

A process-based understanding of regional climate responses to CO₂ forcing

Christopher Skinner, Robin Chadwick, Hervé Douville
and Noah Diffenbaugh



Objective

Introduce an ensemble of AGCM timeslice experiments designed to identify and better understand the mechanisms that shape the response of regional climate to CO₂ forcing.

Research Questions

1. How do regional climate responses in a coupled model arise from the combination of responses to CO₂ forcing?
 - DIRECT CO₂ EFFECT
 - PLANT PHYSIOLOGICAL EFFECT
 - UNIFORM SST WARMING
 - SST PATTERN CHANGE

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2. Which aspects are most important for causing inter-model uncertainty?

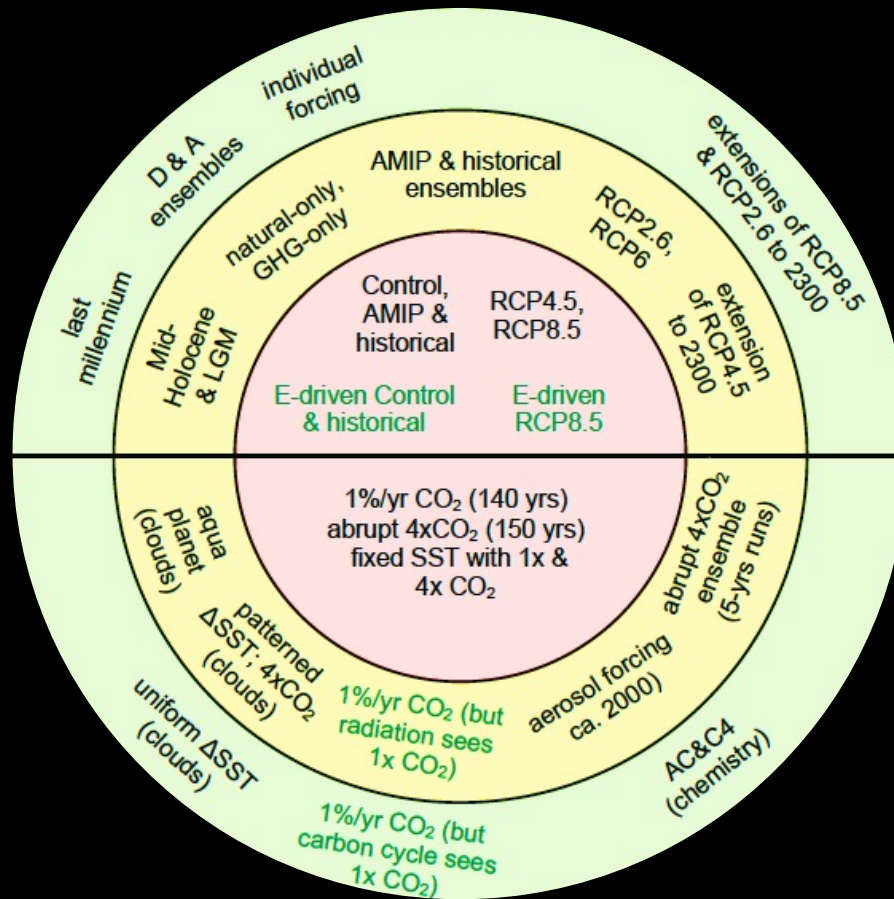
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2. Which aspects are most important for causing inter-model uncertainty?
3. What impact do coupled model SST biases have on regional climate projections?

Presentation Outline

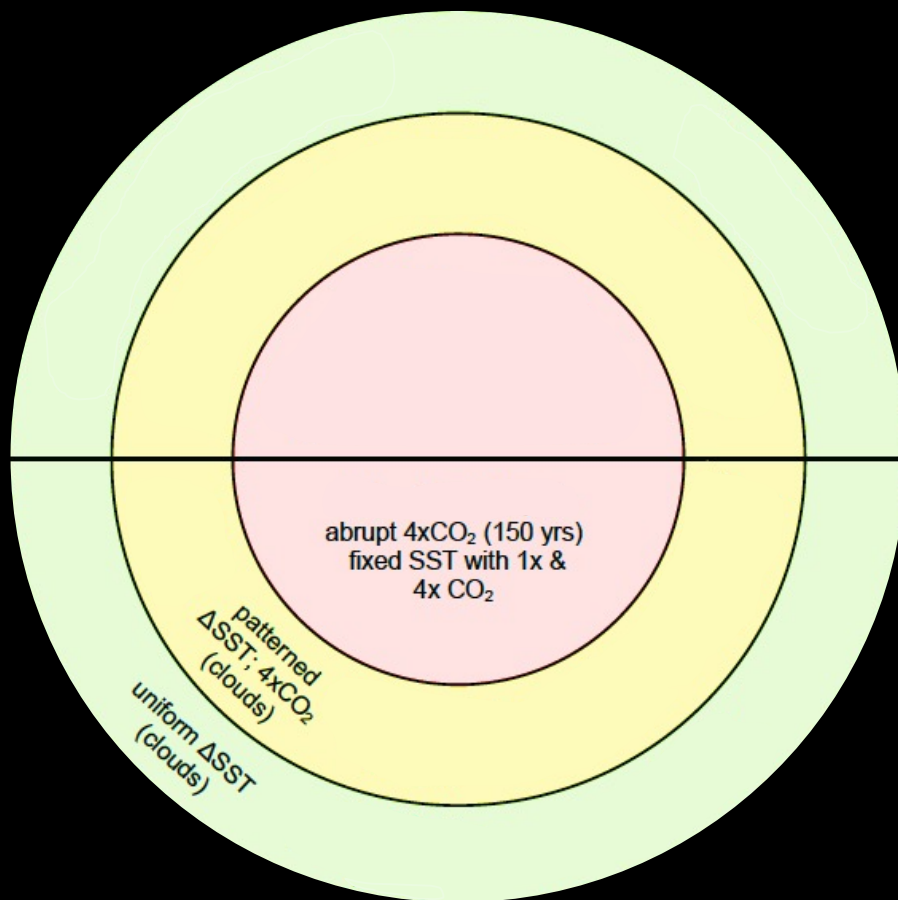
1. CFMIP2/CMIP5 idealized experiments
2. Framework of new idealized experiments
3. Preliminary results
4. Summary

CFMIP2/CMIP5 Experiments



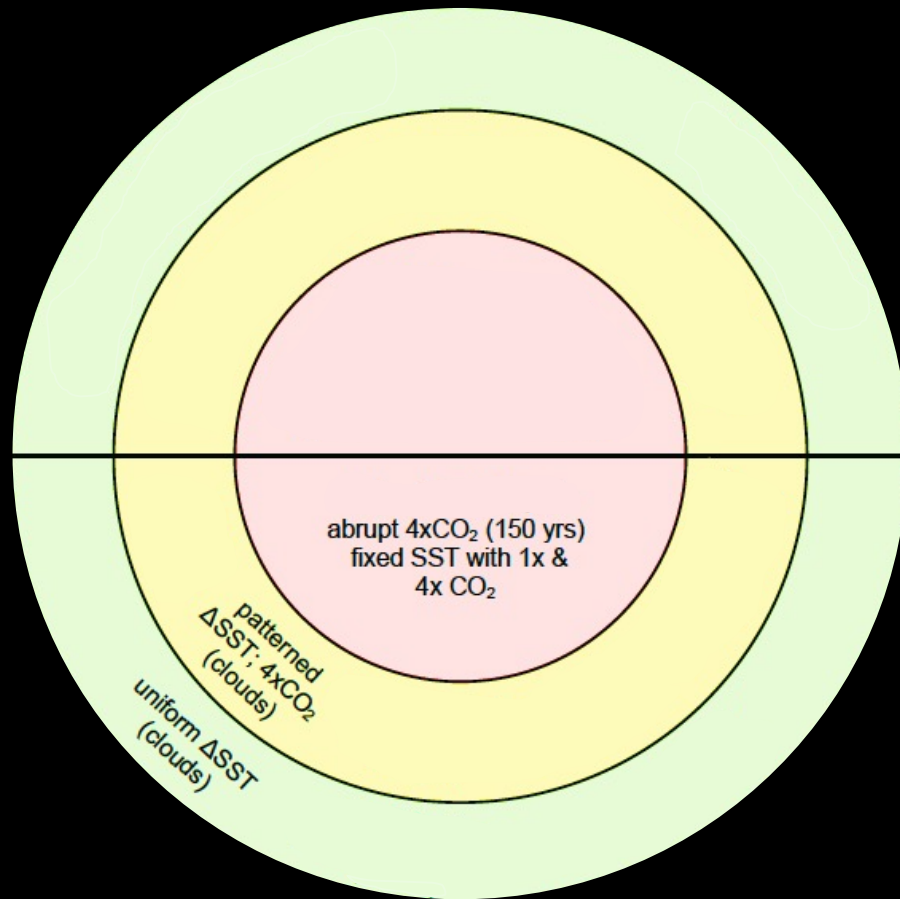
Idealized Experiments to Understand Complex Climate Change Signals

