A satellite view of Earth from space, showing the Americas and the Atlantic Ocean. The text is overlaid on the image.

Mechanisms of Regional Precipitation Change from Anthropogenic Forcing and Decadal Variability

**Jie He
Brian Soden**

***Rosenstiel School for Marine and Atmospheric Science
University of Miami***

NOAA CVP Webinar - Sept 2, 2015

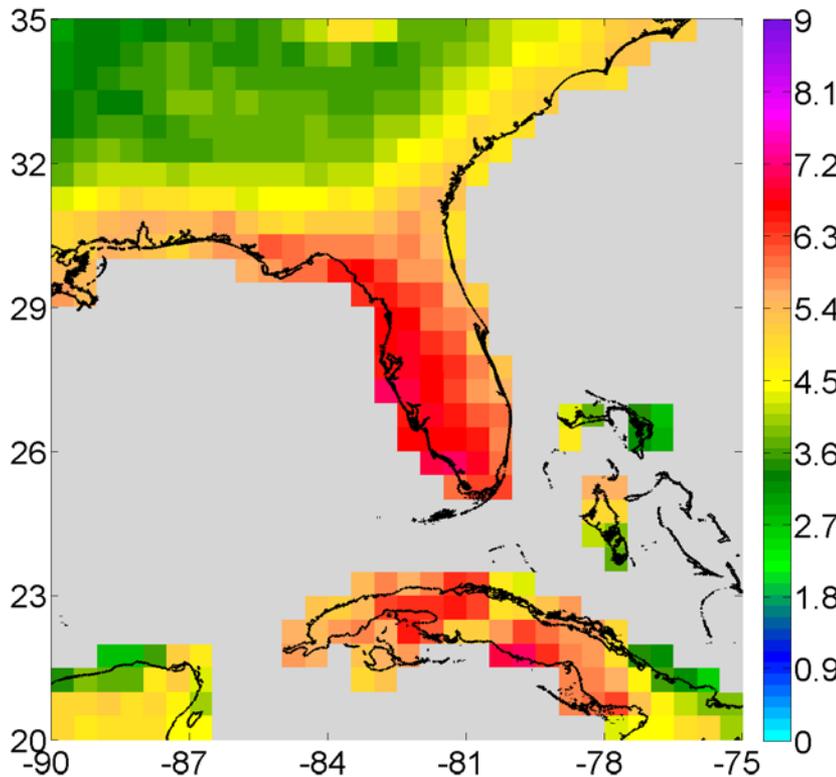
South Florida has an extensive infrastructure to “manage” water



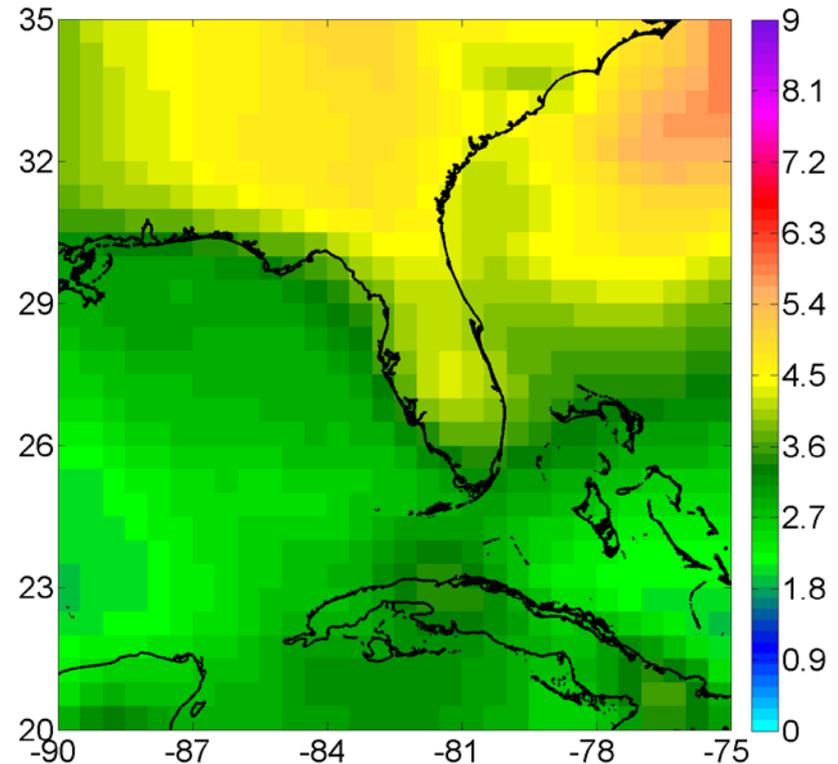
Courtesy: Jayantha Obeysekera

GCM Simulations of the South Florida Climate

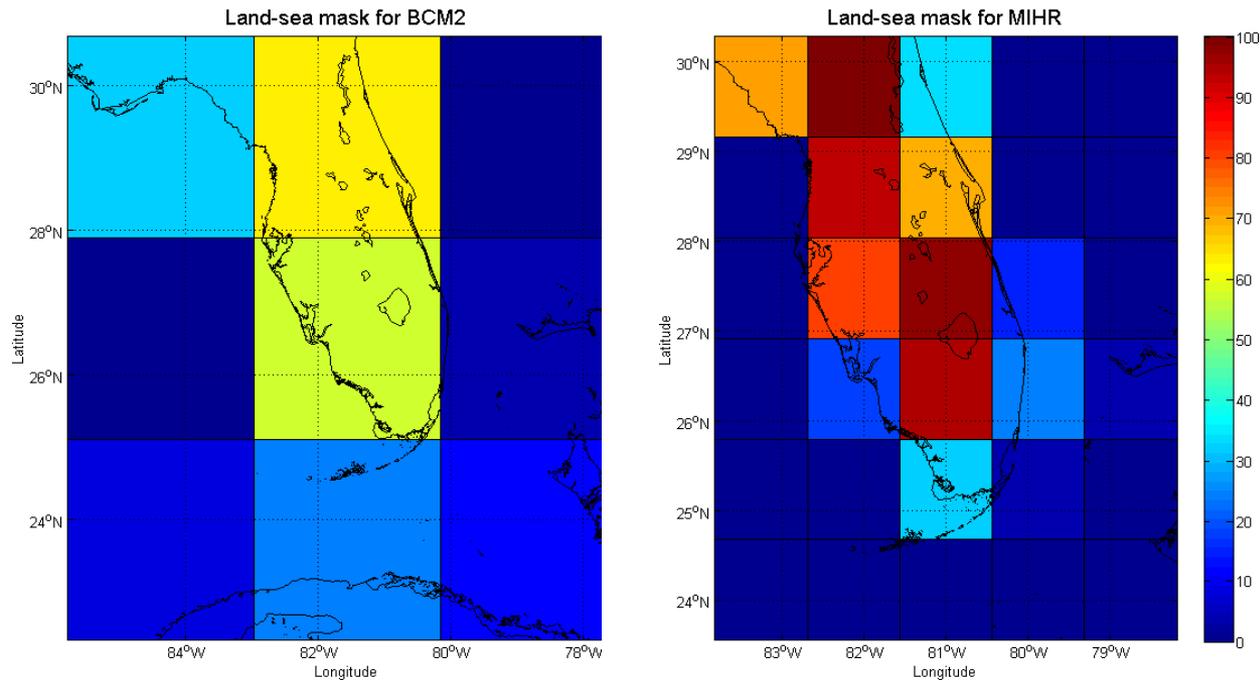
Observed JJA Rainfall (mm)



CMIP5 Mean JJA Rainfall (mm)
Multi-model Ensemble Mean



GCM Simulations of the South Florida Climate

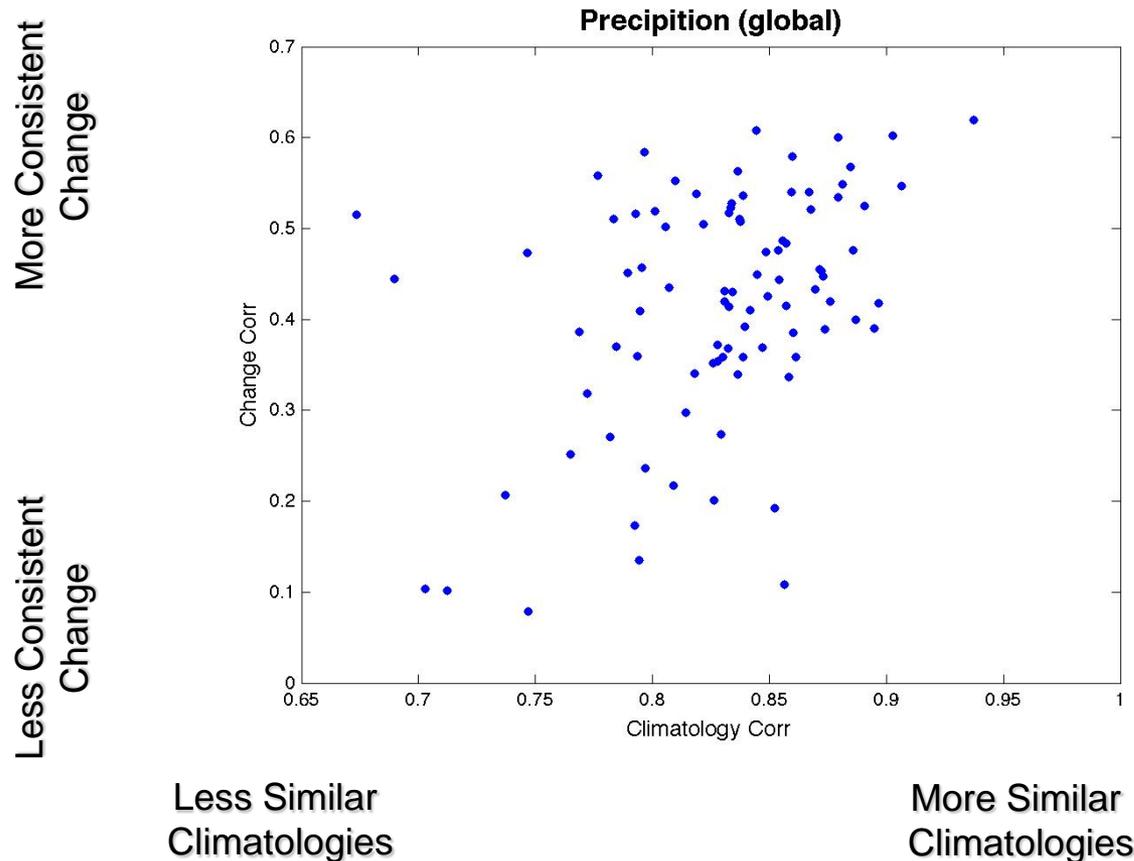


Resolution of various CGCM land-sea masks ...

Can we use high resolution AGCMs or RCMs with prescribed SST?

