

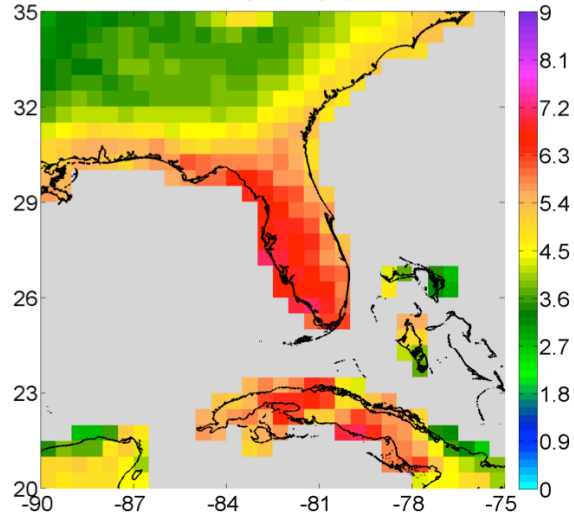
Mechanisms of Regional Precipitation Change from Anthropogenic Forcing

Jie He

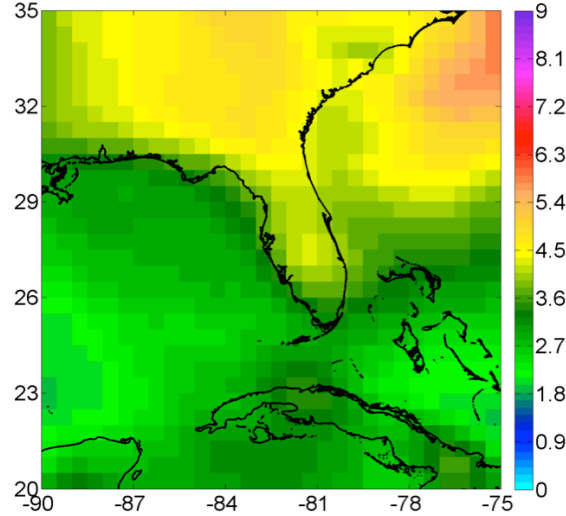
Rosenstiel School of Marine and Atmospheric Science
University of Miami

Challenges in regional precipitation simulation

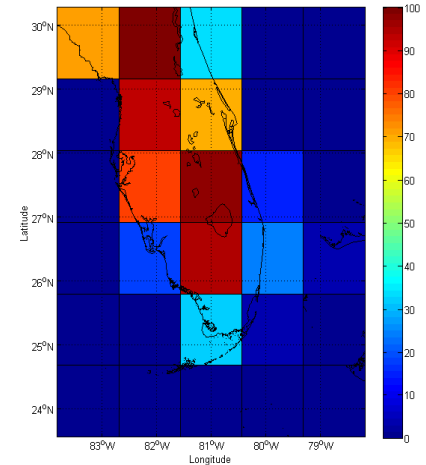
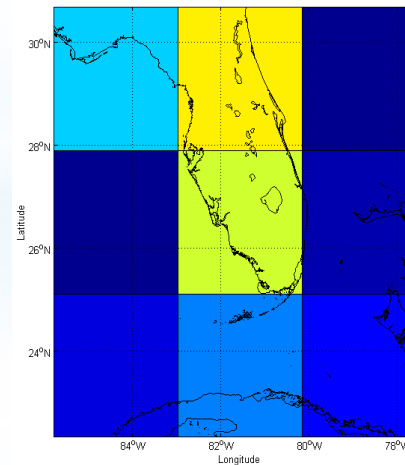
GPCC v5 JJA Rainfall (mm/d)



CMIP5 JJA Rainfall (mm/d)



Low Model Resolution



Courtesy Roque V. Cespedes (UM)

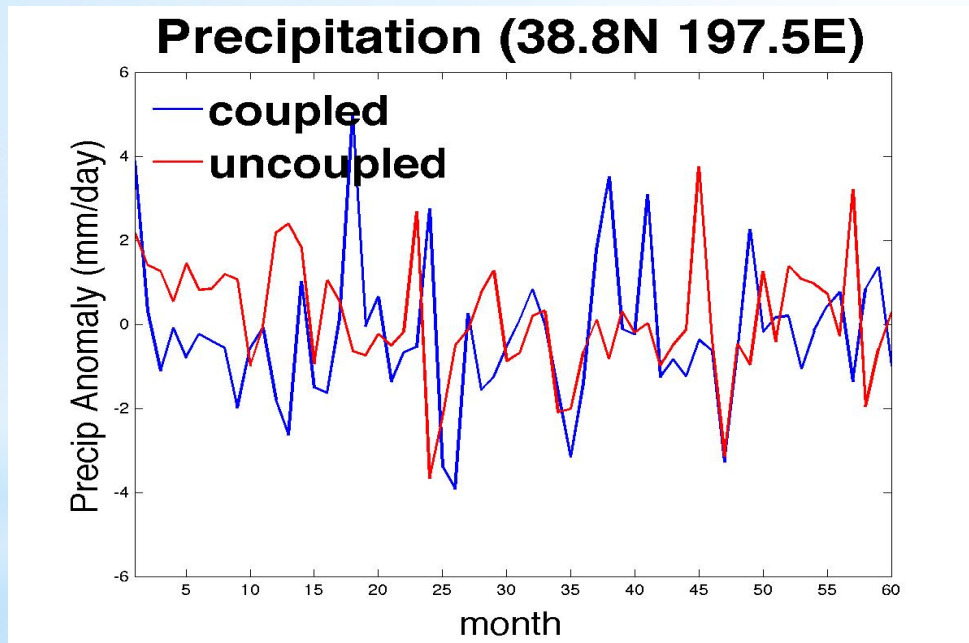
Can we use High Resolution “time-slice” Experiments?

High resolution atmosphere-only models forced with projected changes in SST from CGCMs

1. Is **“two-way” coupling** important for regional climate change?
2. Is **details of SST change** important for regional precipitation change?
3. Are we getting realistic regional climate change from **CGCMs**?
4. What are some practical ways forward?

Impact of Two-way Coupling

Two-way Coupling is important for natural climate variability.



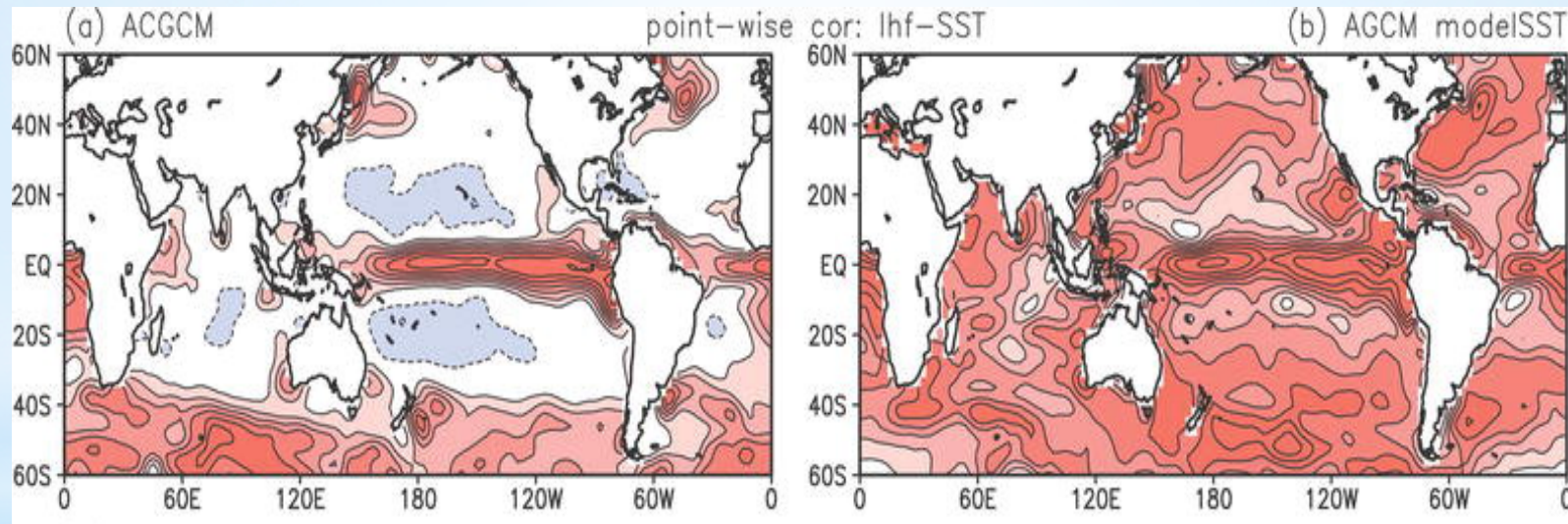
Lack of coupling leads to inconsistency b/w atmos and ocean.

Impact of Two-way Coupling

The importance of two-way coupling for natural climate variability is well documented.

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

coupled VS **uncoupled**



(Wu et al. 2006)

What about anthropogenic climate change?