sstClim
sstClim4xCO2
amip
amip4xCO2
amip4K
amipFuture



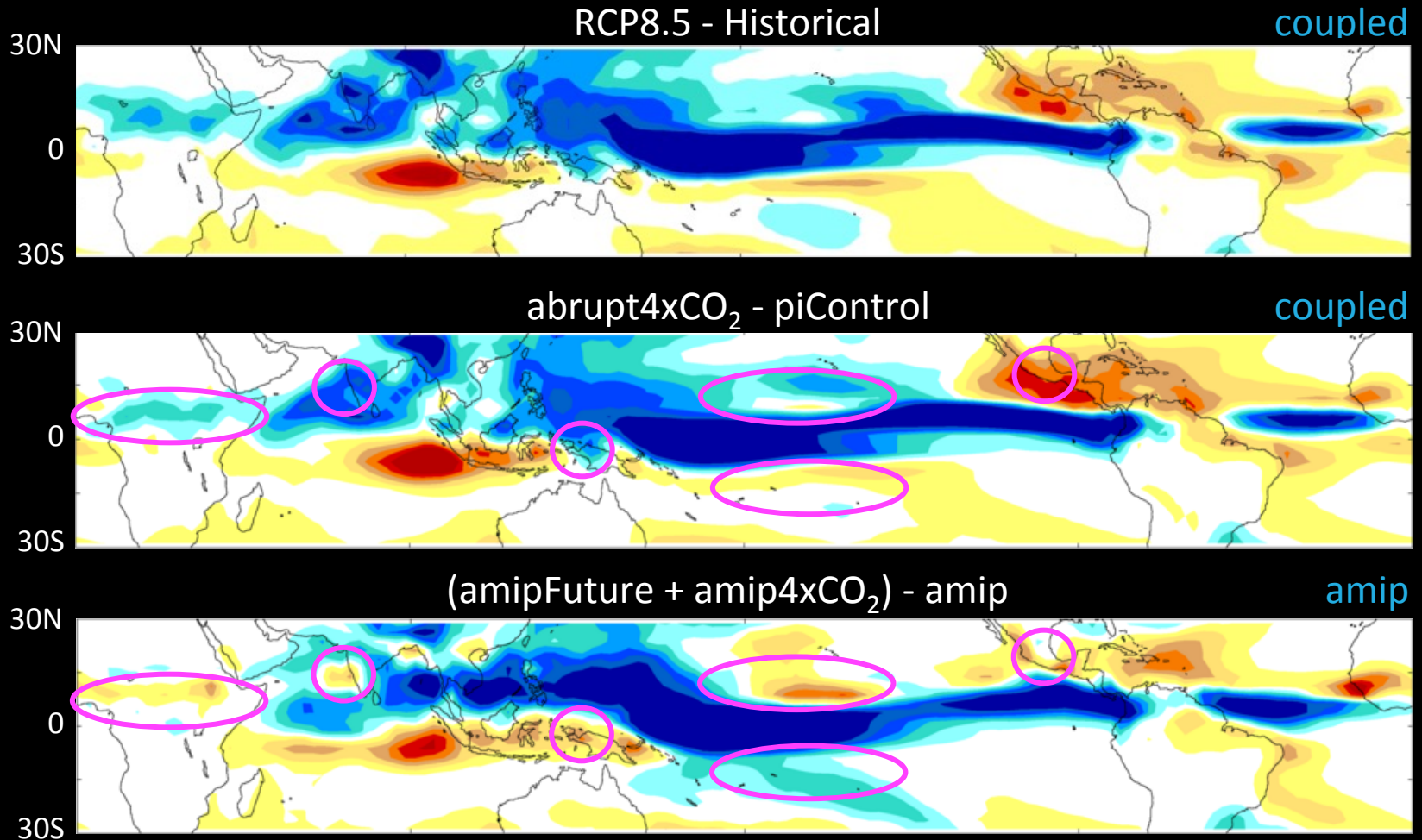
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Limitations?

CMIP5 Multi-model Mean Precipitation Change JJA (mm/day/K)



Current amip, amipFuture, etc... expts are useful, but **do not linearly sum to give the coupled AOGCM response** in many regions.

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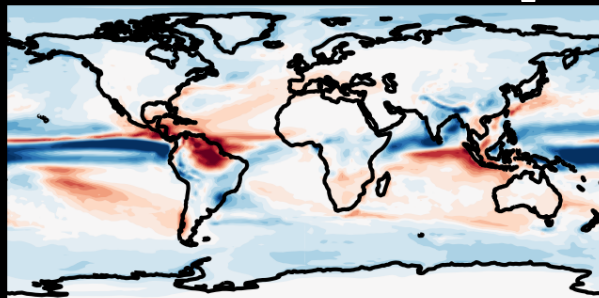
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New Timeslice Experiments

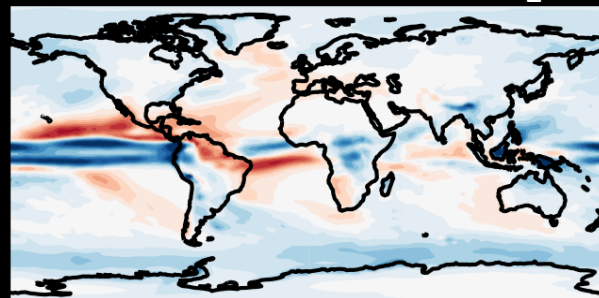
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sstPiFuture	sstPiControl with pattern of future SST anomalies, taken from each model's own abrupt4xCO ₂ expt, normalised to have a global mean perturbation of 4K.
sstPiTot	Combination of sstPiFuture and sstPi4xCO ₂ Veg to test for linearity of response.
amipTot	As sstPiTot but with amip baseline SSTs. Used to test influence of model SST biases on future projections.

Annual Precipitation Change

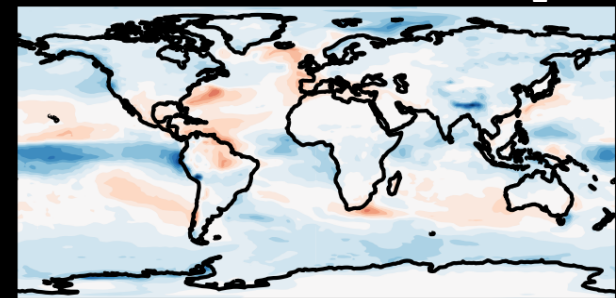
HadGEM2
Coupled abrupt4xCO₂



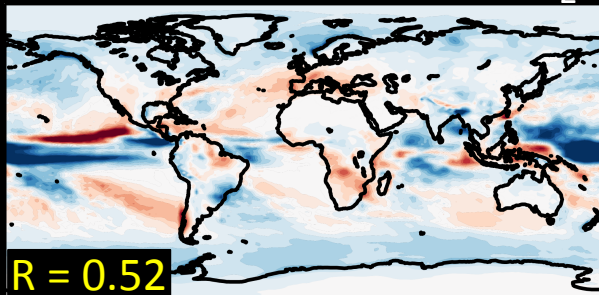
CCSM4
Coupled abrupt4xCO₂



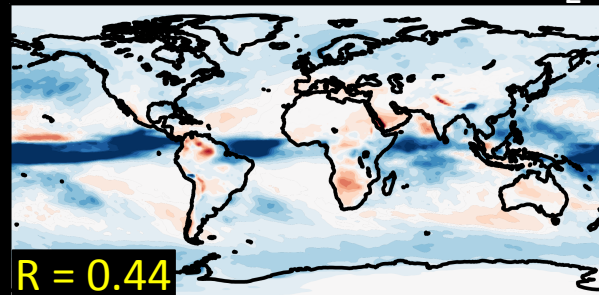
CNRM
Coupled abrupt4xCO₂



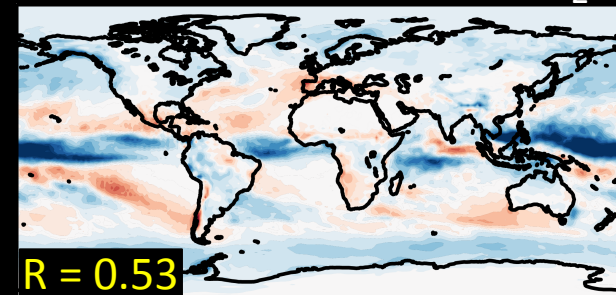
amipFuture + amip4xCO₂



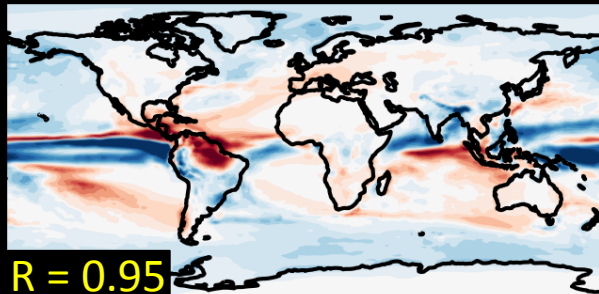
amipFuture + amip4xCO₂



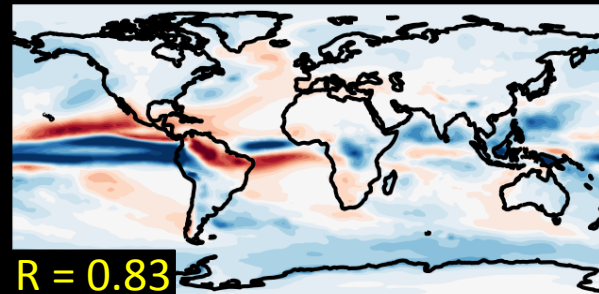
amipFuture + amip4xCO₂



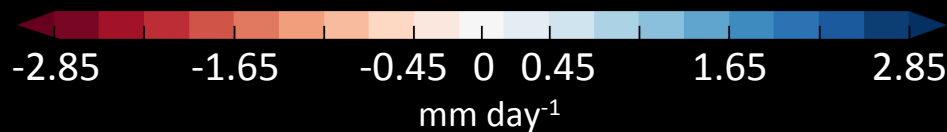
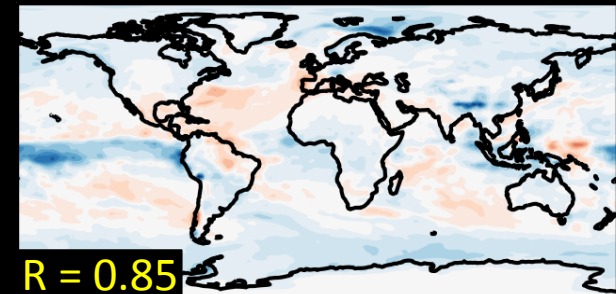
*sstPiTot



