Rethinking the Mechanisms of Subtropical Precipitation Decline from Anthropogenic Forcing

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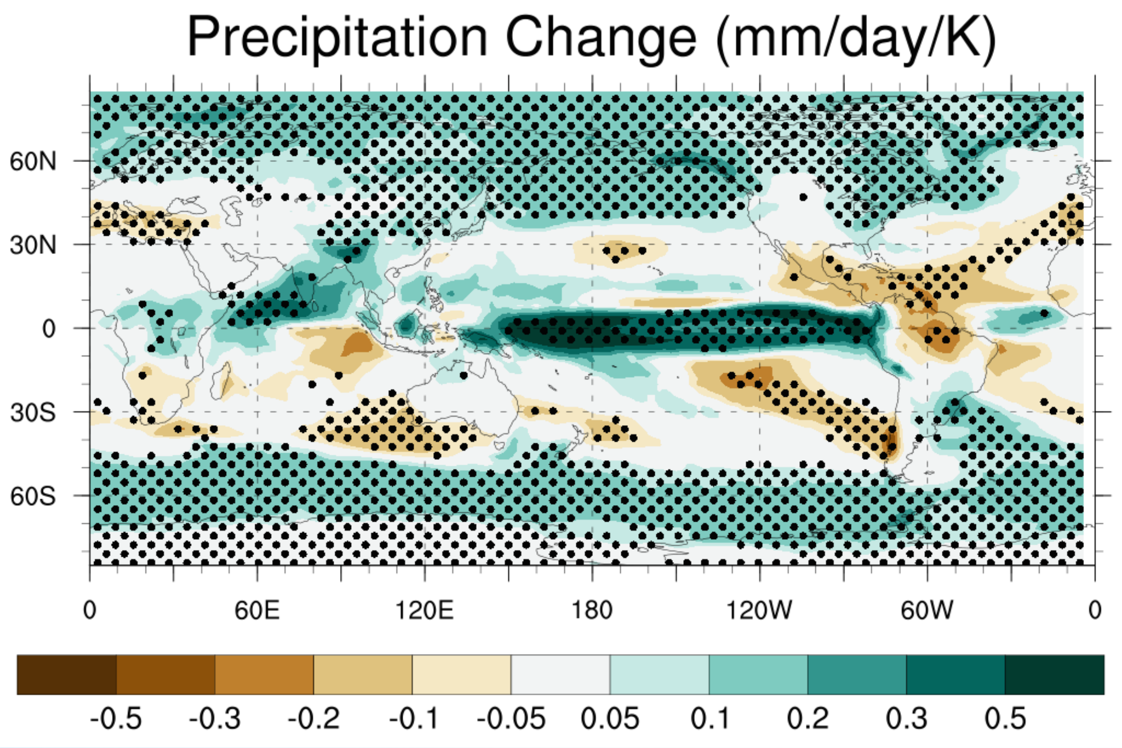
Precipitation declines in the subtropics.

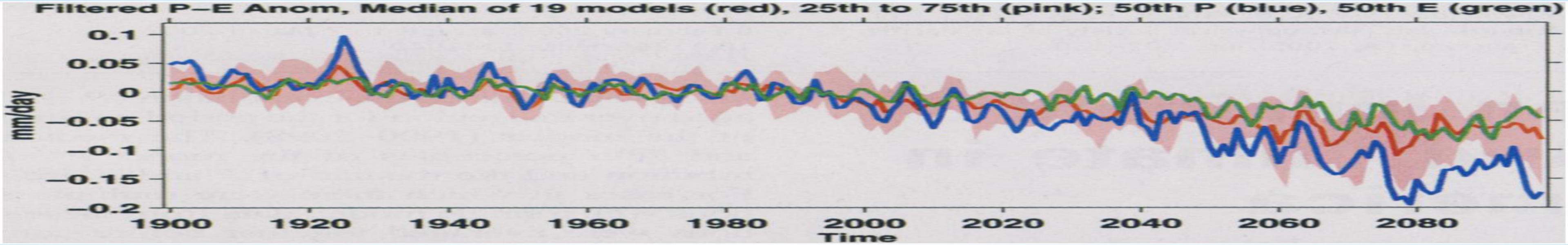
- Model evidence (1pctCO2, mm/day/K)



- Observation

(Neelin et al. 2006 PNAS; Dai 2012 Nature CC; Chadwick et al. 2015 Nature CC)

Why do we care?