Introduction

Method

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Impact of Two-way Coupling

Compare coupled and uncoupled simulations that have the same atmospheric model and SST & sea ice.

Model: CESM

Resolution: approximately 2° for atmosphere & land and 1° for ocean

Simulations:

CGCM, 1pctCO2

AGCM, 1pctCO2 (SST and sea ice from CGCM 1pctCO2)

CGCM, pre-industrial

AGCM, pre-industrial (SST and sea ice from CGCM pre-industrial)

Run time: 150 years

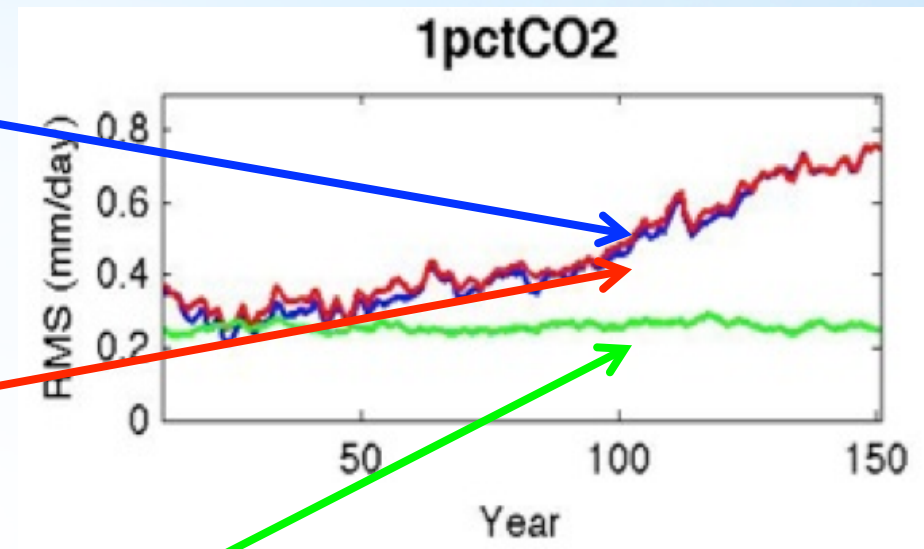
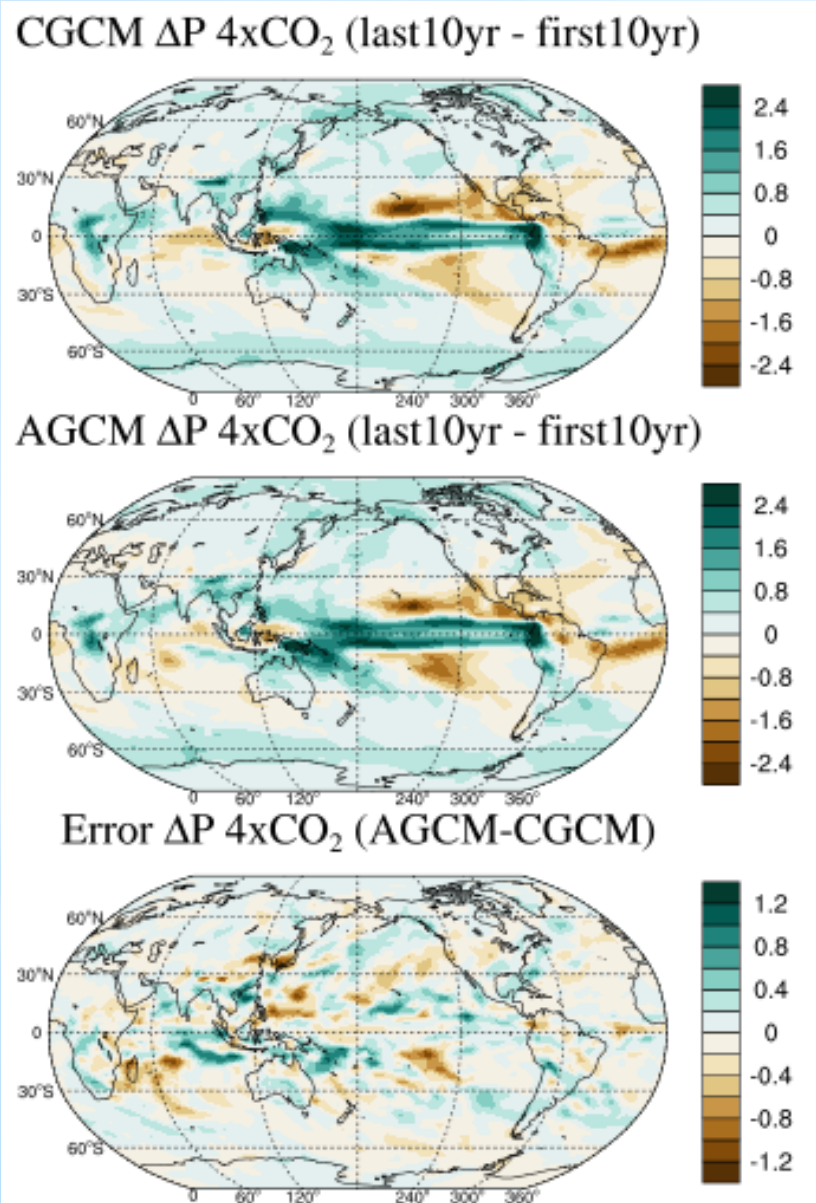
Climate change: 10-year epoch difference

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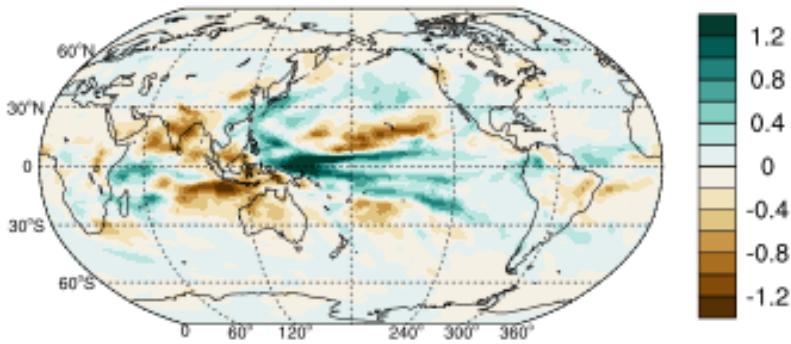
Impact of Two-way Coupling



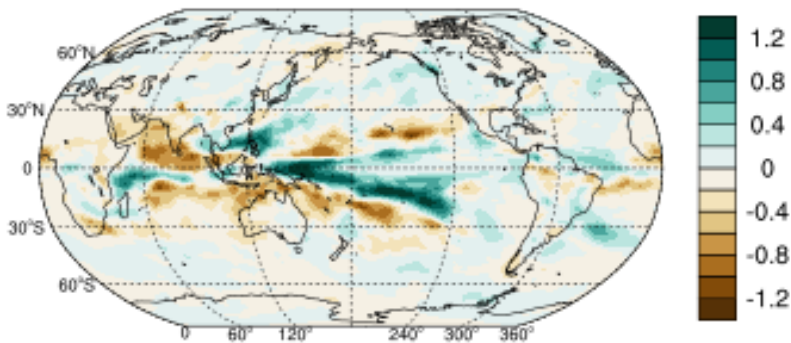
Error due to lack of two-way coupling is independent of external forcing.

Impact of Two-way Coupling

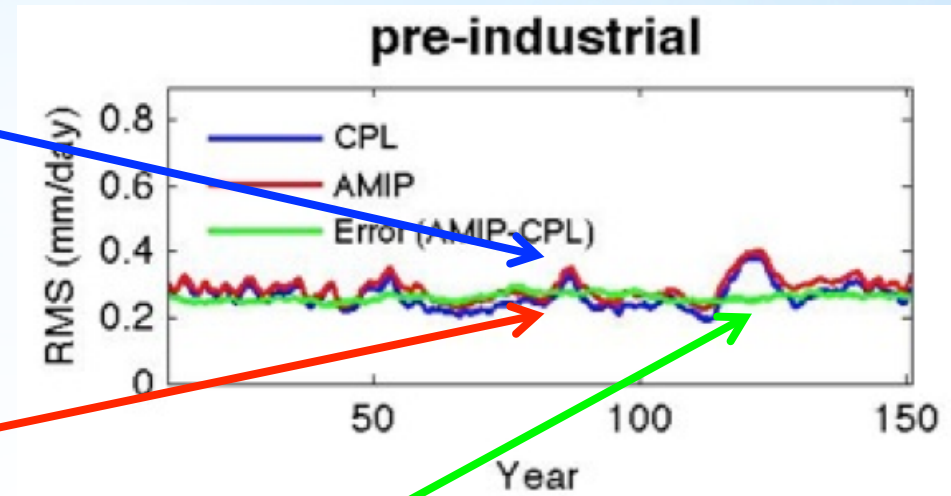
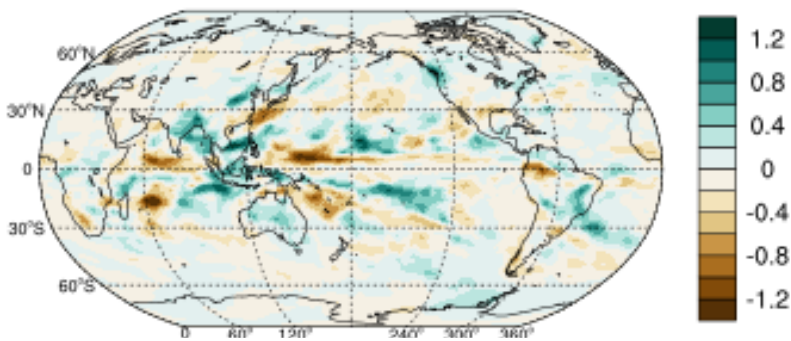
CGCM ΔP CTRL (last10yr - first10yr)