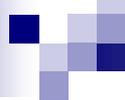
Climatological Biases Affect the Projections

Cross Model Correlation of Precipitation Climatology vs Precipitation Change (CGCM 1%CO2)



He and Soden (2015)

Models with more consistent climatologies predict more consistent changes



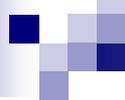
Are Coupled Models Necessary For Simulating Anthropogenic Climate Change?

1) Is ocean coupling necessary for regional climate change?

2) Is regional climate change sensitive to pattern of Δ SST?

3) Does ocean coupling degrade regional projections?

1) Practical Ways Forward



Are Coupled Models Necessary For Simulating Anthropogenic Climate Change?

1) Is ocean coupling necessary for regional climate change?

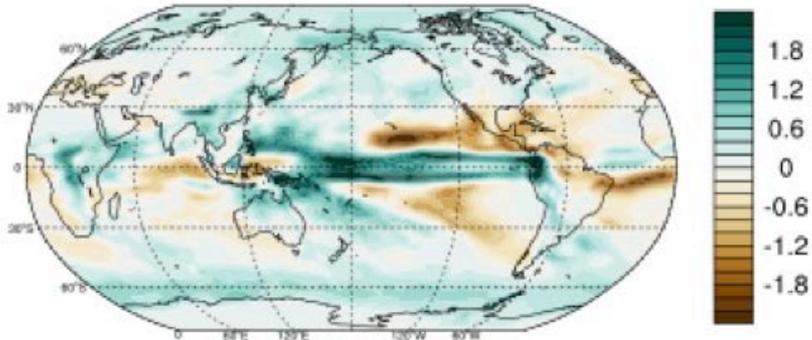
2) Is regional climate change sensitive to pattern of Δ SST?

3) Does ocean coupling degrade regional projections?

1) Practical Ways Forward

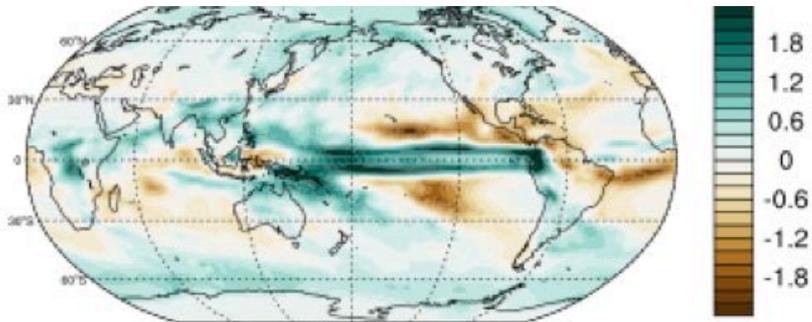
Is Coupling Important for Regional Climate Change?

CGCM: ΔP 4xCO₂ (last 10yr – first 10yr)



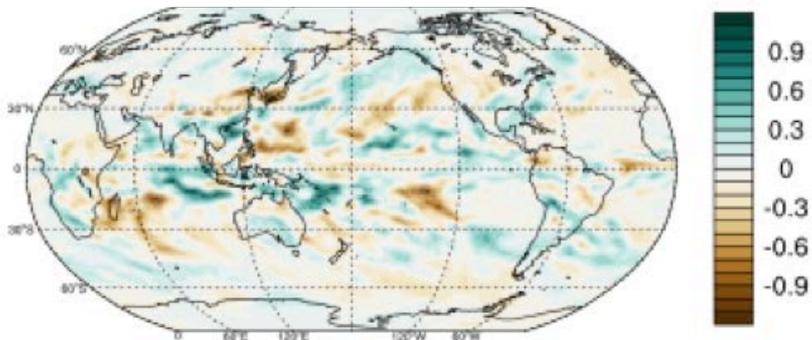
Coupled GCM

AGCM: ΔP 4xCO₂ (last 10yr – first 10yr)



Atmosphere-only GCM
(w/ daily SSTs from CGCM)

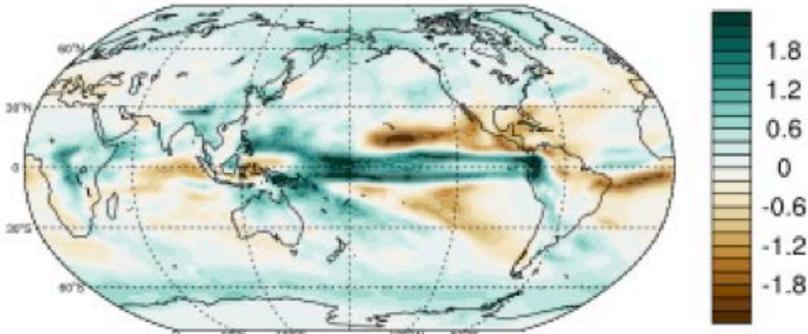
Error: $\Delta P_{\text{CGCM}} - \Delta P_{\text{AGCM}}$



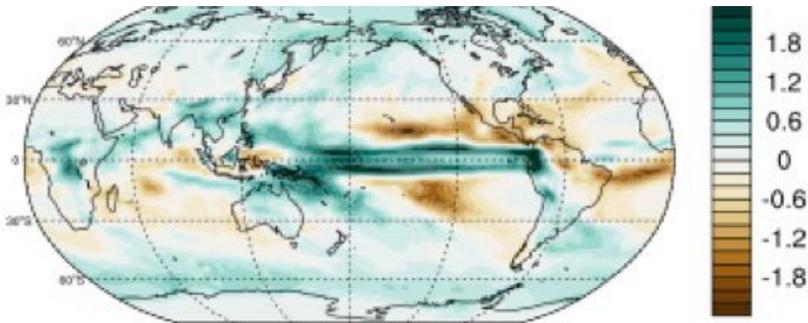
How does the “error” respond to forcing?

Is Coupling Important for Regional Climate Change?

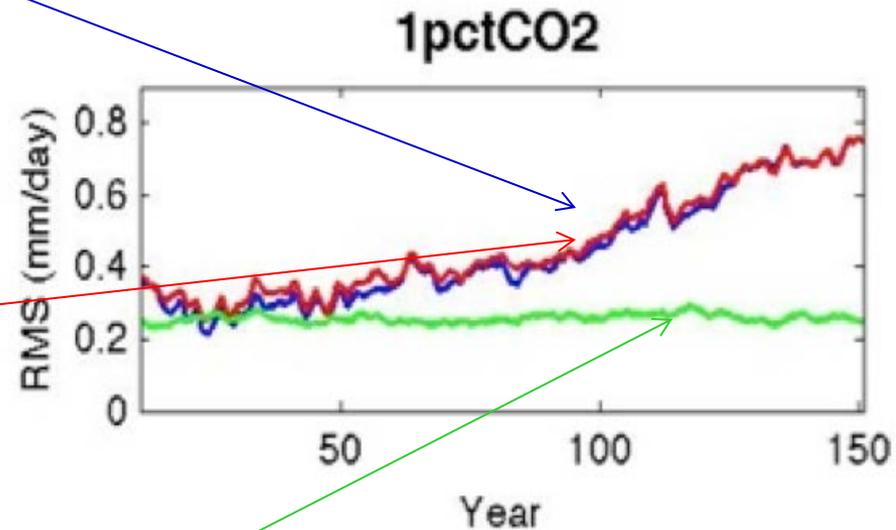
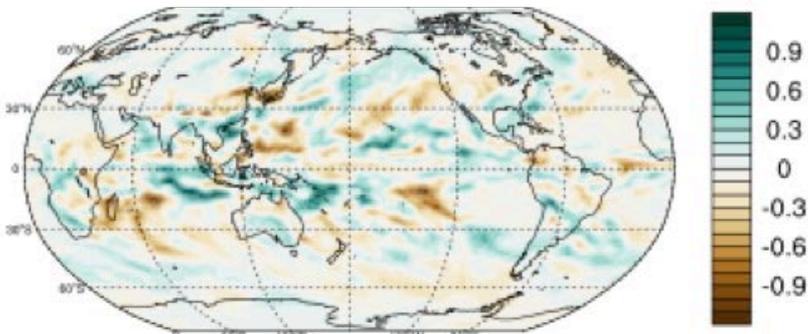
CGCM: ΔP 4xCO₂ (last 10yr – first 10yr)



AGCM: ΔP 4xCO₂ (last 10yr – first 10yr)



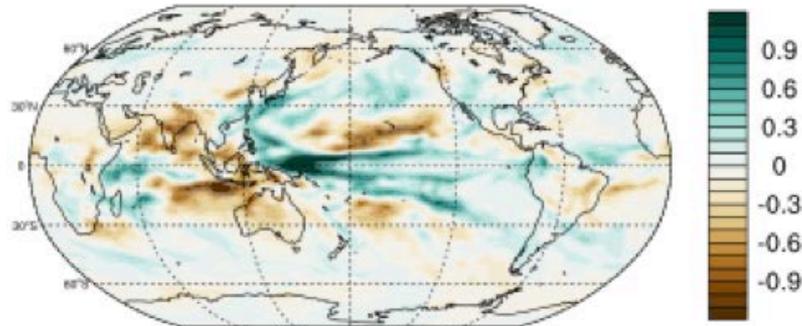
Error: $\Delta P_{CGCM} - \Delta P_{AGCM}$



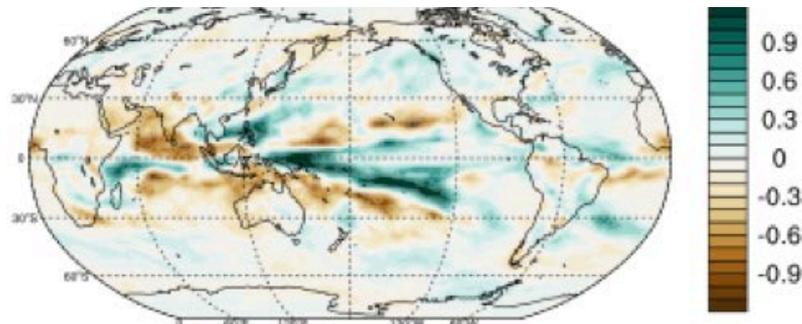
Error due to the neglect of coupling is independent of forcing.

Is Coupling Important for Regional Climate Change?

