Global/Regional Interdependencies in Climate Models and Observations

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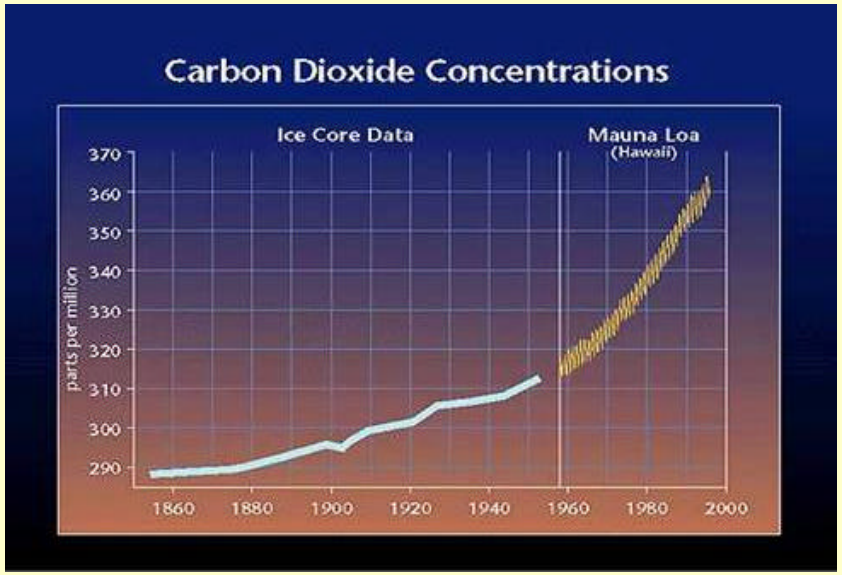
Outline

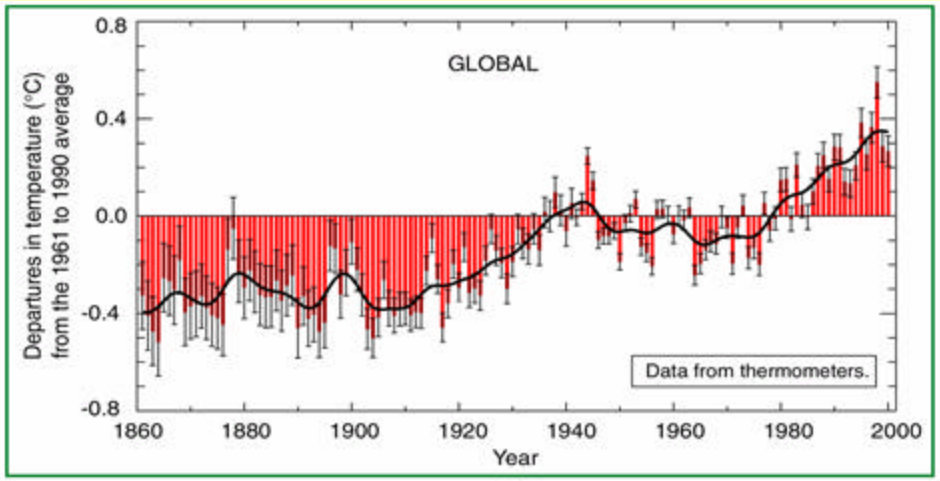
- Introduction to Global Climate Models (GCMs)
- Validation of GCM climate simulations
- Global → Regional climate connections
- Regional → Global climate connections

Introduction to Global Climate Models (GCMs)

Global Climate Models:



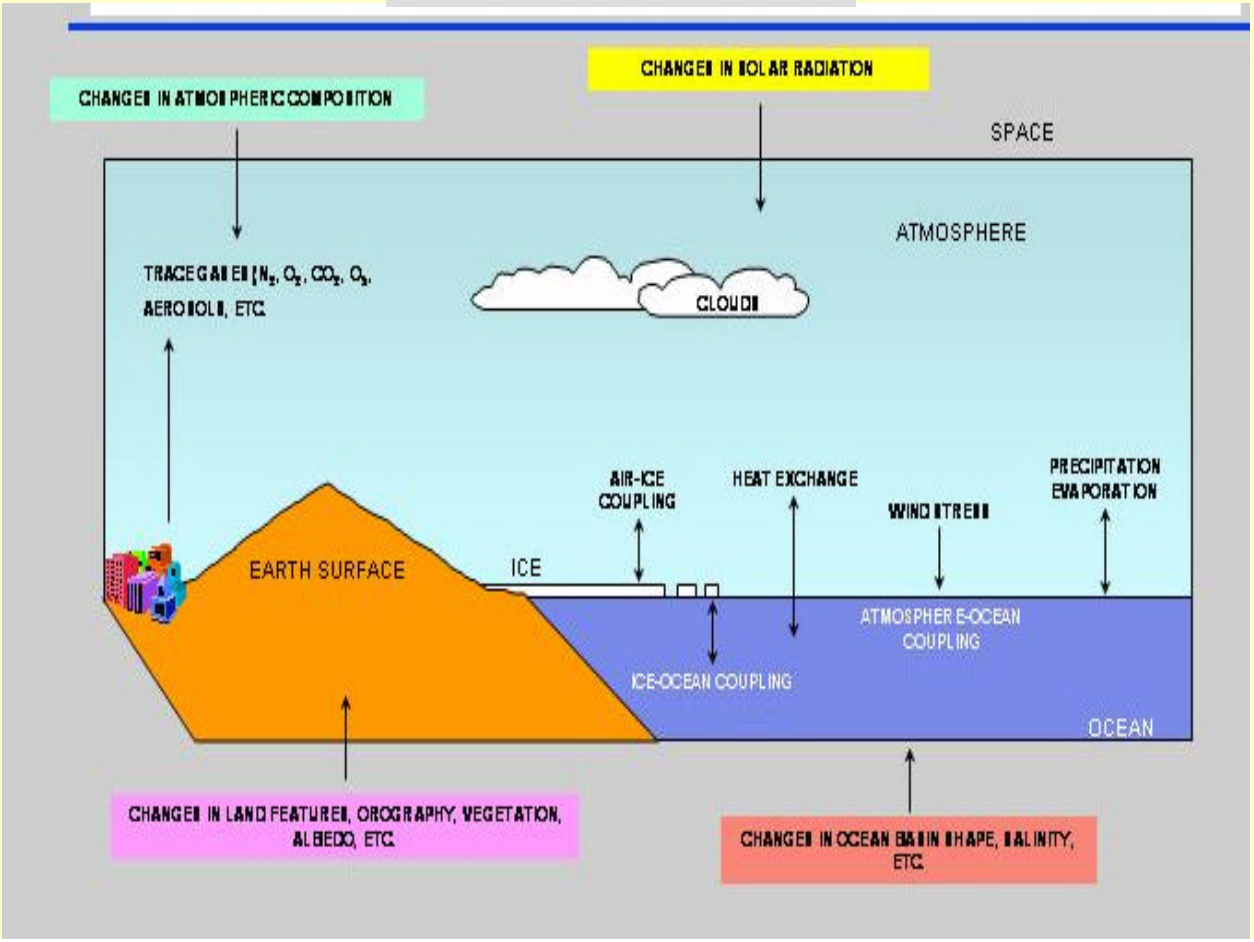
- These complex computer programs (collections of numerical algorithms) are our chief tools for simulating both the historically observed climate and potential future climate change…



Global Climate Models:

- Are based on sets of coupled, nonlinear, time-dependent differential equations that represent physical forcings (e.g. solar heating S, infrared cooling I, turbulent heat transfers H), the dynamics of atmosphere/oceans (e.g. winds and currents), and their interactions with land and sea ice…