AGCM ΔP CTRL (last10yr - first10yr)



Error ΔP CTRL (AGCM-CGCM)

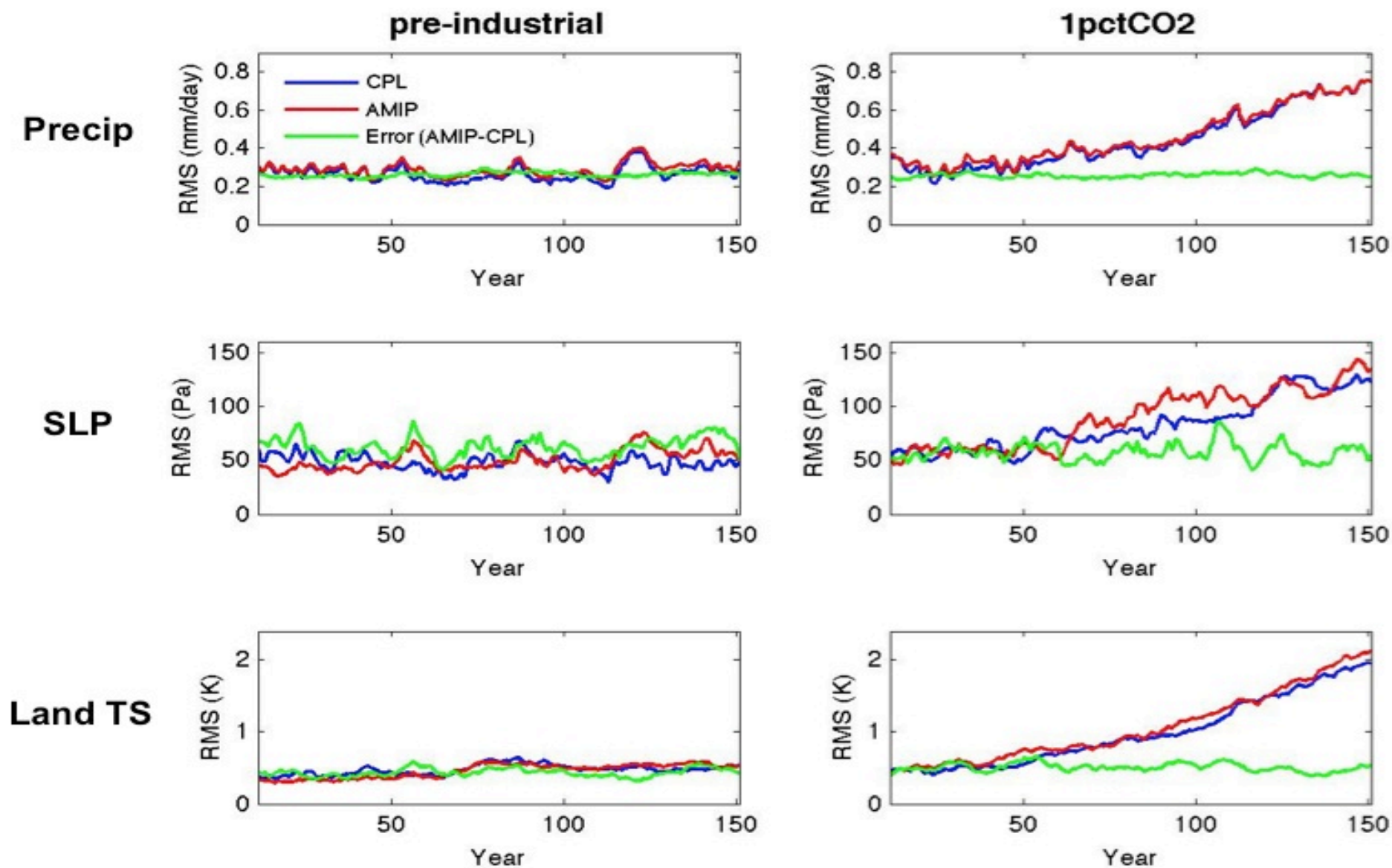


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Impact of Two-way Coupling



Introduction

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Impact of Two-way Coupling

$$\frac{dT_a}{dt} = \lambda_A (SST - T_a) + F_A + N_A$$

$$\frac{dSST}{dt} = \lambda_O (T_a - SST) + F_O$$

T_a: air temperature

SST: sea surface temperature

λ: air-sea interaction coefficient

$$\lambda_A = 23.9 \times 10^{-7} \text{ s}^{-1}$$

$$\lambda_O = 12.7 \times 10^{-8} \text{ s}^{-1}$$

F: radiative forcing and damping

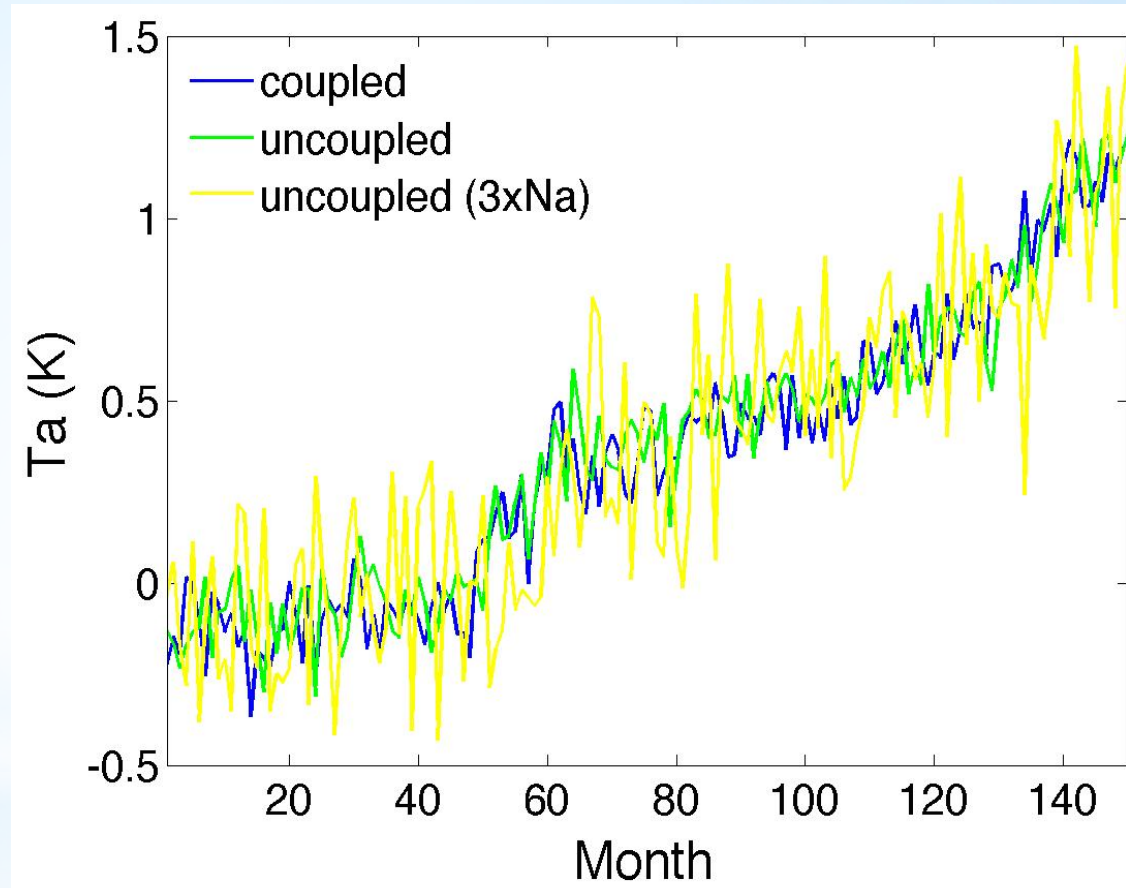
$$F_A = -1.62 \text{ W/m}^2$$

$$F_O = 2.10 \text{ W/m}^2$$

N_A: Stochastic forcing (white noise)