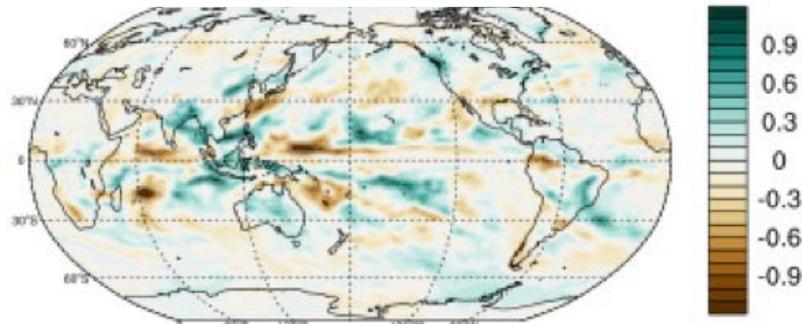
CGCM: ΔP CTRL (last 10yr – first 10yr)



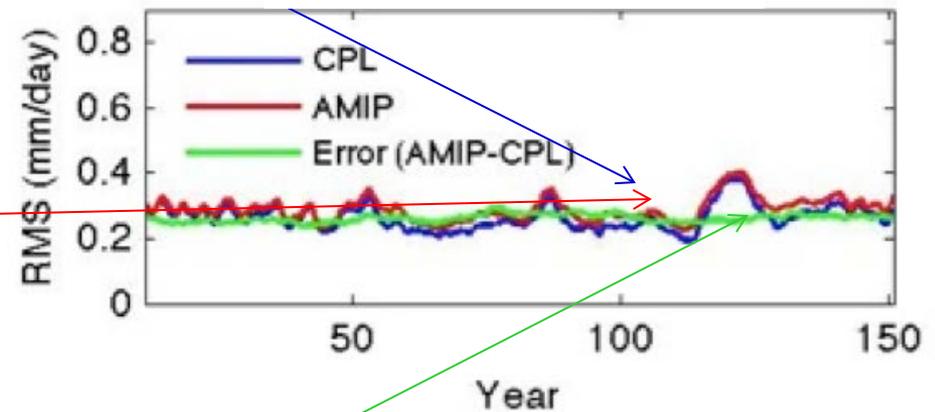
AGCM: ΔP CTRL (last 10yr – first 10yr)



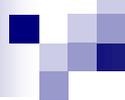
Error: $\Delta P_{CGCM} - \Delta P_{AGCM}$



Pre-Industrial Control



Error due to the neglect of coupling is comparable to the signal from internal decadal variability.



Are Coupled Models Necessary For Simulating Anthropogenic Climate Change?

1) Is ocean coupling necessary for regional climate change?

No (as long as you know the change in SST)

2) Is regional climate change sensitive to pattern of Δ SST?

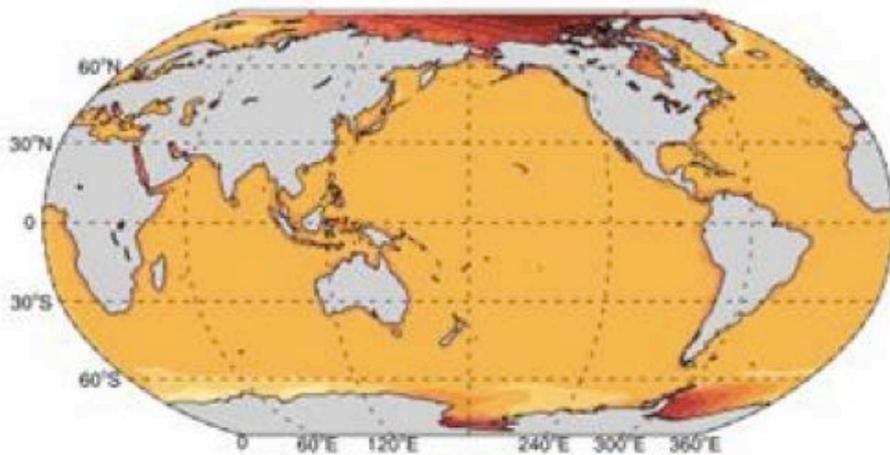
3) Does ocean coupling degrade regional projections?

1) Practical Ways Forward

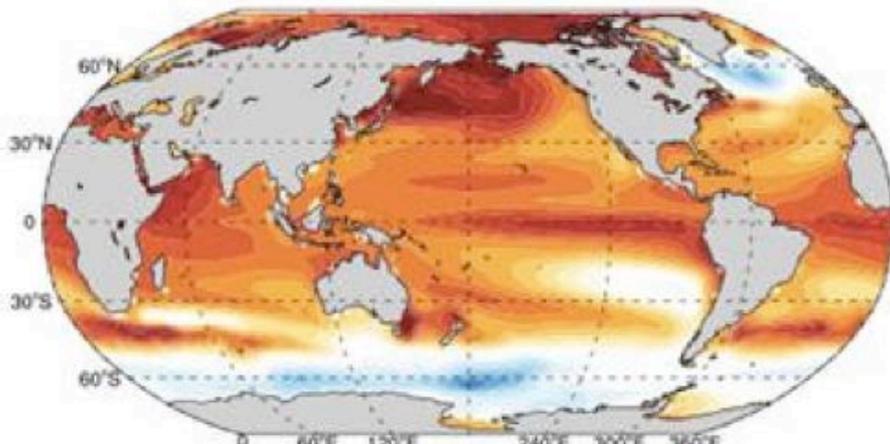
Is Regional Climate Change Sensitive to Details of Projected SST Change?

TS (K/K)

AGCM: Uniform-CTRL



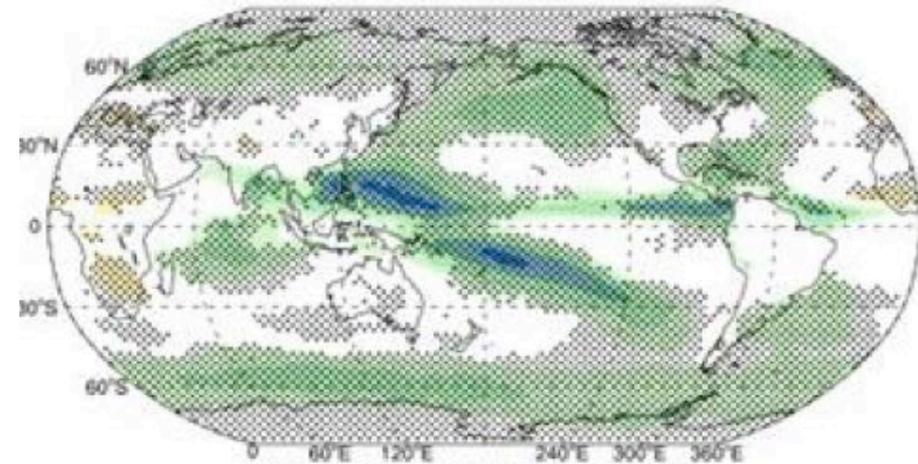
AGCM: Structured-CTRL



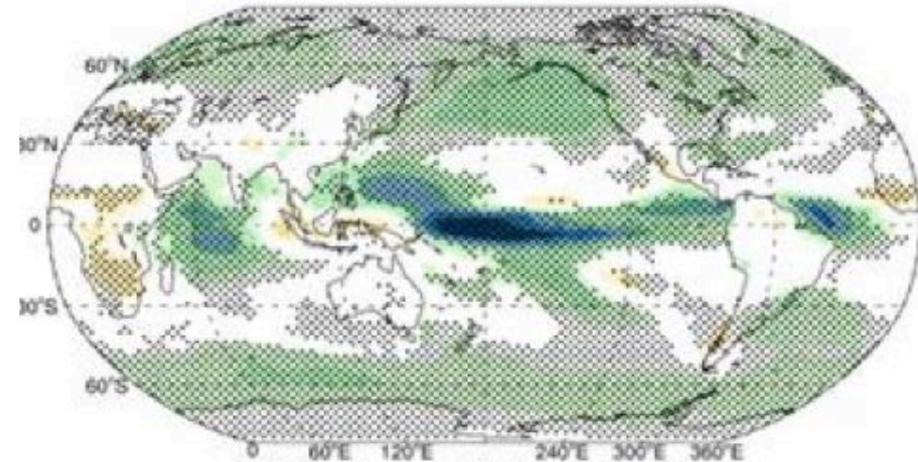
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2

Precip (mm/day/K)

AGCM: Uniform-CTRL



AGCM: Structured-CTRL

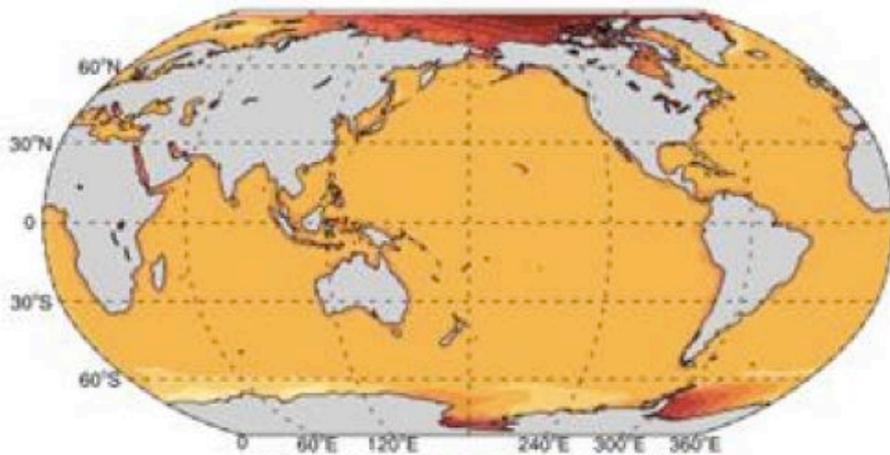


-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8

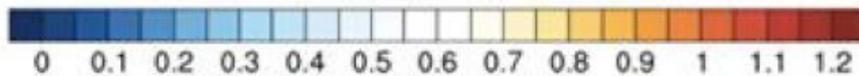
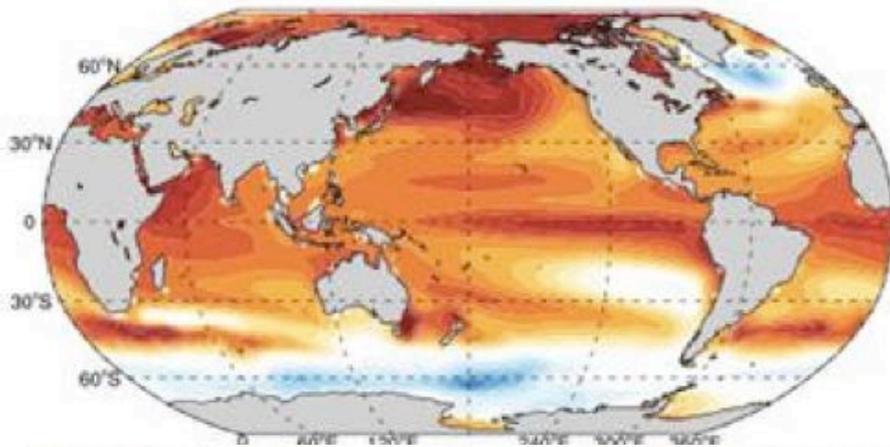
Is Regional Climate Change Sensitive to Details of Projected SST Change?