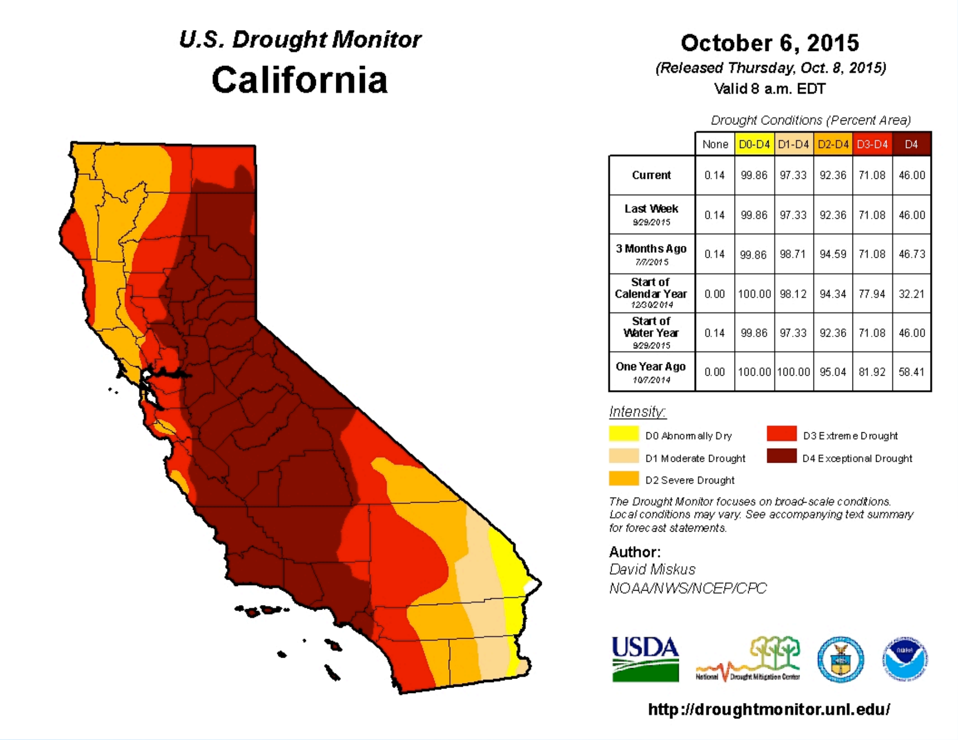


"If these models are correct, the levels of aridity of the recent multi-year drought or the **Dust Bowl** and the 1950s droughts will become the new climatology of the American Southwest within a time frame of years to decades."

-- Seager et al. 2007, Science

Why do we care?

- California Drought (2011-2015)



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:

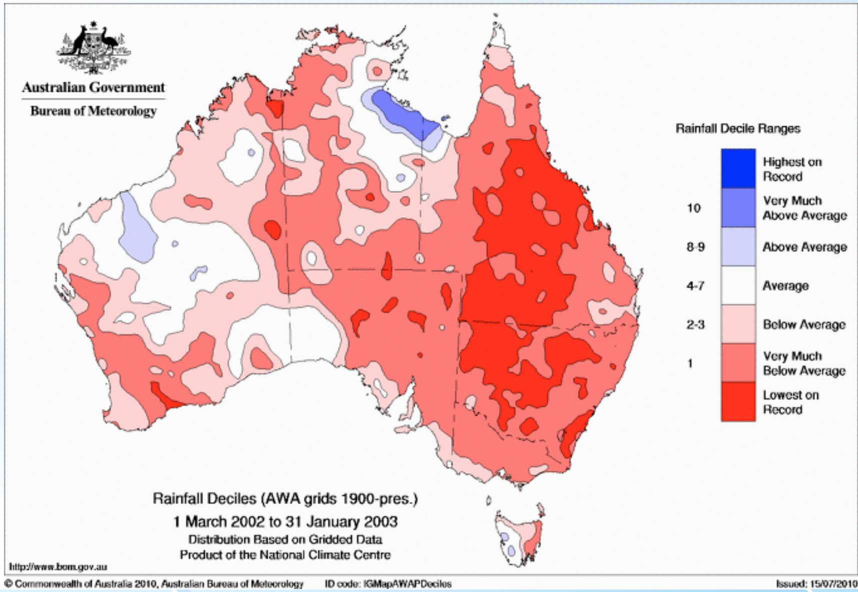
🟨 D0 Abnormally Dry	🟥 D3 Extreme Drought
D1 Moderate Drought	D4 Exceptional Drought
🟧 D2 Severe Drought	

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

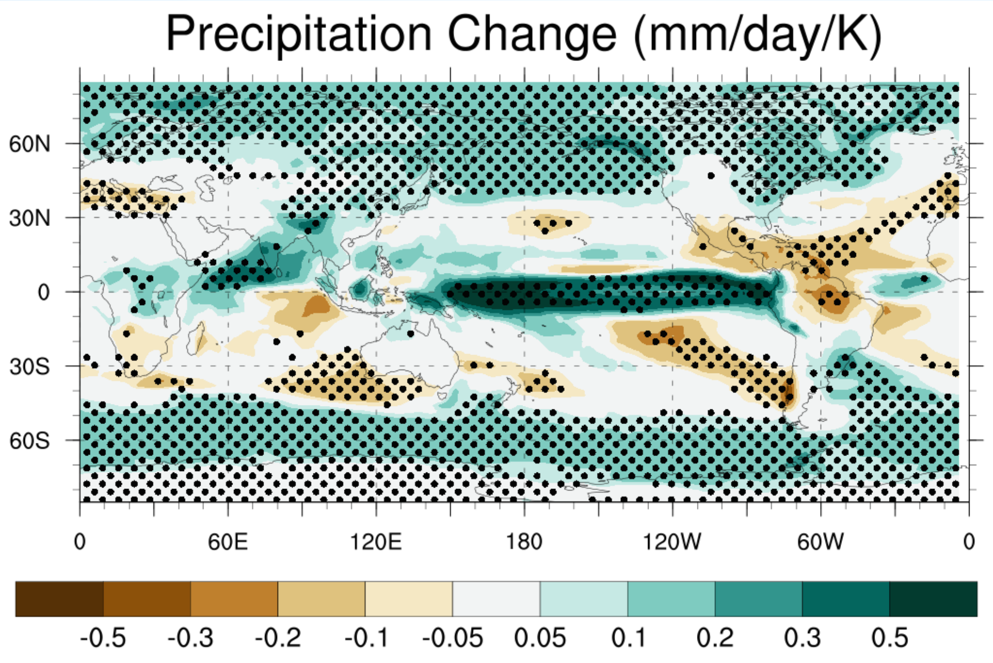
Author:
David Miskus
NOAA/NWS/NCEP/CPC

http://droughtmonitor.unl.edu/

- Australia Drought (1997-2009)



Why less rainfall in the subtropics?



2 prominent mechanisms:

- **“Dry-get-dryer”** ✗
- **Poleward shift** ✗

Why less rainfall in the subtropics?