$$\text{std}(N_A) = 0.2 \text{ K/6days}$$

timestep=6days



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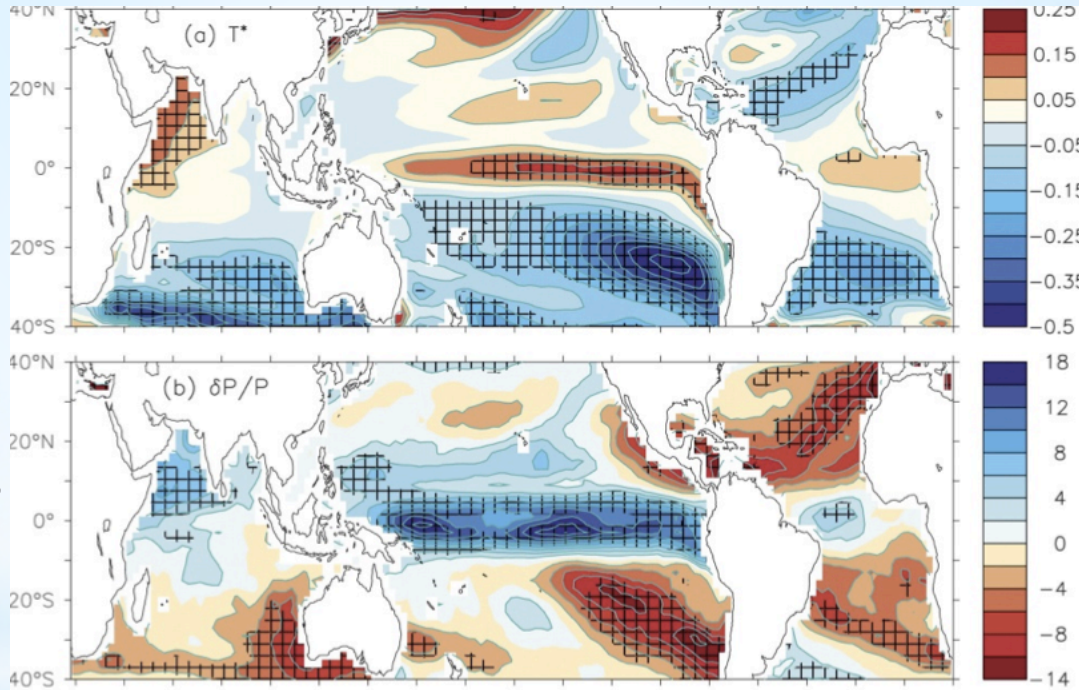
1. Is “two-way” coupling important for regional climate change? **No***
2. Are details of SST change important for regional precipitation change?
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4. What are some practical ways forward?

Pattern of SST Change

Over ocean: “warmer-get-wetter”

(e.g., Xie et al. 2010; Ma and Xie 2013; Chadwick et al. 2013; Kent et al. 2015)

Relative SST
change



Ma and Xie (2013)

Is the pattern of Δ SST important for precipitation change over land?

Introduction

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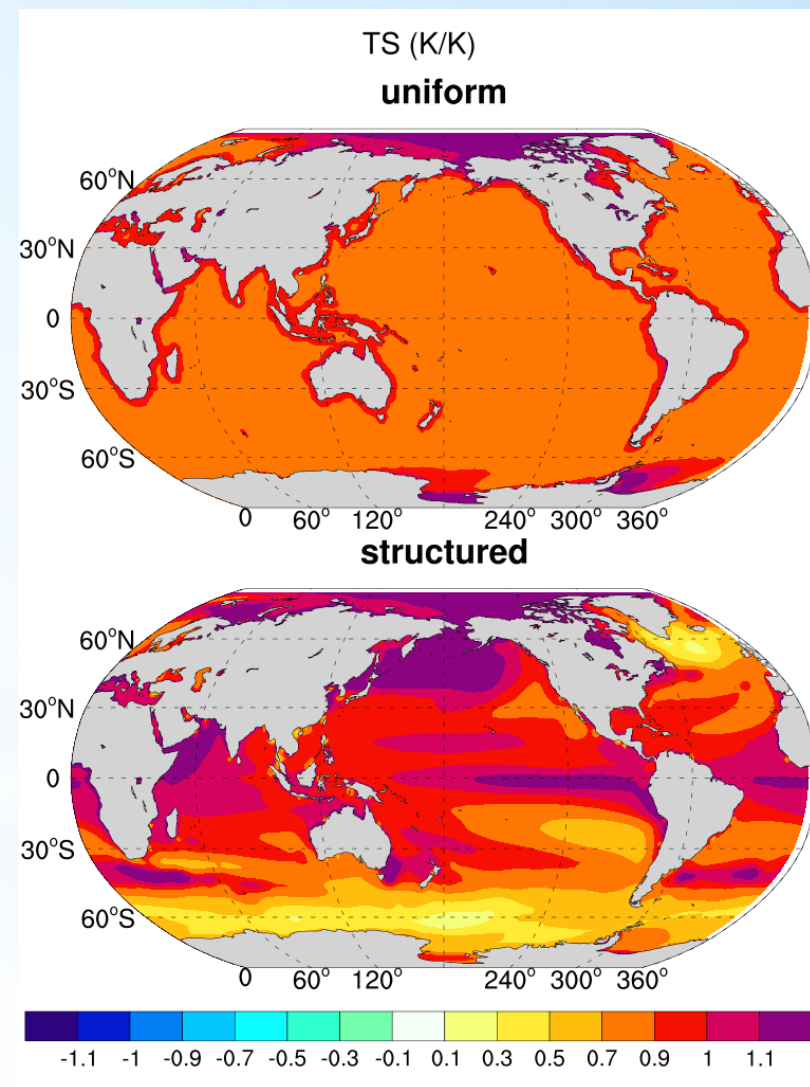
Results

Pattern of SST Change

Model Output: CMIP5 (9 models)

Experiments:

- AMIP control
(1979~2008 obs SST)
- **Uniform Warming**
(+4K)
- **Structured warming**
(Δ SST at 4xCO₂)



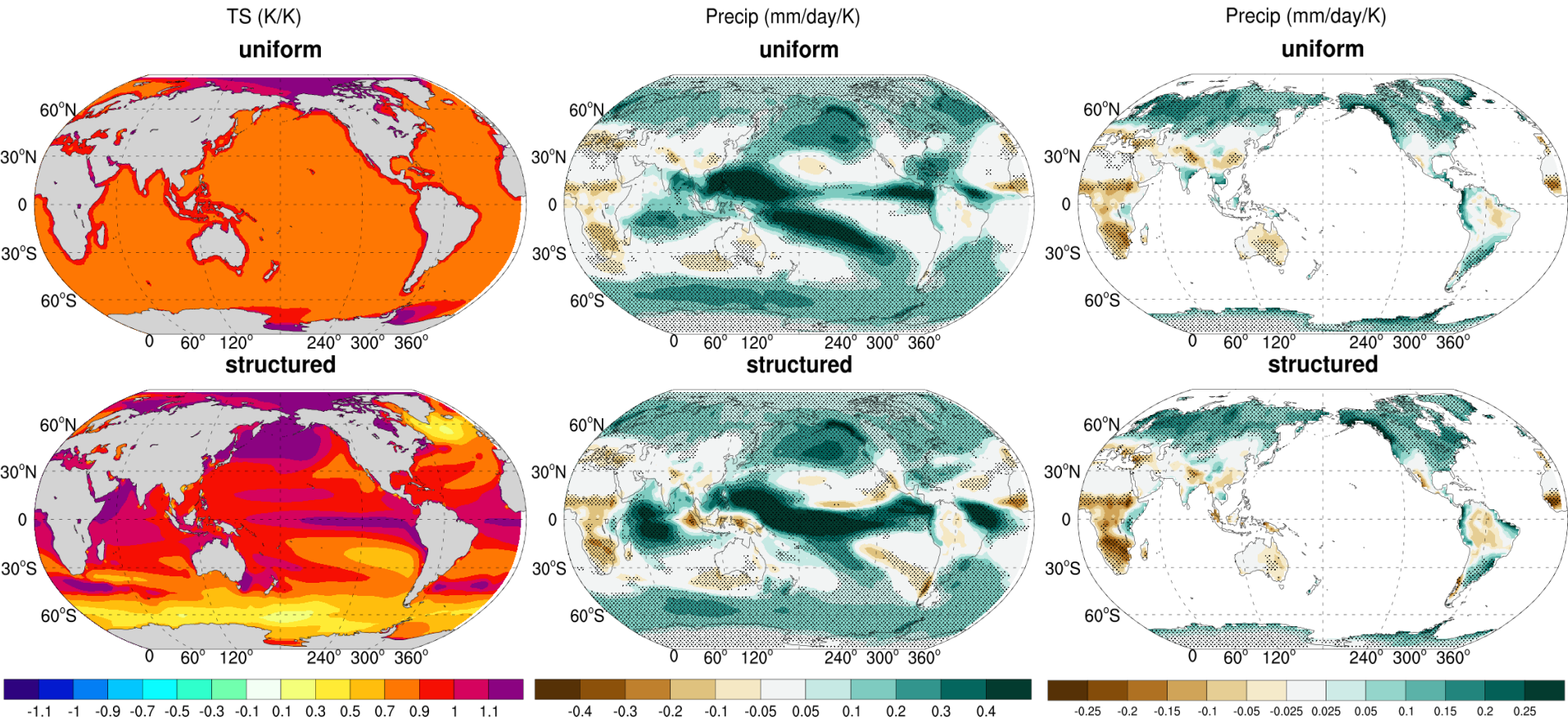
Changes are normalized by each model's global mean TS change.