TS (K/K)

AGCM: Uniform-CTRL

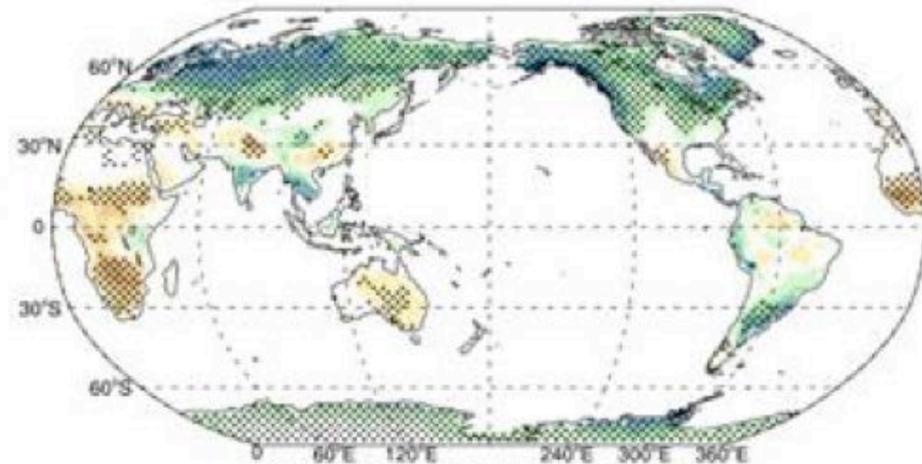


AGCM: Structured-CTRL

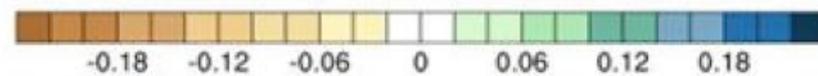
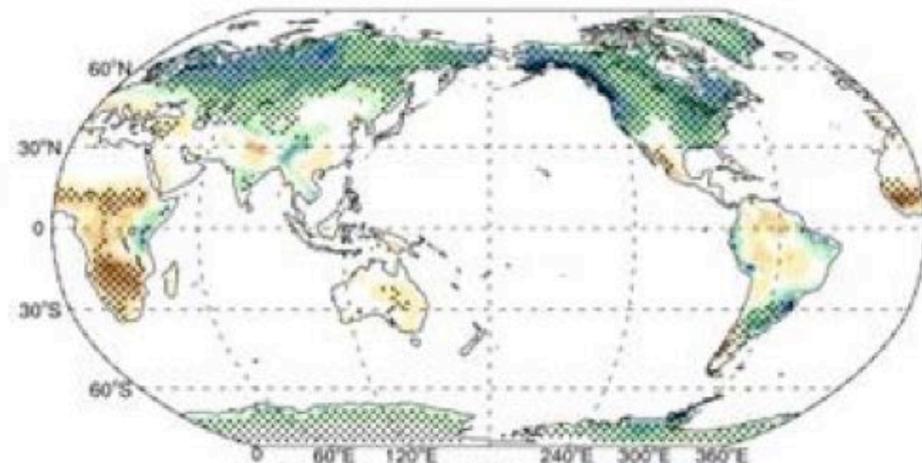


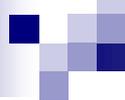
Precip (mm/day/K)

AGCM: Uniform-CTRL



AGCM: Structured-CTRL





Are Coupled Models Necessary For Simulating Anthropogenic Climate Change?

1) Is ocean coupling necessary for regional climate change?

No (as long as you know the change in SST)

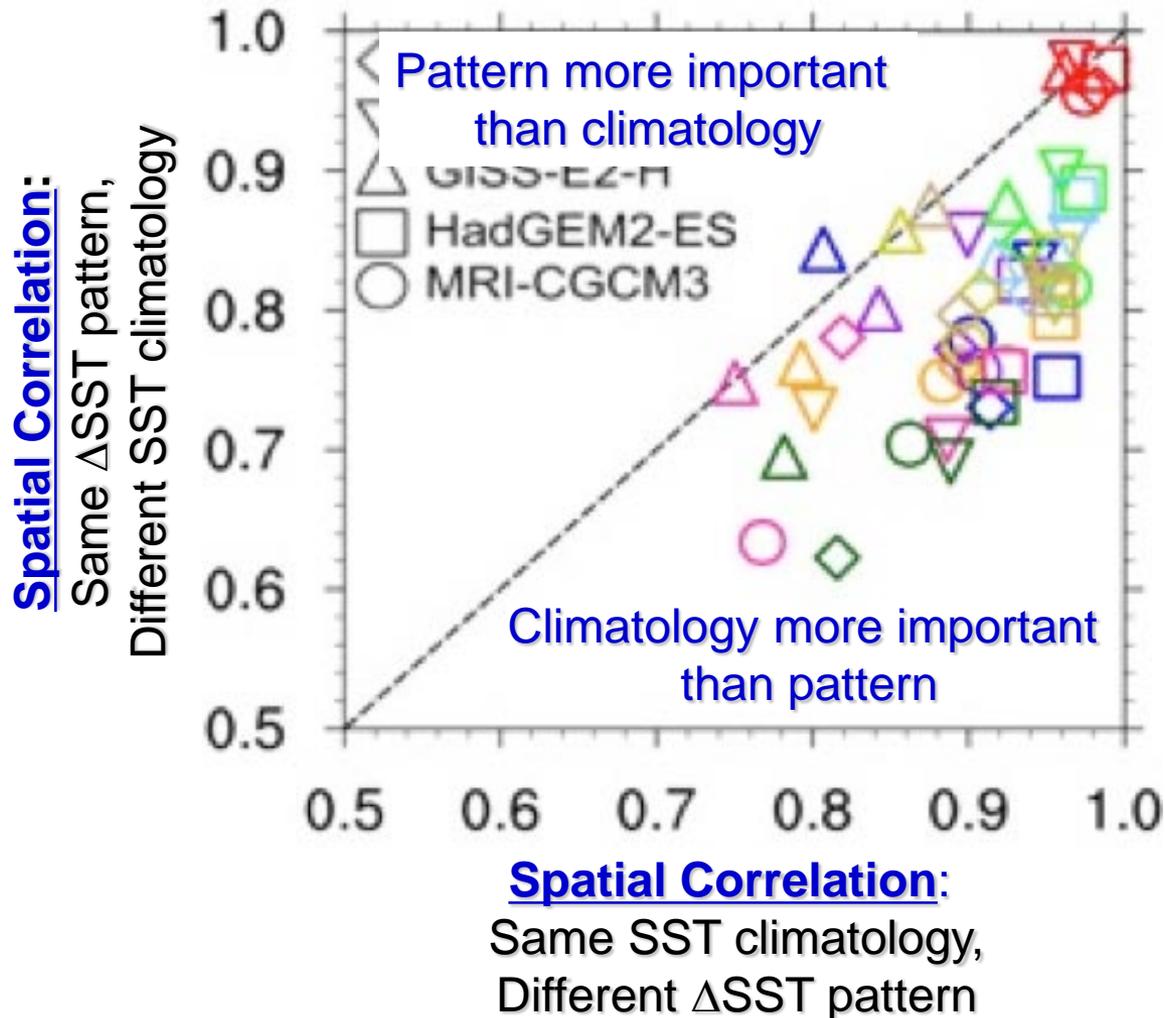
2) Is regional climate change sensitive to pattern of Δ SST?

Not over land

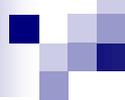
3) Does ocean coupling degrade regional projections?

1) Practical Ways Forward

How Important is SST Climatology vs Pattern of Δ SST?



An accurate climatology of SST is more important than the pattern of SST change



Are Coupled Models Necessary For Simulating Anthropogenic Climate Change?

1) Is ocean coupling necessary for regional climate change?

No (as long as you know the change in SST)

2) Is regional climate change sensitive to pattern of Δ SST?

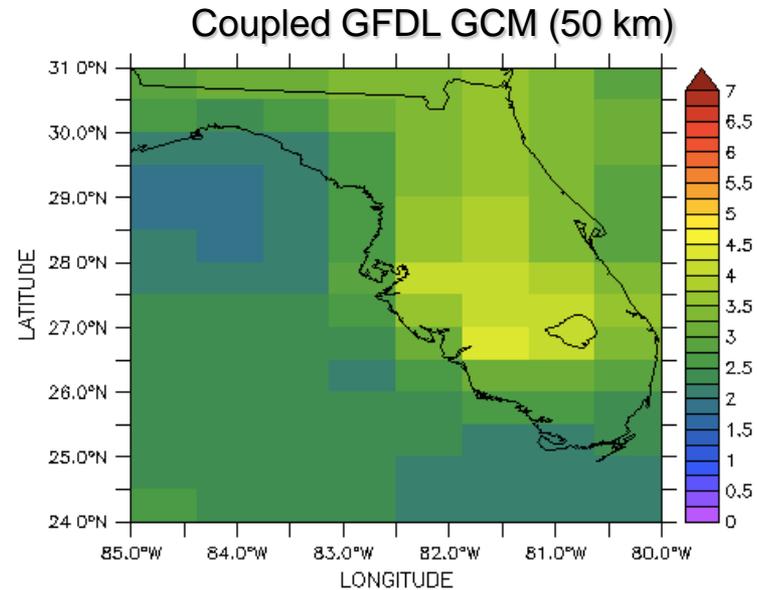
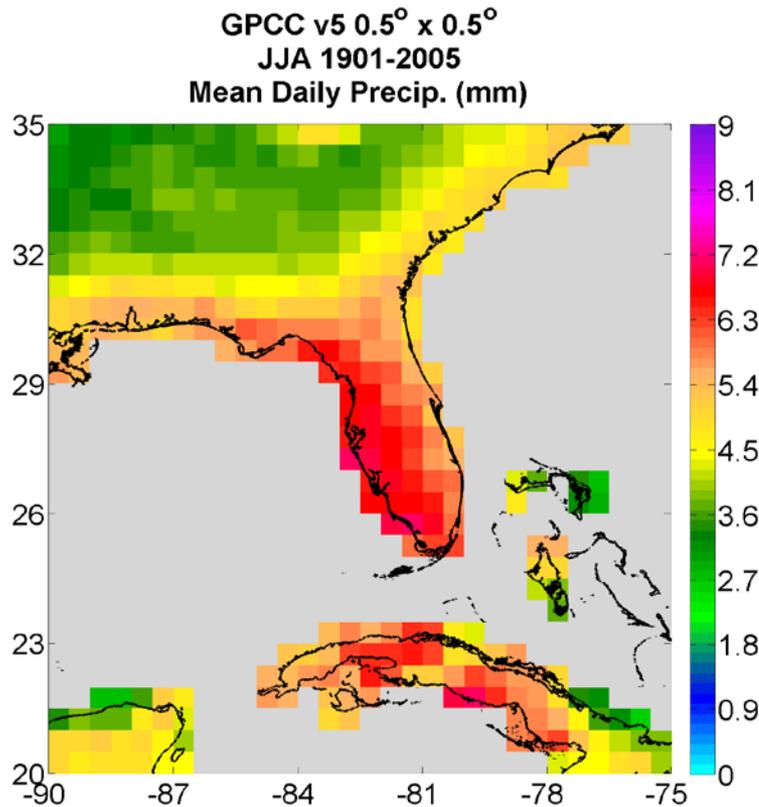
Not over land