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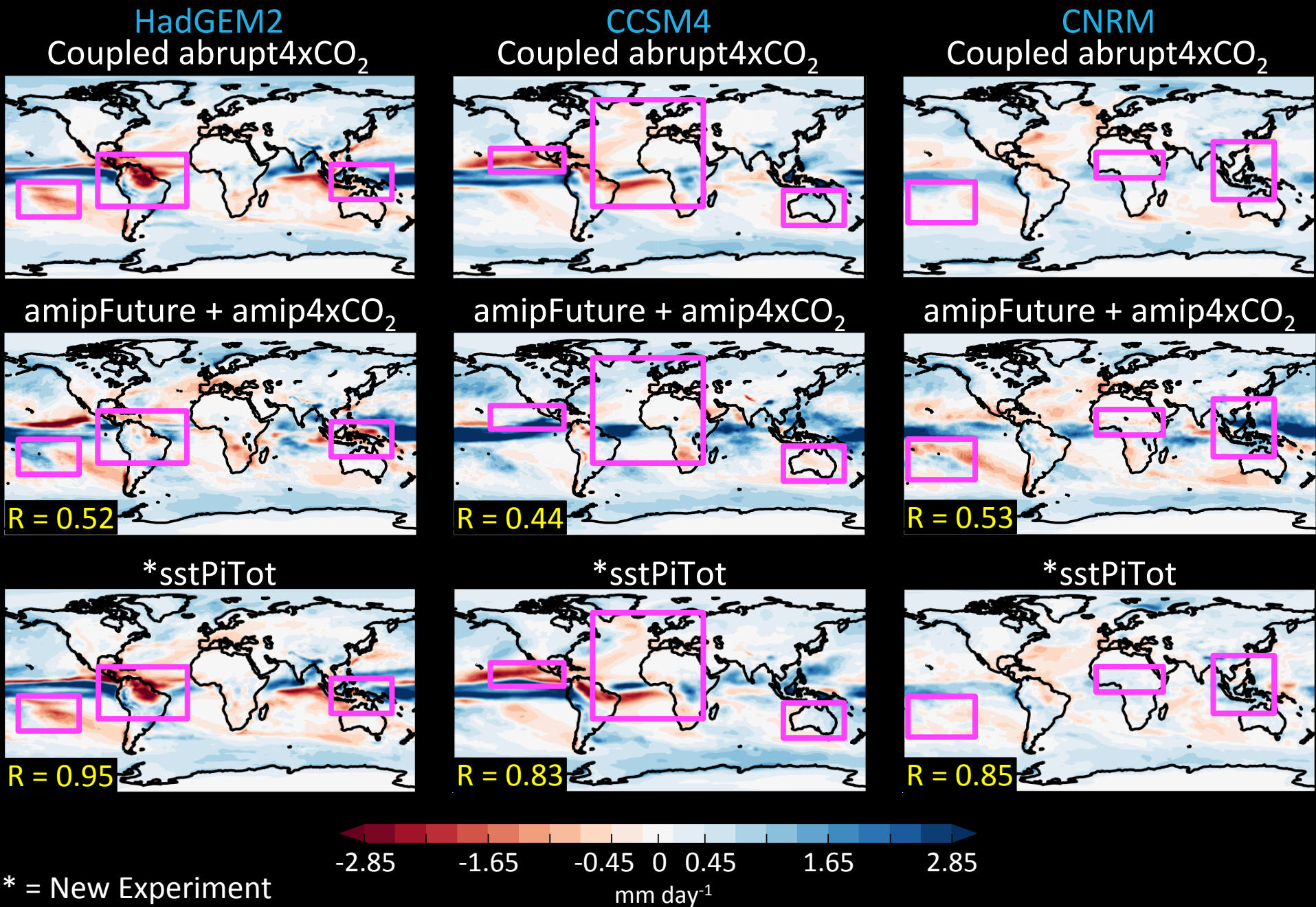