Introduction

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Pattern of SST Change



Land precipitation is insensitive to the pattern of SST change.

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Pattern of SST Change

Tropical Δ SST can impact land remotely through
Rossby Wave Propagation

(e.g., Sardeshmukh and Hoskins 1988; Ting and Sardeshmukh 1993; Schneider et al. 2003)

Rossby Wave Source (RWS)

$$\frac{\partial \zeta}{\partial t} + V_{\psi} \cdot \nabla \zeta = -\zeta \cdot D - V_{\chi} \cdot \nabla \zeta$$

ζ Absolute vorticity

V_{ψ} Rotational wind

D Divergence

V_{χ} Divergent wind

$$RWS' = (-\zeta \cdot D - V_{\chi} \cdot \nabla \zeta)'$$

$$RWS' = -\zeta' \cdot D - \zeta \cdot D' - \zeta' \cdot D' - V_{\chi}' \cdot \nabla \zeta - V_{\chi} \cdot \nabla \zeta' - V_{\chi}' \cdot \nabla \zeta'$$

$$RWS' = -\zeta \cdot D'$$

Absolute Vorticity Changes in upper-level divergence

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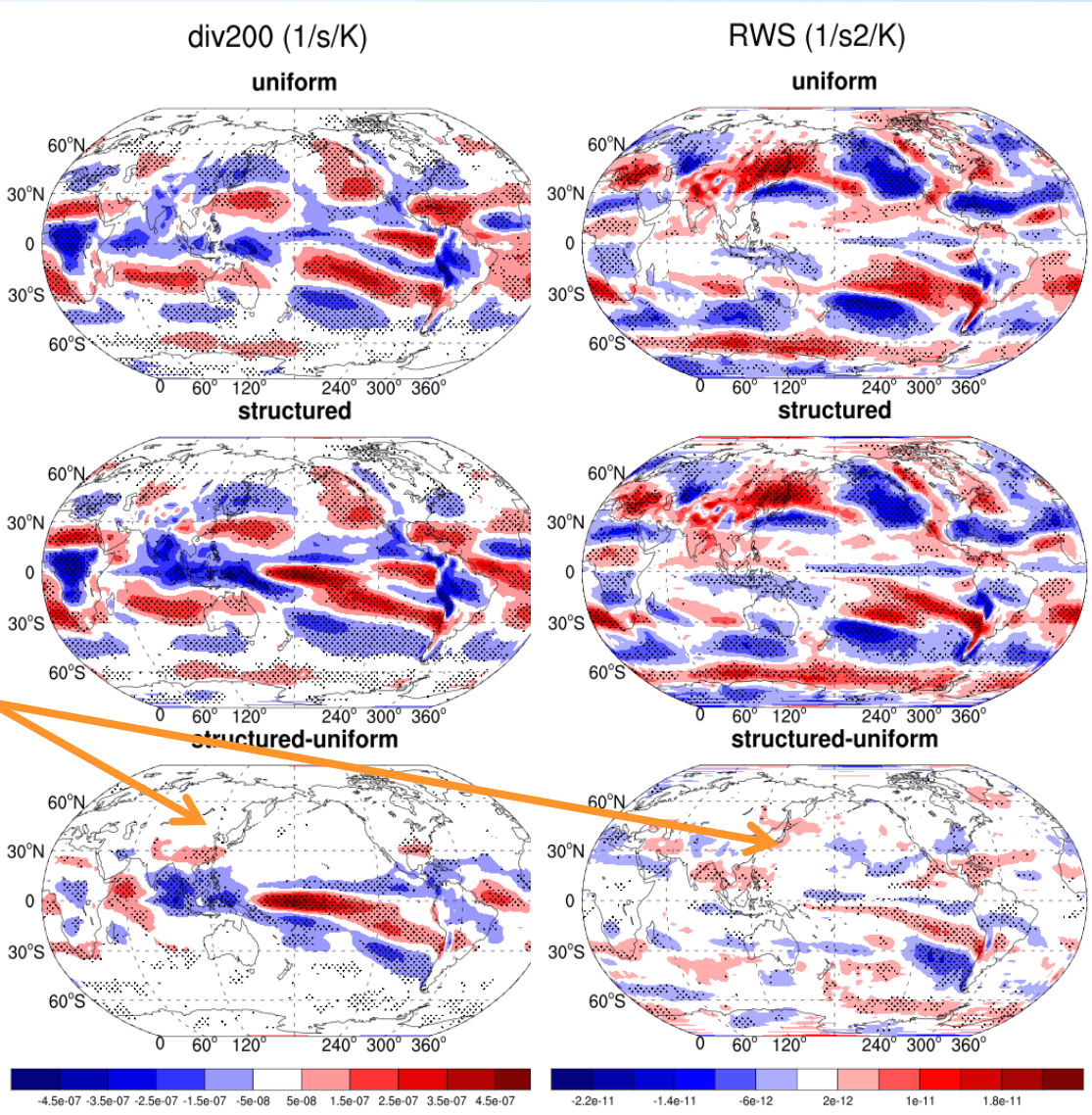
Pattern of SST Change

tropical $\Delta SST \rightarrow$ land
 Rossby Wave Propagation

Absolute Vorticity Changes in upper-level divergence

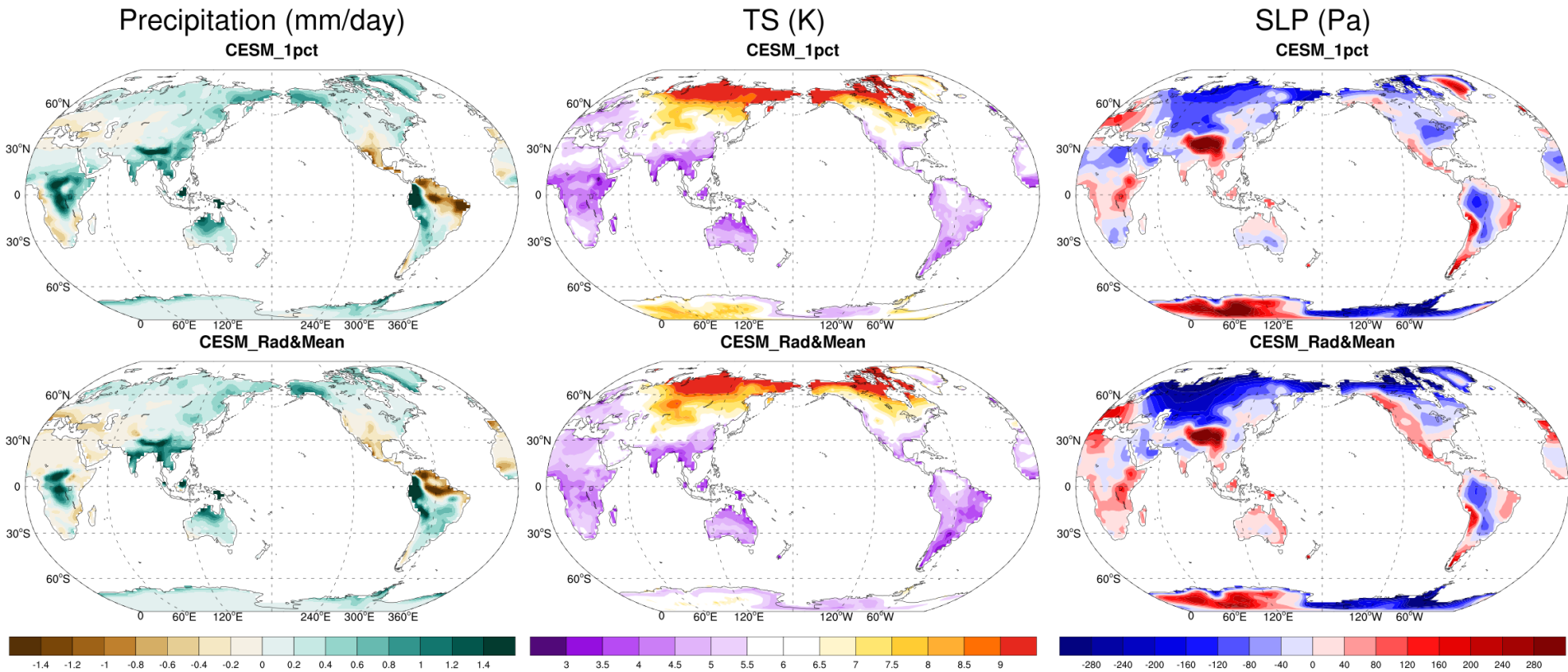
$$RWS' = -\zeta \cdot D'$$

Very little Rossby Waves are generated by the pattern of ΔSST .