The Climate System



Schematic Example:

$$\frac{dT_s}{dt} = S - I - H$$

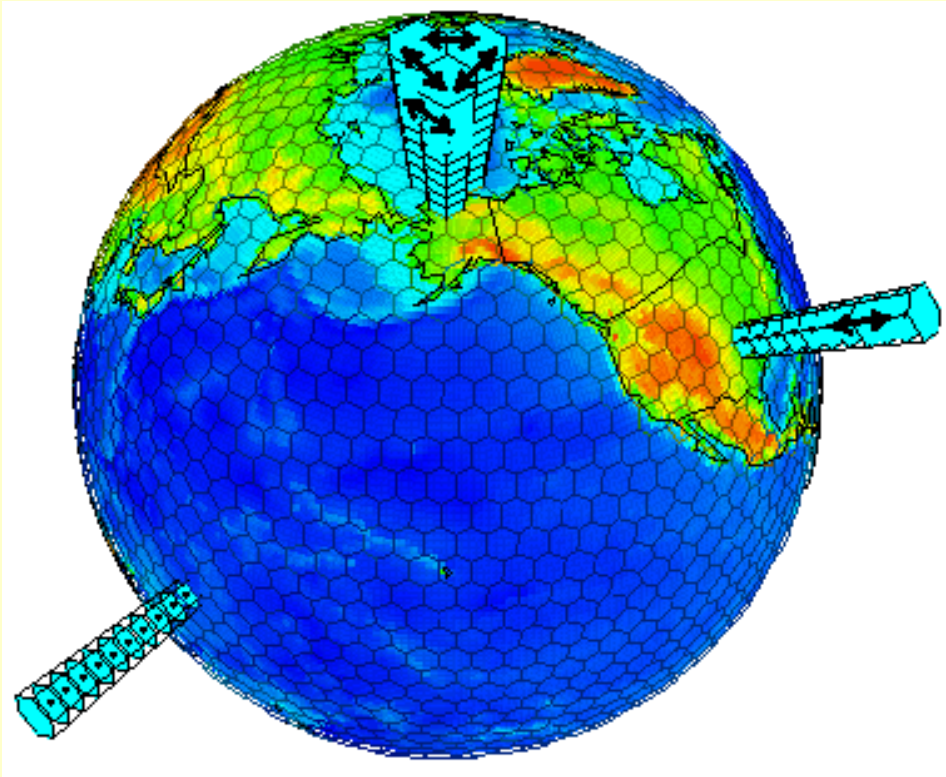
where

$\frac{dS}{dt}$, $\frac{dI}{dt}$, and $\frac{dH}{dt}$

depend nonlinearly on other variables

Global Climate Models:

- The governing differential equations are approximated as *finite differences* that are solved (on computers) in grid boxes that map the globe



Typical resolution of a GCM grid box:

~ 3 x 3 degrees latitude/longitude

~ 25 vertical levels in both atmosphere and oceans

Global Climate Models:

Subgrid-scale processes must be “parameterized” in terms of variables that can be solved on the GCM grid.

For example, GCM precipitation is approximated as a function of grid-scale predictions of atmospheric moisture, temperature, and vertical motion, but *not* subgrid-scale cloud physics.

Global Climate Models:

Simulate the evolution of the climate system, one short step at a time…

Schematic time-difference equation for eastward wind speed u:

$$\frac{\Delta u}{\Delta t} = -k\frac{\Delta p}{\Delta x}$$

where:

u = eastward wind speed

t = time

Δp = eastward pressure gradient

Δx

Solve for Δu:

$$\Delta u = -k\left(\frac{\Delta p}{\Delta x}\right)\Delta t$$

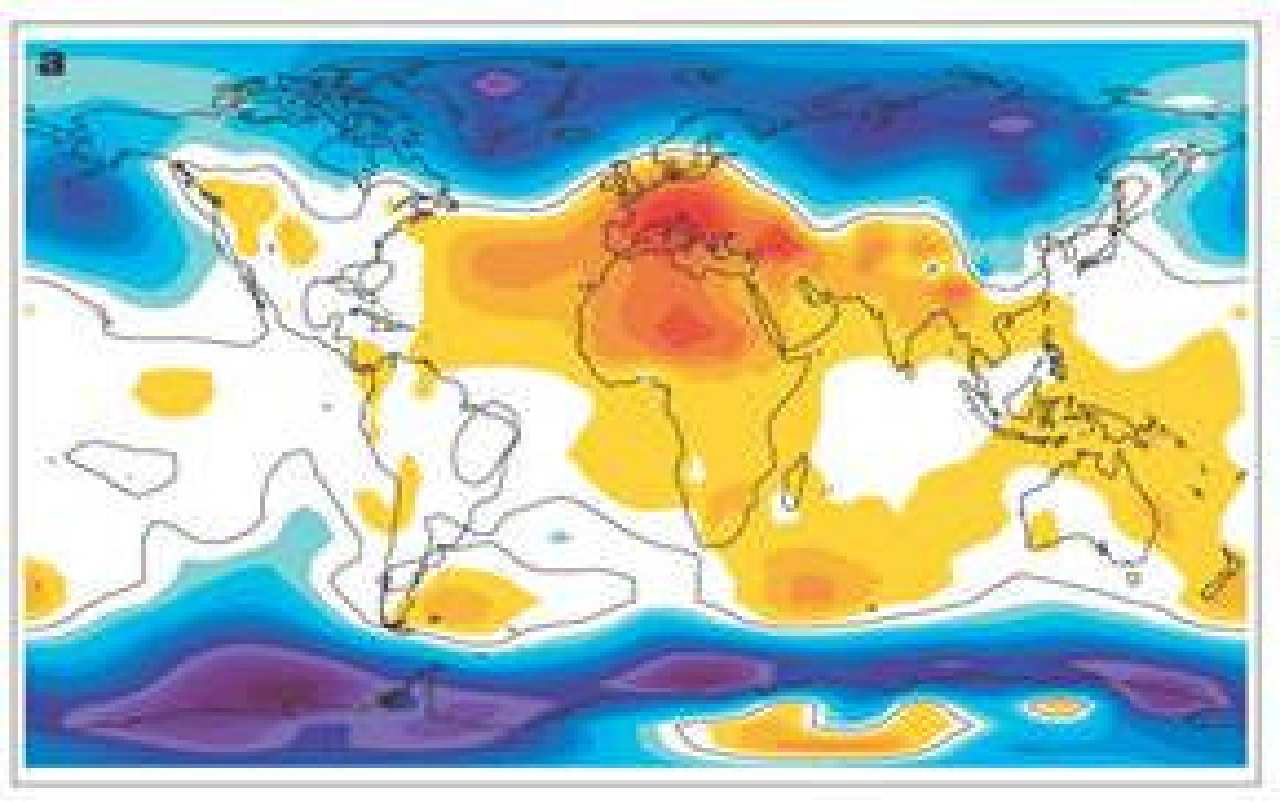
where, typically, Δt ~ 15-20 minutes

Then new wind speed $u' = u + \Delta u$

“Climate”--a statistical concept

Global Climate = Mean, variance, or higher statistical moments of a long time series of

