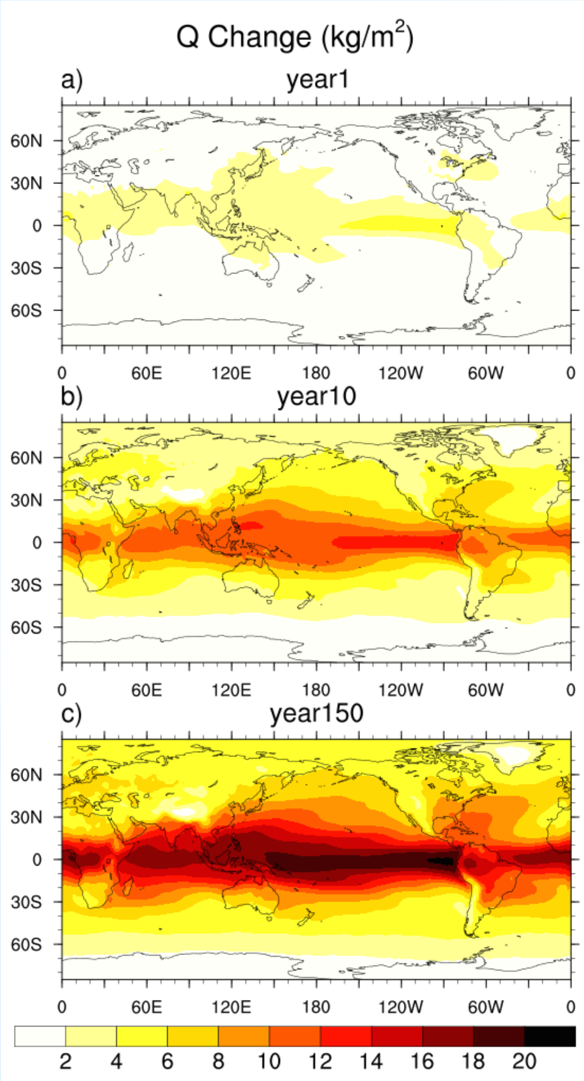


Direct CO_2 forcing
Land-sea warming contrast → Fast
Pattern of SST change

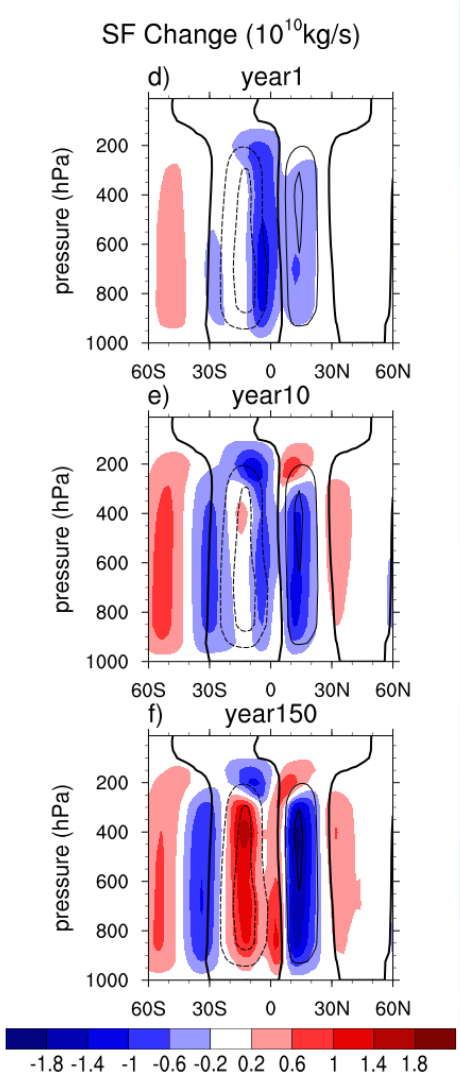
Mean SST warming → Slow

Fast VS Slow responses

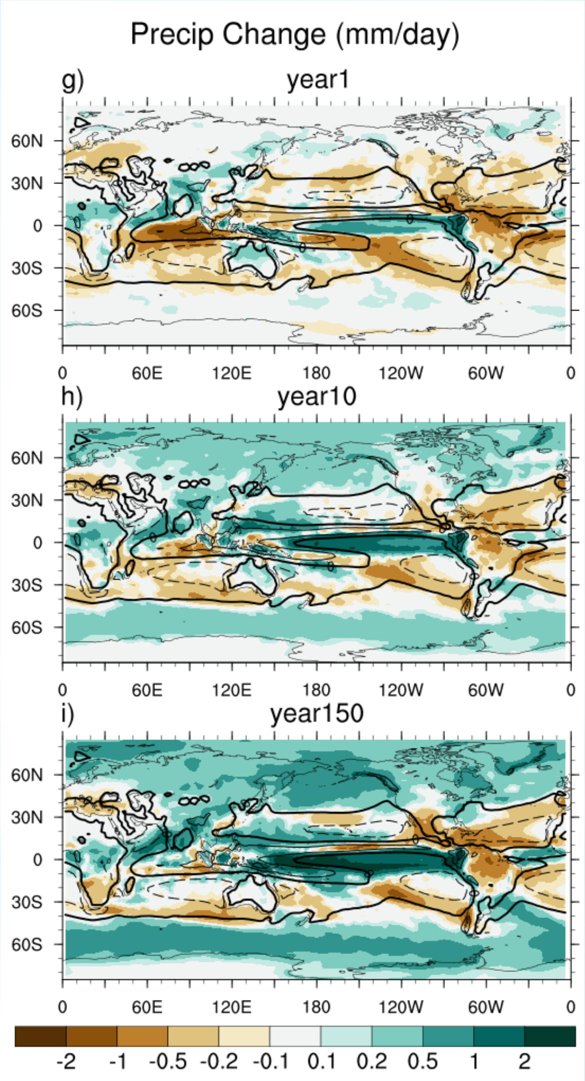
“Dry-get-drier”