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

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

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

$$\big\downarrow$$

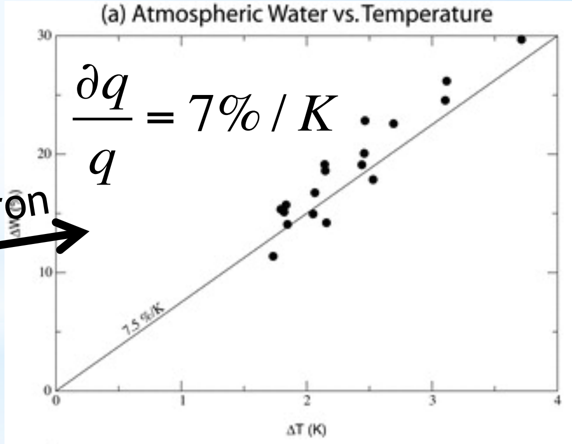
$$\delta(P-E)=-\int\nabla\cdot(\delta q\cdot V)-\int\nabla\cdot(q\cdot\delta V)-\int\cancel{\nabla\cdot(\delta q\cdot\delta V)}$$

$$\big\downarrow\ \delta V\approx 0$$

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

$$\big\downarrow\ \delta q\approx q\times 7\%/K \xrightarrow{\text{Clausius-Clapeyron}}$$

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


(a) Atmospheric Water vs. Temperature

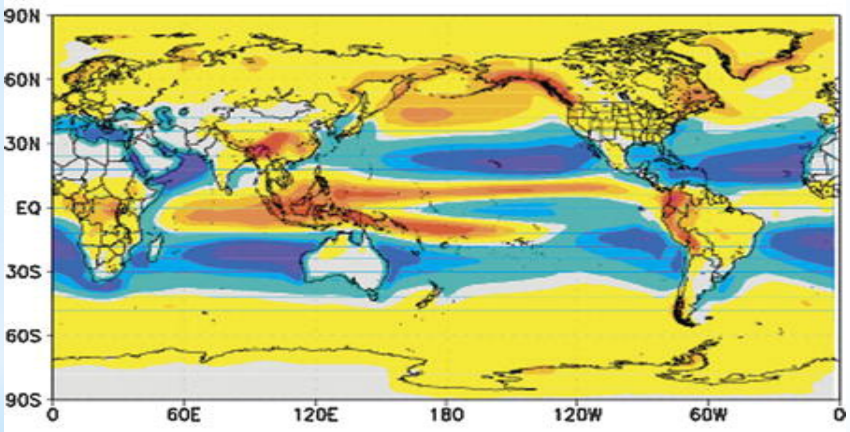
$$\frac{\partial q}{q}=7\%/K$$

Why less rainfall in the subtropics?

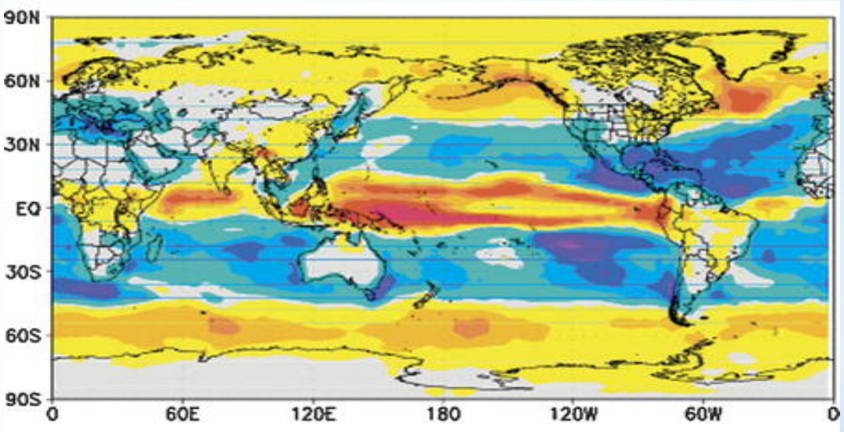
- **"Dry-get-dryer"** (Held and Soden 2006, *J. Climate*)

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

Climatological (P-E)x7%/K



Change in P-E



↓

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

Why less rainfall in the subtropics?

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

Subtropical precipitation decline

↑

Increased moisture export

↑

Increase in moisture

↑

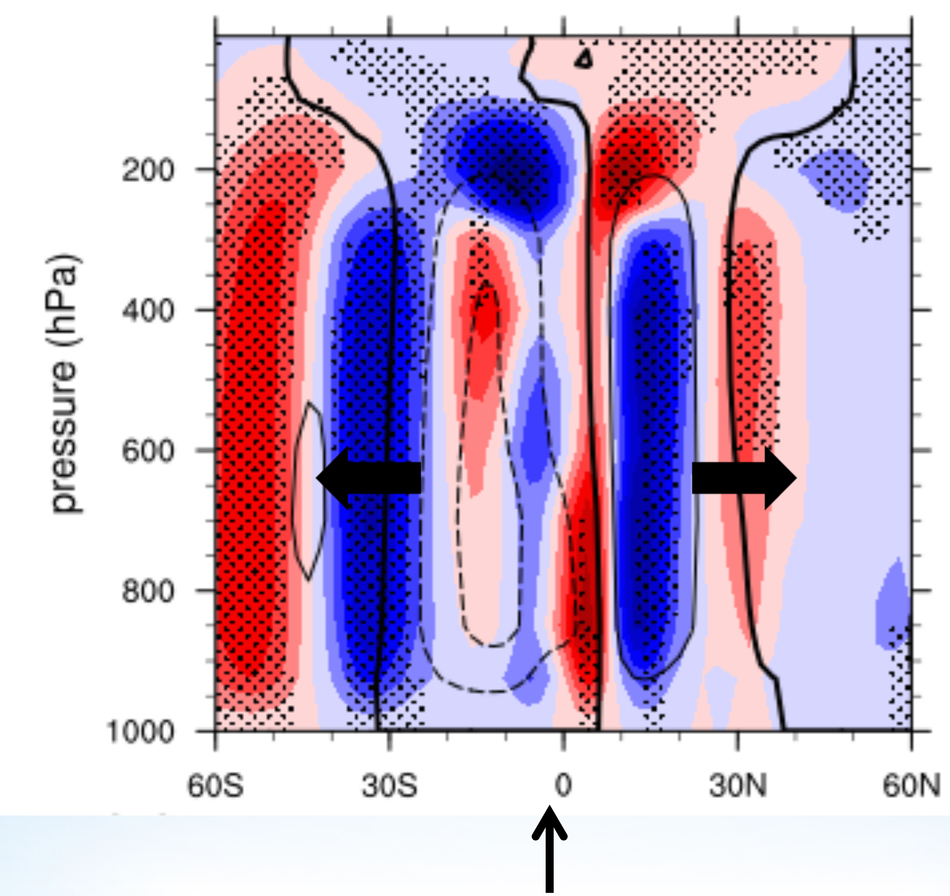
Global mean warming

(a thermodynamic response)

Why less rainfall in the subtropics?