*sstPiTot



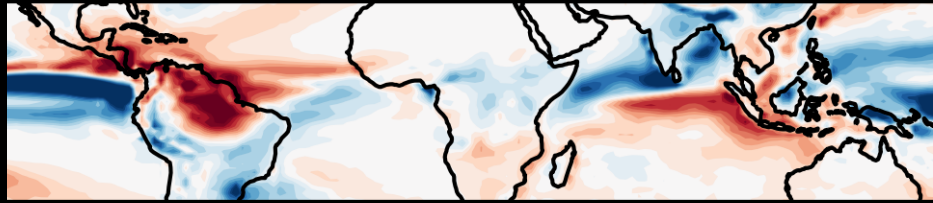
* = New Experiment

Annual Precipitation Change

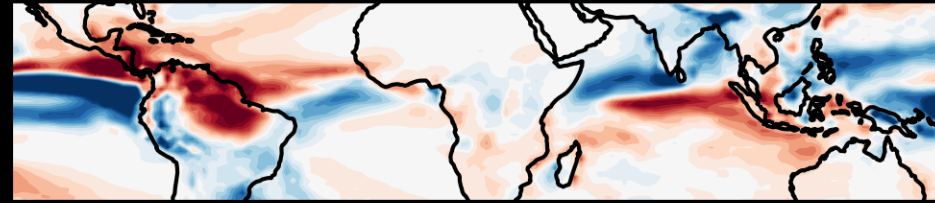


Annual Precipitation Change HadGEM2

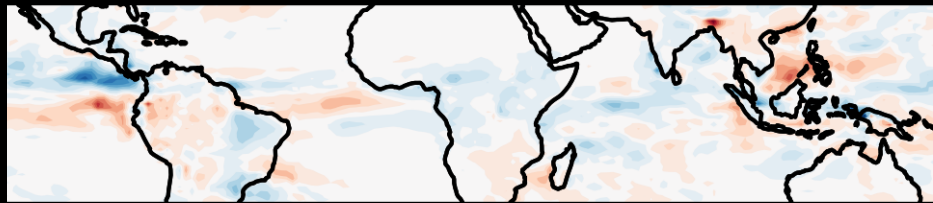
Coupled abrupt4xCO₂



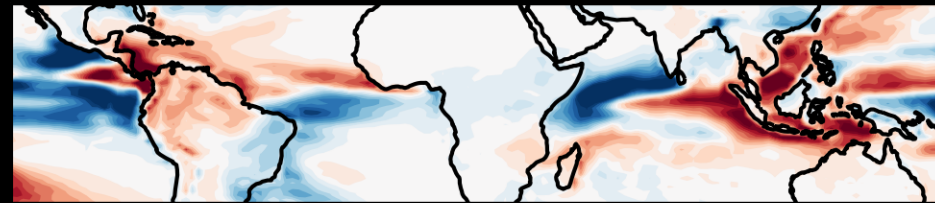
sstPiTot



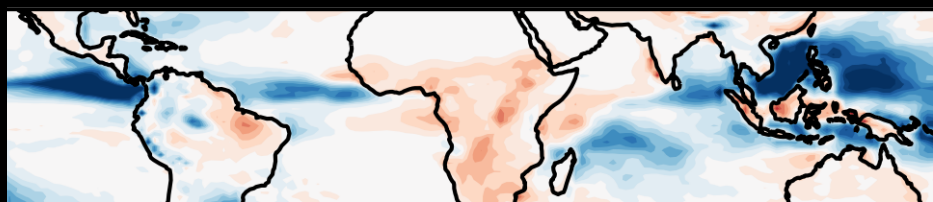
Coupled abrupt4xCO₂ - sstPiTot



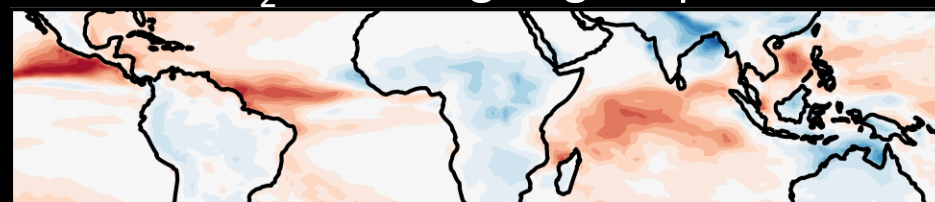
SST Pattern-Only



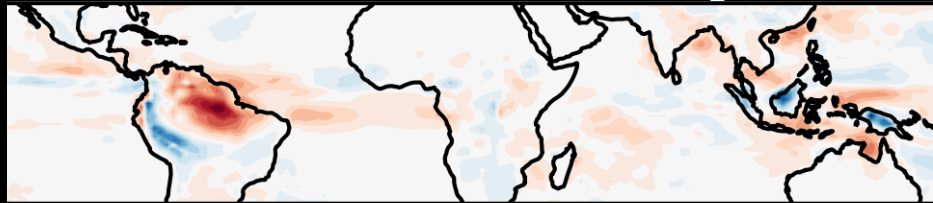
SST Uniform +4K



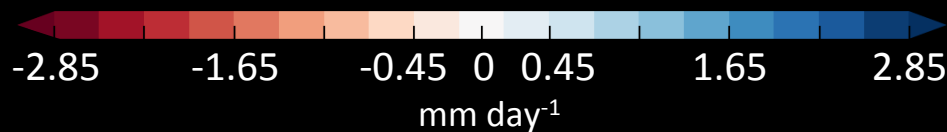
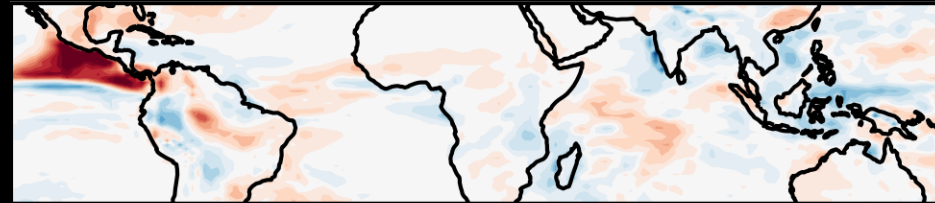
4xCO₂ Excluding Veg Response



Veg Response to 4xCO₂



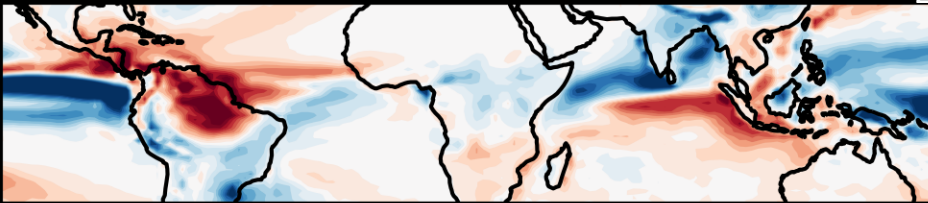
Nonlinear Response



Annual Precipitation Change

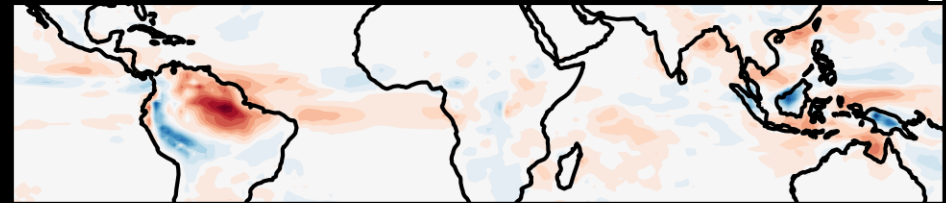
HadGEM2

Coupled abrupt4xCO₂



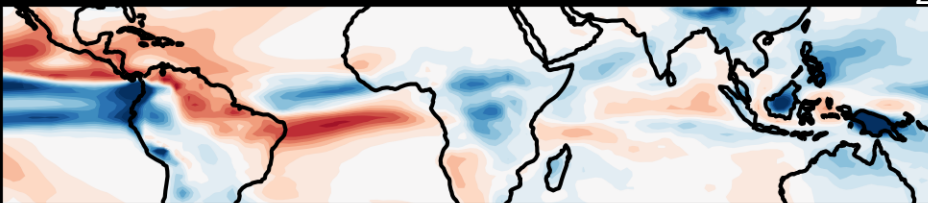
HadGEM2

Vegetation Response to 4xCO₂



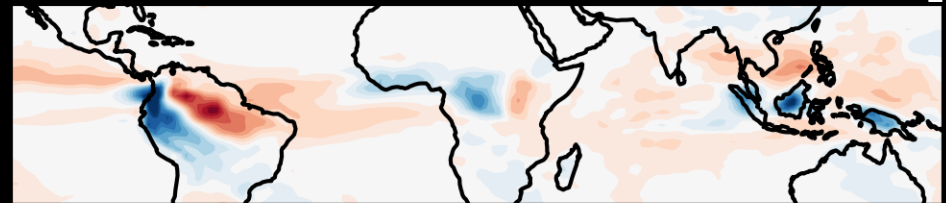
CCSM4

Coupled abrupt4xCO₂



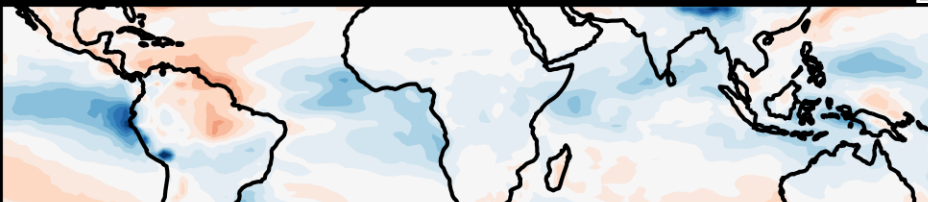
CCSM4

Vegetation Response to 4xCO₂



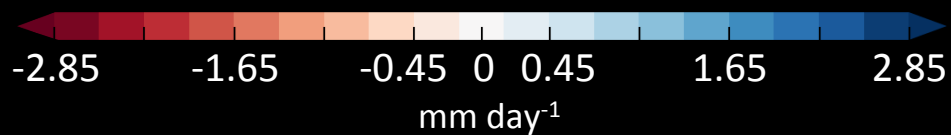
CNRM

Coupled abrupt4xCO₂



CNRM

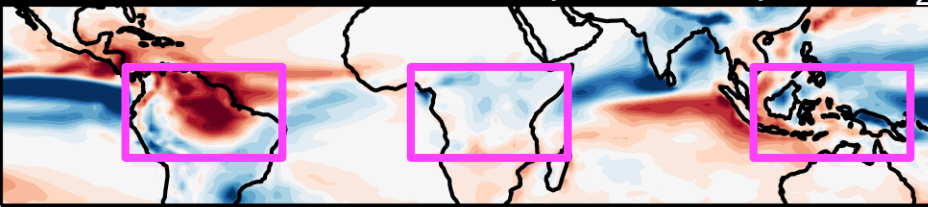
Vegetation Response to 4xCO₂



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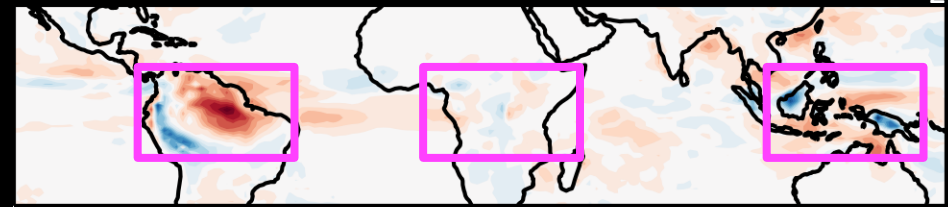
HadGEM2

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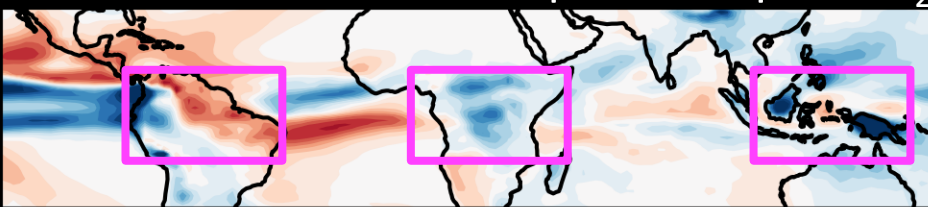
HadGEM2