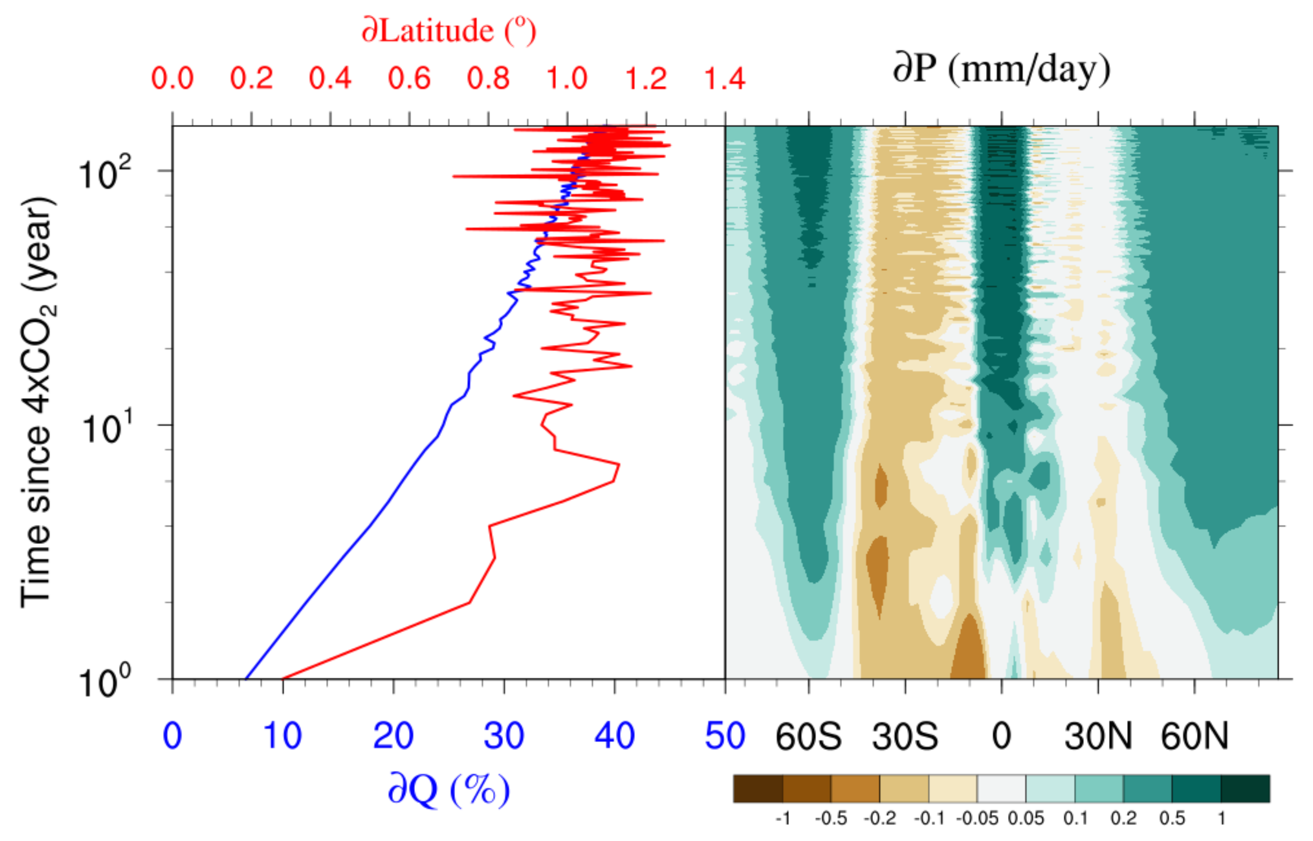
Poleward expansion



Fast precipitation decline



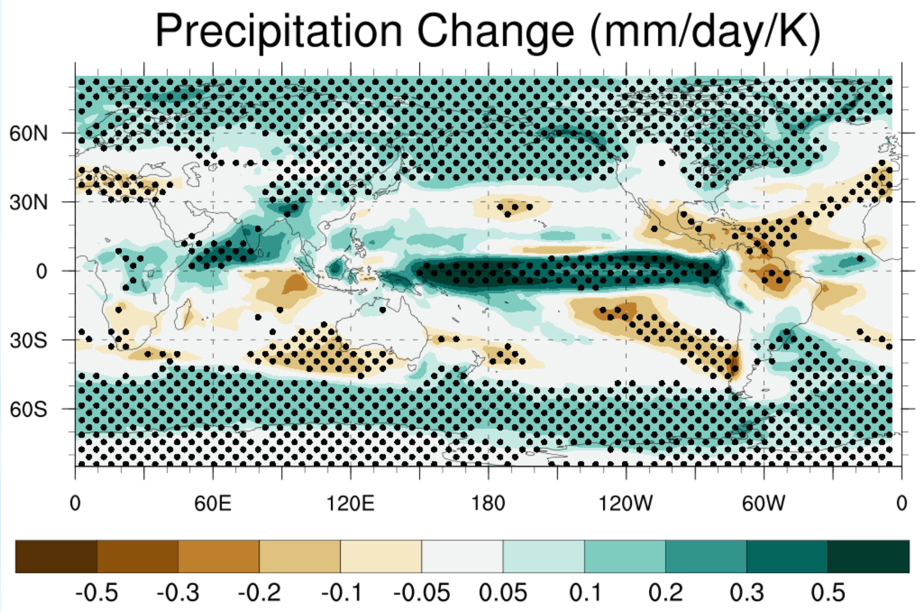
Fast VS Slow responses

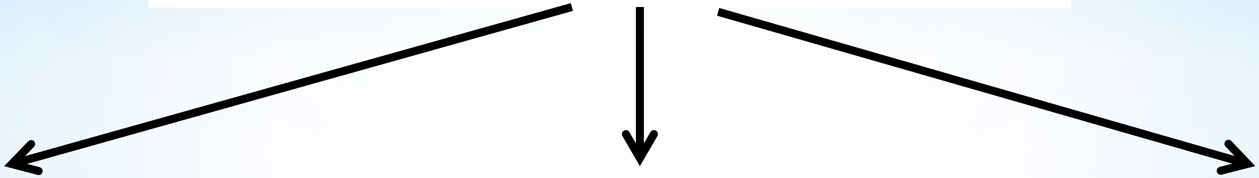


- Neither “Dry-get-drier” nor poleward expansion is required for the subtropical precipitation decline.
- Neither of the two mechanisms contributes substantially to the subtropical precipitation decline.

A more realistic scenario…

Total Change (1pctCO2)