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

Change in zonal mean stream function (kg/s/K)

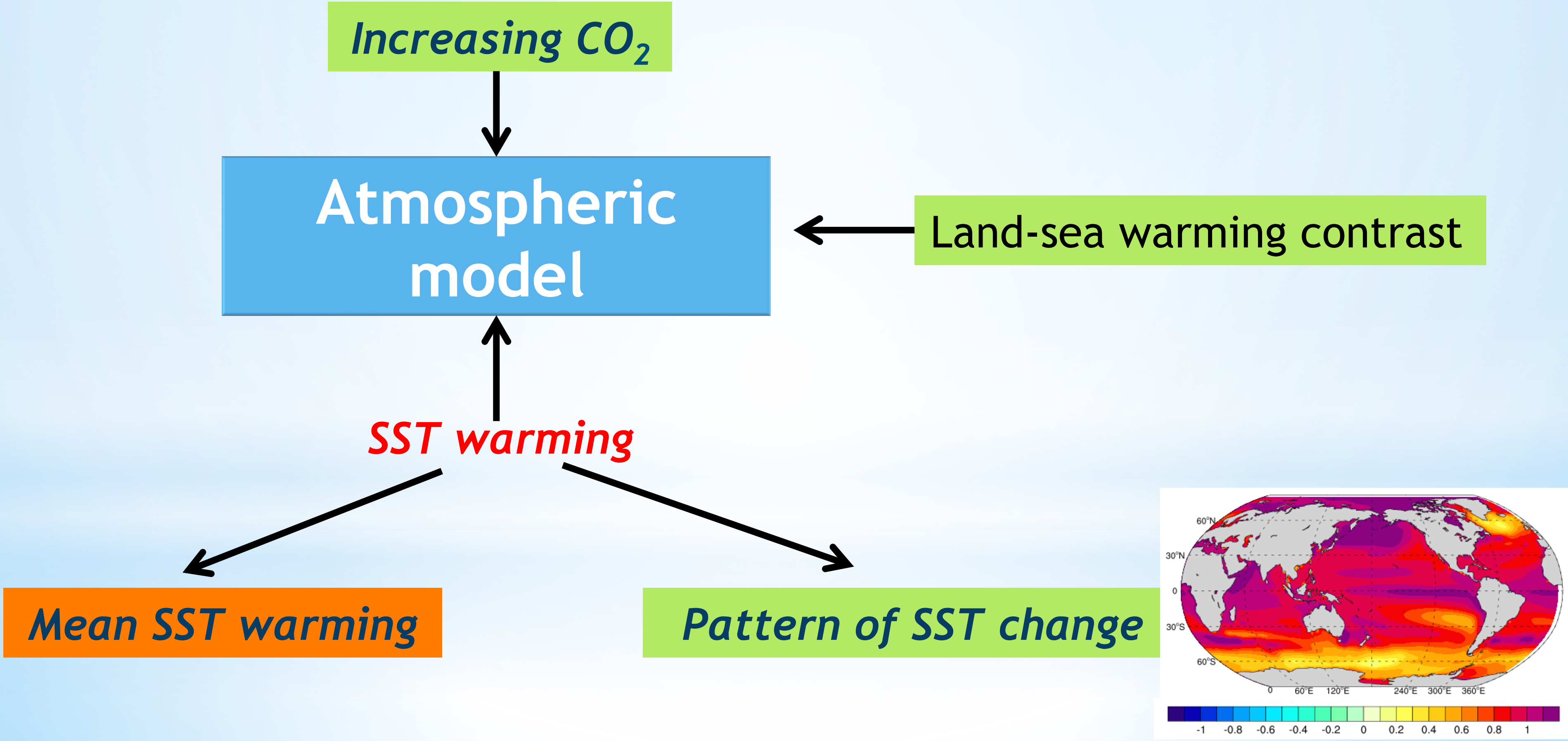


Global mean warming (He and Soden 2015, *J. Climate*)