Vegetation Response to 4xCO₂



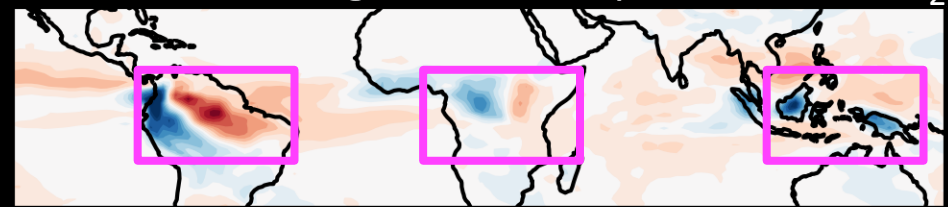
CCSM4

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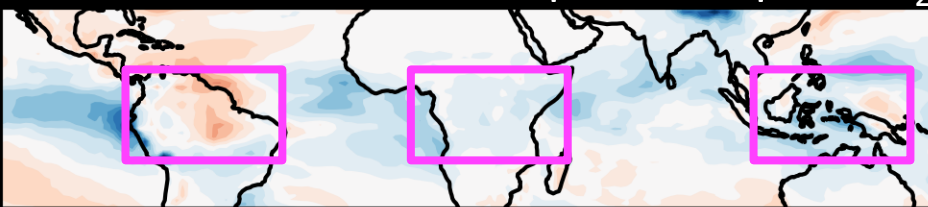
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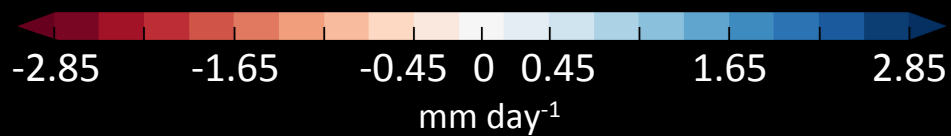
CNRM

Coupled abrupt4xCO₂



CNRM

Vegetation Response to 4xCO₂



Seasonal Precipitation Change Vegetation Response to 4xCO₂

HadGEM2

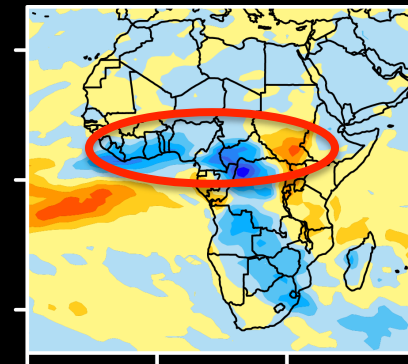
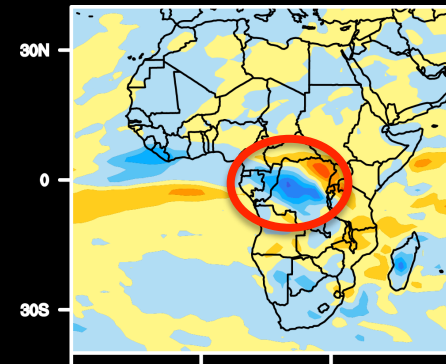
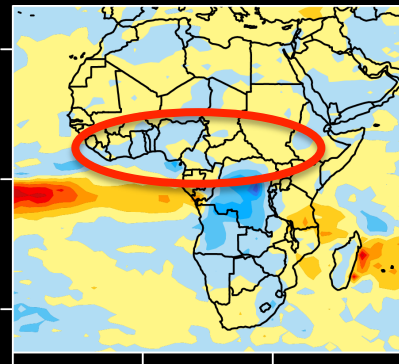
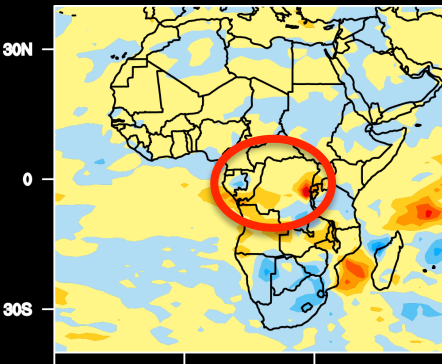
CCSM4

DJF

MAM

DJF

MAM

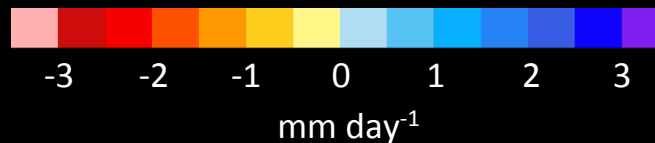
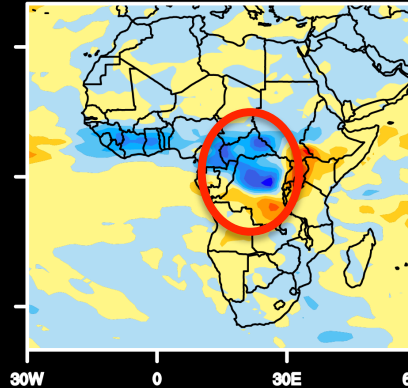
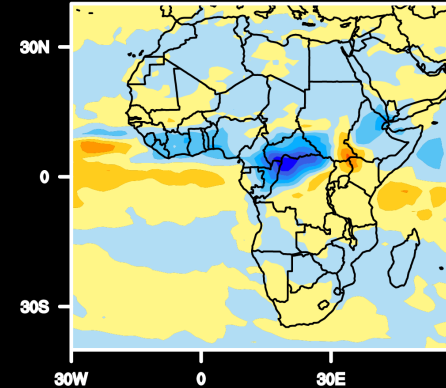
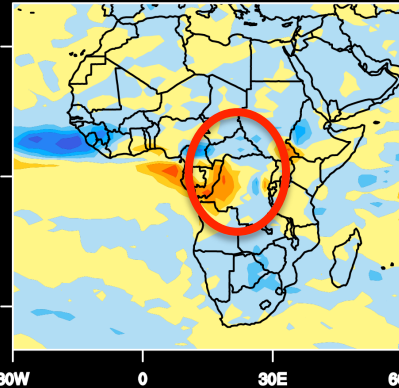
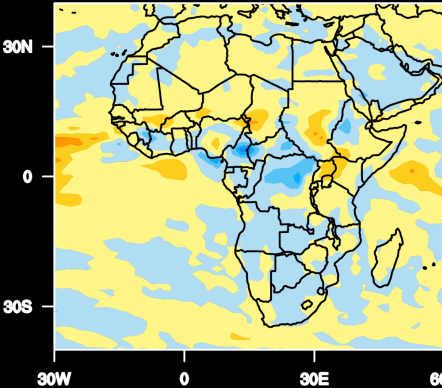


JJA

SON

JJA

SON



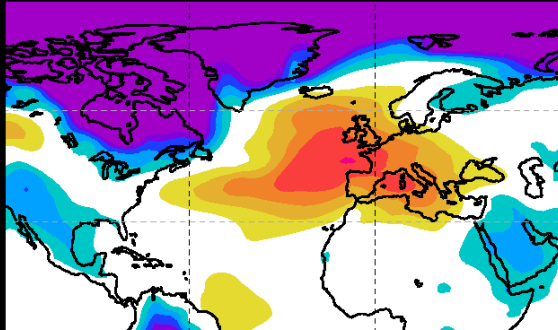
REMARKABLY DIFFERENT PATTERN

sstPi4xCO₂Veg – sstPi4xCO₂

Sea Level Pressure Change DJFM (hPa)

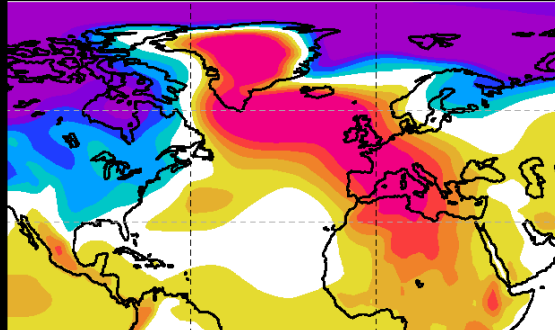
HadGEM2

Coupled abrupt4xCO₂



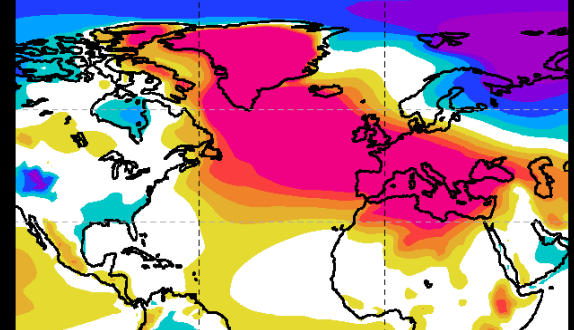
CNRM

Coupled abrupt4xCO₂



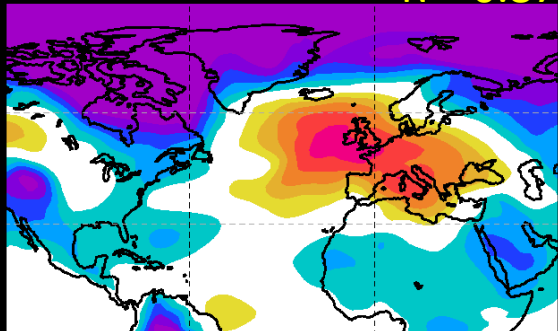
CCSM4

Coupled abrupt4xCO₂



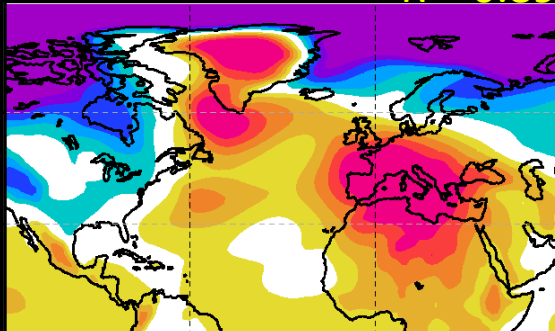
sstPiTot

R = 0.87



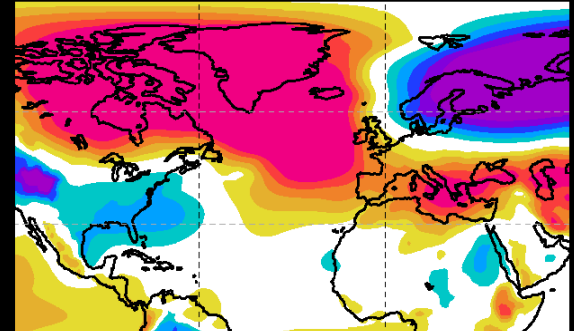
sstPiTot

R = 0.89



sstPiTot

R = 0.74



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- Can successfully decompose the coupled model response into individual responses to CO₂ forcing
- Use of model's own SST patterns and inclusion of vegetation response to CO₂ greatly improves agreement with coupled model response.
- Vegetation response to CO₂ may contribute substantially to inter-model spread in precipitation projections within tropical forest regions.
- SST pattern change largely responsible for the pattern of precipitation responses over oceans