3) Does ocean coupling degrade regional projections? **Yes,**

when there are biases in climatological SSTs

4) Practical Ways Forward

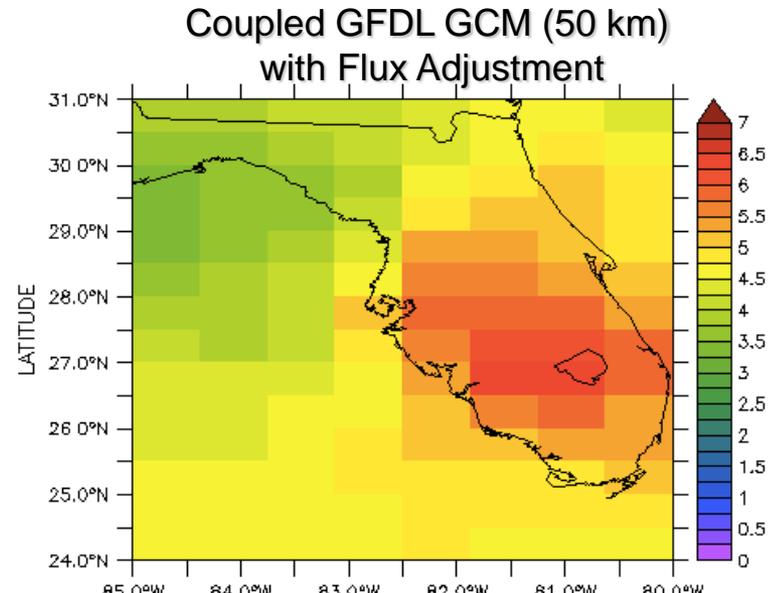
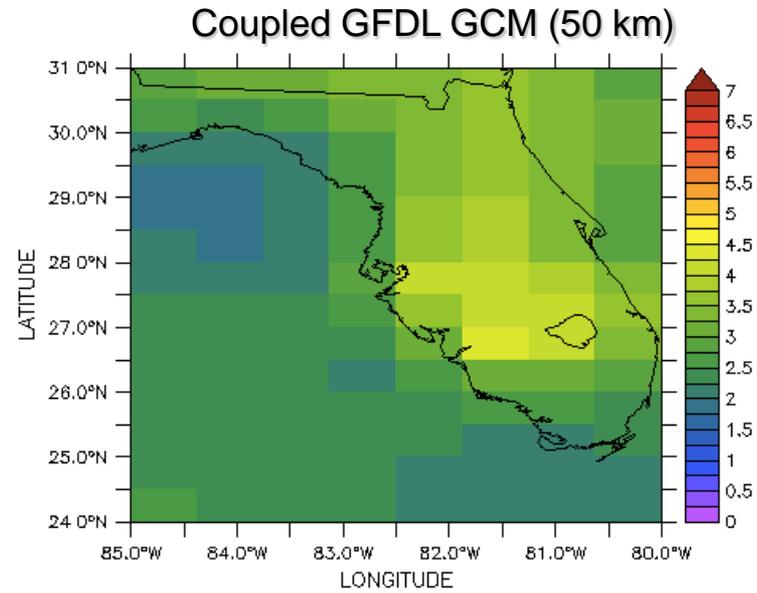
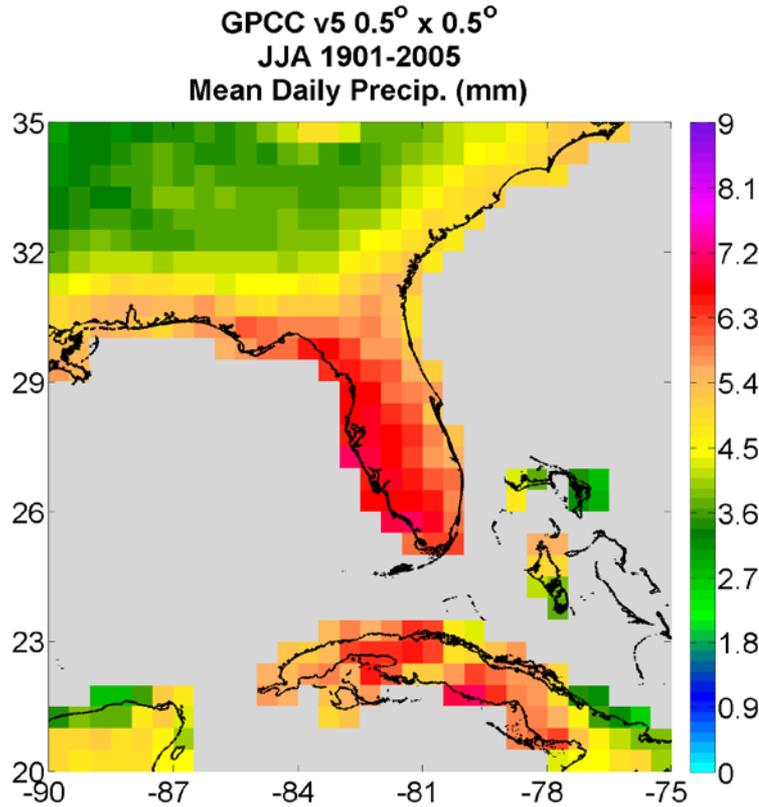
What are some practical ways forward?



Courtesy Gabe Vecchi (GFDL)

Better than CMIP5 models,
but precipitation is still too weak

What are some practical ways forward?





Summary

1) Errors due to the neglect of coupling in AGCMs is important for internal variability, but does not significantly affect the externally-forced change.

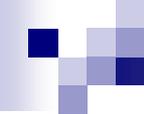
1) Regional changes in precipitation (and other variables) over land are remarkably insensitive to the pattern of SST change.

2) Differences in the “control” climate significantly significantly to the uncertainty in future projections of regional precipitation change.

3) Flux adjusted CGCMs or AGCMs with prescribed SSTs would allow for improved regional projections over land.

4) Internal decadal variability over North America in the NCAR CCSM is dominated by atmospheric noise.





He, J., B.J. Soden, and B.P. Kirtman, 2014: The robustness of the atmospheric circulation and precipitation response to future anthropogenic surface warming, *Geophys. Res. Lett.*, doi:10.1002/2014GL059435.

He, J. and B.J. Soden, 2015: The role of ocean coupling in model simulations of anthropogenic climate change, *J. Climate*, in press.

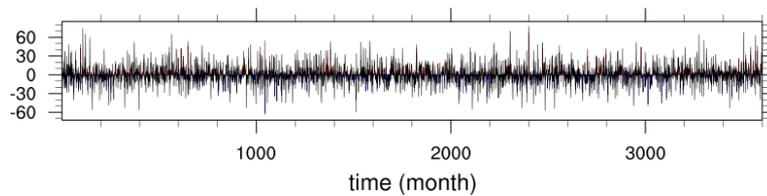
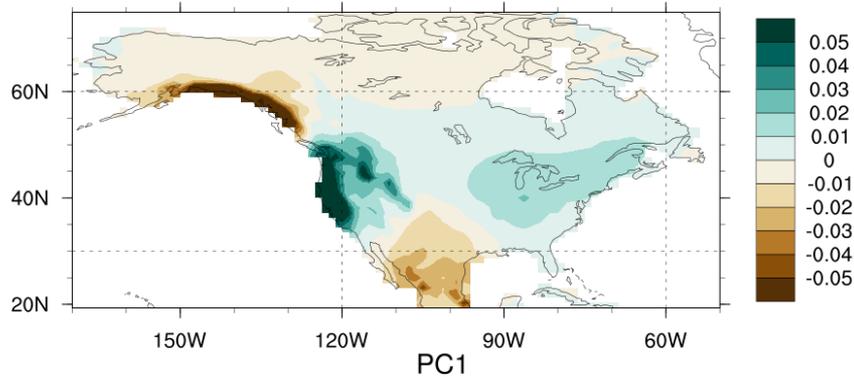
He, J. and B.J. Soden, 2015: The impact of SST biases on projections of anthropogenic climate change: A greater role for atmosphere-only models?, submitted *Nature Clim. Change*.

Decadal Variability in North American Precip

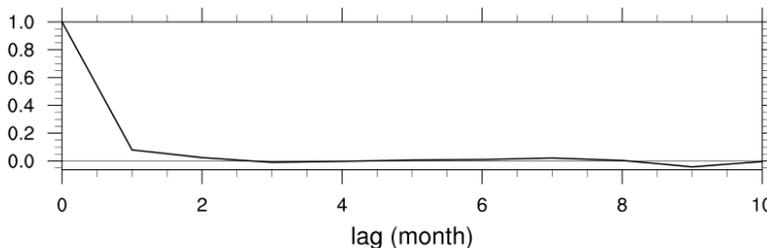
NCAR CCSM5 1000 year integrations

Full Coupled Model

coupled EOF1 11.0%

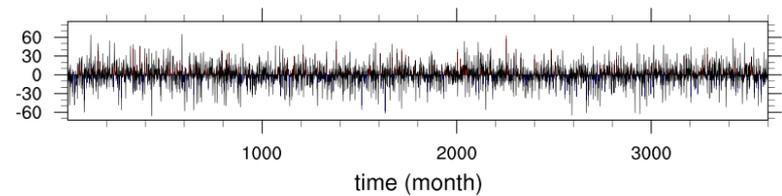
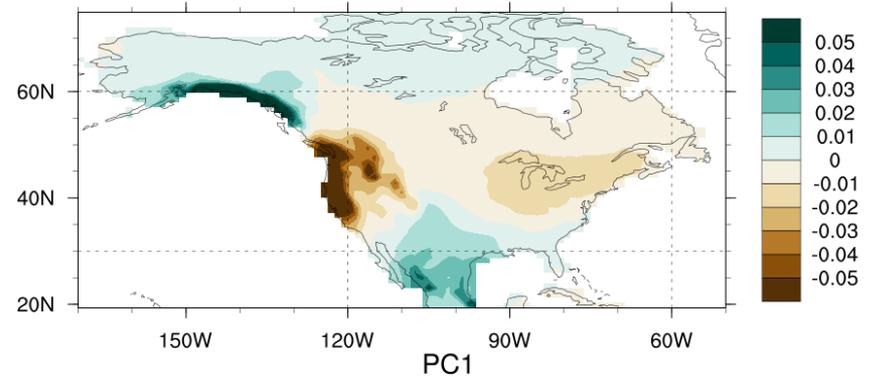