A new perspective…

- “Dry-get-dryer”
- Poleward shift

→ Mean SST warming



Increasing CO_2

Atmospheric model

Land-sea warming contrast

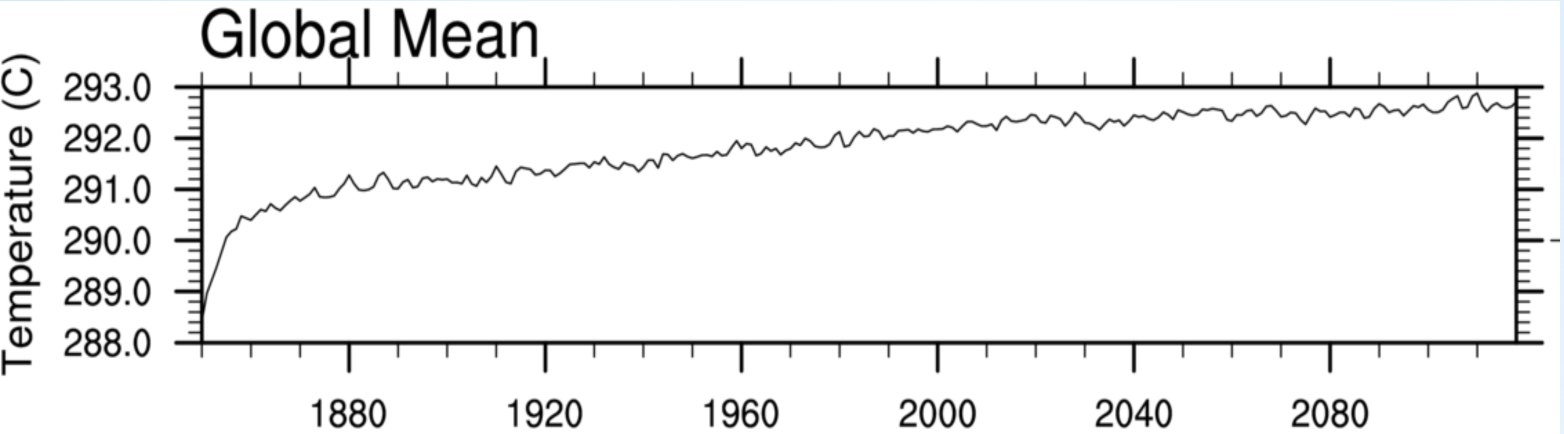
SST warming

Mean SST warming

Pattern of SST change

A new perspective…

Abrupt4xCO2 (14 CGCMs, CMIP5)

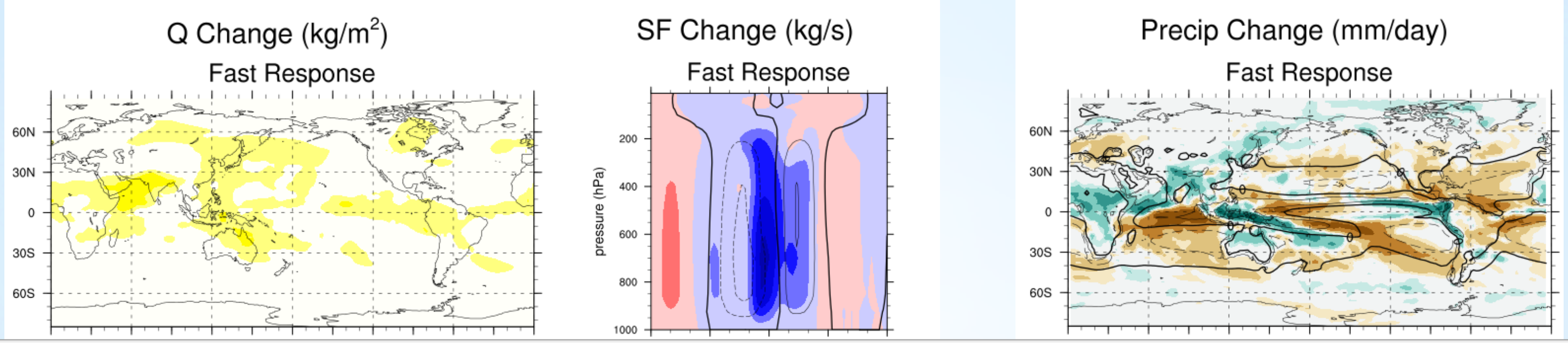


Direct CO_2 forcing
Land-sea warming contrast → Fast
Pattern of SST change

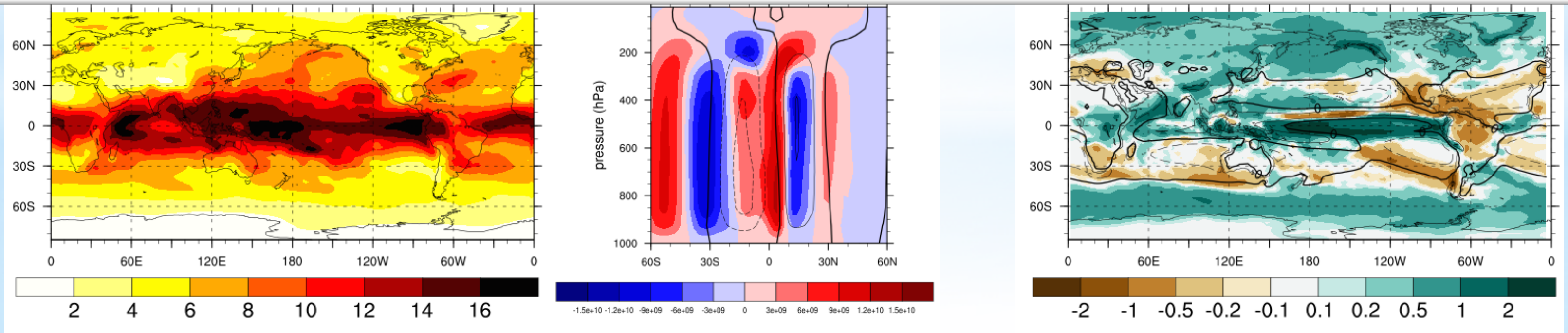
Mean SST warming → Slow

Fast VS Slow responses

“Dry-get-dryer” | Poleward shift | Fast precipitation decline

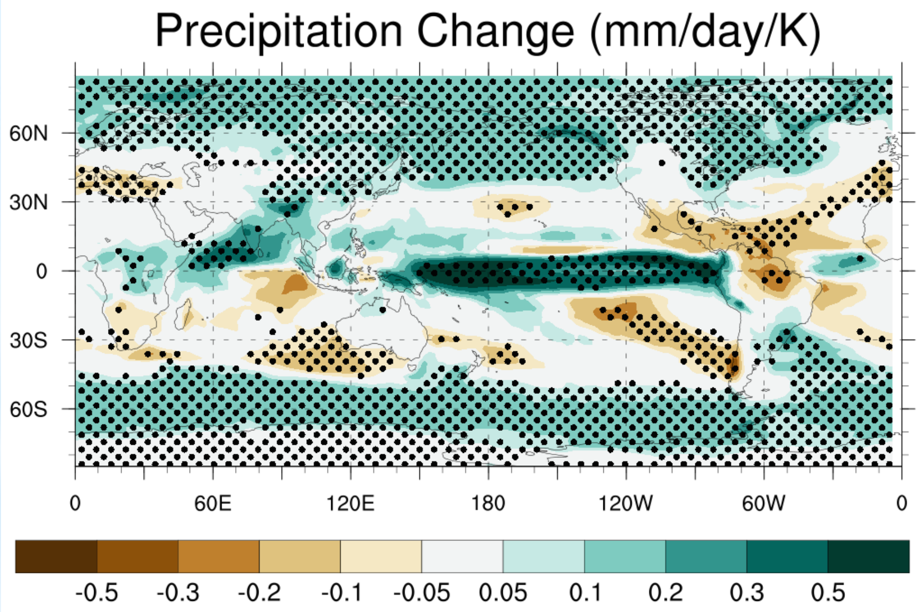


- **Neither “Dry-get-dryer” nor poleward shift is not required for the subtropical precipitation decline.**
- **Neither of the two mechanisms contributes to the subtropical precipitation decline.**