Extra Slides

Sea Level Pressure Change DJFM (hPa)

HadGEM2

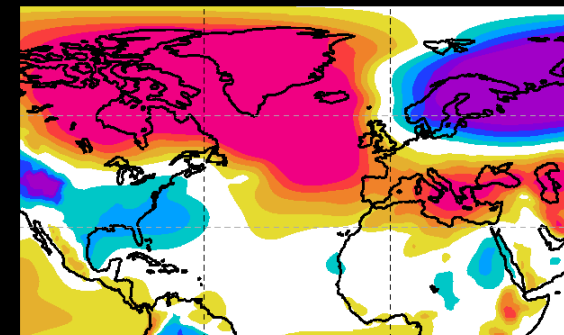
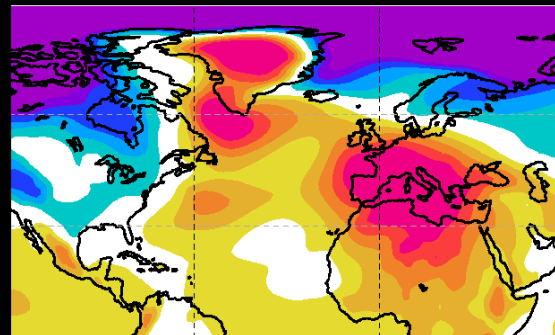
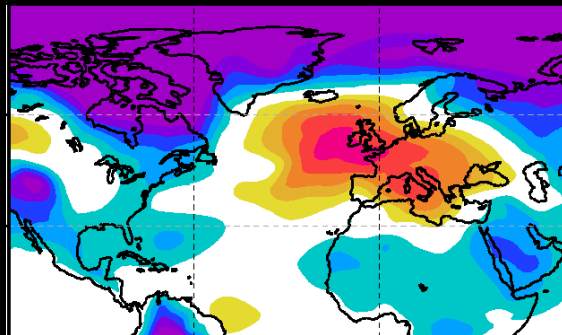
CNRM

CCSM4

sstPiTot

sstPiTot

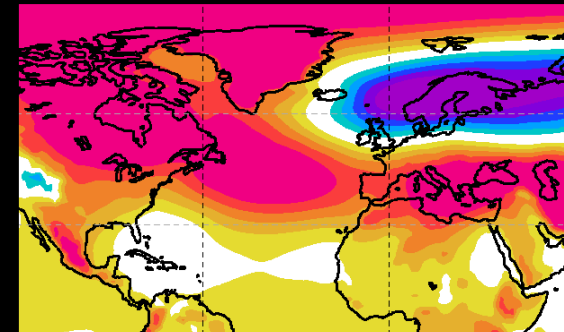
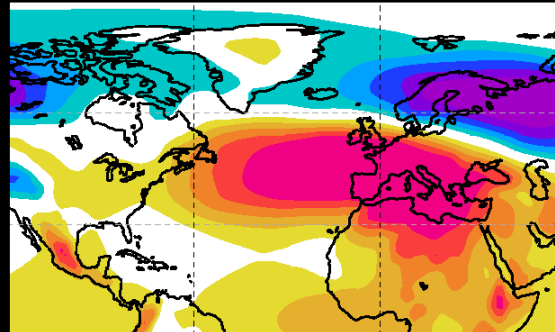
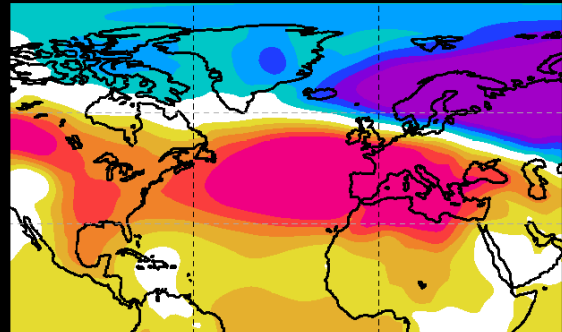
sstPiTot



SST Uniform +4K

SST Uniform +4K

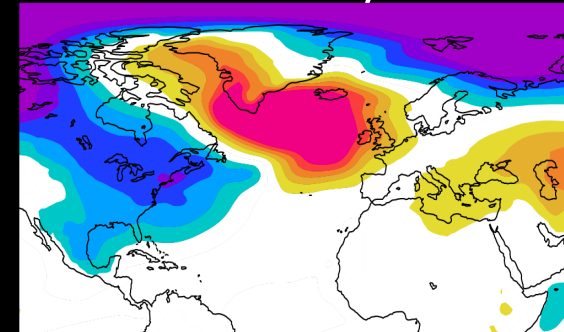
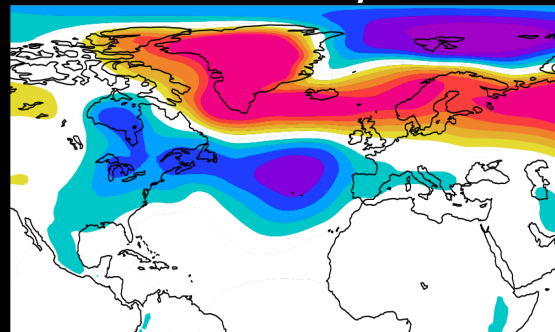
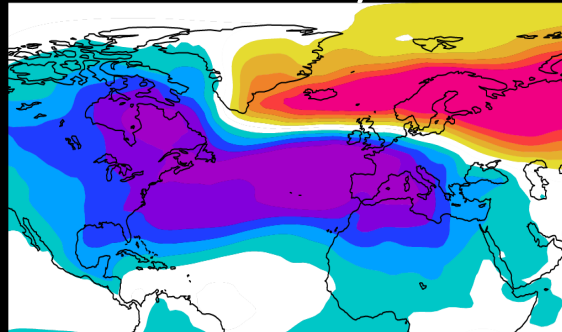
SST Uniform +4K



SST Pattern-Only

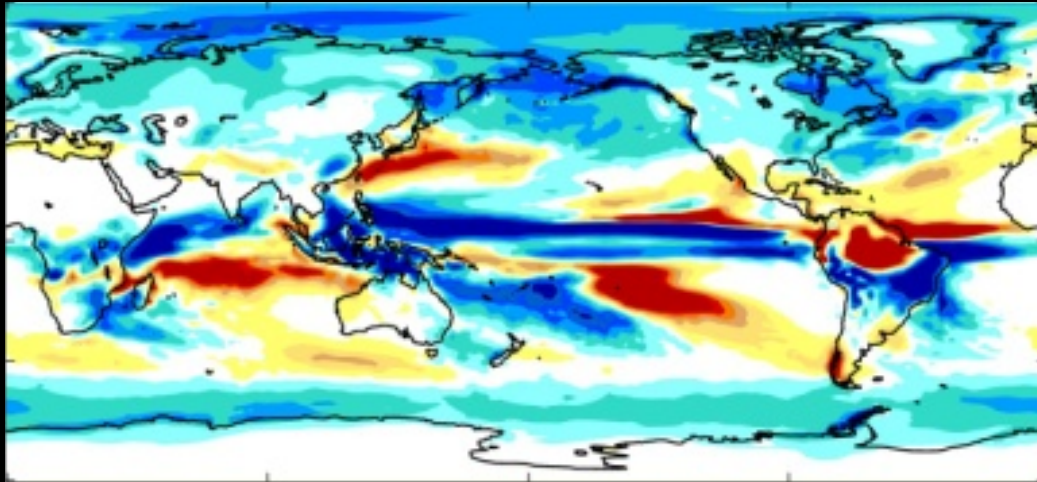
SST Pattern-Only

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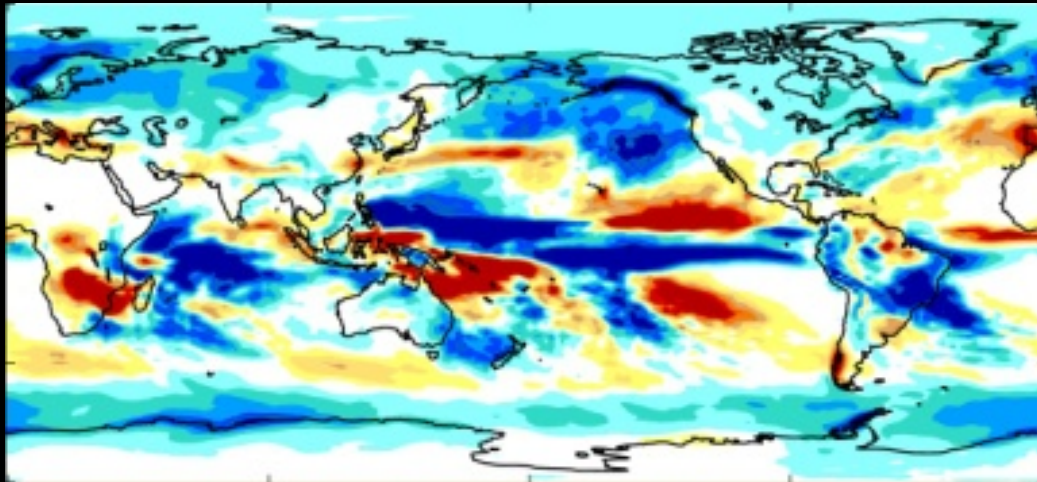