auto-correlation of PC1

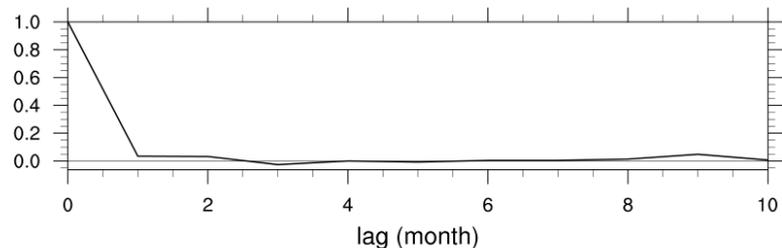


AGCM with Climatological SSTs

ClimSST EOF1 11.9%



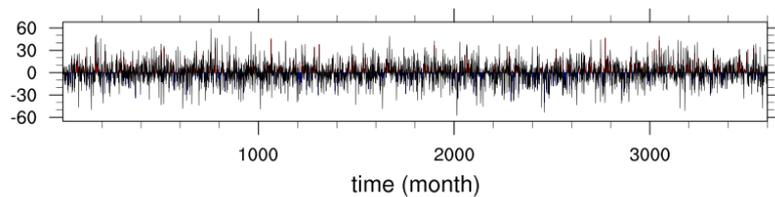
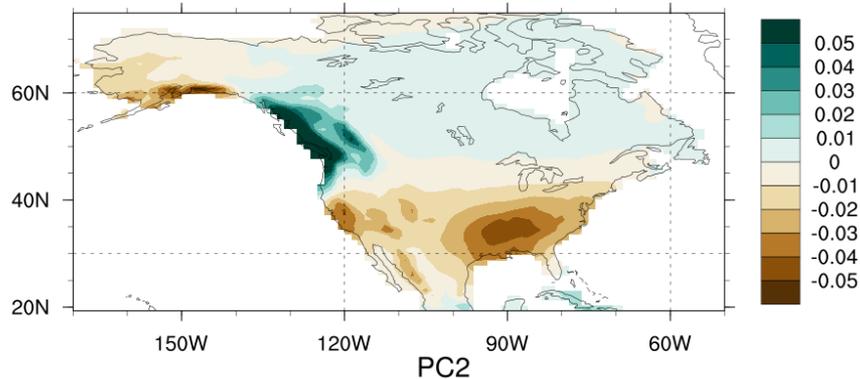
auto-correlation of PC1



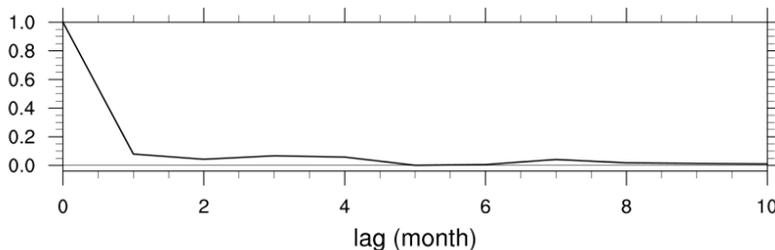
Decadal Variability in North American Precip

NCAR CCSM5 1000 year integrations

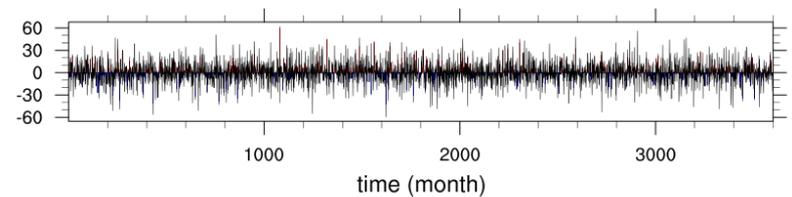
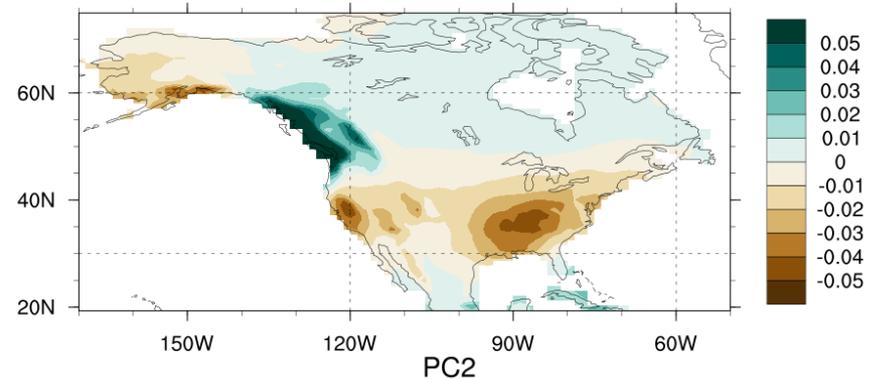
Full Coupled Model
coupled EOF2 9.2%



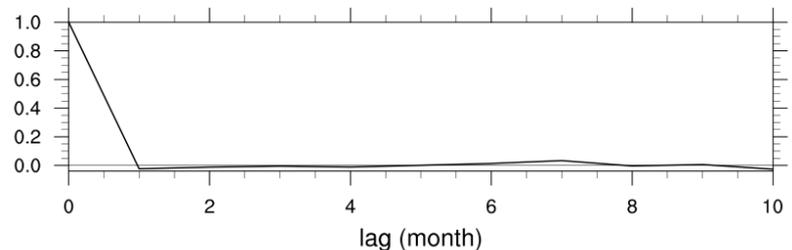
auto-correlation of PC2



AGCM with Climatological SSTs
ClimSST EOF2 9.2%



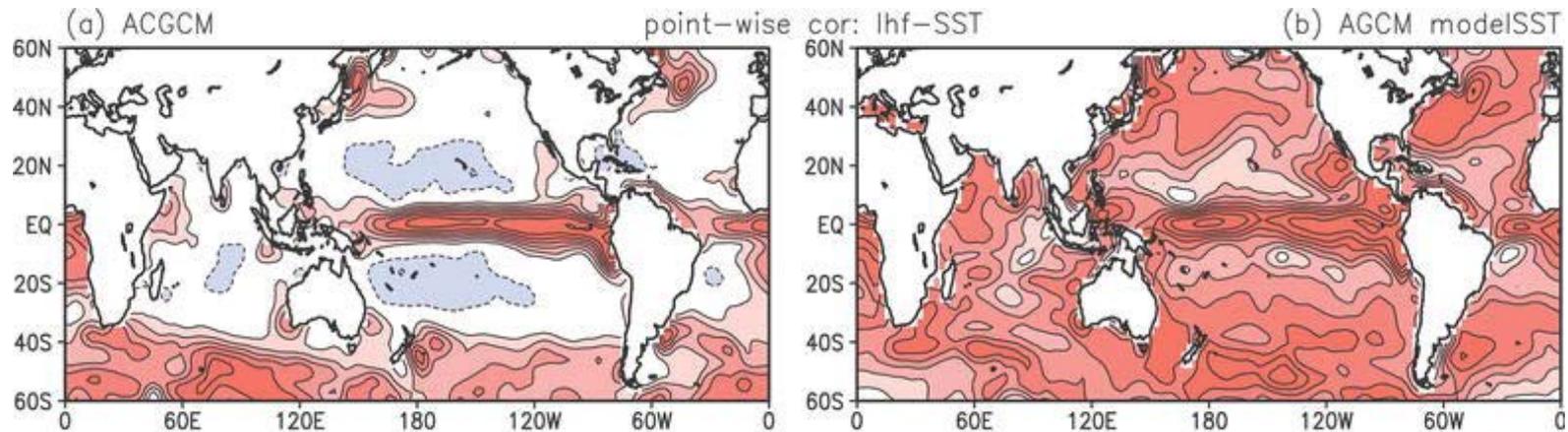
auto-correlation of PC2



Is Coupling Important for Regional Climate Change?

The importance of atmosphere-ocean coupling for internal variability is well documented

(Barsugli and Battisti 1998; Kirtman et al., 2005; Wu et al. 2006; Wang et al. 2005)



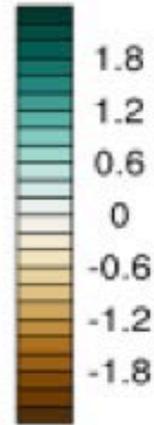
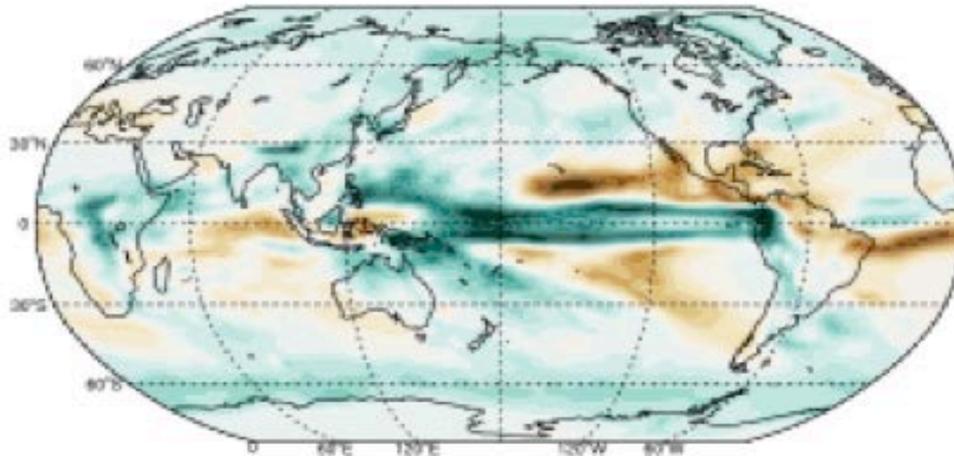
Wu et al. (2006)

Coupled GCM

Atmospheric GCM
(w/ same SSTs)

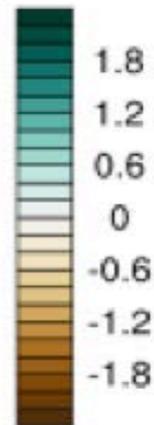
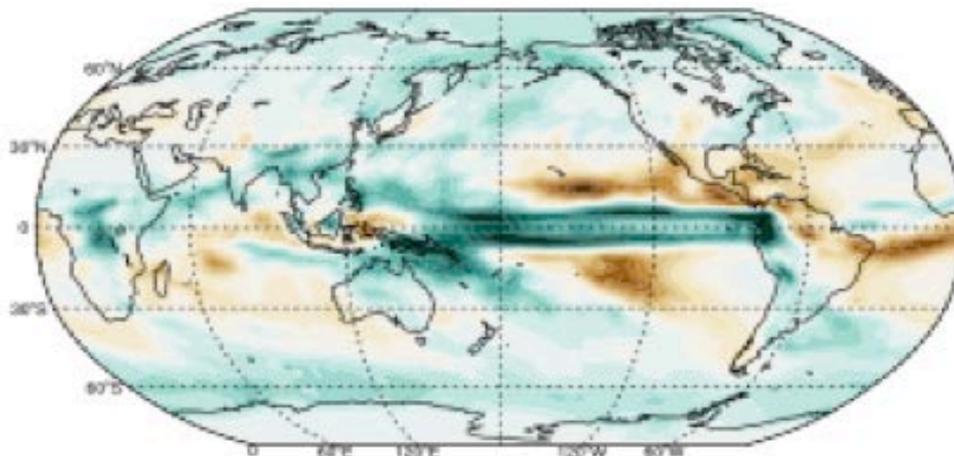
Is Coupling Important for Regional Climate Change?