Pattern of SST Change

We can simulate land climate change using AGCM forced with only increased CO_2 and a uniform warming.
(results from CESM)



corr=0.86 (pr), 0.95 (TS), 0.85 (SLP)

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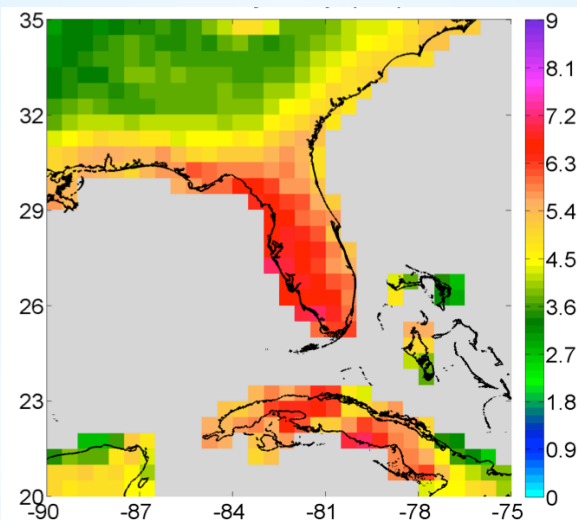
Results

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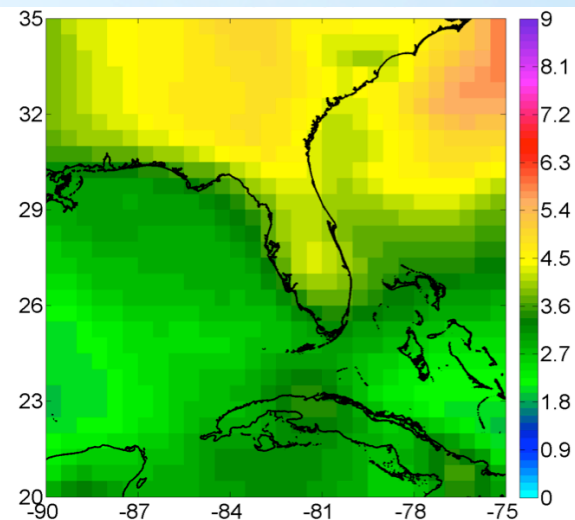
Climatological Biases

How could we get realistic projections if we could not even simulate the climatology?

GPCC v5 JJA Rainfall

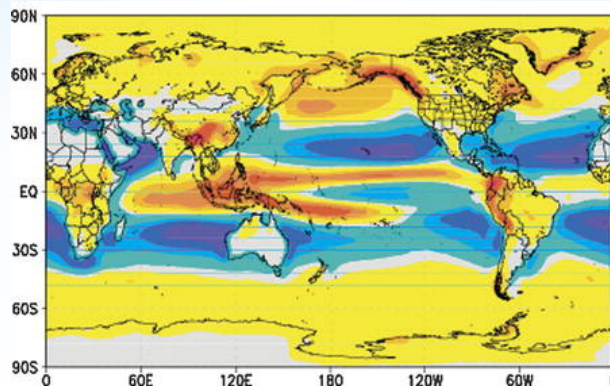


CMIP5 JJA Rainfall

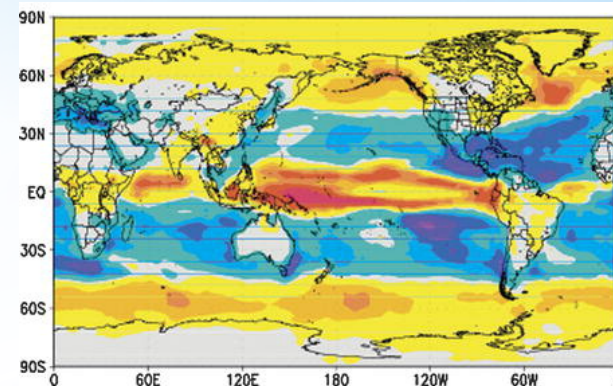


Dependence of precipitation change on climatology
“wet-get-wetter”
(Held and Soden 2006)

Climatological P-E

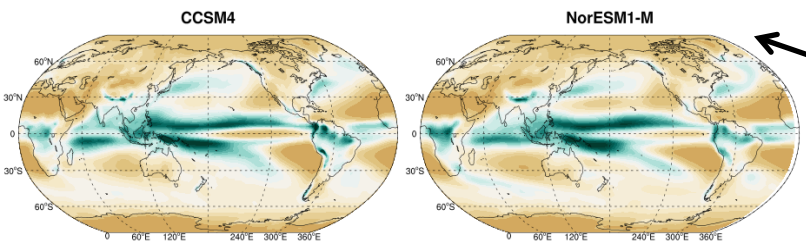


Change in P-E

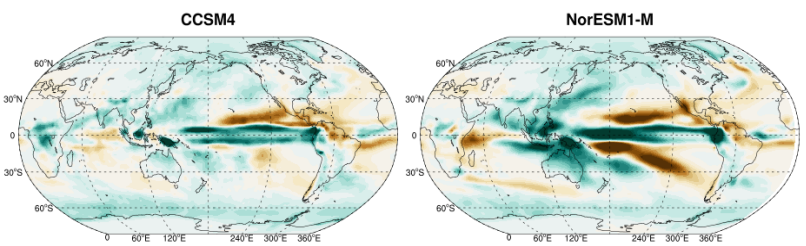


Climatological Biases

Similar Climatology (mm/day)

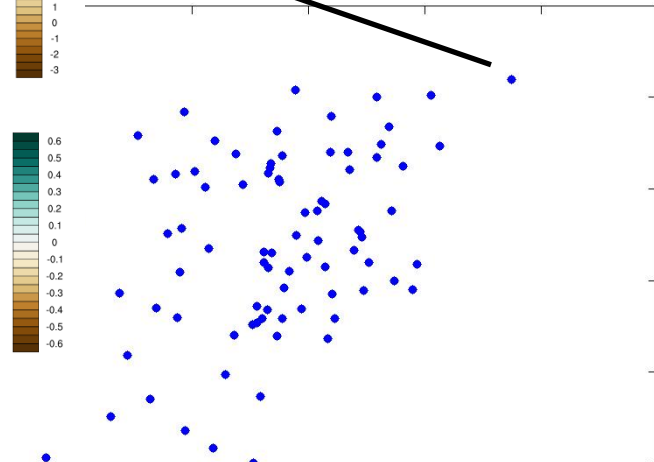


Similar Change (mm/day/K)

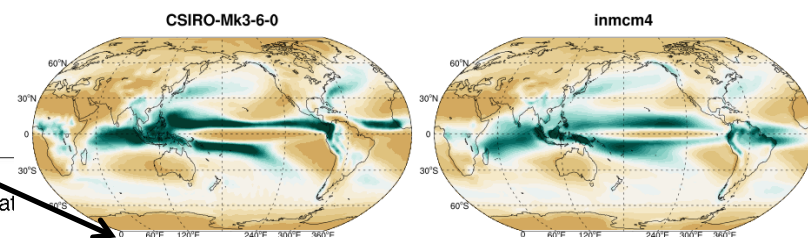


atation Climatology vs Precipitation Change
M 1pctCO2)

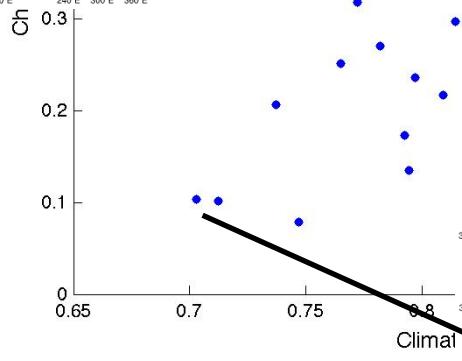
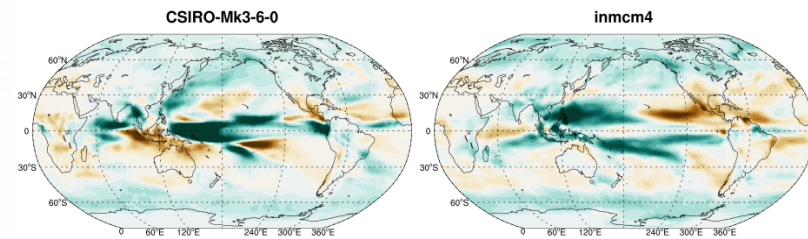
Precipitation (global)



Dissimilar Climatology (mm/day)