HadGEM2 Mean Precipitation Change DJF (mm/day)

abrupt4xCO₂

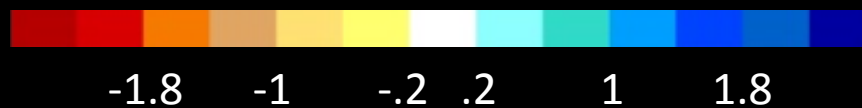


amipFuture (CMIP3 Pattern) + amip4xCO₂



R = 0.34

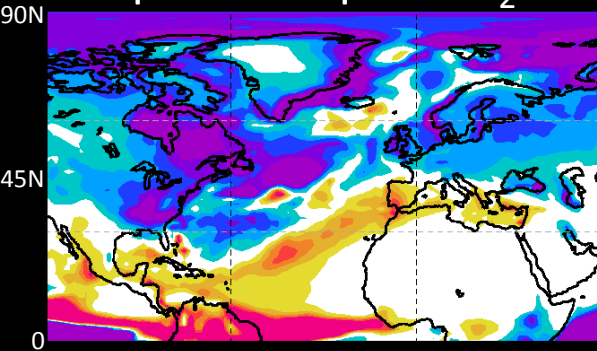
Poor pattern agreement



Precipitation Change DJFM (mm/day)

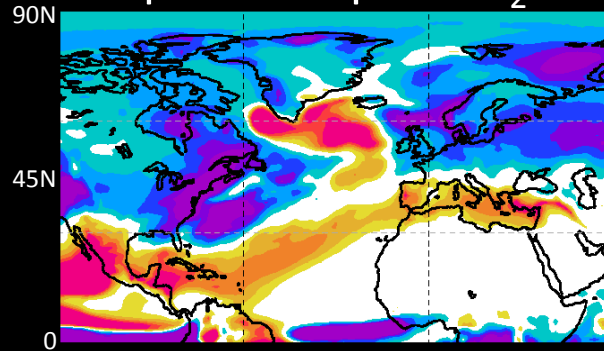
HadGEM2

Coupled abrupt4xCO₂



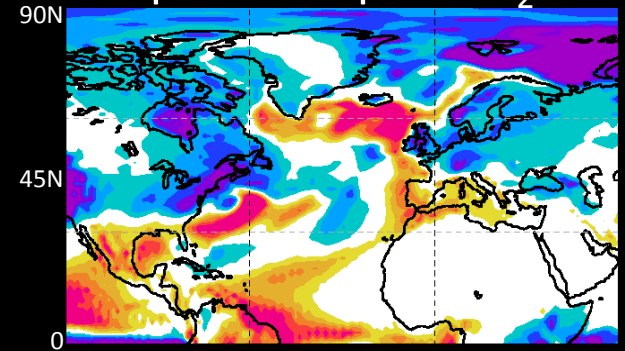
CCSM4

Coupled abrupt4xCO₂



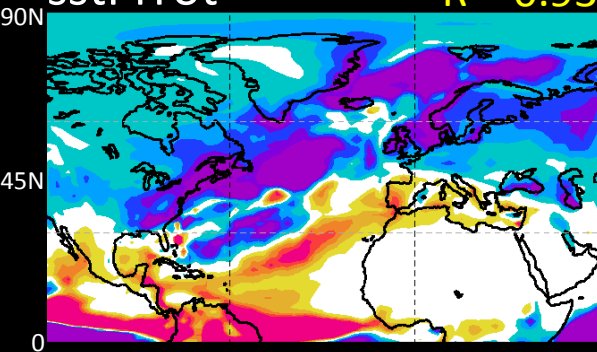
CNRM

Coupled abrupt4xCO₂



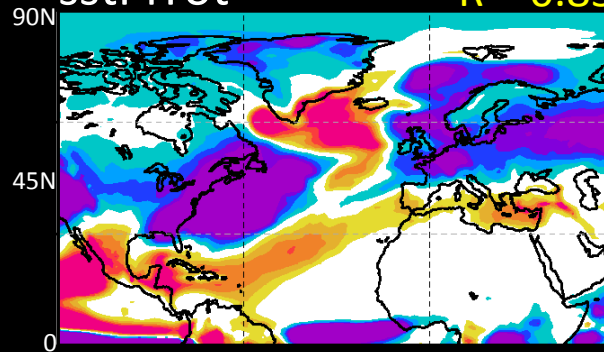
sstPiTot

R = 0.93



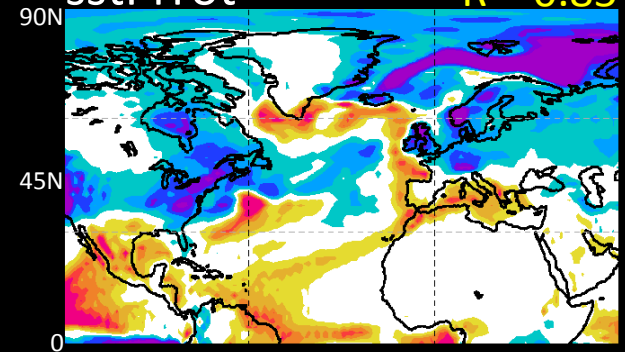
sstPiTot

R = 0.85



sstPiTot

R = 0.85



-1.0

-0.6

-0.2

0.2

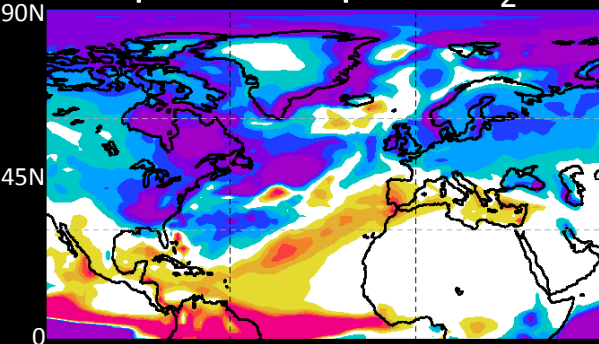
0.6

1.0

Precipitation Change DJFM (mm/day)

