Reducing Uncertainties in Climate Change Projections: Is There Hope?

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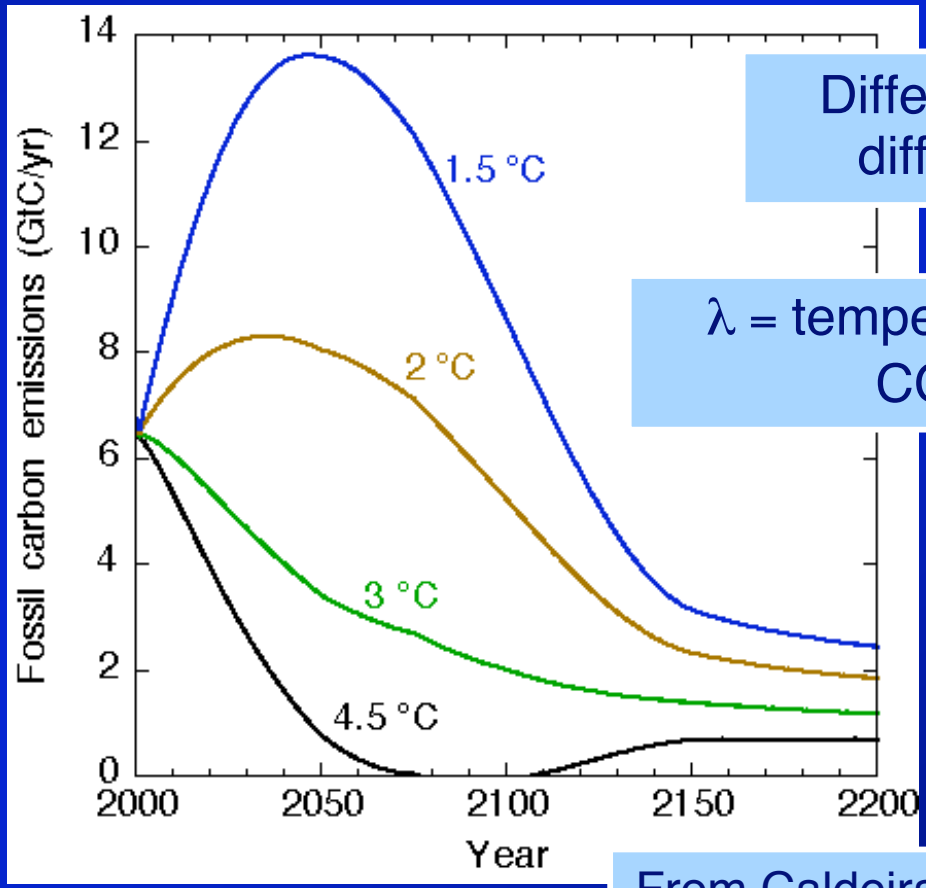
Contents

- *Motivation*:
  Why climate change uncertainties are important.
- *Climate change uncertainties:*
  How bad are they?
- *Is there hope?*
  What is being done to reduce uncertainties.

Allowable C emissions depend strongly on climate sensitivity, λ

CO_2 emissions to stabilize climate at 2° C warming



Different curves are for different values of λ

λ = temperature change per CO_2 doubling

From Caldeira *et al*, *Science*, 2003

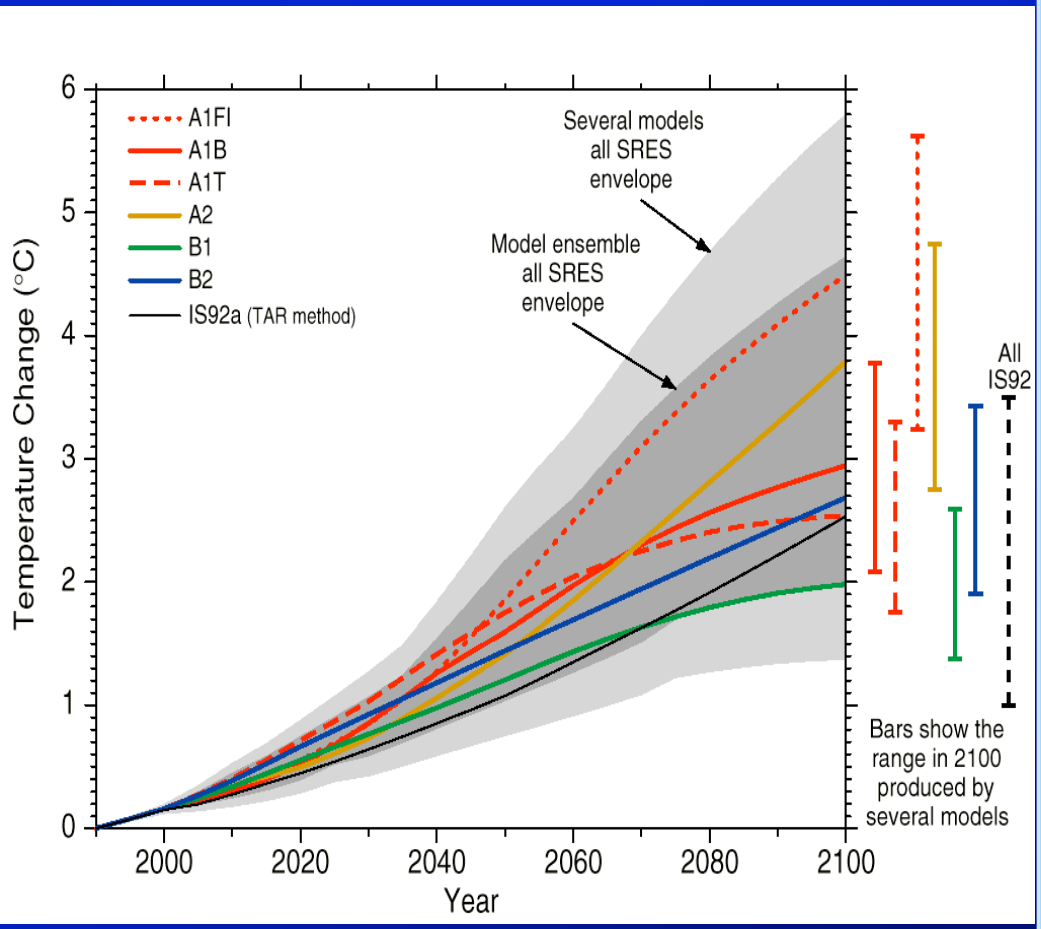
Why is future climate so uncertain?

Projecting Into The Future: Temperature Change

- Global Increase Ranging From 1.4 to 5.8 ºC from 1990 to 2100.

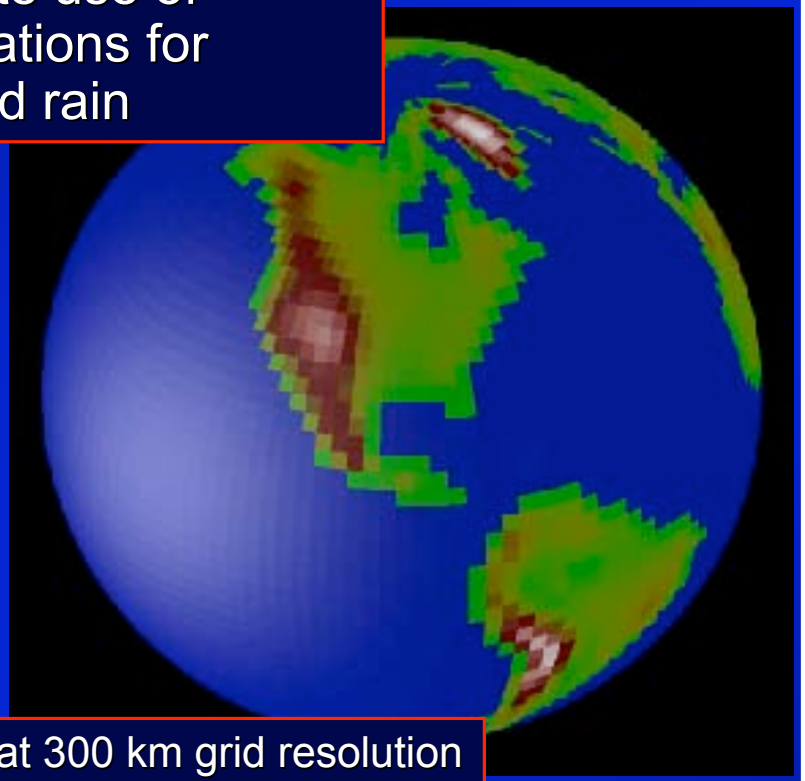
- Uncertainty in future warming arises from ***uncertainty in future greenhouse gas emissions***, and ***model errors***.

- These two sources of uncertainty contribute ~equally to uncertainty in future warming.



A Big Unknown: Clouds and Water Vapor Changes in Climate Models

Coarse spatial grids in typical climate models necessitate use of approximations for clouds and rain



Topography at 300 km grid resolution

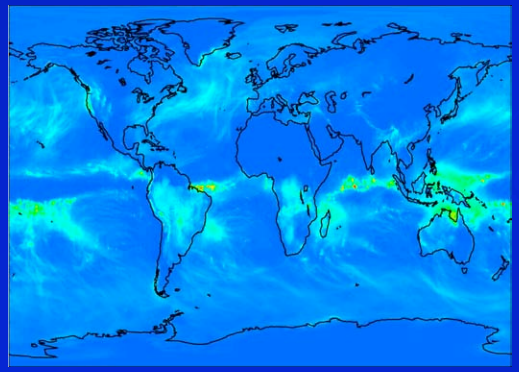
The global mean temperature response of climate models to a doubling of CO_2 varies from about 1.5 to 4.5 ºC.