CGCM: ΔP 4xCO₂ (last 10yr – first 10yr)



Coupled GCM

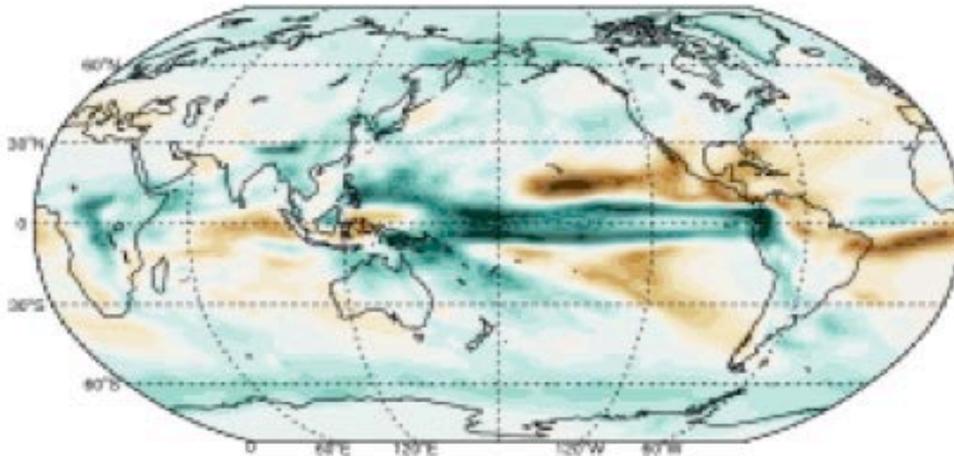
AGCM: ΔP 4xCO₂ (last 10yr – first 10yr)



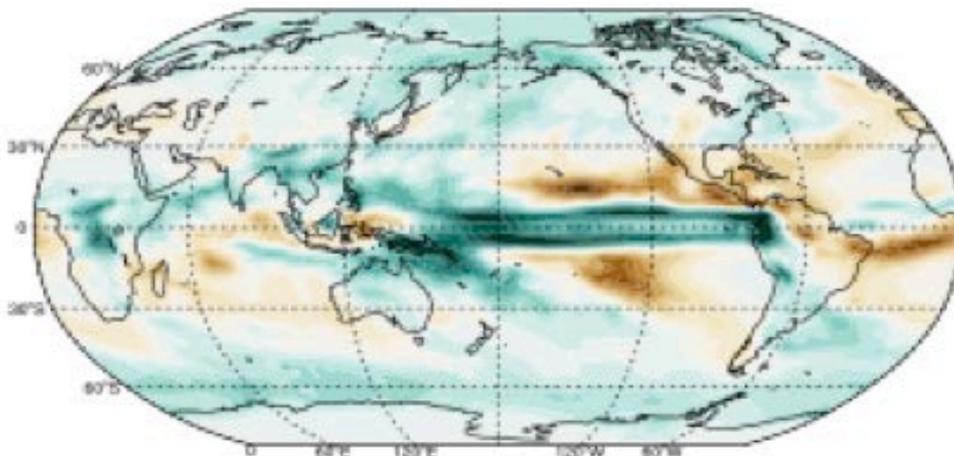
Atmosphere-only GCM
(w/ daily SSTs from CGCM)

Is Coupling Important for Regional Climate Change?

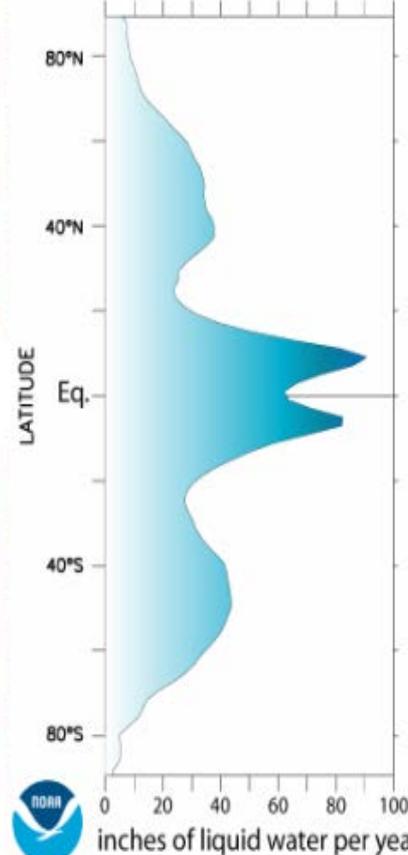
CGCM: ΔP 4xCO₂ (last 10yr – first 10yr)



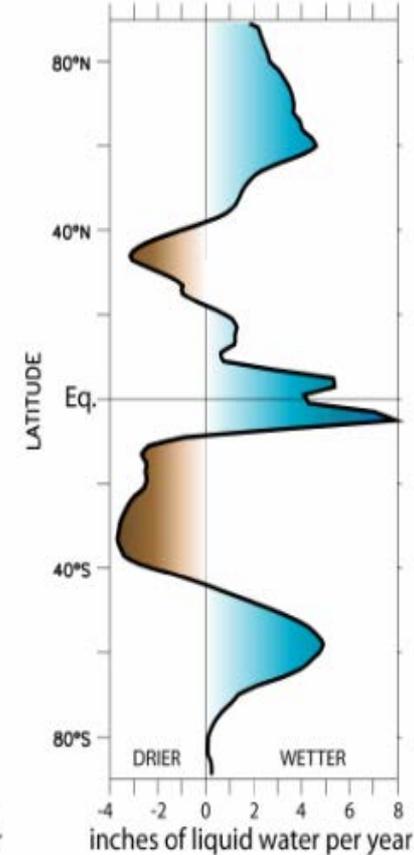
AGCM: ΔP 4xCO₂ (last 10yr – first 10yr)



LONGITUDINALLY AVERAGED
1950-2000 PRECIPITATION
as modeled by NOAA/GFDL CM2.1

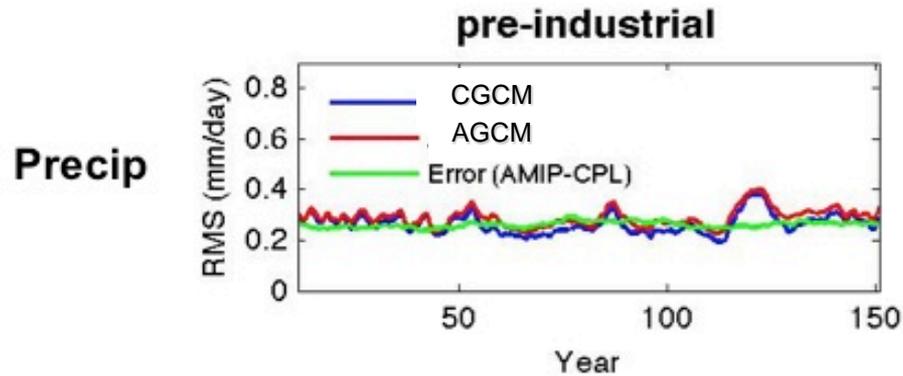


LONGITUDINALLY AVERAGED
21st Cy PRECIPITATION CHANGE
as projected by NOAA/GFDL CM2.1

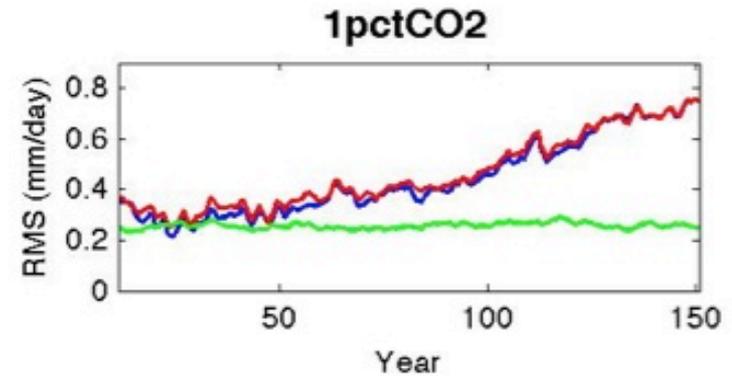


“wet get wetter”

Is Coupling Important for Regional Climate Change?

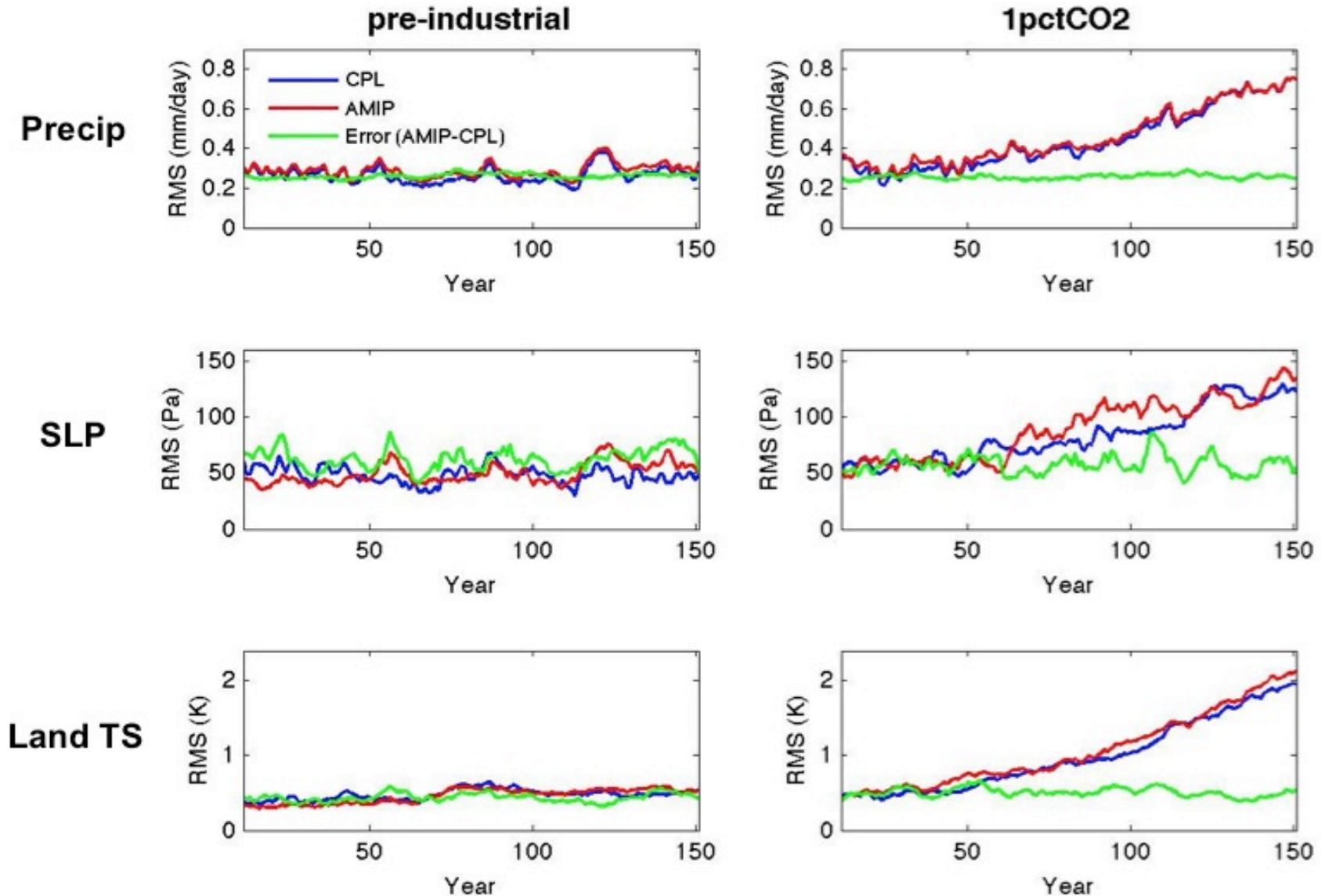


Error is as large as the signal from internal decadal variability.