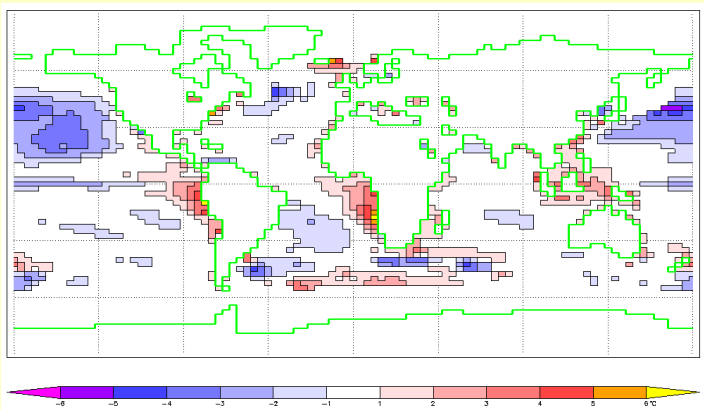
- **Aggregated local weather observations —“Observed Climate”**
- **GCM simulation output (many time steps) at each grid box— “Model Climate”**

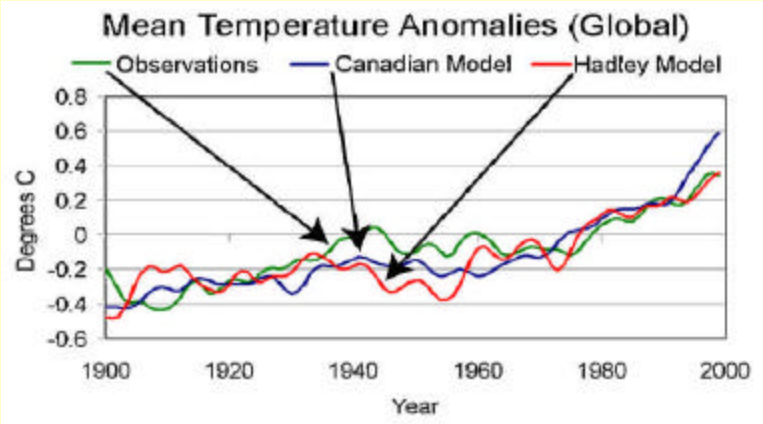


Validation of GCM climate simulations

Validating GCM historical climate simulations

GCM Sea Surface Temperature Errors





- **Observations in space/time of a climate variable V obtained by a variety of methods (e.g. *in situ* measurements, balloon sondes, ocean buoys, satellites) are aggregated and mapped on a global grid**

  → Derive gridded global observational reference datasets

- **The temporal statistics (e.g. time means, variances) of the GCM simulation of climate variable V and those of the corresponding observations of V are compared, *after remapping to a common grid***

  → Determine GCM - Observational statistical differences for variable V

- **GCM climate statistics of V also are compared with those of other observations of V, when these are available**

  → Estimate current observational uncertainties, and significance of GCM errors

Validating GCM historical climate simulations

Phillips and Gleckler, 2006 *Water Resources Research*

WATER RESOURCES RESEARCH, VOL. 42, W03202, doi:10.1029/2005WR004313, 2006

Evaluation of continental precipitation in 20th century climate simulations: The utility of multimodel statistics

Thomas J. Phillips[1] and Peter J. Gleckler[1]

Received 3 June 2005; revised 28 October 2005; accepted 30 November 2005; published 18 March 2006.

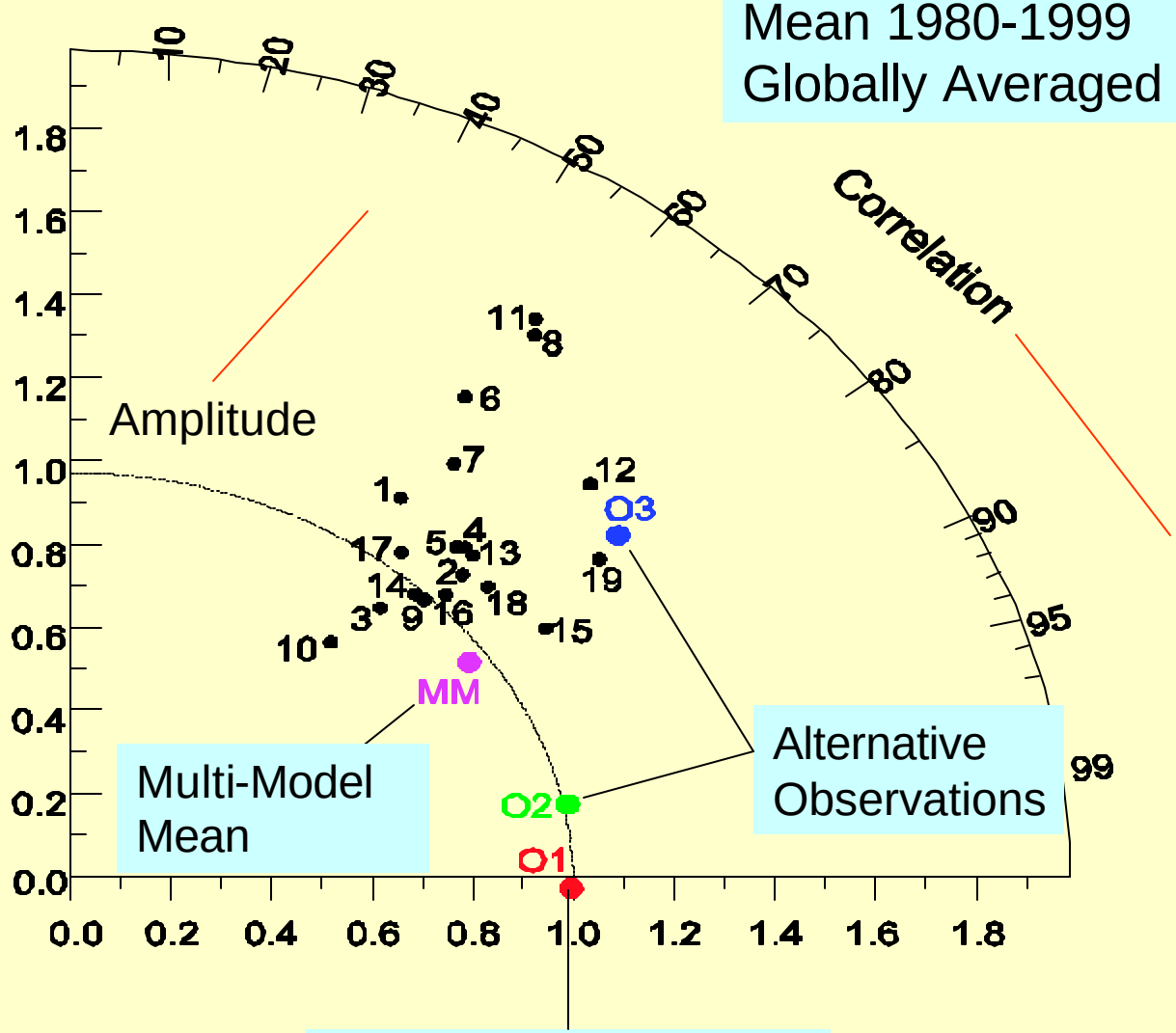
[1] In support of the Intergovernmental Panel on Climate Change (IPCC), simulations of 20th century climate have been performed recently with some 20 global coupled ocean-atmosphere models. In view of its central importance for biological and socioeconomic systems, model-simulated continental precipitation is evaluated relative to three observational estimates at both global and regional scales. Many models are found to display systematic biases, deviating markedly from the observed spatial variability and amplitude/phase of the seasonal cycle. However, the pointwise ensemble mean of all the models usually shows better statistical agreement with the observations than does any single model. Deficiencies of current models that may be responsible for the simulated precipitation biases as well as possible reasons for the improved estimate afforded by the multimodel ensemble mean are discussed. Implications of these results for water resource managers also are briefly addressed.