This uncertainty is mostly due to poor knowledge of climate feedbacks from water vapor and clouds

Uncertainties in projections of regional climate change

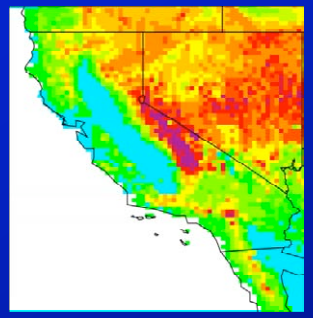
Regional-scale climate is often predicted using linked dynamical models:

Global Climate Model (GCM)



~300 km grid size

Regional Climate Model (RCM)

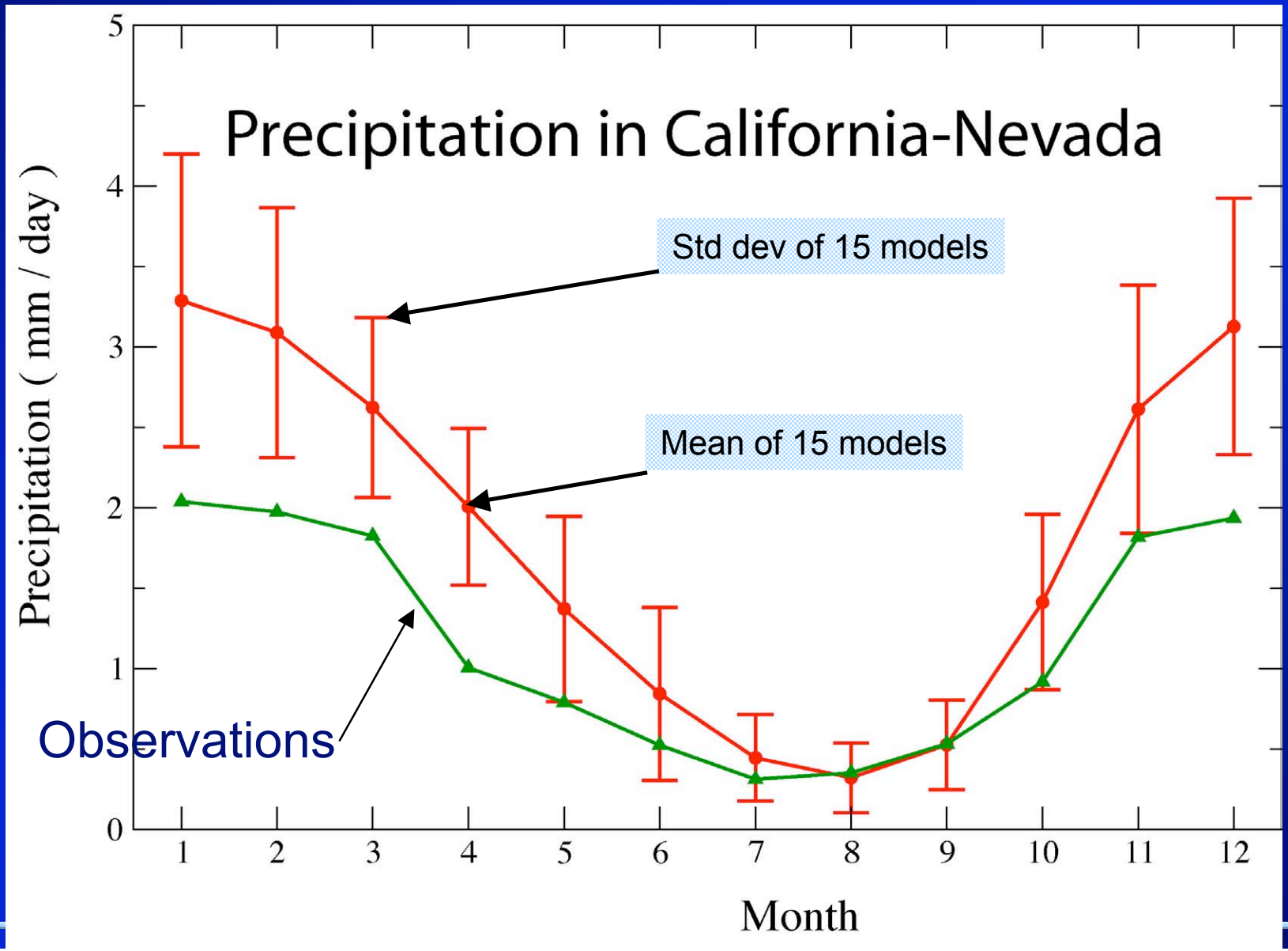


~50 km grid size

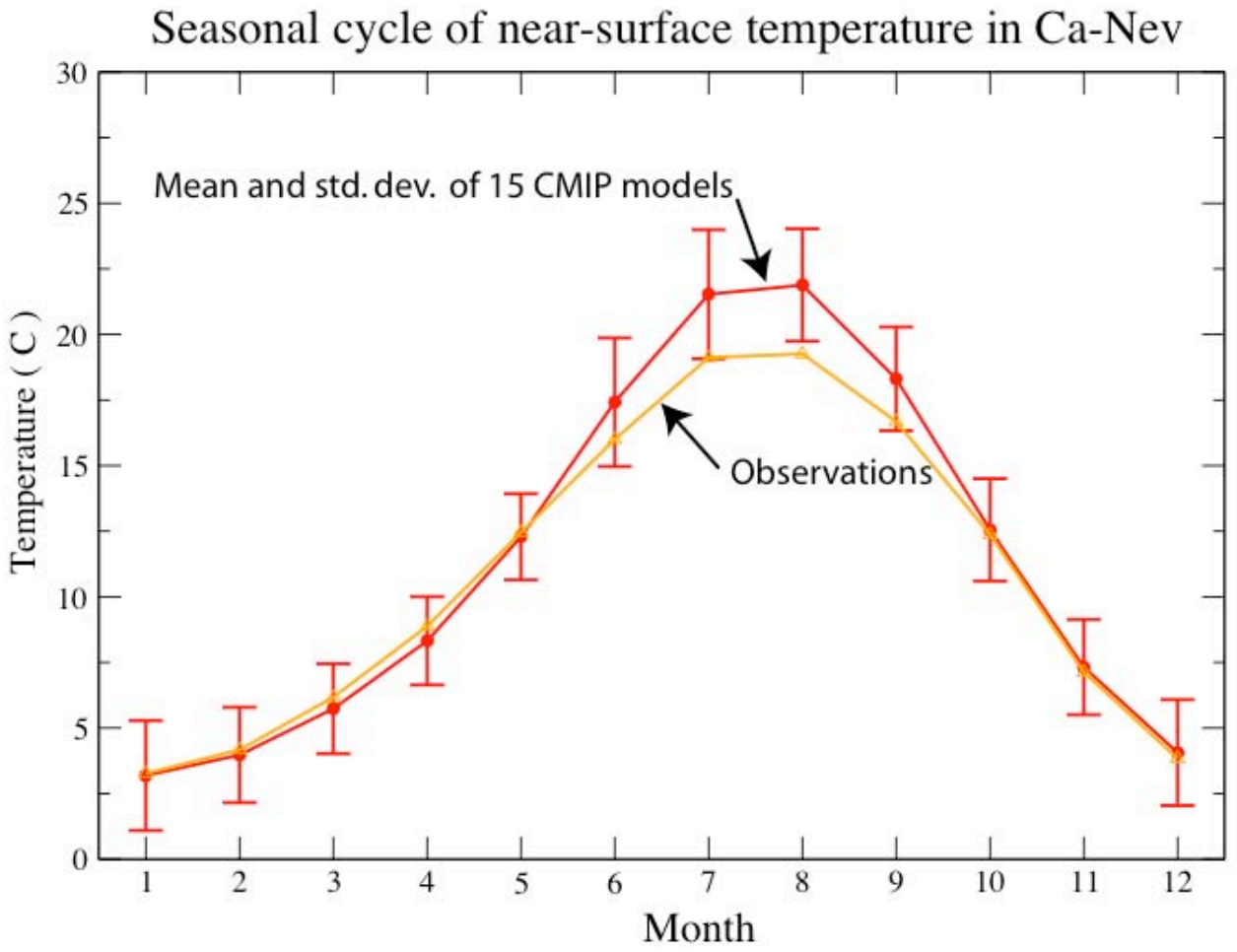
We studied regional-scale results in 15 global climate models participating in CMIP

1. How well do models simulate present-day regional-scale climate? (So-so.)
2. What is range of projected climate responses to increased greenhouse gases? (Big.)
3. Can we narrow this range by considering only models that reproduce observations relatively well? (No.)