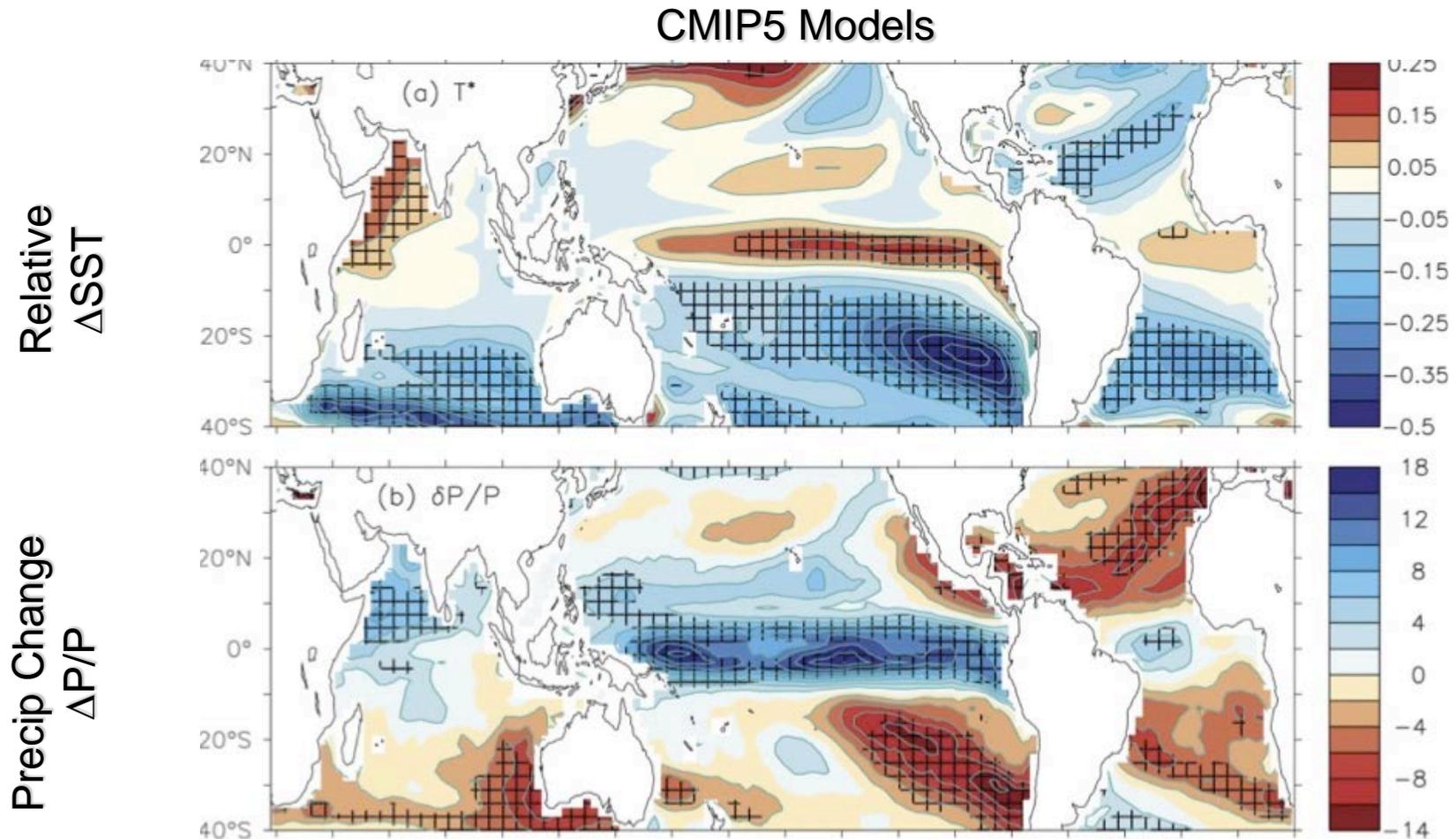


Error is independent of externally forced response.

Is Coupling Important for Regional Climate Change?



Is Regional Climate Change Sensitive to Details of Projected SST Change?

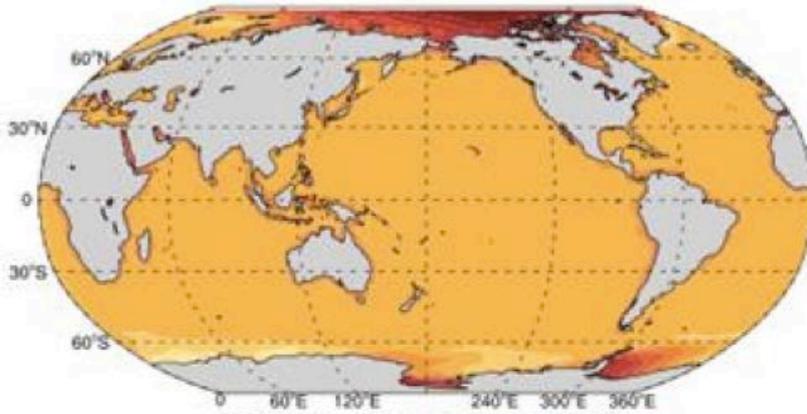


Precipitation change closely follow SST change
“warmer get wetter” (Ma and Xie 2011)

Is Regional Climate Change Sensitive to Details of Projected SST Change?

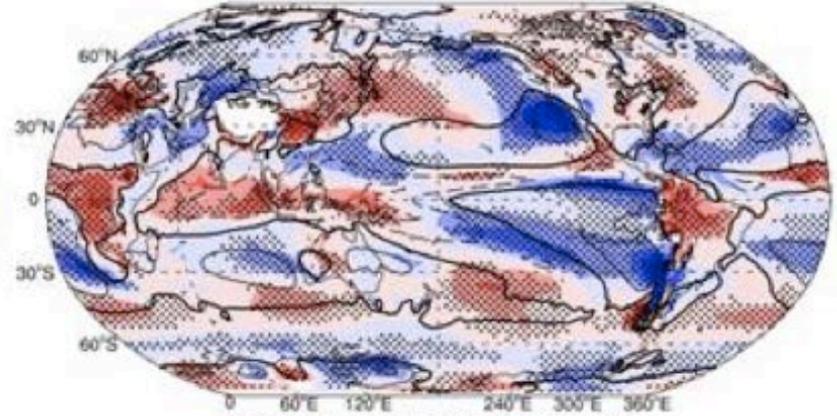
TS (K/K)

AGCM: Uniform-CTRL



ω_{500} (Pa/s/K)

AGCM: Uniform-CTRL



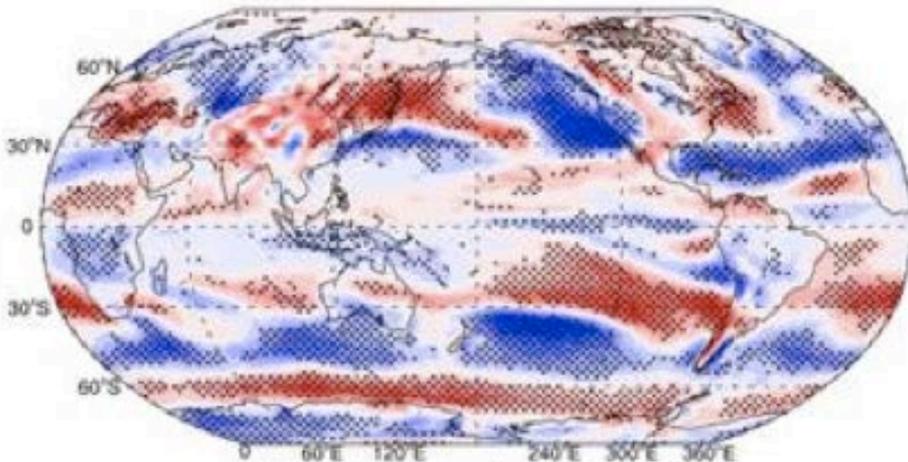
When the tropics is warmed, the atmospheric circulation weakens.

This weakening tends to oppose the mean state;
(i.e., ascending regions experience anomalous subsidence)

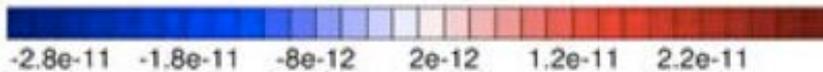
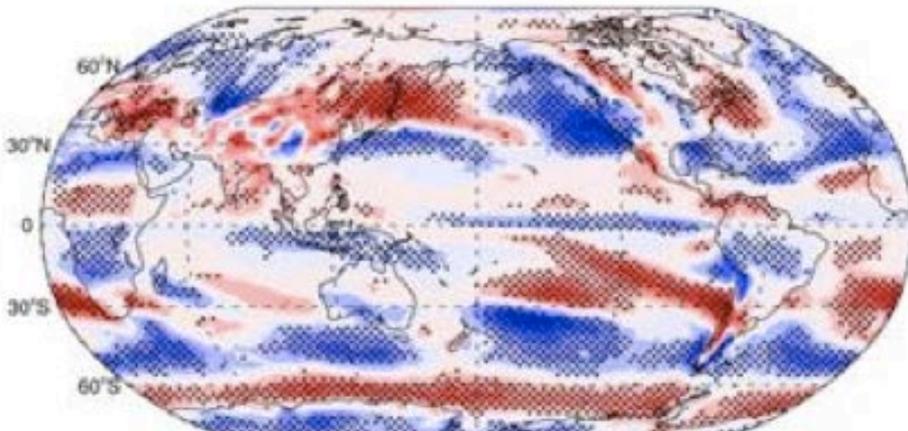
Is Regional Climate Change Sensitive to Details of Projected SST Change?

Rossby Wave Source (ΔRWS)

AGCM: Uniform-CTRL



AGCM: Structured-CTRL



($1/s^2/K$)

However, near-equatorial divergence is ineffective in generating Rossby waves (due to small planetary vorticity).

Thus, the remote forcing of extratropical circulation from Rossby waves is dominated by subtropical changes which are less sensitive to SST pattern.