Citation: Phillips, T. J., and P. J. Gleckler (2006), Evaluation of continental precipitation in 20th century climate simulations: The utility of multimodel statistics, *Water Resour. Res.*, *42*, W03202, doi:10.1029/2005WR004313.

Validating global continental precipitation in multiple GCMs

From Phillips & Gleckler, 2006 *WRR*

Mean 1980-1999
Globally Averaged Statistics



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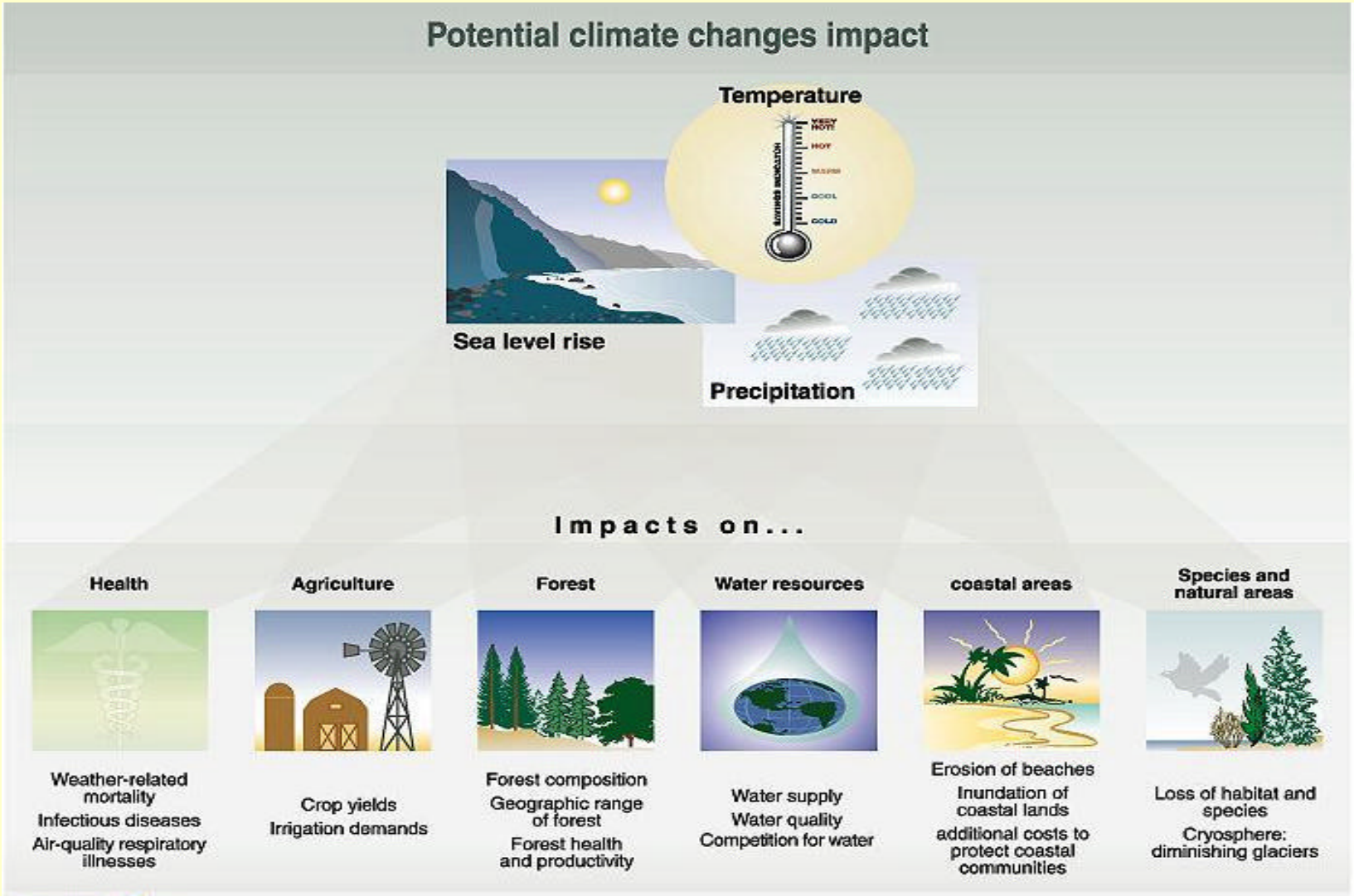
However, climate impacts are experienced on regional scales…

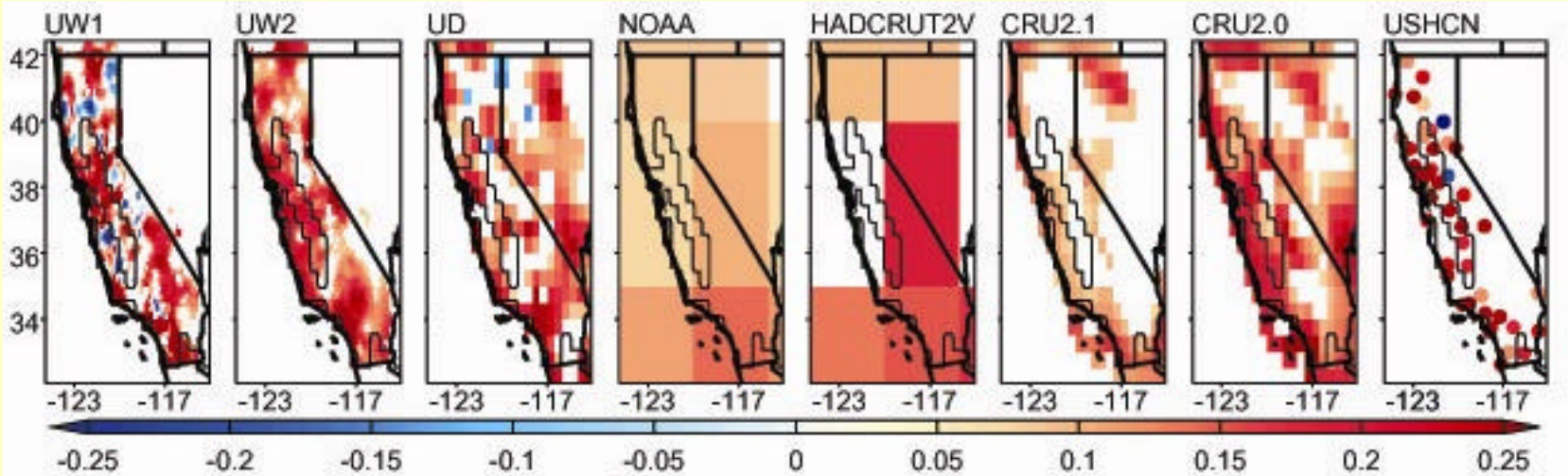


Global → Regional climate connections

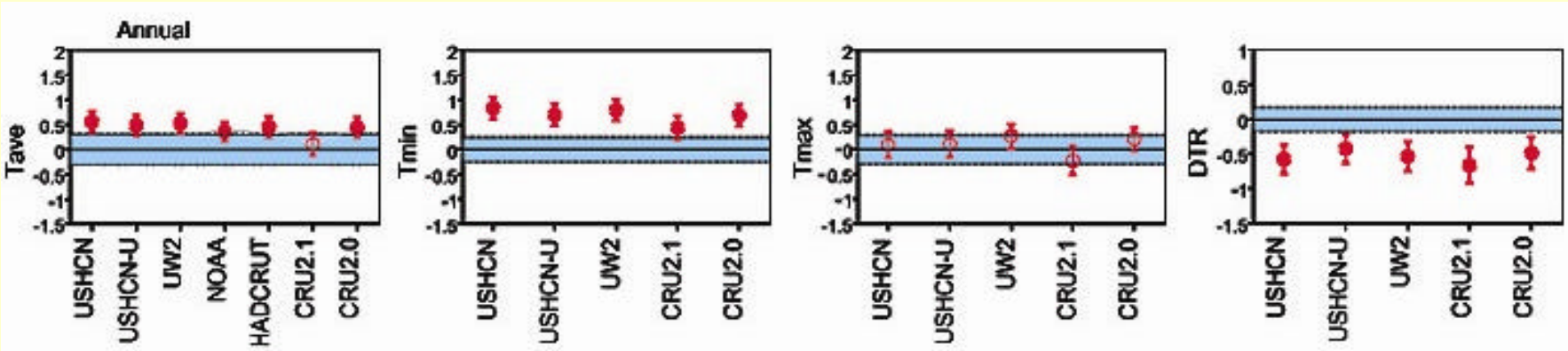
Using inter-GCM differences to assess observed CA temperature trends