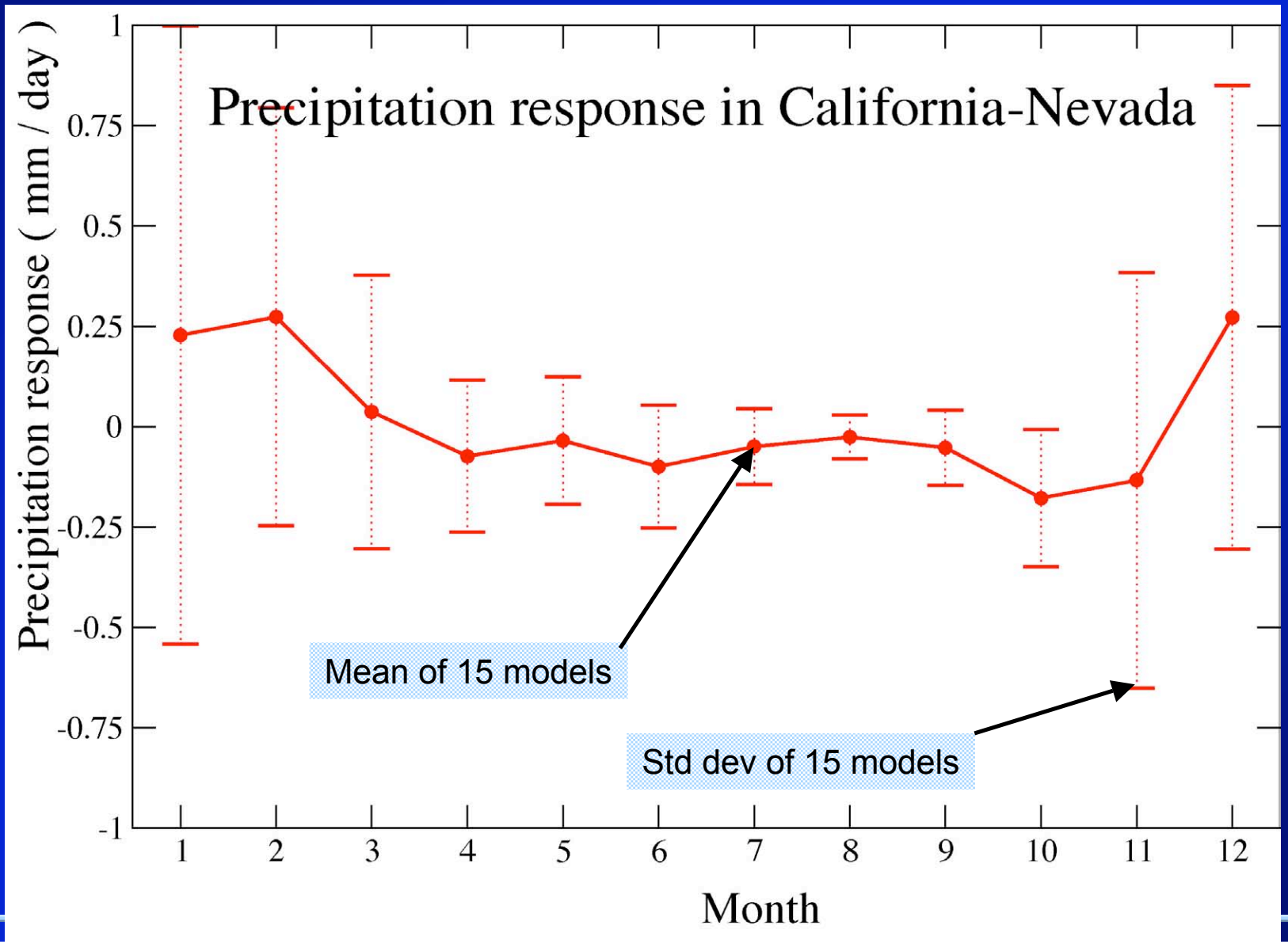
Global climate models have biases…



Global climate models have biases…

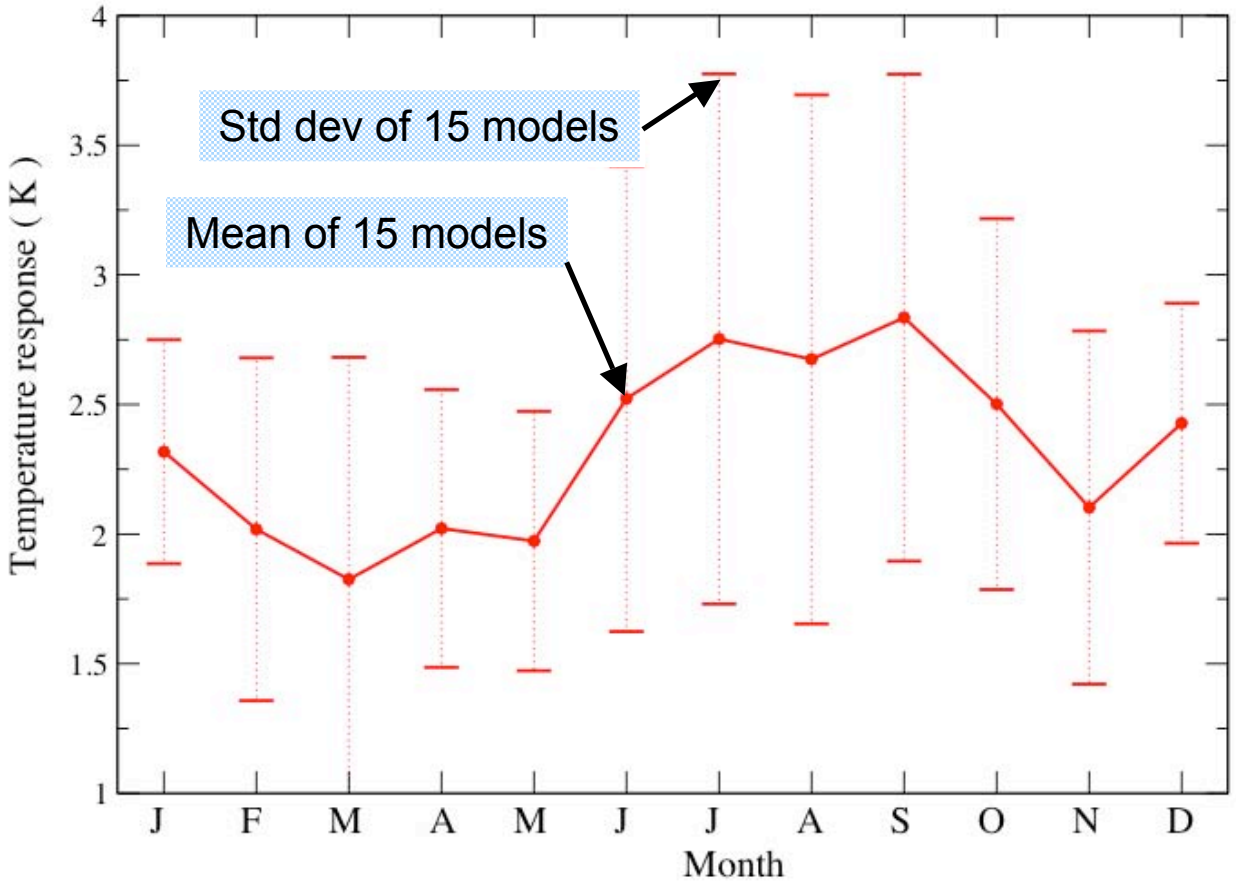


…and don't agree on precipitation response to doubled CO_2

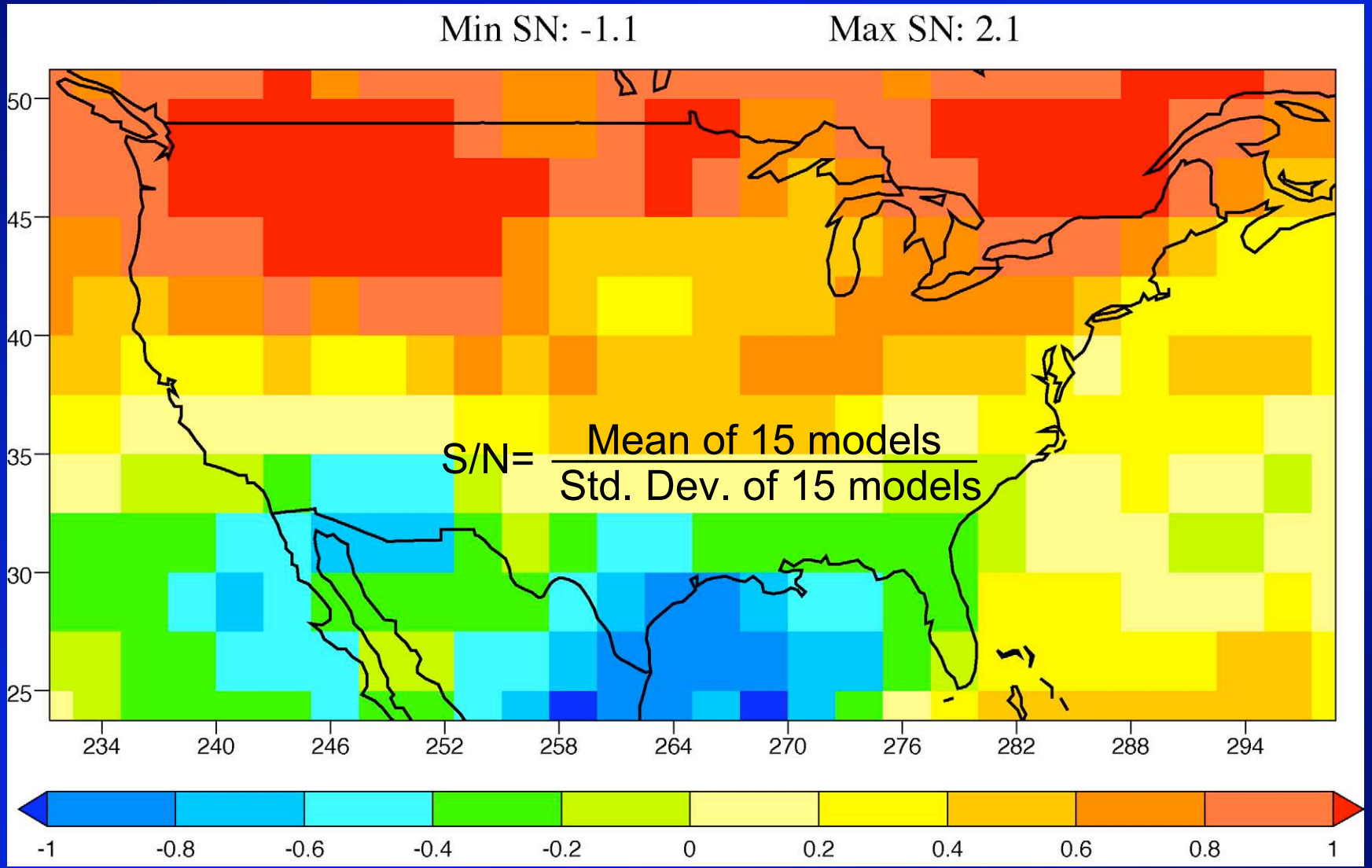


Models agree better on temperature response

Regional response in near-surface temperature to 2x atmospheric CO_2



"Signal/Noise Ratio" in predicted precipitation response to doubled CO_2

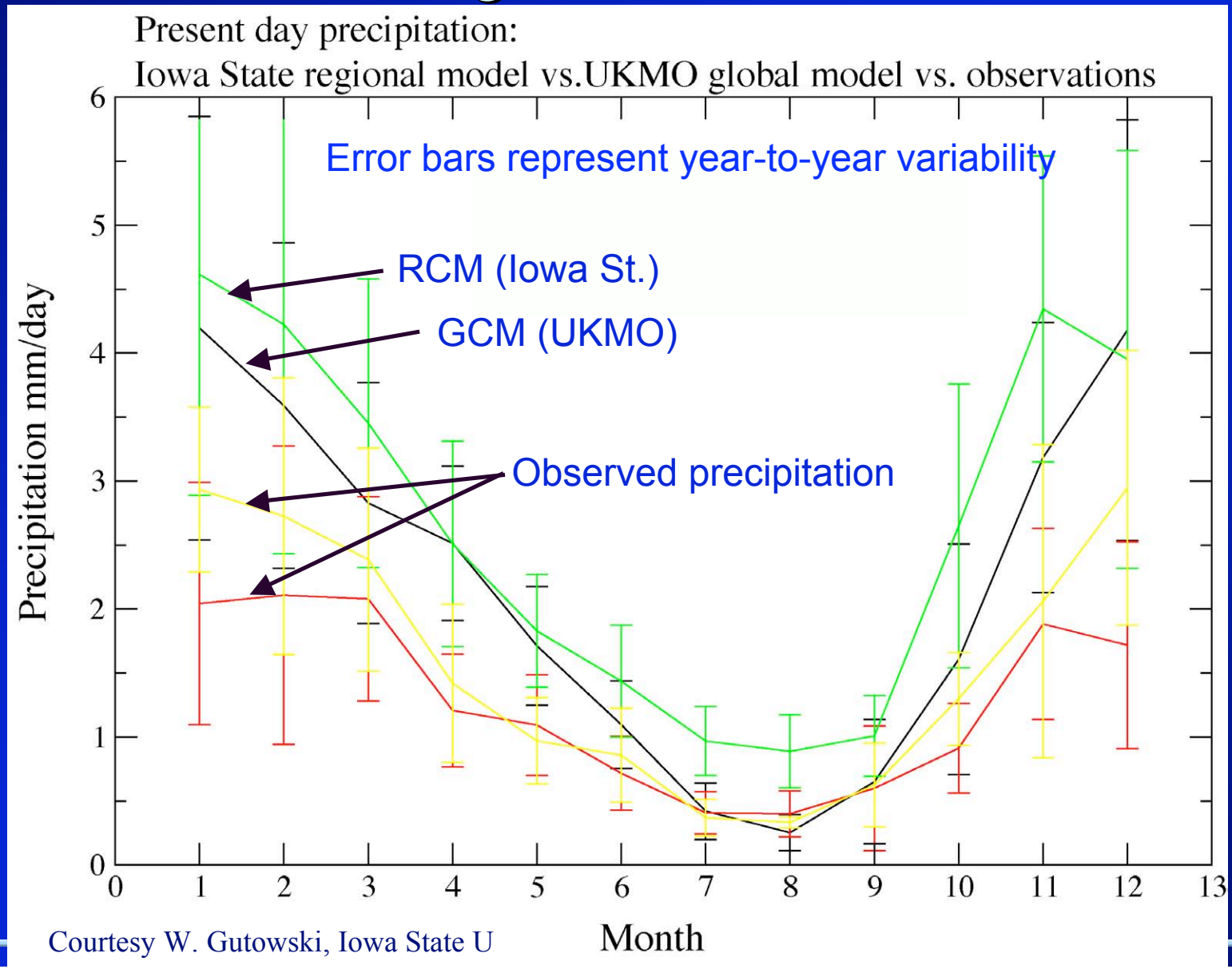


We studied results of existing simulations with 4 RCMs

• Participating groups:	RCM	Driving GCM
W. Gutowski (Iowa St.)	RegCM2	UKMO HadCAM2
J. Kim (UCLA)	MAS	UKMO HadCAM2
R. Leung (PNNL)	MM5	DOE/NCAR PCM
J. Roads (UCSD)	RSM	DOE/NCAR PCM