A more realistic scenario…

Total Change
(1pctCO2)



AMIP_CO_2

CO_2 + land-sea contrast

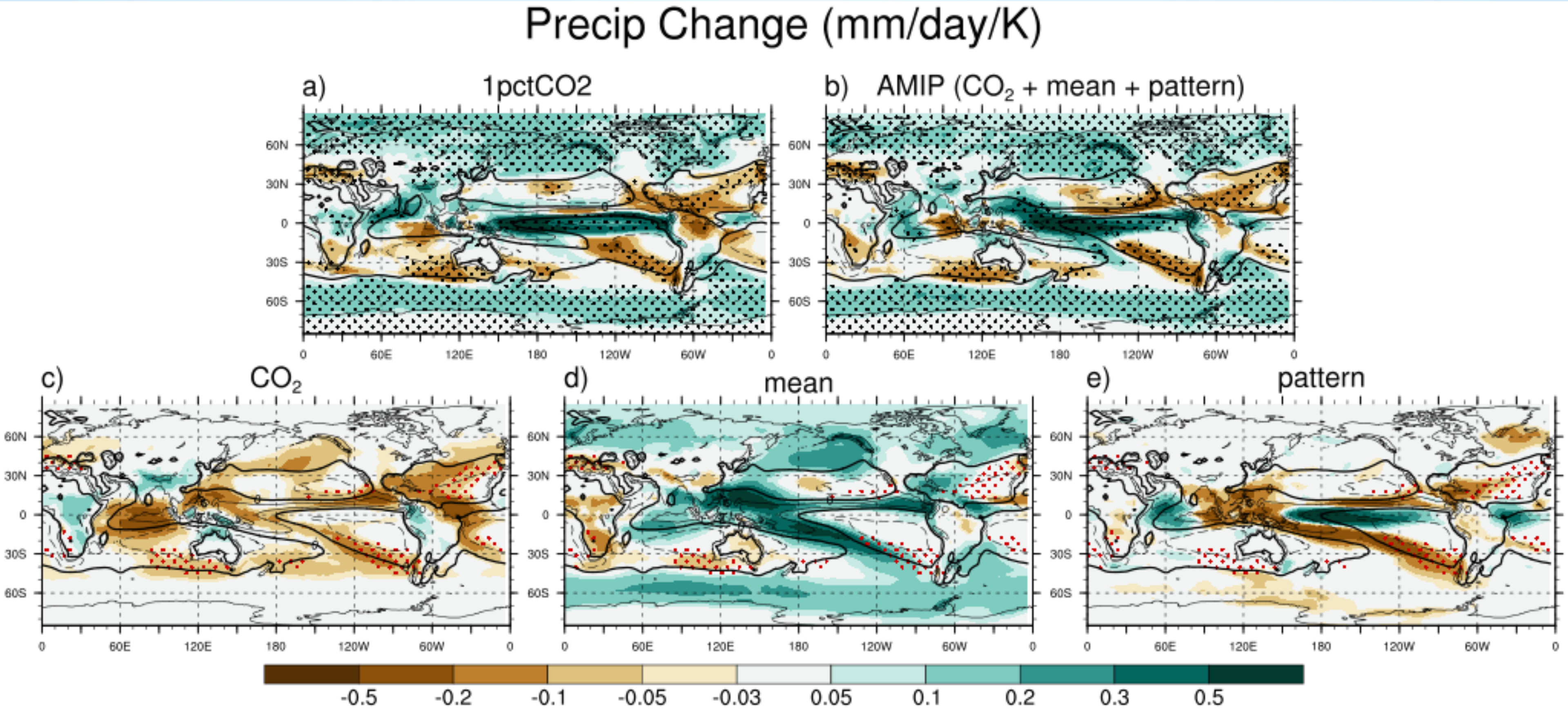
AMIP_mean

Mean SST warming only

AMIP_pattern

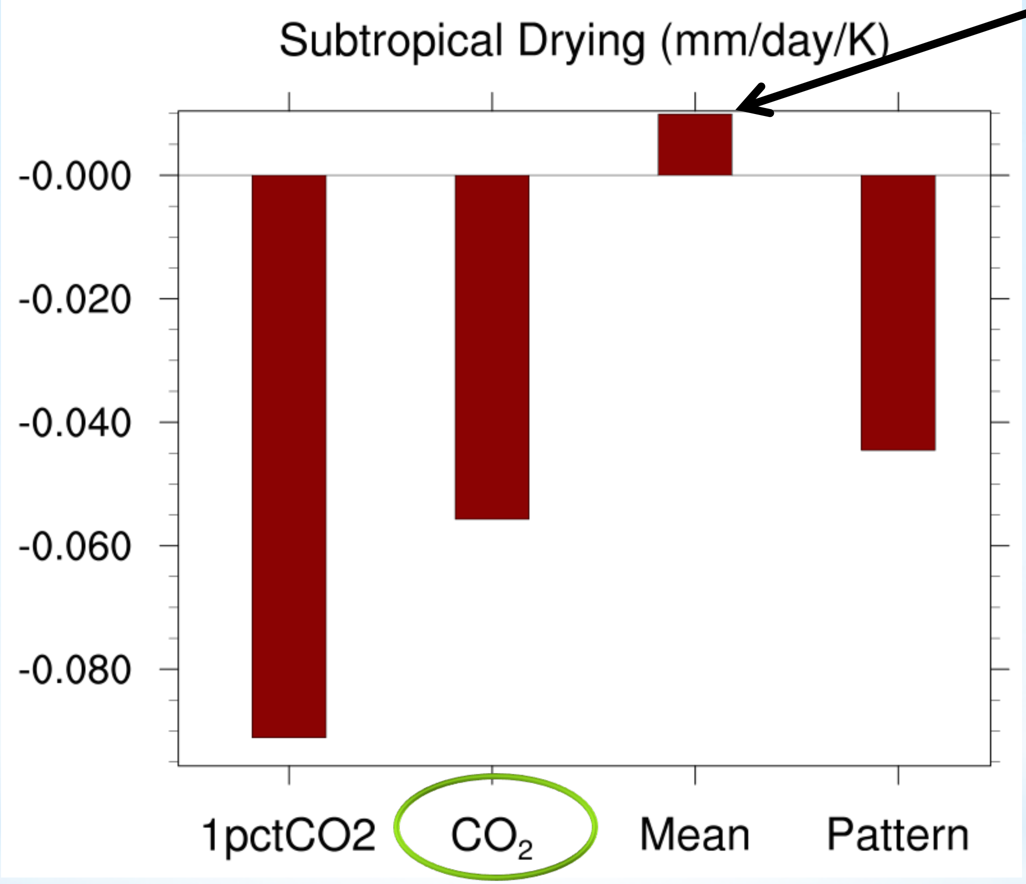
Pattern of SST change only

A more realistic scenario…



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

A more realistic scenario…

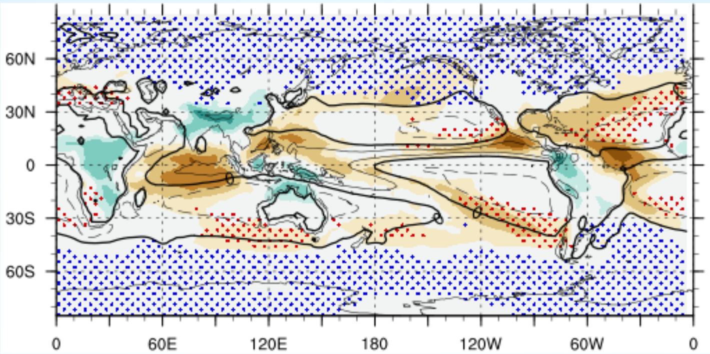