From Bonfils et al. , 2006 *Climatic Change*

50-Year Trends in Daily Surface Temperatures for Different Observational Datasets



CA-Average Trends in Daily Mean, Max, Min, and Max - Min Temperatures vs. GCM 2s dev'ns



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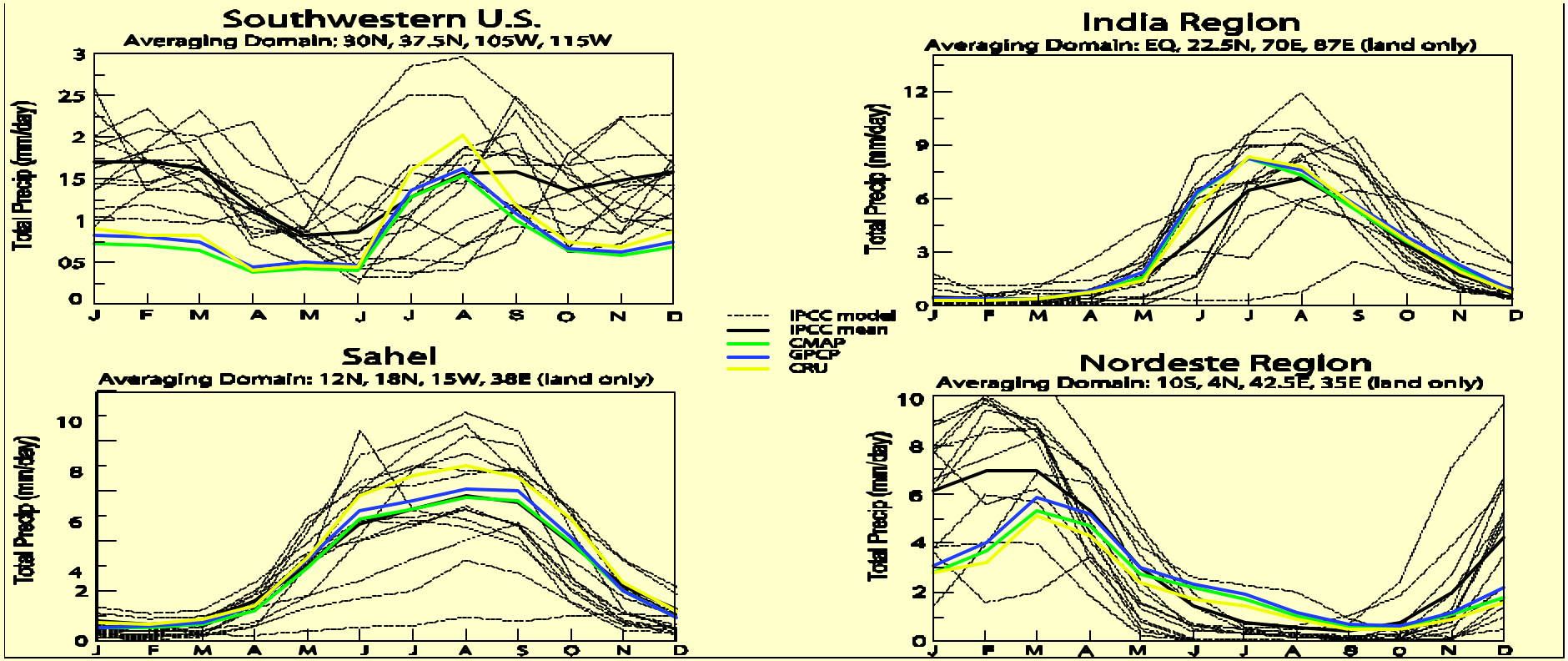
Validating regional continental precipitation in multiple GCMs