AMIP_CO$_2$

CO$_2$ + land-sea contrast

AMIP_mean

Mean SST warming only

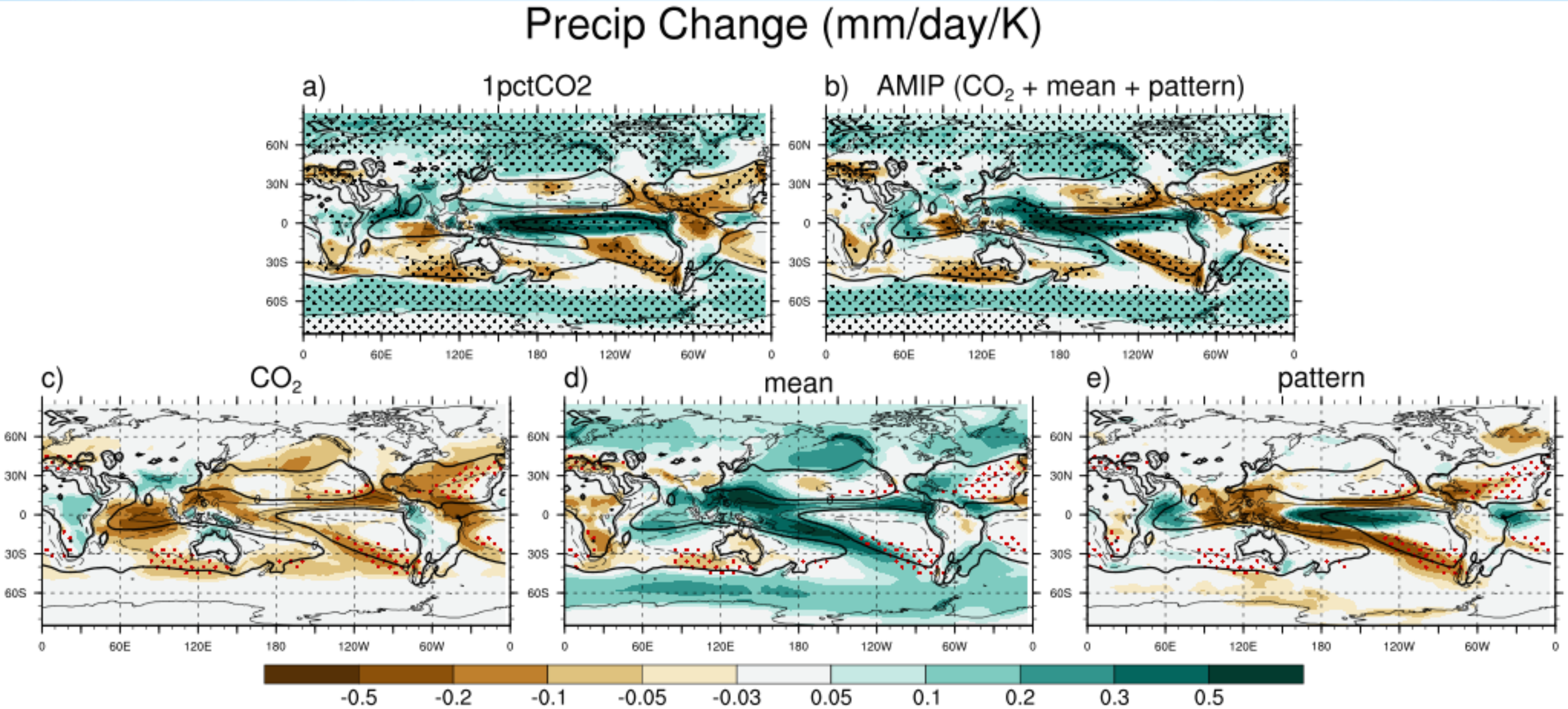
AMIP_pattern

Pattern of SST change only

CO_2 VS mean VS pattern

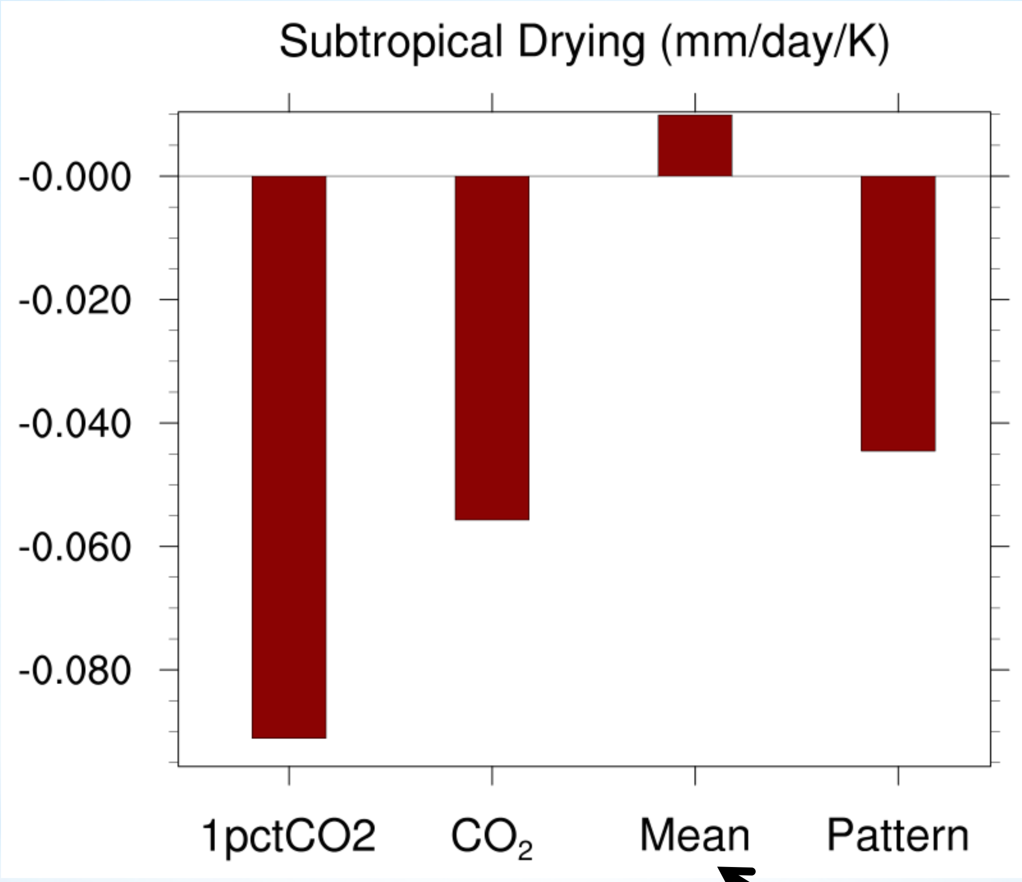
CMIP5 9-model mean

AMIP_pattern = AMIP_future – AMIP_mean