“Dry-get-dryer” & poleward shift

Direct CO_2 forcing
Land-sea warming contrast

Direct CO$_2$ VS Land-sea contrast

δP in AMIP_CO2



Stabilization

(Bony et al. 2013, Nature CC)

or

Land-sea?

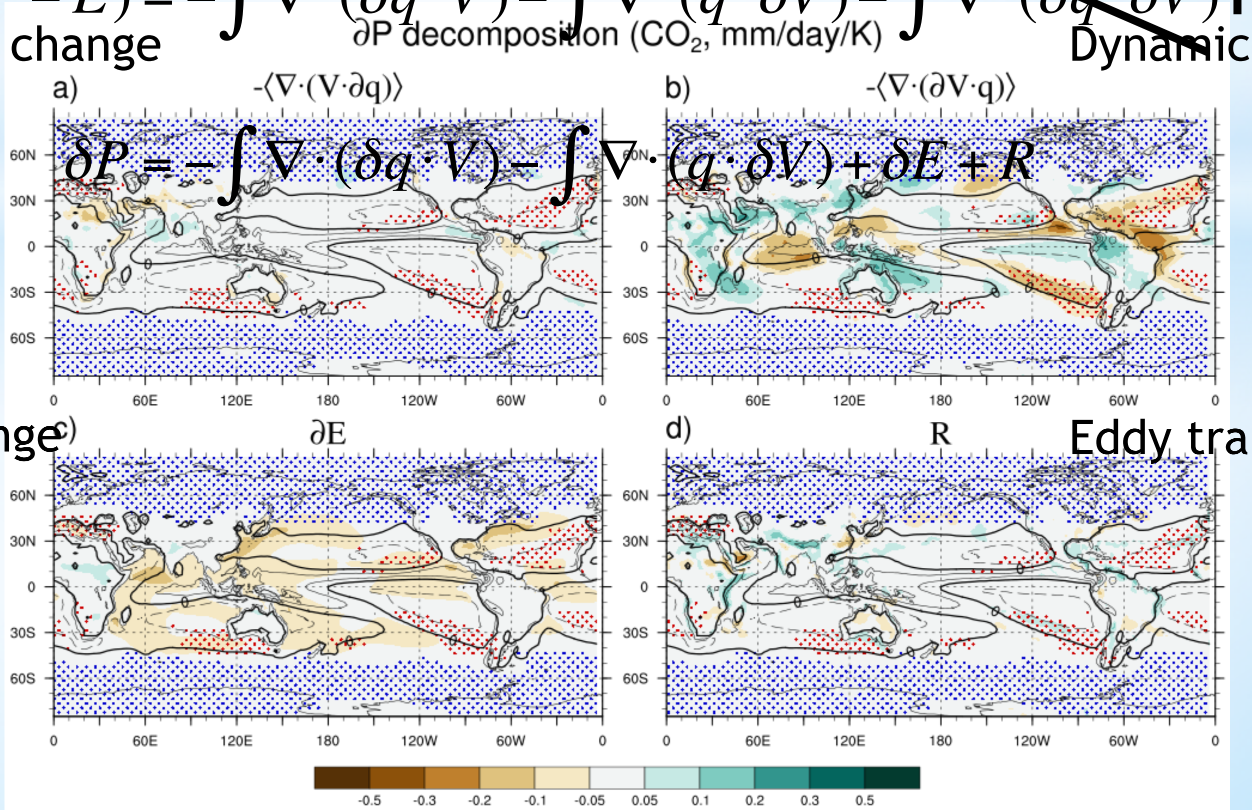
$$\delta(P-E) = -\int \nabla\cdot(\delta q\cdot V) - \int \nabla\cdot(q\cdot\delta V) - \cancel{\int \nabla\cdot(\delta q\cdot\delta V)} \uparrow$$