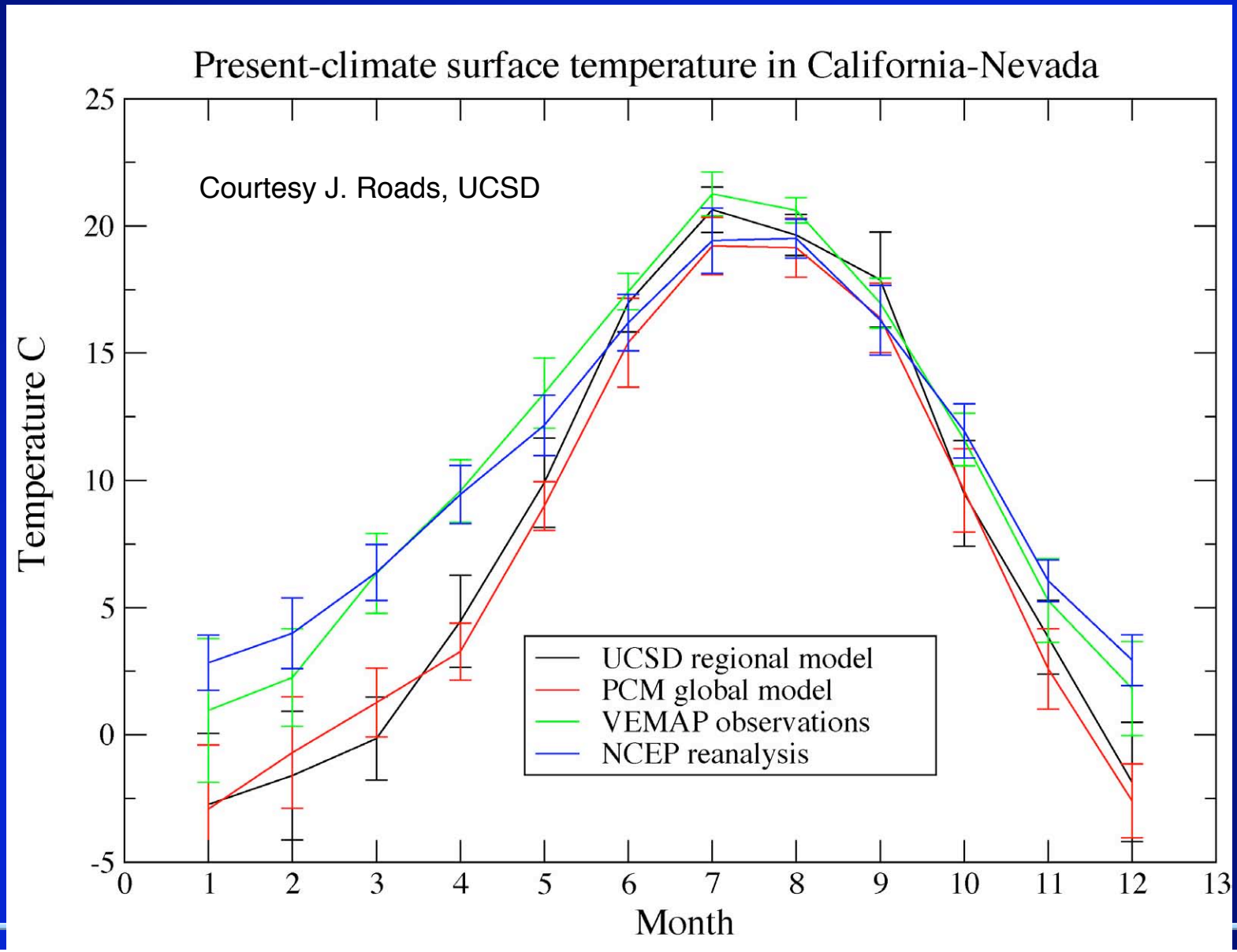
- We looked at simulations of present and future climates.
- Each model used a different increased GHG scenario.

Regional models tend to share biases of global model

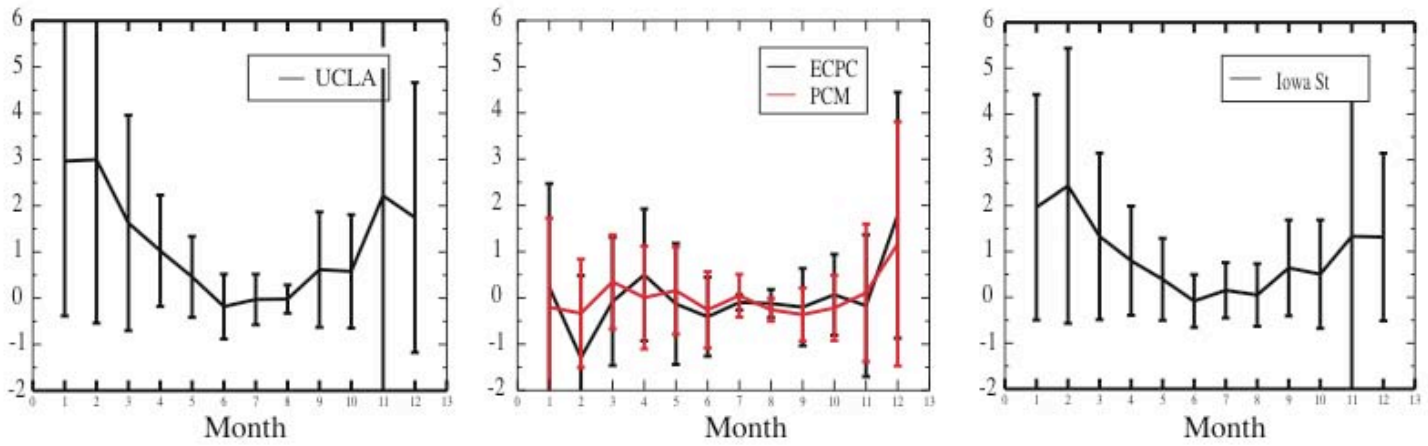


Courtesy W. Gutowski, Iowa State U

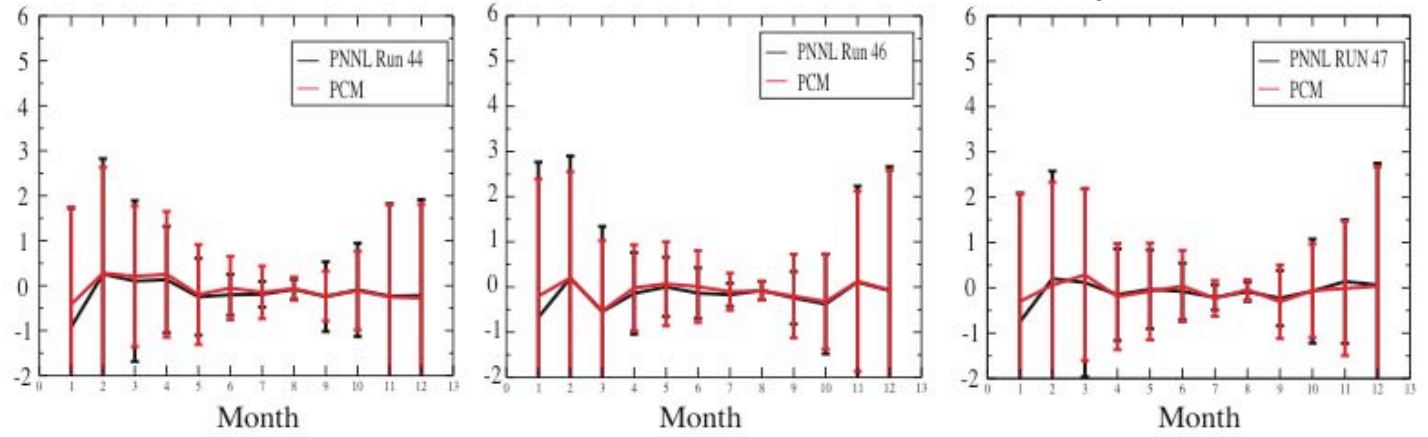
Regional models tend to share biases of global model…



Regional model response tends to follow global model response

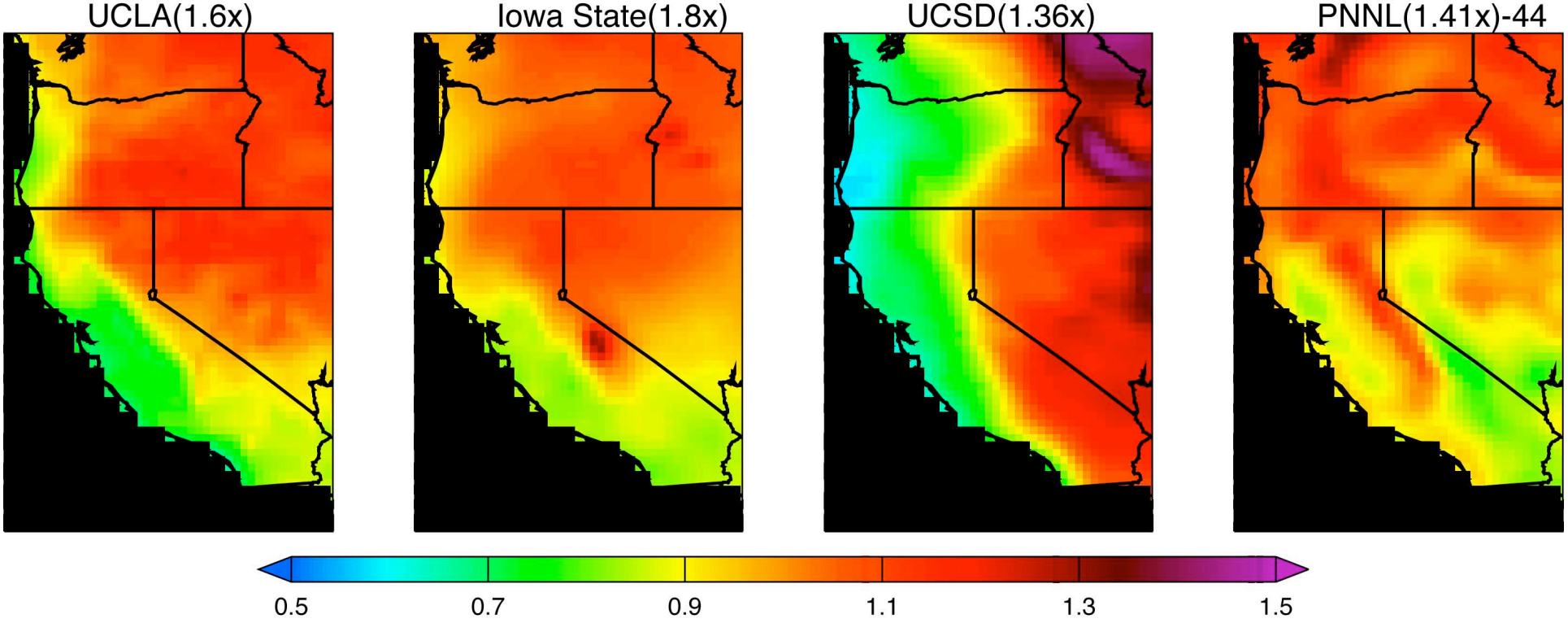


Precipitation response (mm/day) to increased atmospheric CO_2
Error bars represent std. deviation of 10 years