- **Subtropical precipitation decline does not depend on the global mean SST warming.**

CO_2 VS mean VS pattern

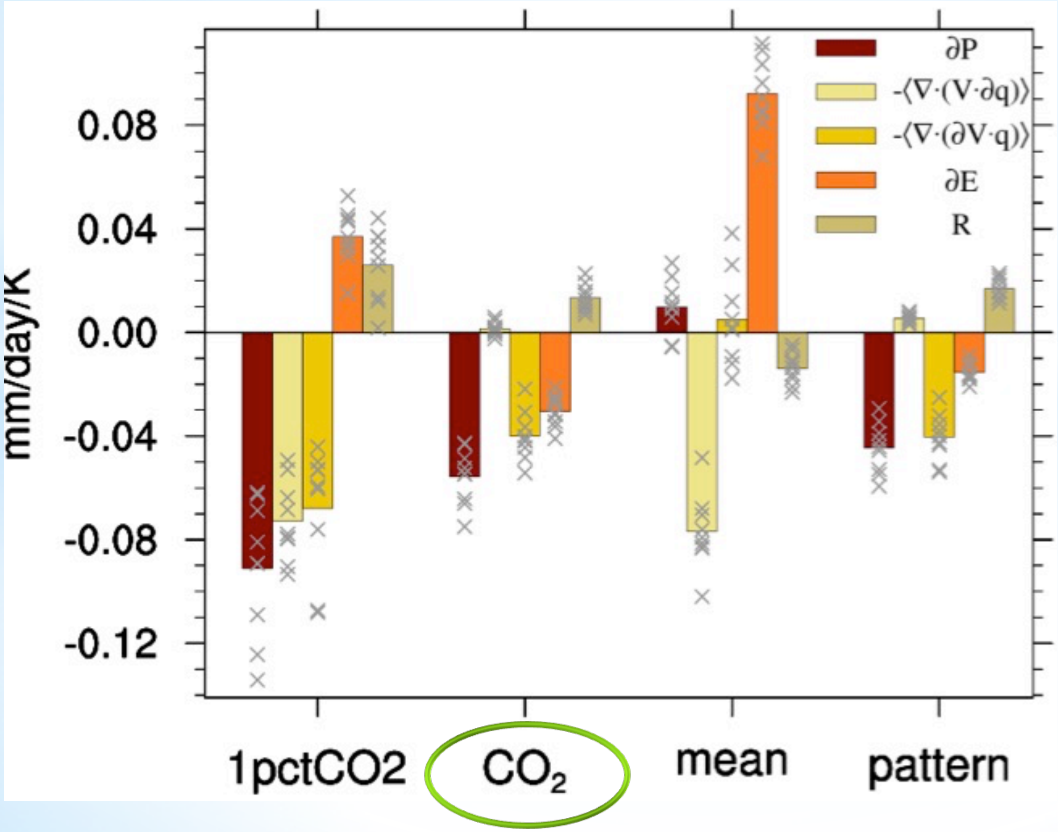


"Dry-get-drier"
& poleward expansion

CO_2 VS mean VS pattern

$$\delta(P-E) = -\int\nabla\cdot(\delta q\cdot V) - \int\nabla\cdot(q\cdot\delta V) - \int\cancel{\nabla\cdot(\delta q\cdot\delta V)}$$