Thermodynamic change

Dynamic change

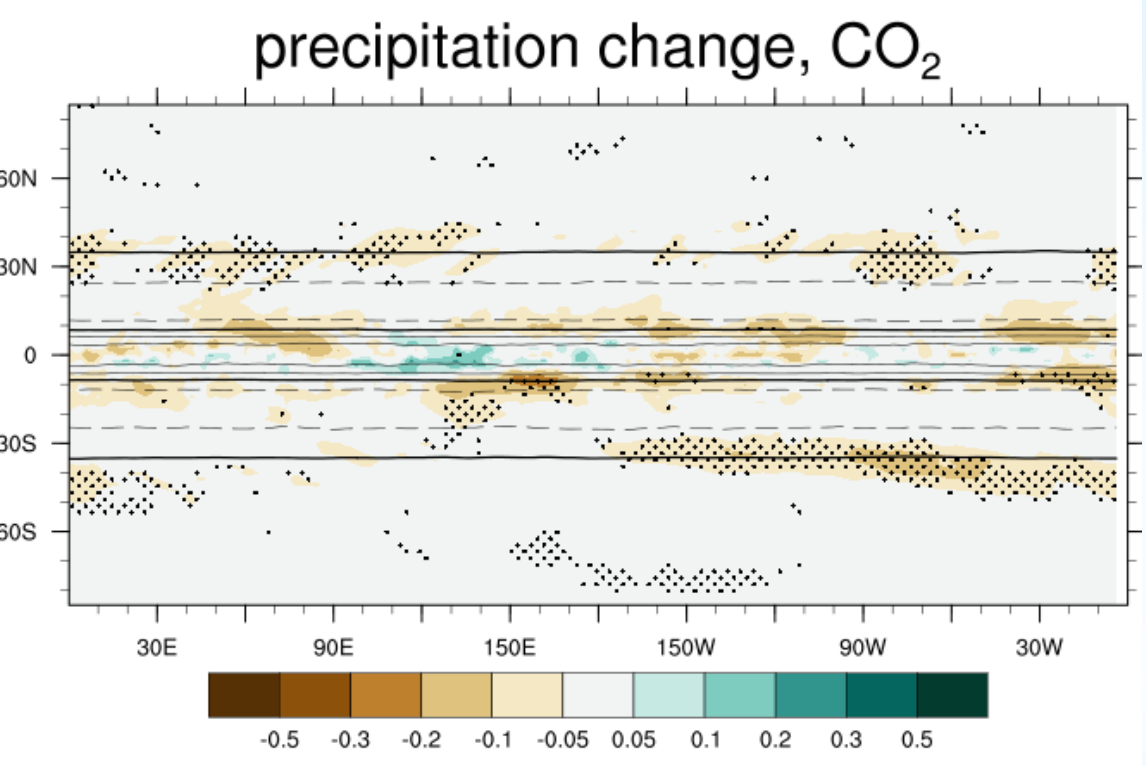
Evaporation change

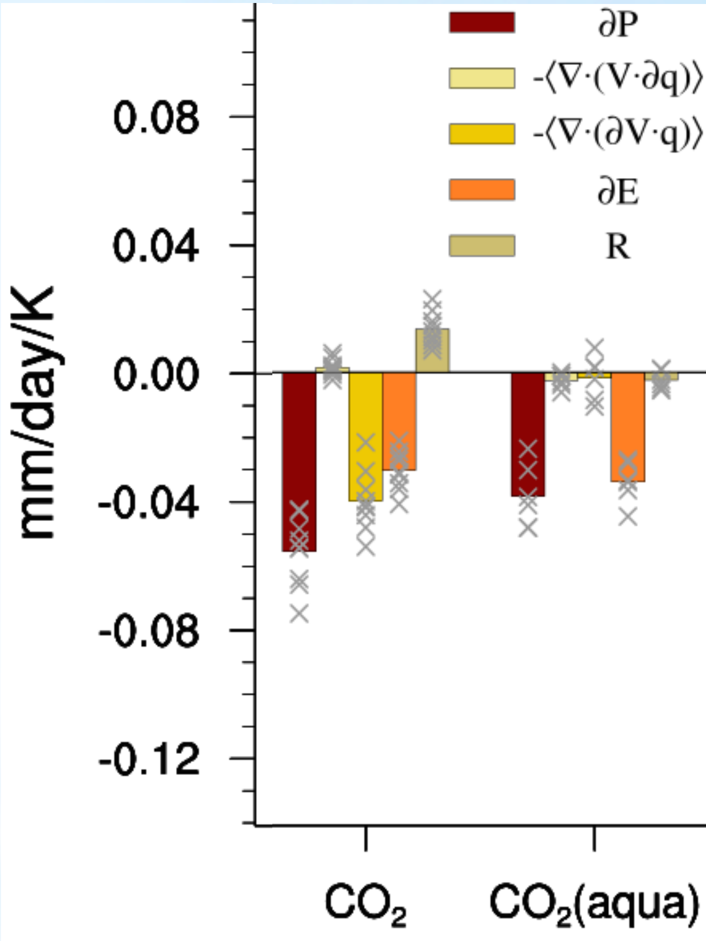
Eddy transport



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

Direct CO_2 VS Land-sea contrast





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

Summary

- Conventional wisdom: “dry-get-dryer” and poleward shift.
- Subtropical precipitation decline is primarily a fast response and does not depend on the global mean SST warming.
- The large-scale subtropical precipitation decline is driven by the direct CO_2 forcing and land-sea warming contrast and, in certain regions, pattern of SST change.

References

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Questions?