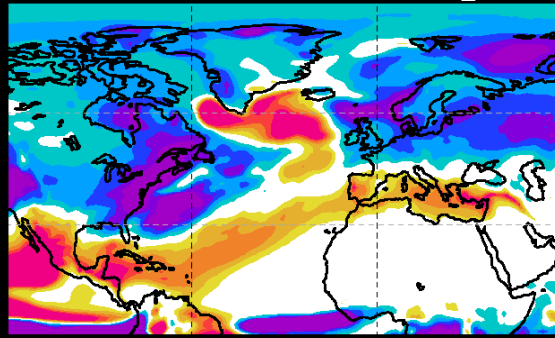
HadGEM2

Coupled abrupt4xCO₂



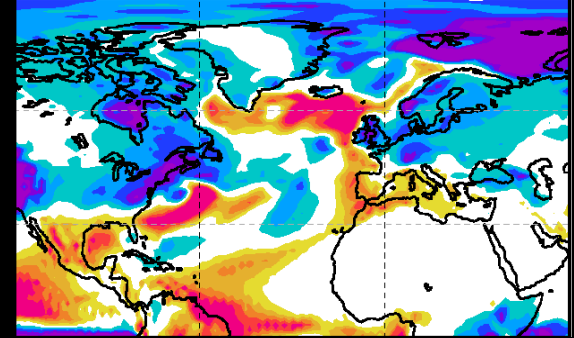
CCSM4

Coupled abrupt4xCO₂



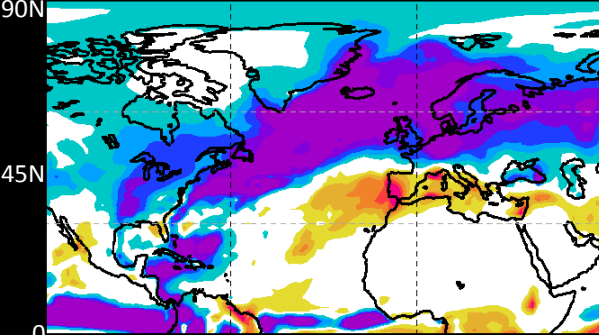
CNRM

Coupled abrupt4xCO₂



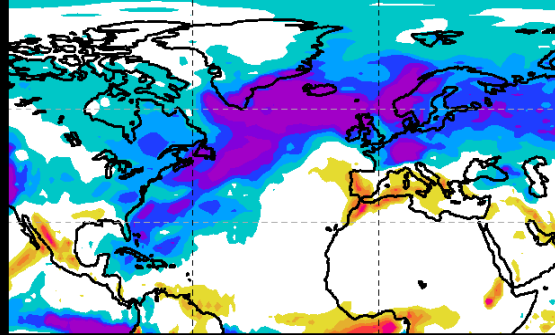
sstPi4K

R = 0.12



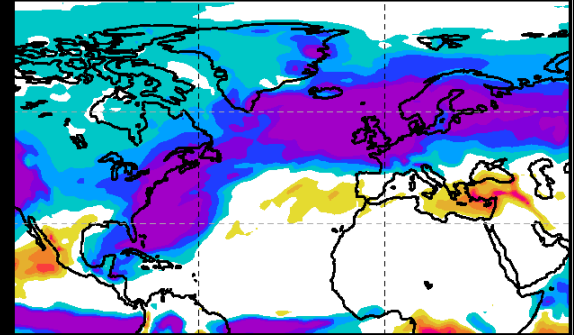
sstPi4K

R = 0.44



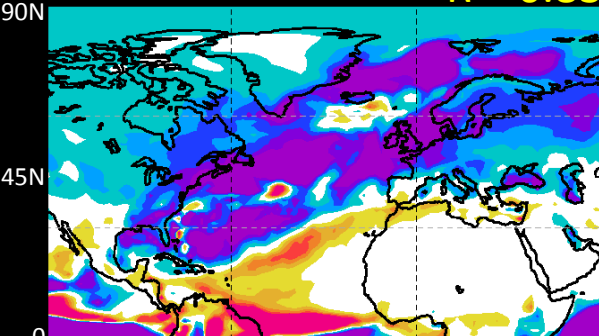
sstPi4K

R = 0.28



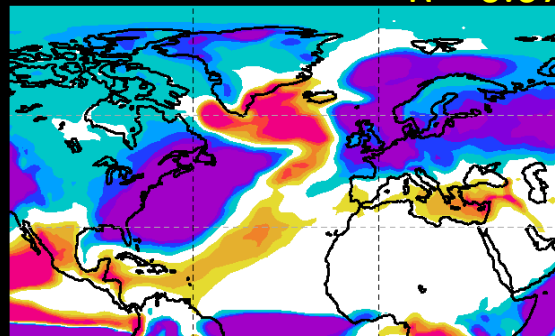
sstPiFuture

R = 0.83



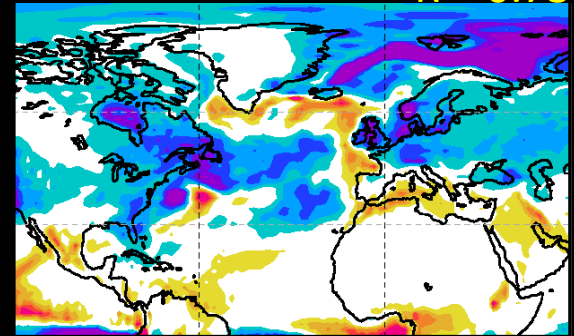
sstPiFuture

R = 0.67



sstPiFuture

R = 0.73



Direct CO2 Effect (w/o Vegetation Physiological Effect) Seasonal Precipitation Change

HadGEM2

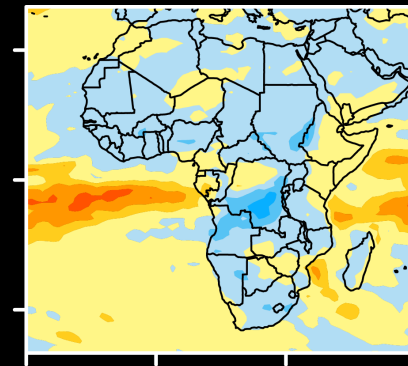
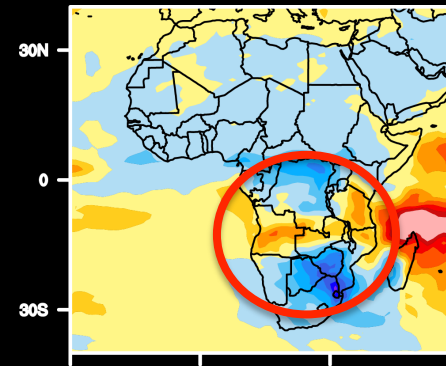
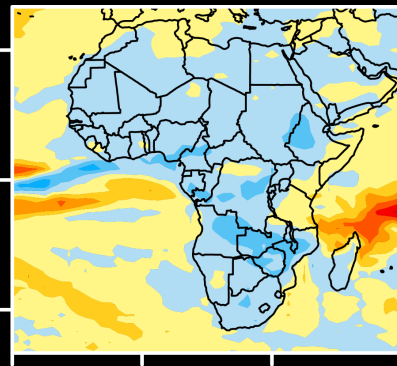
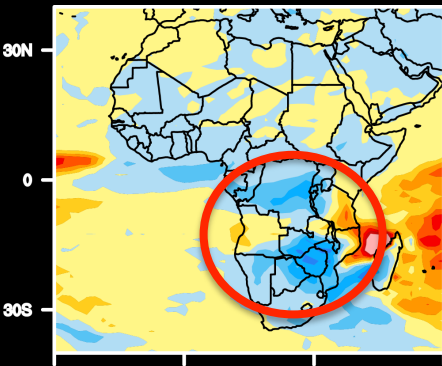
CCSM4

DJF

MAM

DJF

MAM

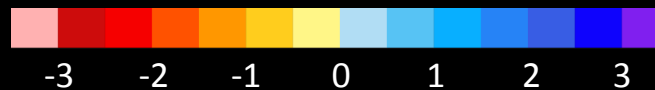
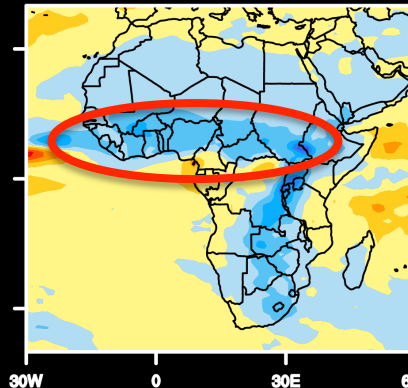
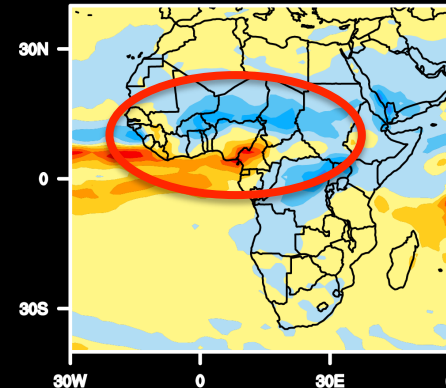
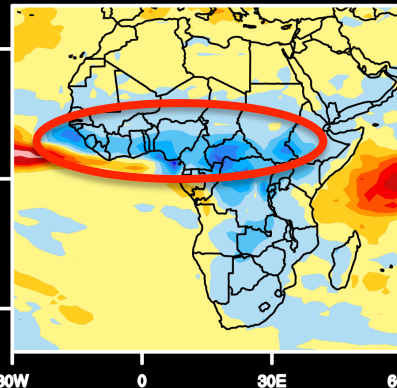
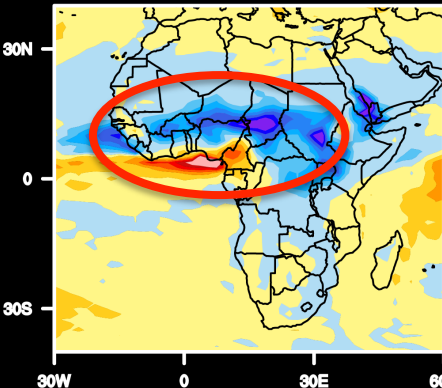


JJA

SON

JJA

SON



-3 -2 -1 0 1 2 3

mm day⁻¹

REMARKABLY SIMILAR PATTERN

sstPi4xCO2 - sstPi

Potential Refinement of Experiments

- Rather than 4K warming, use global mean SST anomaly from each model's own coupled abrupt4xCO2 run.
 - Use in all “future” sst experiment runs

Potential Refinement of Experiments

- Rather than 4K warming, use global mean SST anomaly from each model's own coupled abrupt4xCO2 run.
 - Use in all “future” sst experiment runs
- Rather than add the 50-year mean anomaly of future SSTs to the time-varying preindustrial SSTs, use the time-varying monthly SSTs from the coupled abrupt4xCO2 run.
 - Use in sstPiFuture and sstPiTot runs
 - Include future sea ice concentrations?