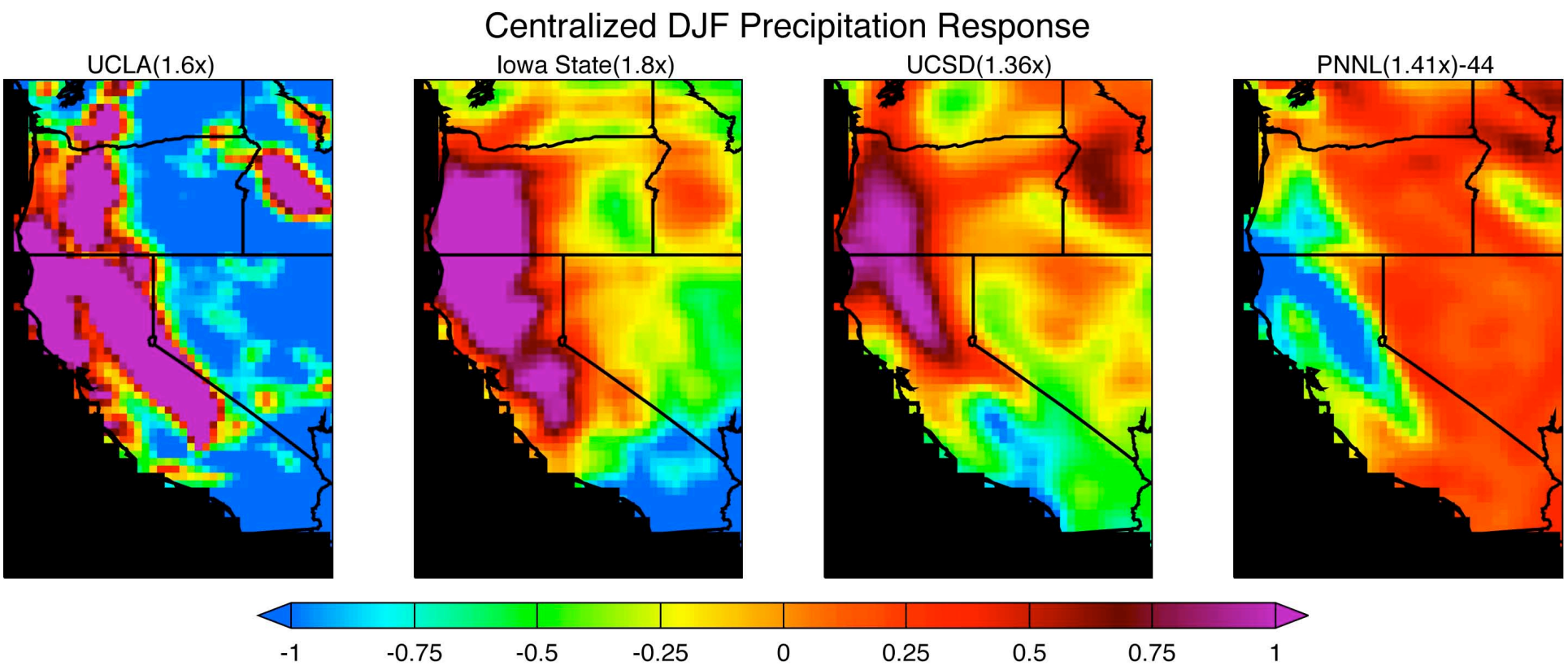
Models don't agree on pattern of temperature response

Normalized Annual Temperature Response



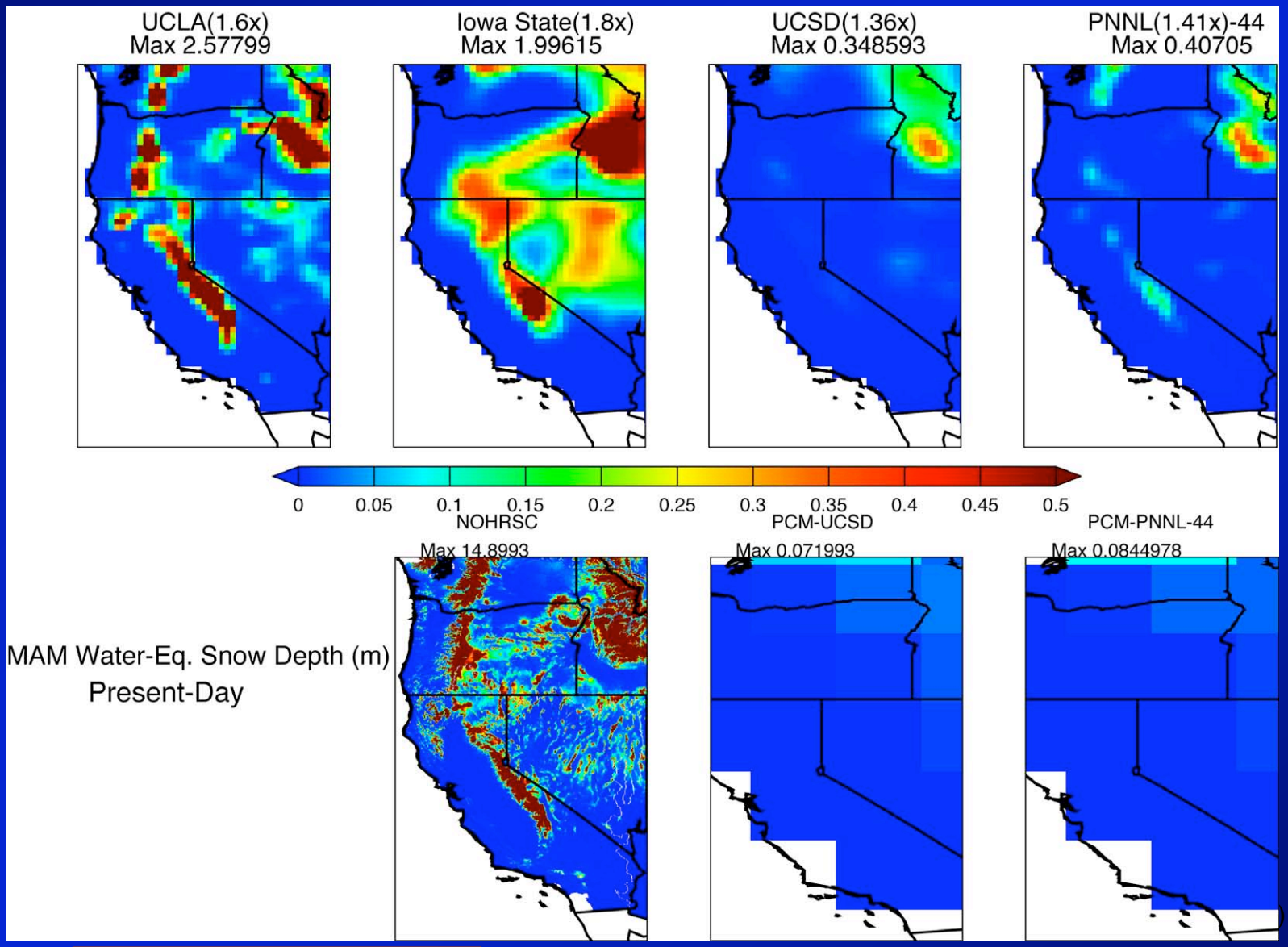
Results courtesy J. Kim (UCLA), W. Gutowski (Iowa St.), J. Roads (UCSD), and R. Leung (PNNL)

Models don't agree on pattern of precipitation response



Courtsey J. Kim (UCLA), J. Roads (UCSD), W. Gutowski (Iowa State), R. Leung (PNNL)

Simulating snow in California is difficult



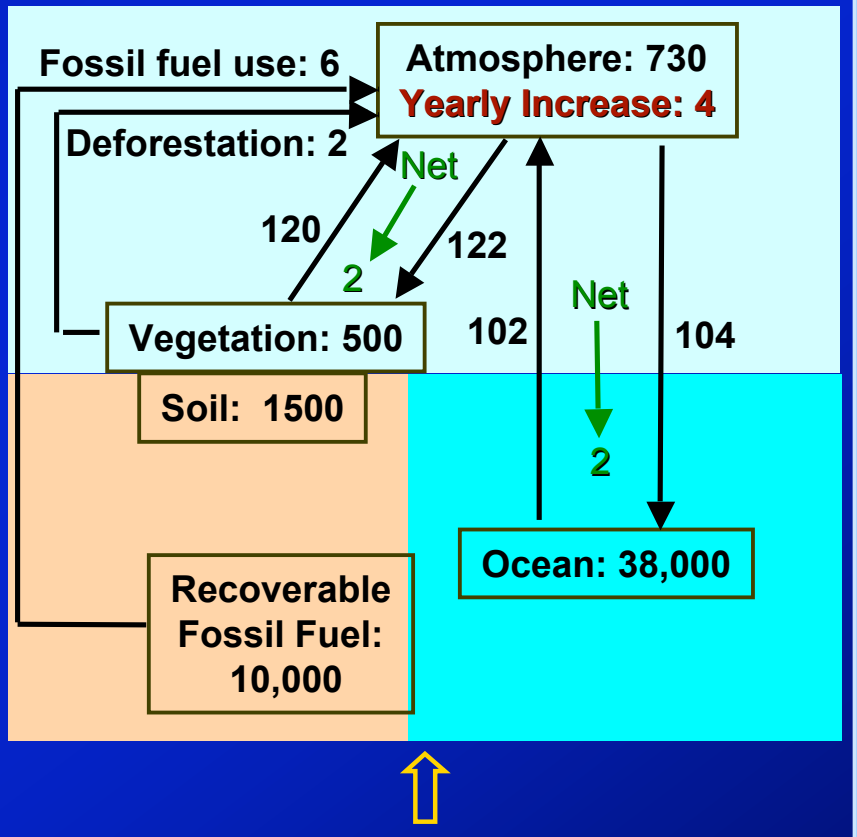
It gets worse…

The Global Carbon Cycle Is Sensitive to Climate Change

- Human activities perturb the natural carbon cycle.
- We put about 8 gigatons of carbon (as CO_2) into the atmosphere per year:

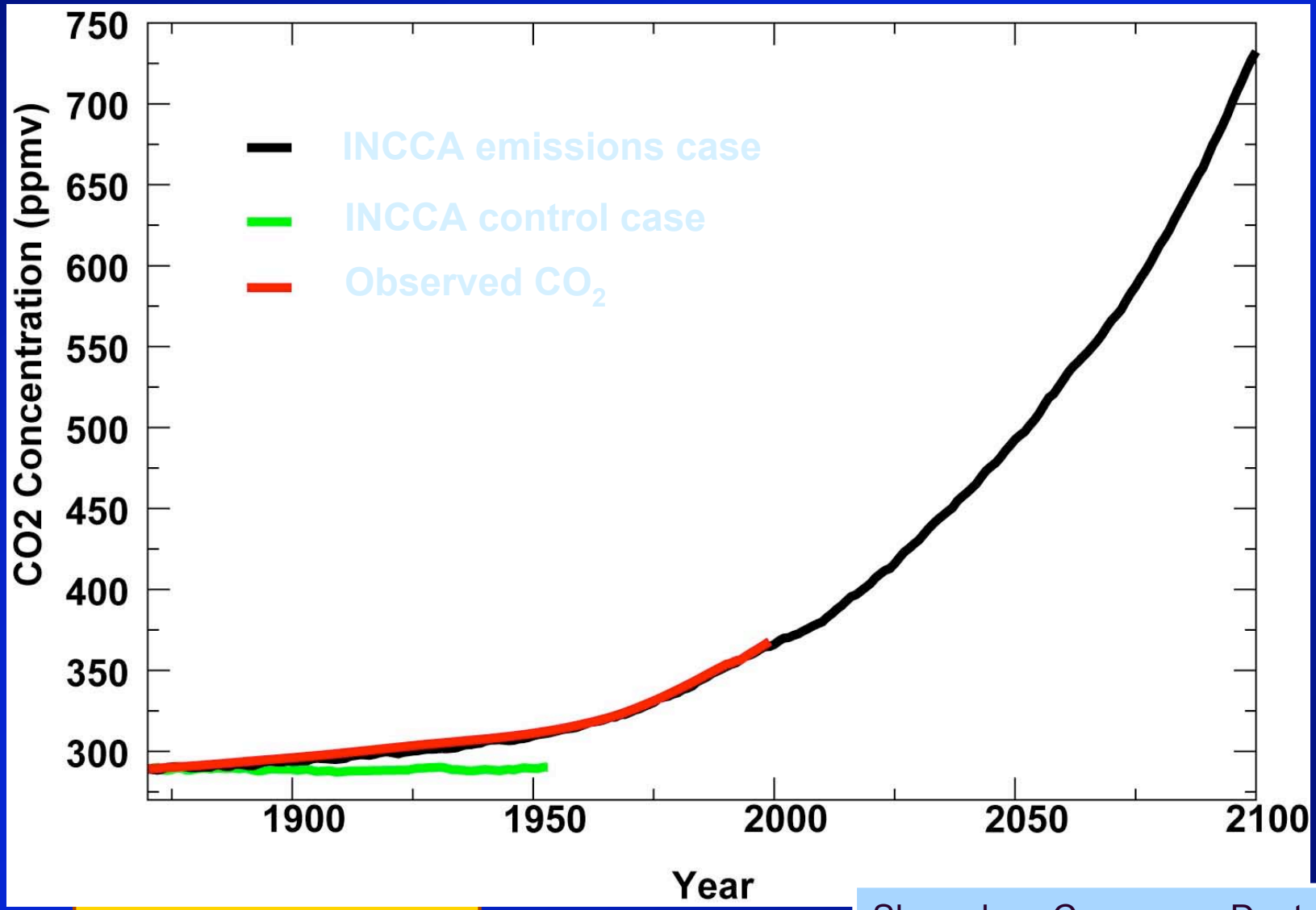
Manmade Source	Gt C/yr
Fossil Fuel Burning:	6
Cement Production:	0.1
Land Use Change:	1.7

- About half the emitted CO_2 accumulates in the atmosphere. The remainder is taken up by the land and oceans.



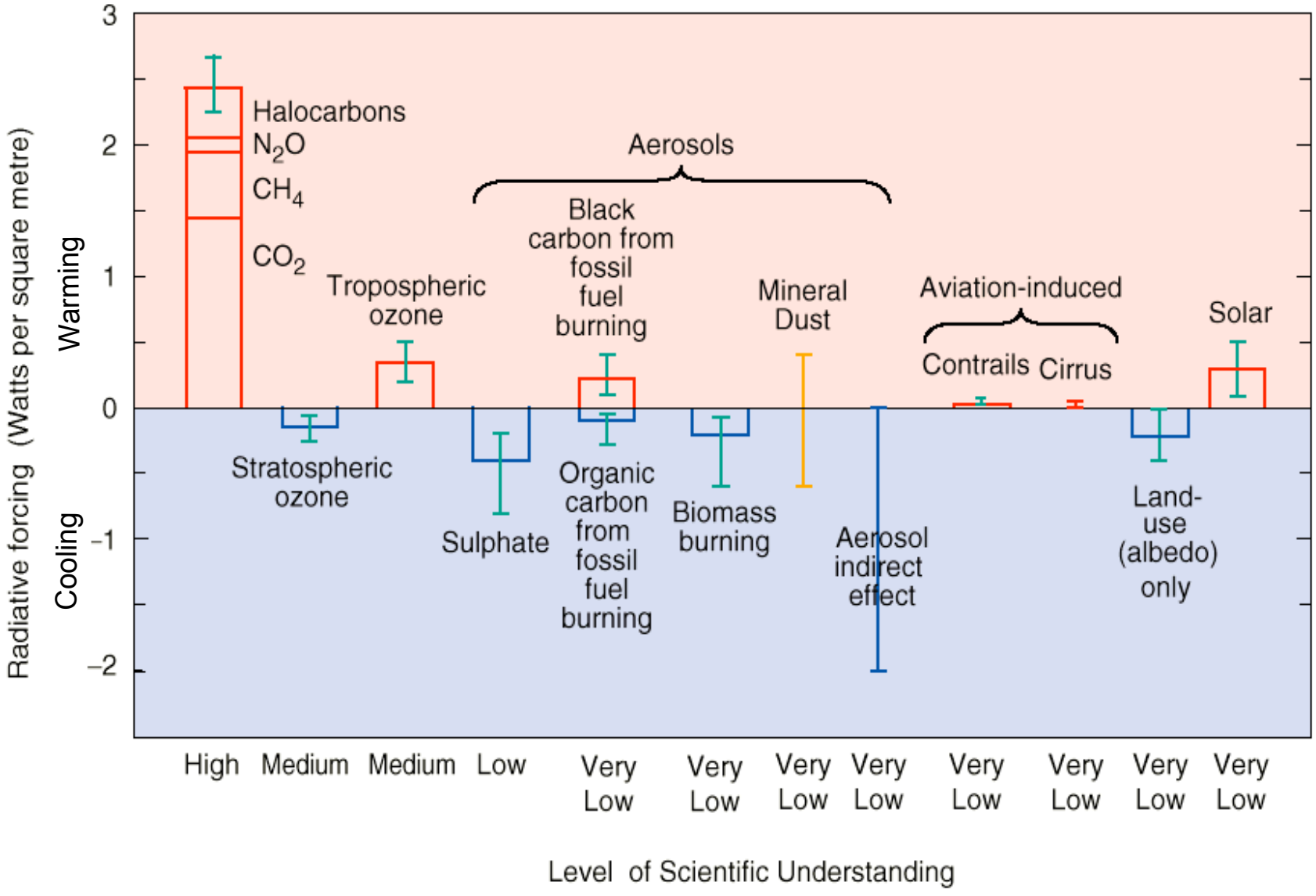
The Global Carbon Cycle. Numbers indicate annual flows and reservoirs in gigatons of carbon.

“INCCA” model is a GCM with interactive C cycle



Shameless Commerce Dept.

Many important climate forcings are very poorly known

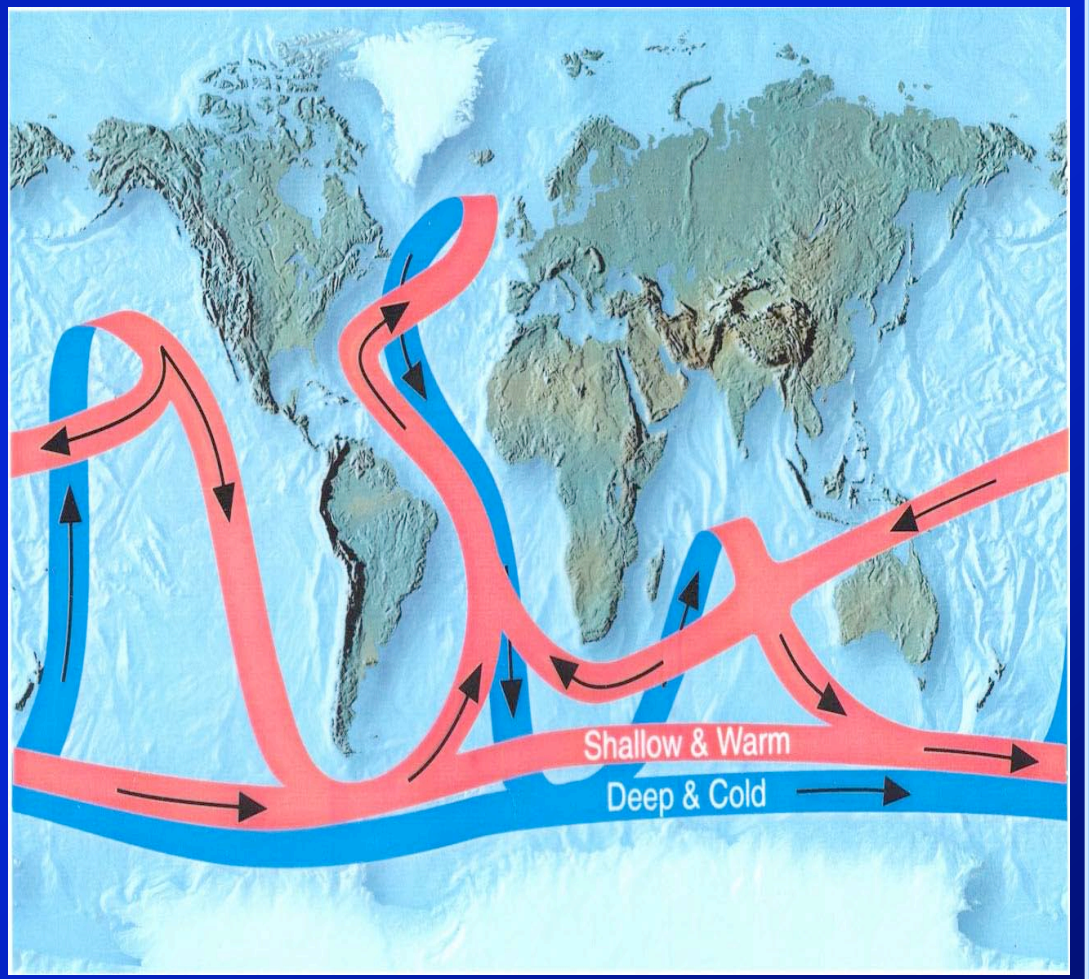


Climate "surprises" are possible

The overturning circulation is driven by the sinking of dense water at high latitudes