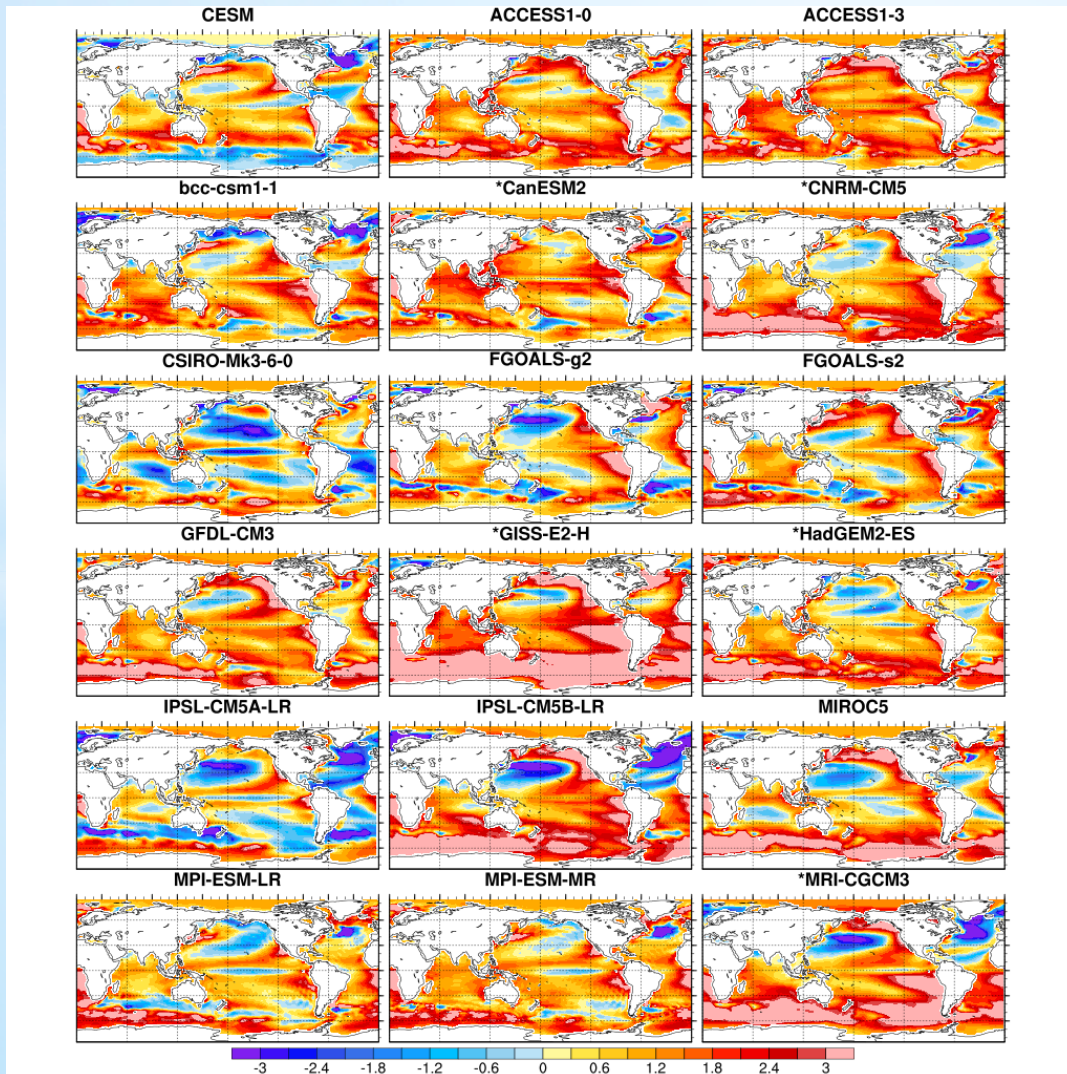
Dissimilar Change (mm/day/K)



Climatological biases affect projection.

Climatological Biases

Biases in climatological SST from CMIP5 CGCMs



Observation:
Hadley-NOAA/OI (1982-2011)

CGCMs:
*Historical (1982-2011)
1pctCO2 (0011-0040)

Introduction

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Climatological Biases

Model: CESM

Resolution: 2° for the atmosphere

1. AGCM simulations with SST climatologies from observation and CGCMs.

ObsSST AGCM

VS

Coupled CESM

(1pctCO₂)

modelSST AGCM

(CanESM2, CNRM-CM5, GISS-E2-H, HadGEM2-ES, MRI-CGCM3)

Same Δ SST,
Different SST climatology.

2. AGCM simulations with patterns of SST change from individual CGCMs.

Uniform AGCM

VS

Coupled CESM

(1pctCO₂)

modelPattern AGCM

(CanESM2, CNRM-CM5, GISS-E2-H, HadGEM2-ES, MRI-CGCM3)

Same SST climatology,
Different Δ SST.

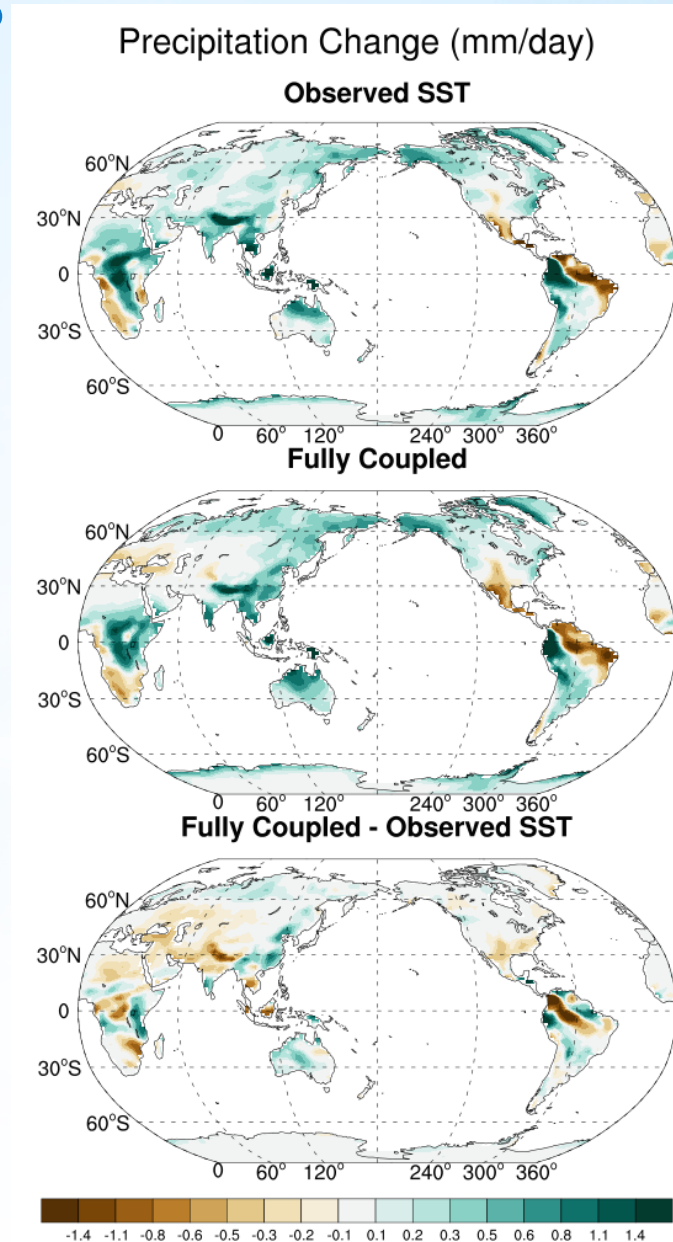
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Climatological Biases

Errors due to biases in climatological SST.