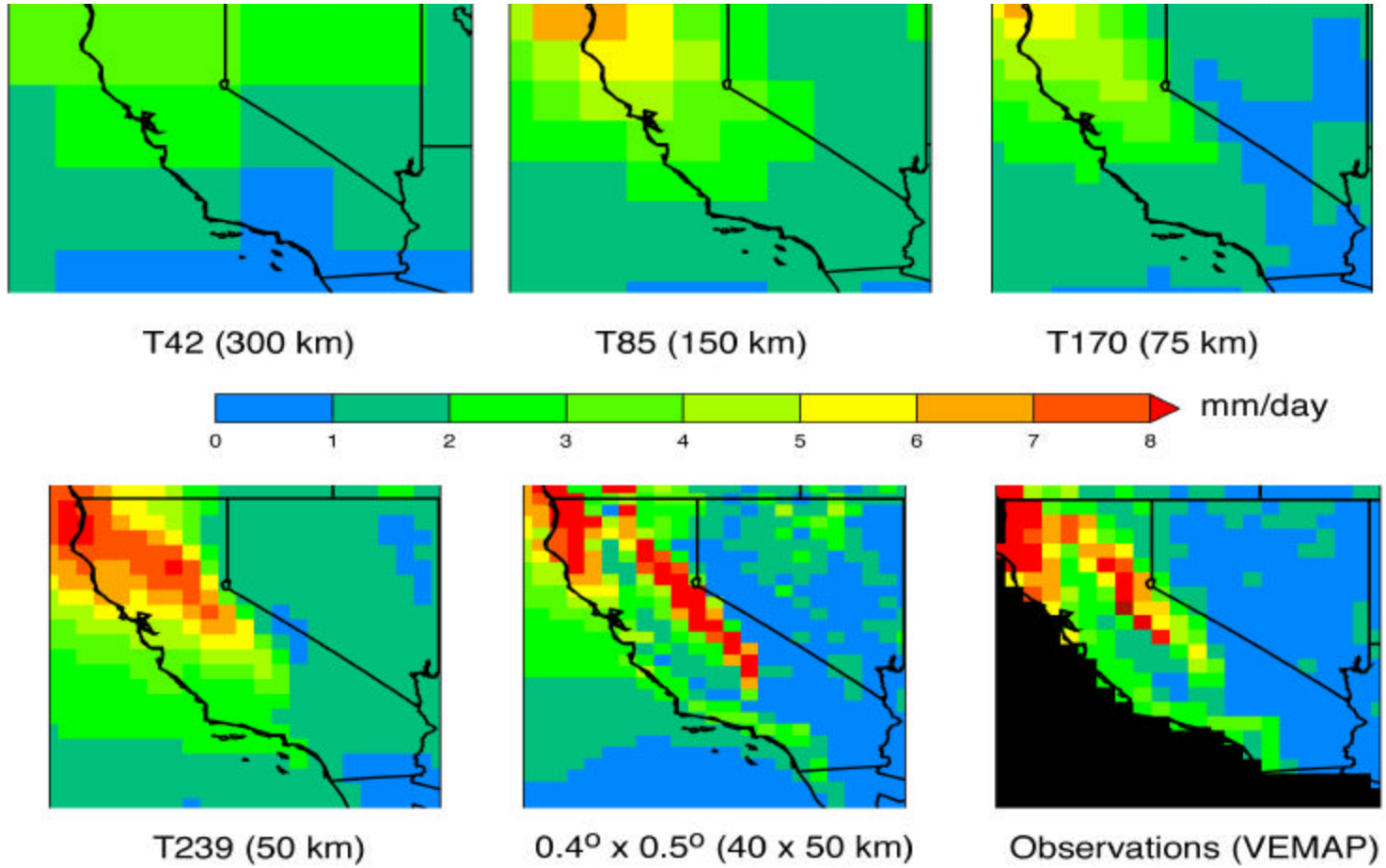
From Phillips & Gleckler, 2006 *WRR*

Multi-GCM Simulations of Seasonal Cycle of Precipitation in Different Regions



High-resolution GCMs can approximate regional climate…
…but only at great computational expense:

Winter CA Precipitation Simulated at Progressively Higher Resolutions



Acknowledgments: Phil Duffy

Downscaling of *standard* GCM simulations → Regional scales

Two Approaches

By developing a statistical relationship between local hydroclimatic variables and model predictors

Statistical DOWNSCALING

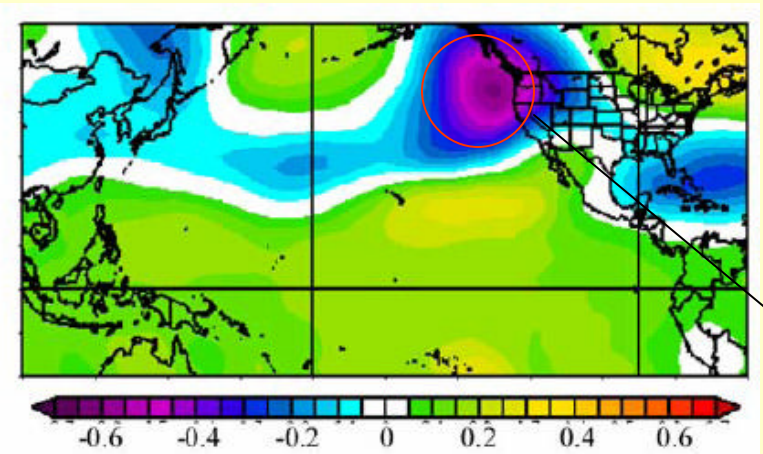
By explicitly resolving process-based physical dynamics of the regional climate system

Dynamic DOWNSCALING

Statistical downscaling of GCM climate

Statistical downscaling models

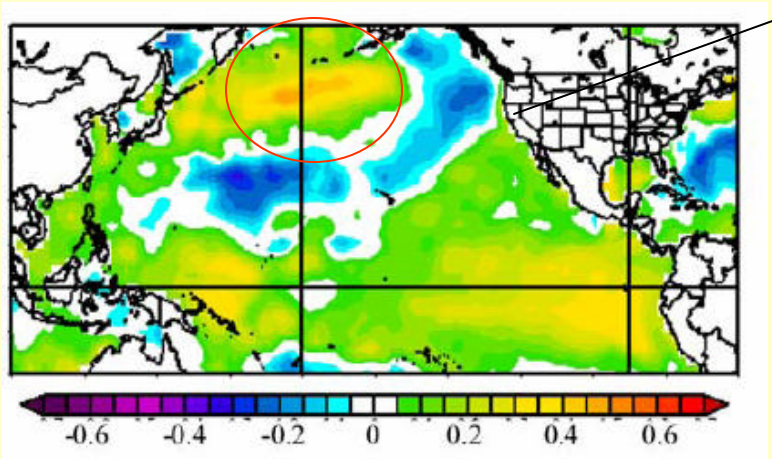
- Can estimate climate at catchment scales from large-scale predictors
- Still rely on GCMs to simulate large-scale climate variables



From Grantz et al., 2005 WRR

Observed lagged correlation of Apr-Jun Streamflow in the Carson River of CA, with Dec-Feb Pressures

Carson River, CA



Observed lagged correlation of Apr-Jun Streamflow in the Carson River of CA, with Dec-Feb Sea Surface Temperatures

Acknowledgments: Yun Duan

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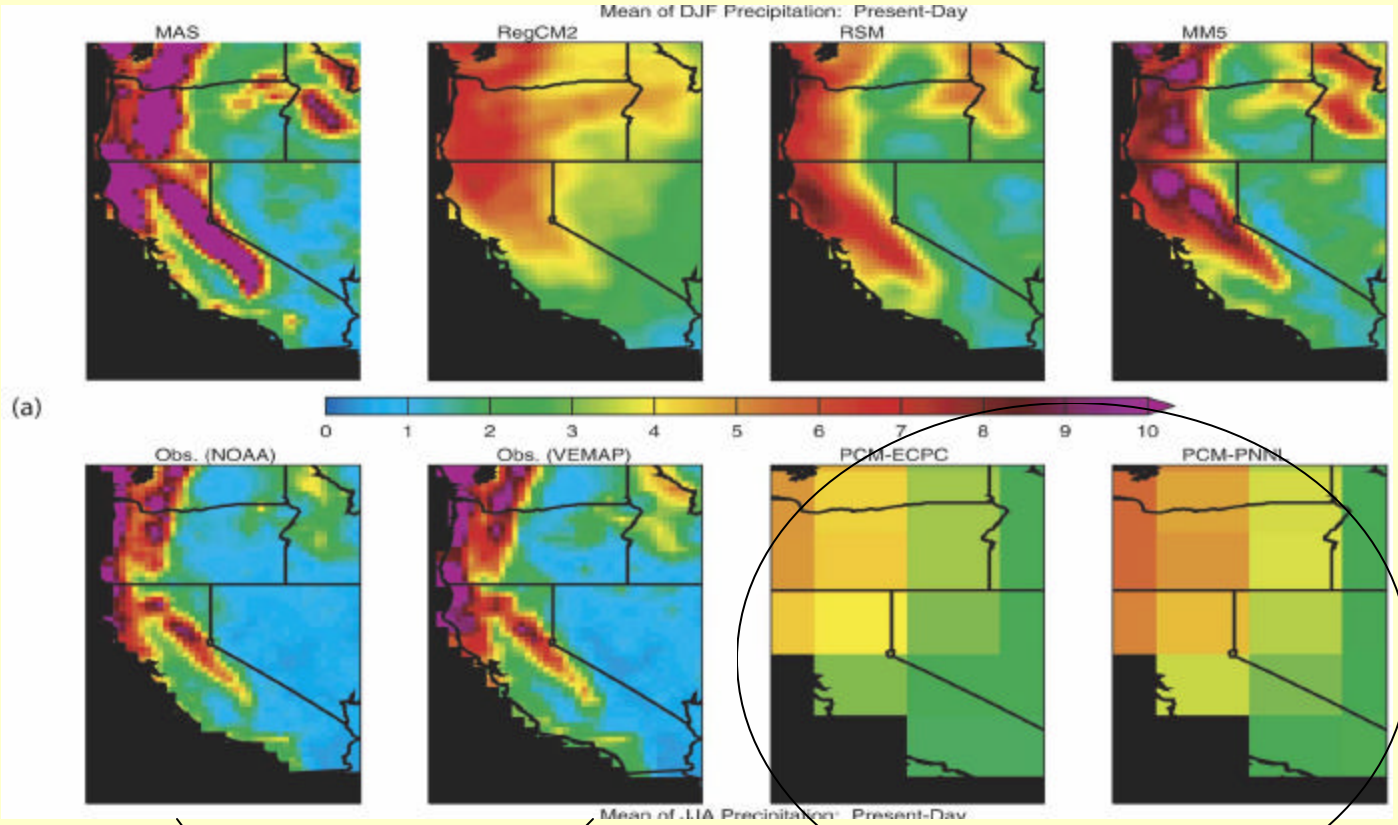
Dynamical downscaling of global→ regional climate:

Regional Climate Models (RCMs)

- **Regional dynamics and parameterizations of subgrid-scale processes (e.g. precipitation formation) *can* be more realistic than those in GCMs**
- **Still must rely on GCMs to provide lateral boundary conditions--so, *improving GCM parameterizations remains important***

From Duffy et al. 2006 Journal of Climate



Winter precip In 4 RCMs

Standard GCMs

Observations

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Regional → Global climate connections

Example:
The CCPP-ARM Parameterization Testbed ('CAPT')

U.S. Dept. of Energy Programs

Phillips et al., 2004 *Bulletin of the American Meteorological Society*:

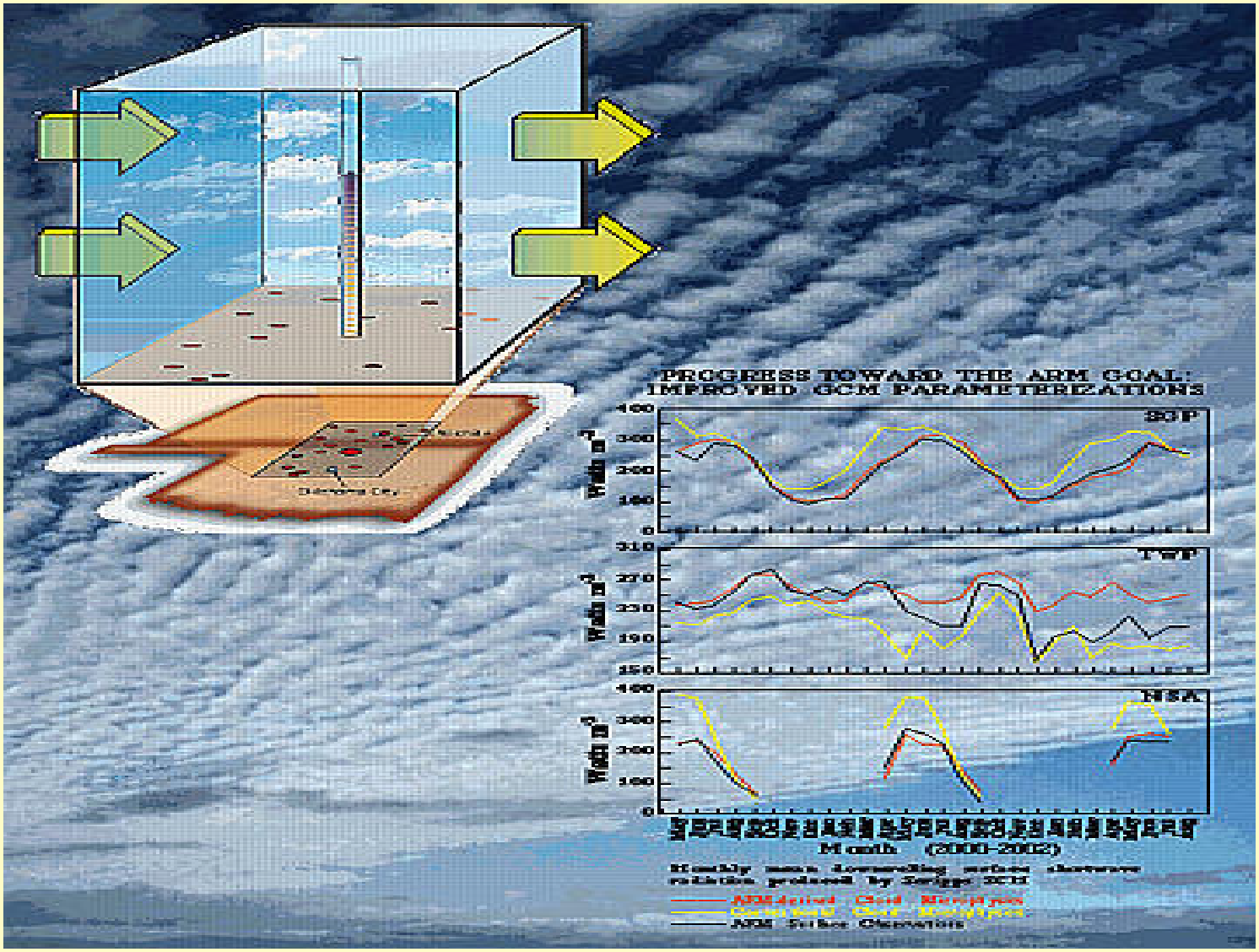
EVALUATING PARAMETERIZATIONS IN GENERAL CIRCULATION MODELS:

Climate Simulation Meets Weather Prediction

BY THOMAS J. PHILLIPS, GERALD L. POTTER, DAVID L. WILLIAMSON, RICHARD T. CEDERWALL, JAMES S. BOYLE, MICHAEL FIORINO, JUSTIN J. HNILO, JERRY G. OLSON, SHAOCHENG XIE, AND J. JOHN YIO

Numerical weather prediction methods show promise for improving parameterizations in climate GCMs.

Local high-frequency (~ hourly) ARM observations (and other field data) can be used to evaluate GCM parameterized processes



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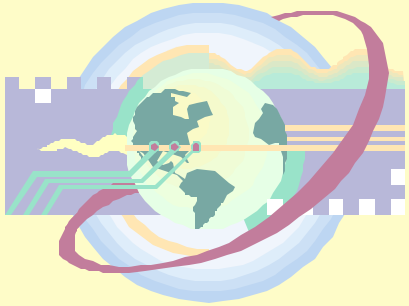
Using local observations to evaluate parameterizations



1) Initialize GCM state variables *realistically* from global weather observations *for a particular day*

2) Make a daily weather forecast, and compare its hourly evolution at the grid point closest to the local site with corresponding hourly observations there