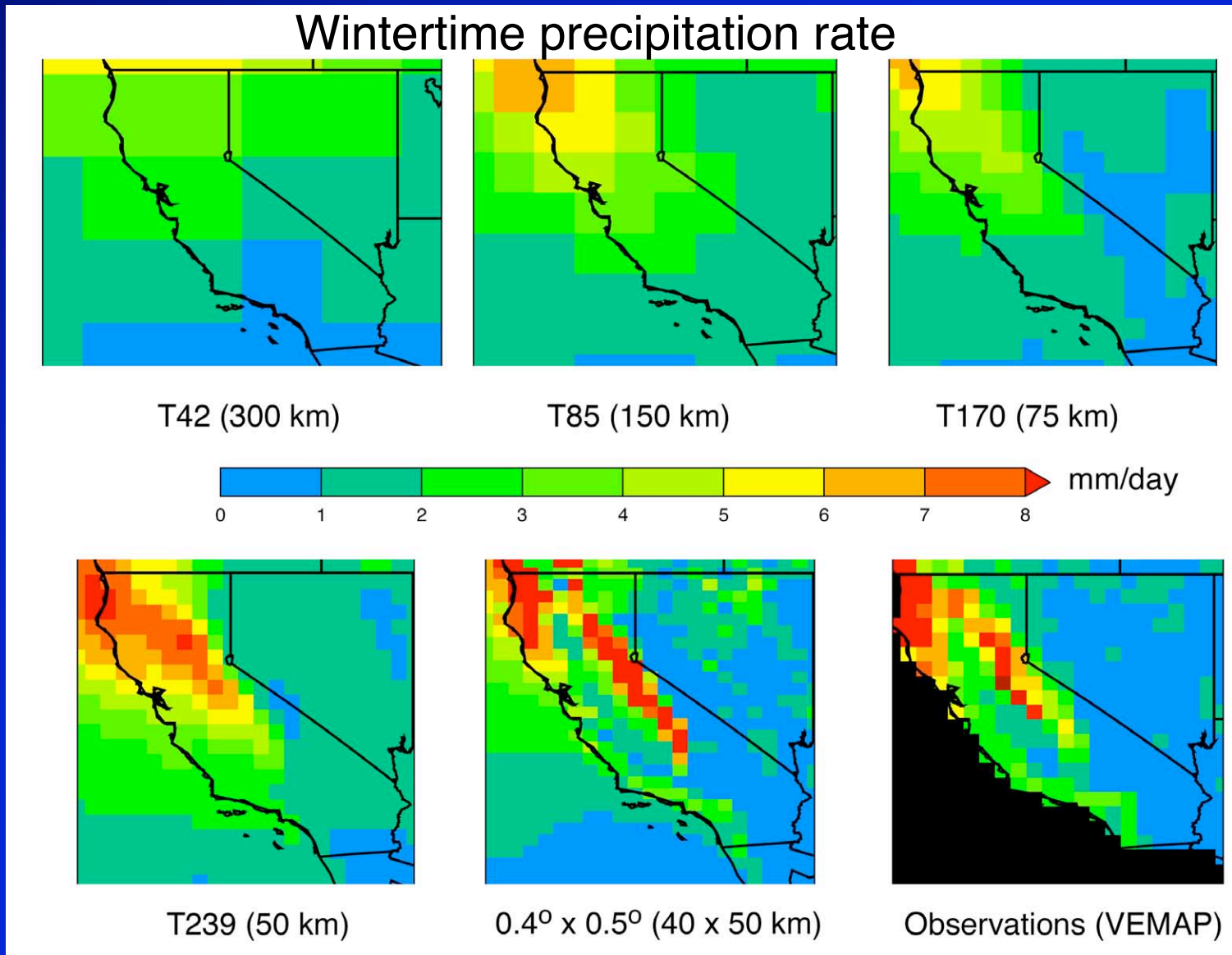
Density is determined by temperature and salinity, thus the term *thermohaline circulation* (*THC*)

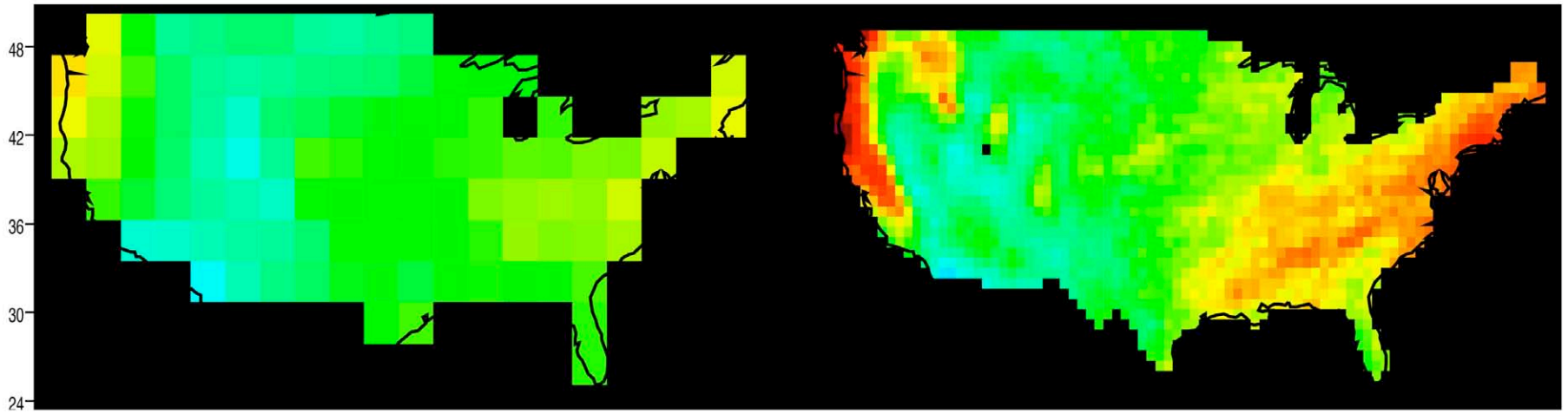
The overturning THC component in the Atlantic Ocean is important for northern hemisphere heat balance



Is there hope?

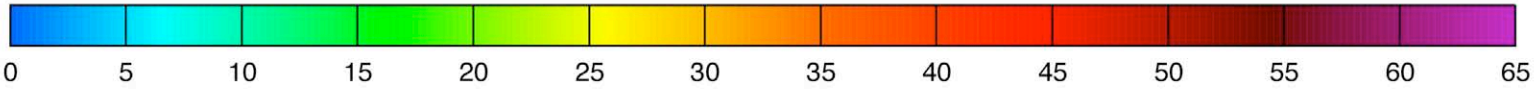
Higher spatial resolution helps…



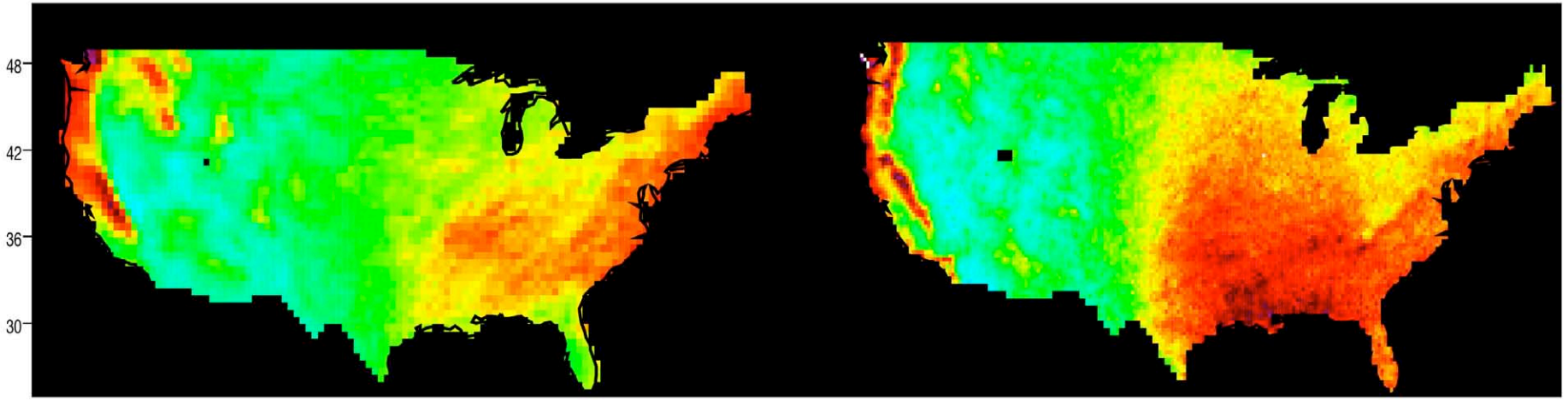


CCM3 at T42 (300 km)

CCM3 at T170 (750 km)



99th %-ile Daily Precipitation Rate (mm/day)

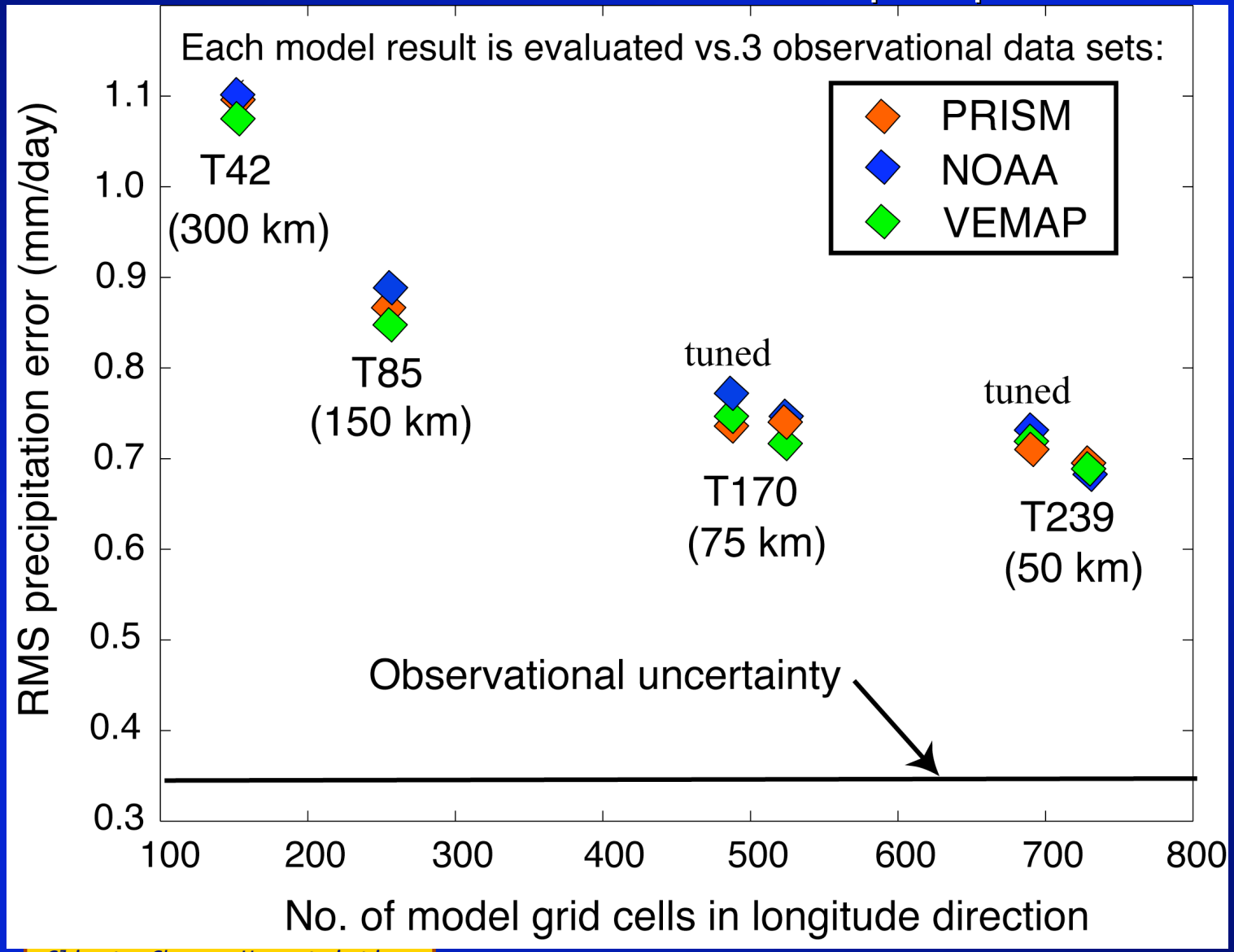


CCM3 at T239 (50 km)