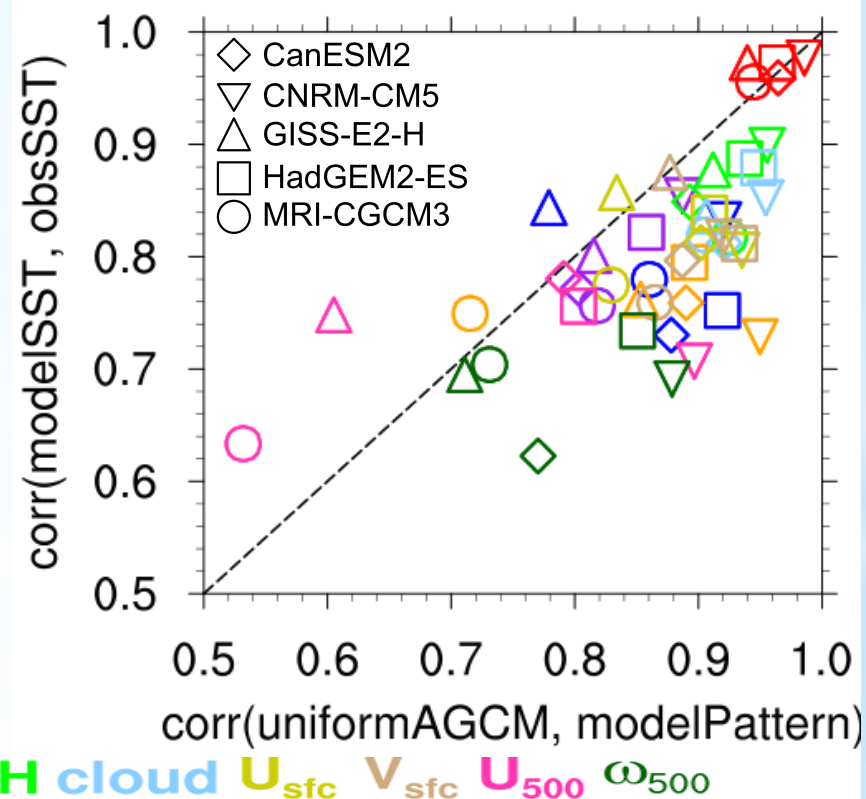
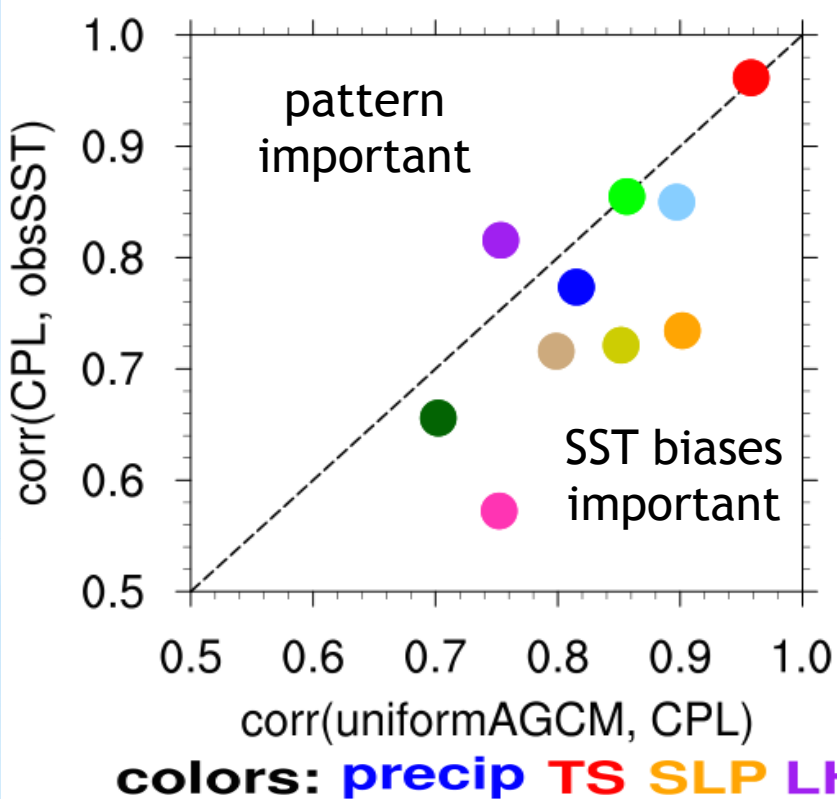
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Climatological Biases

SST biases VS pattern of Δ SST (land)



SST biases have greater impact than a total removal of pattern of Δ SST (below the diagonal).

1. Is “two-way” coupling important for regional precipitation change? **No***
2. Are details of SST change important for regional precipitation change? **Not for land***
3. Are we getting realistic regional climate change from CGCMs? **Climatological biases***
4. What are some practical ways forward?

High-resolution AGCM?

for projecting land climate change

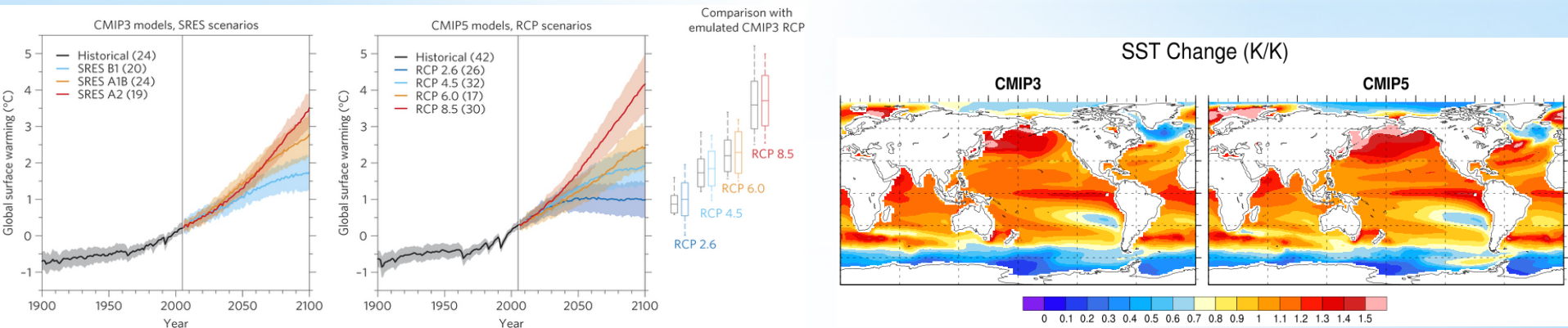
Pros:

- Computationally efficient
- Unbiased SST climatology → “best” starting point (precip climatology)

Con:

- Can't simulate SST changes directly

*But.. the pattern of Δ SST is not important;
 Δ SST hasn't changed much from CMIP3 to CMIP5.*

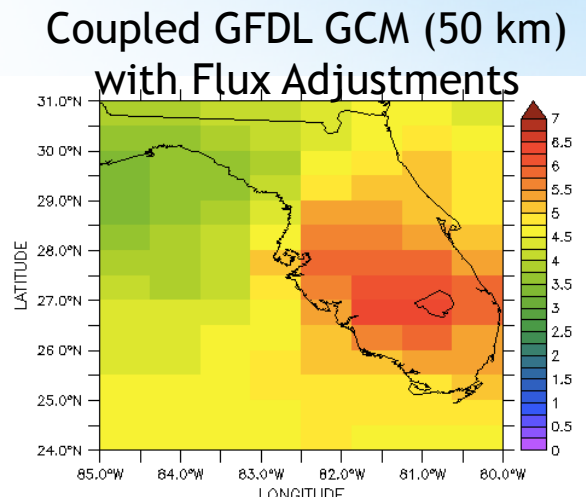
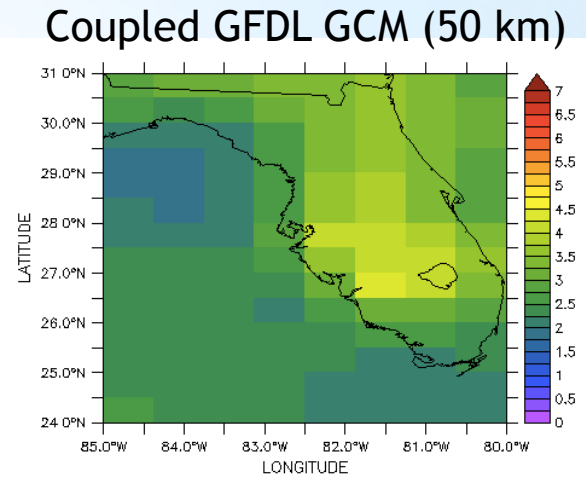
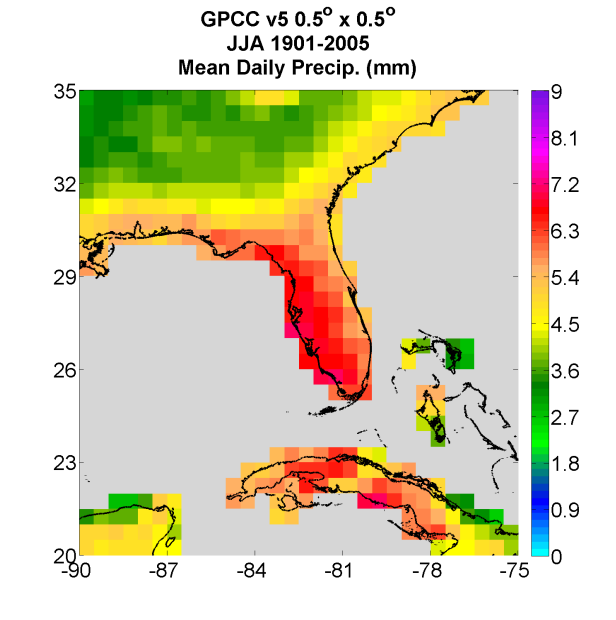


Knutti and Sedláček (2013)

1. High-resolution AGCM with observed SST and ensemble mean Δ SST.

Similar ideas for seasonal predictions:
FLOR (Vecchi et al. 2014; Jia et al. 2015)

2. Flux adjustments?



Courtesy Gabriel Vecchi (GFDL)

1. Is “two-way” coupling important for regional precipitation change? **No***
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4. What are some practical ways forward?
HR AGCM? Flux adjustments?

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Questions?