$$\delta P = -\int\nabla\cdot(\delta q\cdot V) - \int\nabla\cdot(q\cdot\delta V) - \int\cancel{\nabla\cdot(\delta q\cdot\delta V)} + \delta E + R$$ (Seager et al. 2010, *J. Climate*)

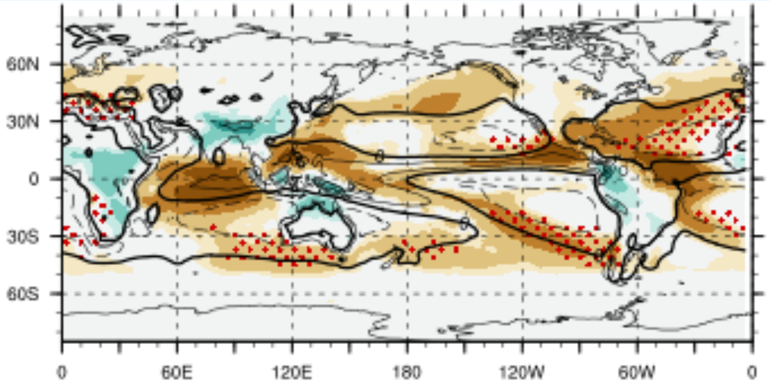


Direct CO_2 forcing *(Bony et al. 2013, Nature Geo)*

Land-sea warming contrast *(Chadwick et al. 2014, GRL; He & Soden 2015, J. Climate)*