Observations (NOAA)

…But we also need better subgrid scale physics

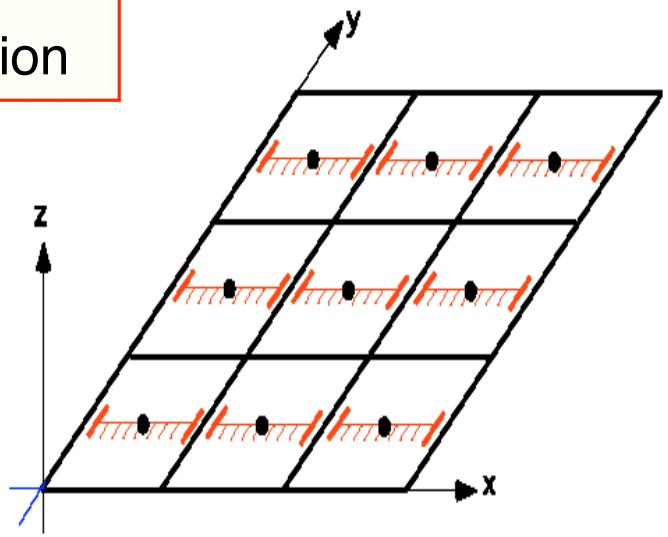
RMS errors in U.S. annual mean precipitation



The "Superparameterization"

- Developed by Khairoutdinov and Randall at Colorado State Univ.
- Replace deep convection and stratiform parameterizations in GCM with an embedded "Cloud System Resolving Model (CSRM) at 4 km resolution.
- Computational cost is 200x cost of GCM with traditional parameterizations*

* This is same as cost of GCM at 50 km resolution



Cloud model samples space within GCM grid cell

Black squares are GCM grid cells ->
Red lines are domain of cloud-resolving model ->

Summary: The bad news

- *Future climate perturbations (CO_2 increases etc.) are not well known.*
- *The global climate response to a given climate perturbation is uncertain by a factor of 3.*
- *We don't know how much climate change is acceptable, because we don't understand the societal impacts of climate change.*
    - *In any case how much climate change is acceptable will vary from region to region.*

Summary: The good news

- *Higher resolution in climate models will help give more accurate projections.*
- *New approaches to representing subgrid scale processes are promising.*
- *All this is terribly expensive computationally.*
- *Climate model evaluation should focus on simulated response to perturbations (e.g. seasonal cycle) not the time-averaged climate.*

The end

Motivation

How much "carbon-free" energy do we need?

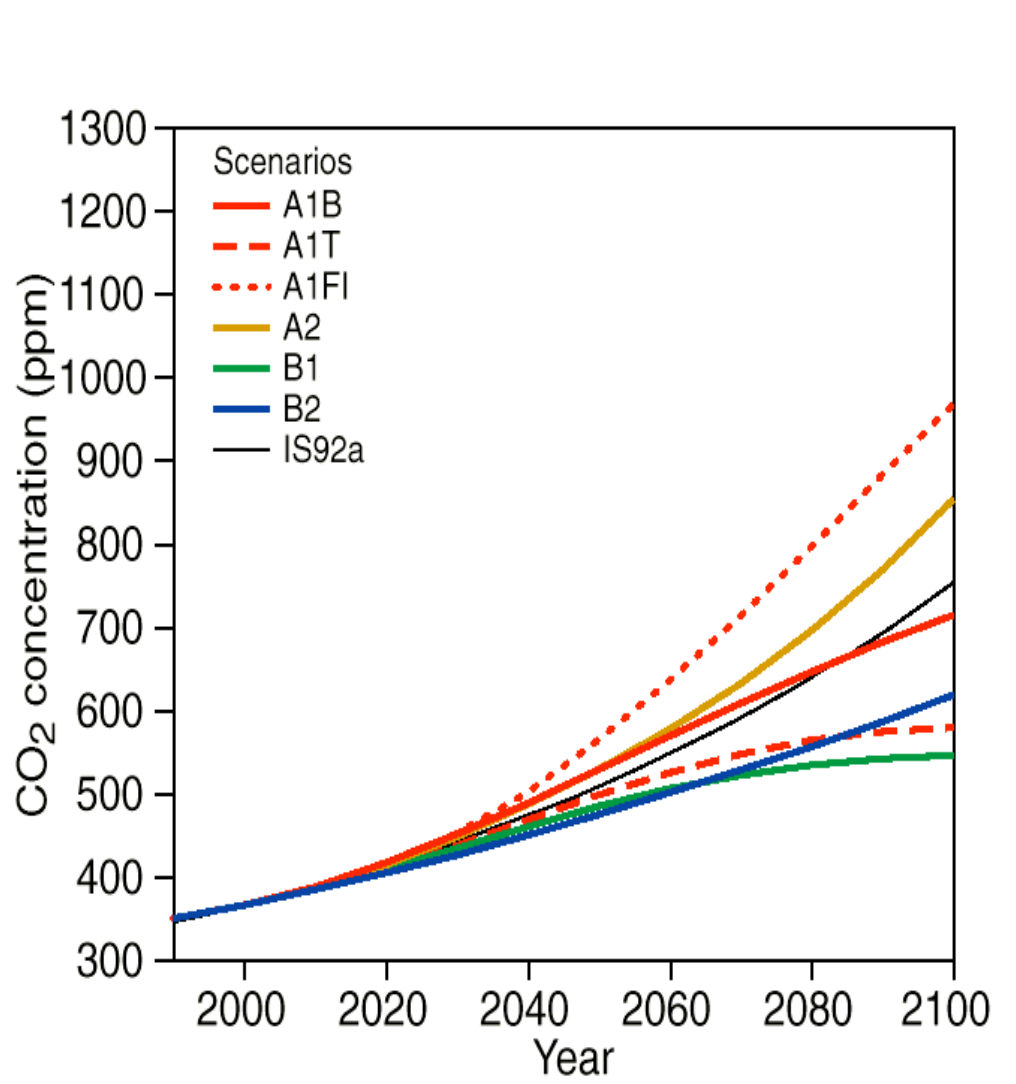
How much fossil fuel can we burn without causing "dangerous interference" in the climate system?

How much climate change is caused by a given increase in atmospheric CO_2?

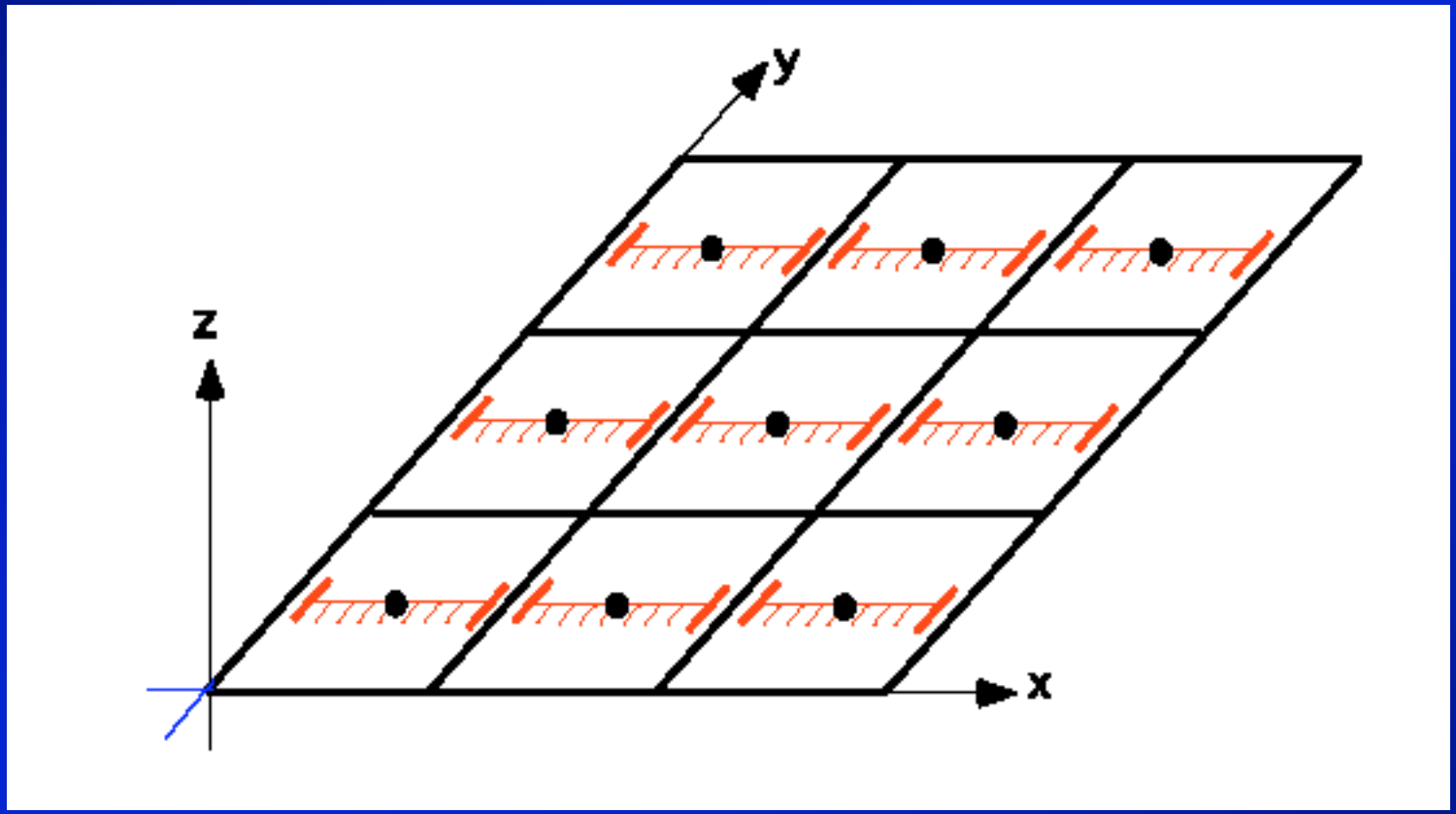
How much climate change is acceptable?

Future CO_2 increases are uncertain

- Emissions of CO_2 due to fossil fuel burning will be the dominant influence on atmospheric CO_2 in the 21st century
- Stabilization of CO_2 at twice the pre-industrial level will require emissions to drop to below 1990 levels in less than 50 years.
- Emissions will need to continue to decrease steadily thereafter to a very small fraction of current emissions.



“Superparameterization” samples space within GCM grid cells using a high-resolution cloud-resolving model



Black squares are GCM grid cells

Red lines are domain of cloud-resolving model

Institute for Research on Climate Change and its Societal Impacts (IRCCSI)

A University of California "Intercampus Research program."

Formed by UC President's Office

Goal: To promote collaborative research into societal impacts of climate change

Approach: Encourage and fund collaborations between climate modeling groups and campus-based expertise in societal impacts.

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