Direct CO_2 VS Land-sea contrast

δP in AMIP_CO2

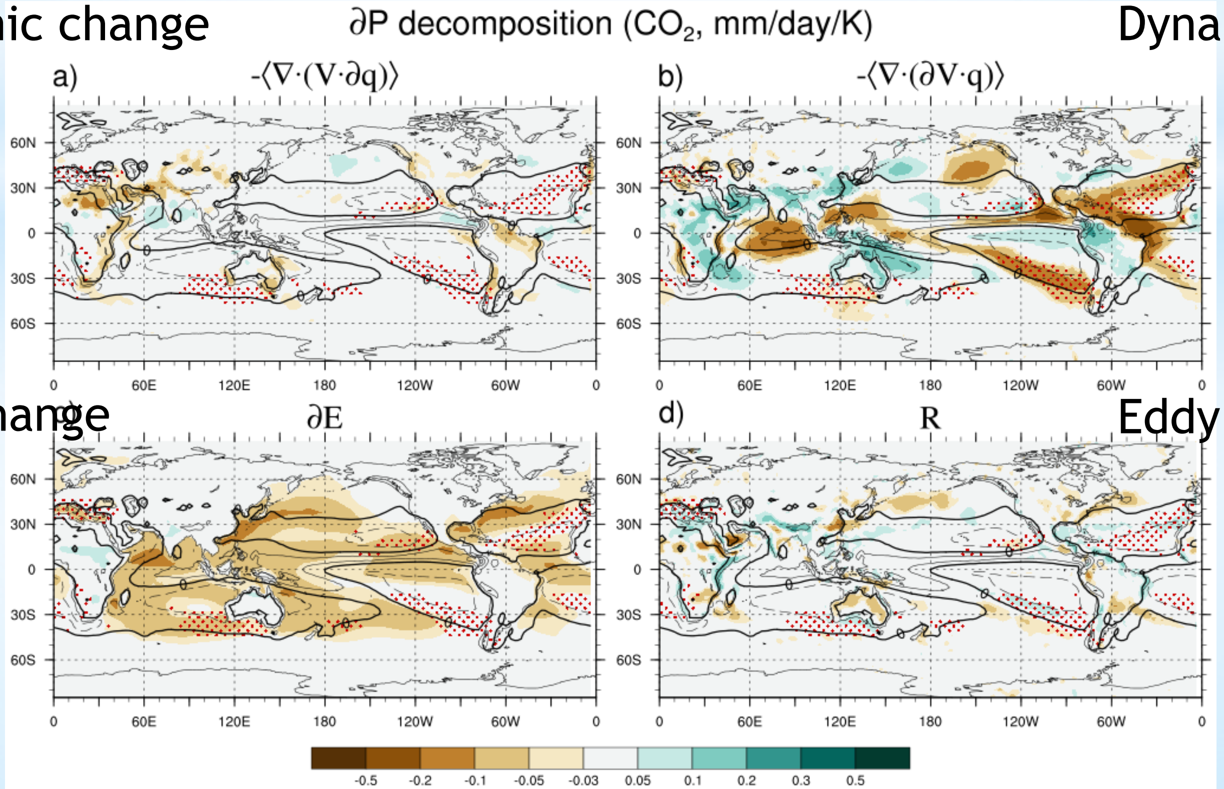


Thermodynamic change

Dynamic change

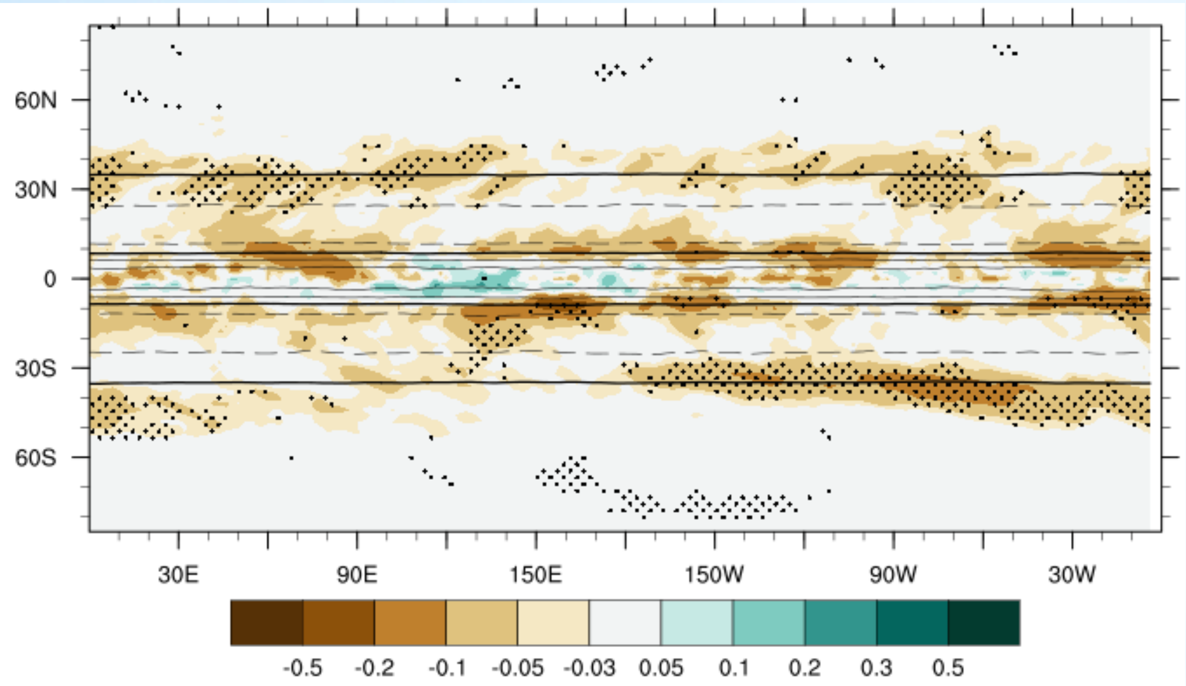
Evaporation change

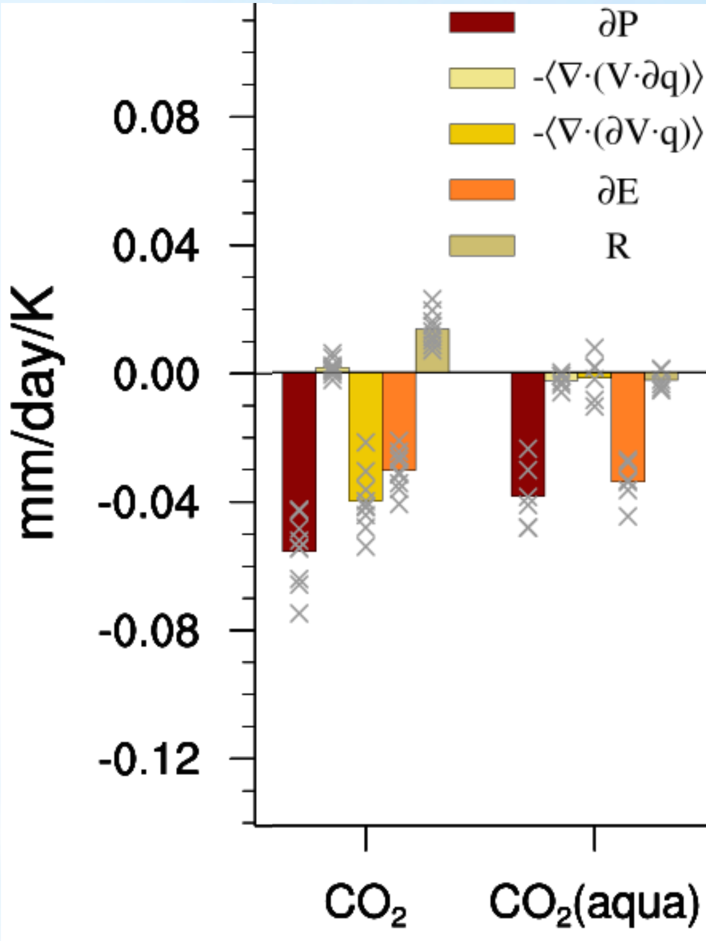
Eddy transport



Direct CO_2 VS Land-sea contrast

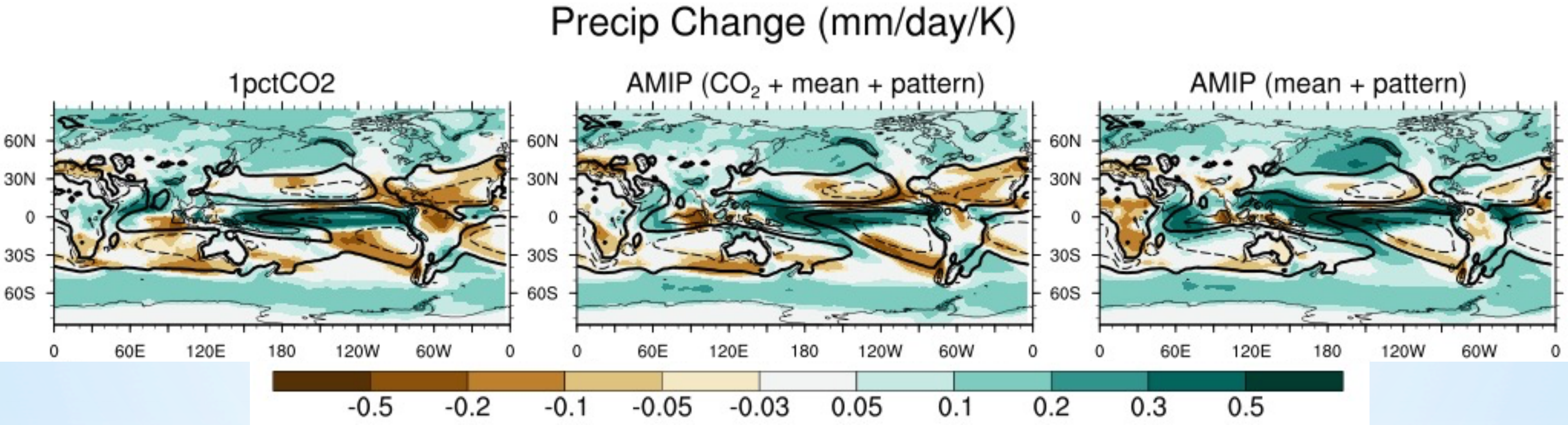
δP in aqua_CO2 (mm/day/K)





- Land-sea contrast drives dynamic change.
- Direct CO_2 forcing reduces evaporation (He and Soden 2015, *J. Climate*).

Land-sea warming contrast



- Land-sea warming contrast drives precipitation decline over ocean but counteracts the precipitation decline over land, which would otherwise happen due to SST change.

Summary

- Conventional wisdom: “dry-get-drier” and poleward expansion.
- Subtropical precipitation decline is primarily a fast response and does not depend on changes in moisture or poleward expansion of the Hadley cell.
- The large-scale subtropical precipitation decline is driven by the land-sea warming contrast, direct CO_2 forcing and, in certain regions, pattern of SST change.
- The land-sea warming contrast drives precipitation decline over subtropical ocean but counteracts the precipitation decline over land.

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Thank you ☺