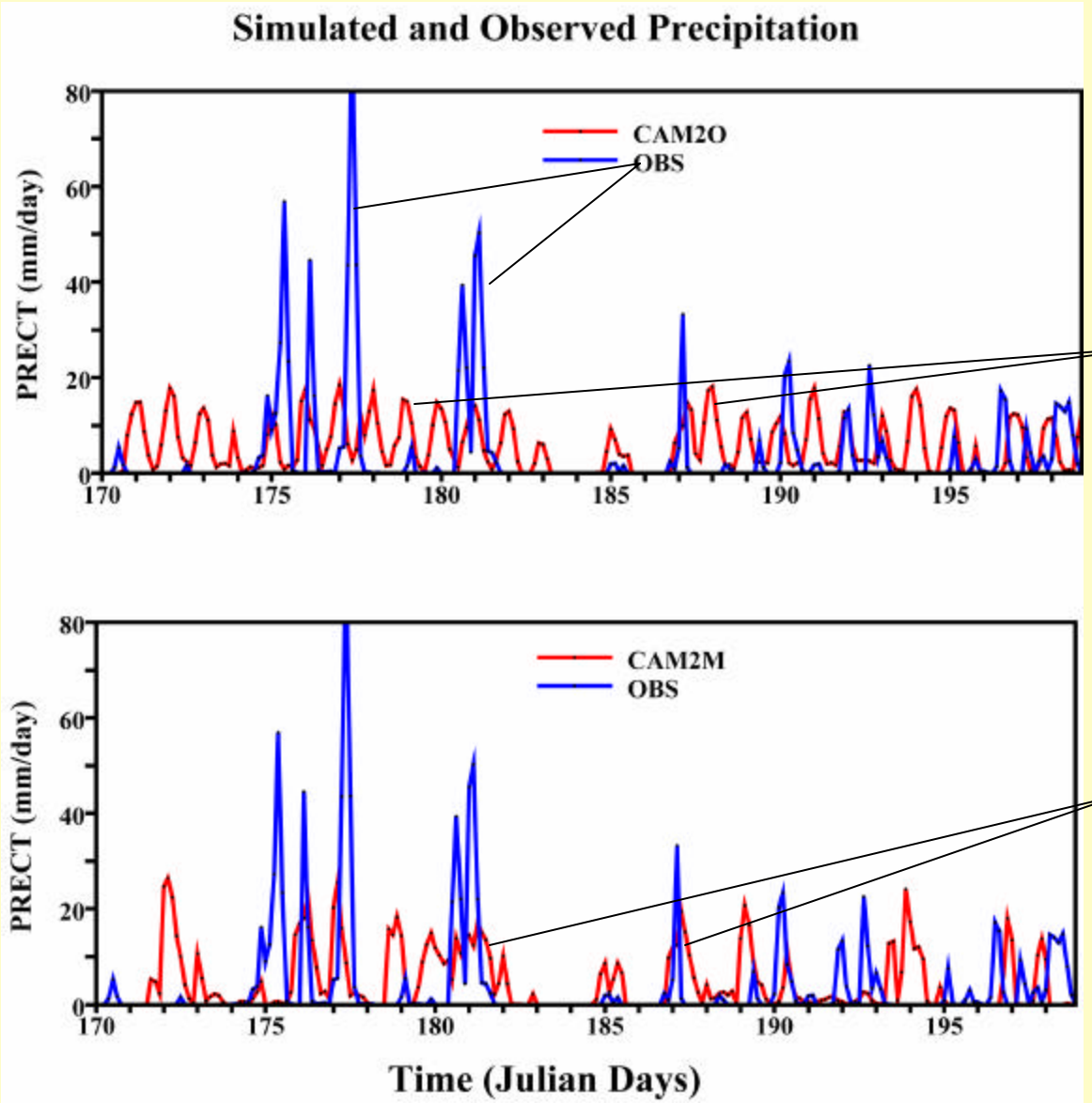
3) Identify local forecast errors, and infer possible shortcomings in a relevant process parameterization (e.g. in a convective precipitation scheme)

4) Modify this parameterization, repeating steps 2-3 until there is *overall* error reduction in model forecasts

5) Run GCM with the modified parameterization in a long climate simulation, and see whether the simulated climate statistics agree better with observations

Example:

Improving *local precipitation forecasts* by modifying GCM convective "trigger"



Location/Time:
ARM Southern Great Plains Site during June/July 1997

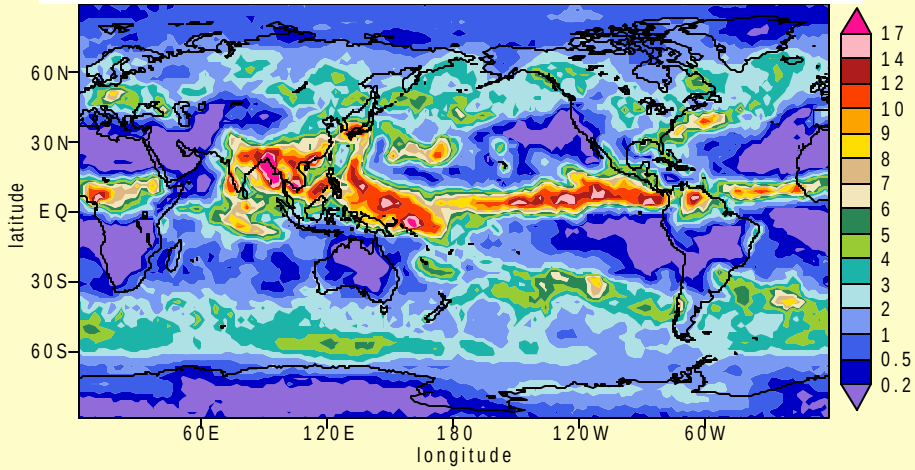
Standard GCM shows convective "drizzle"

GCM with modified convective trigger shows improved precip prediction

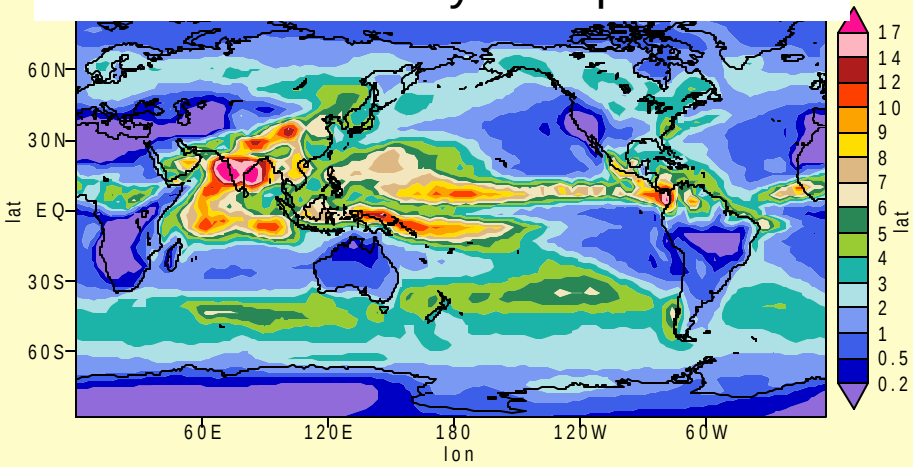
Example:

Improving *global precipitation climate* by modifying GCM convective "trigger"

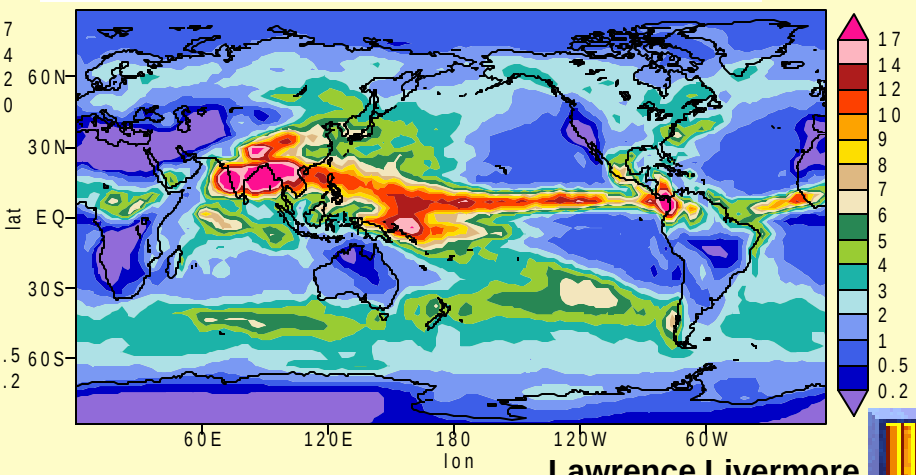
Observed July 1997 Precipitation



Standard GCM July Precipitation



Modified GCM July Precipitation



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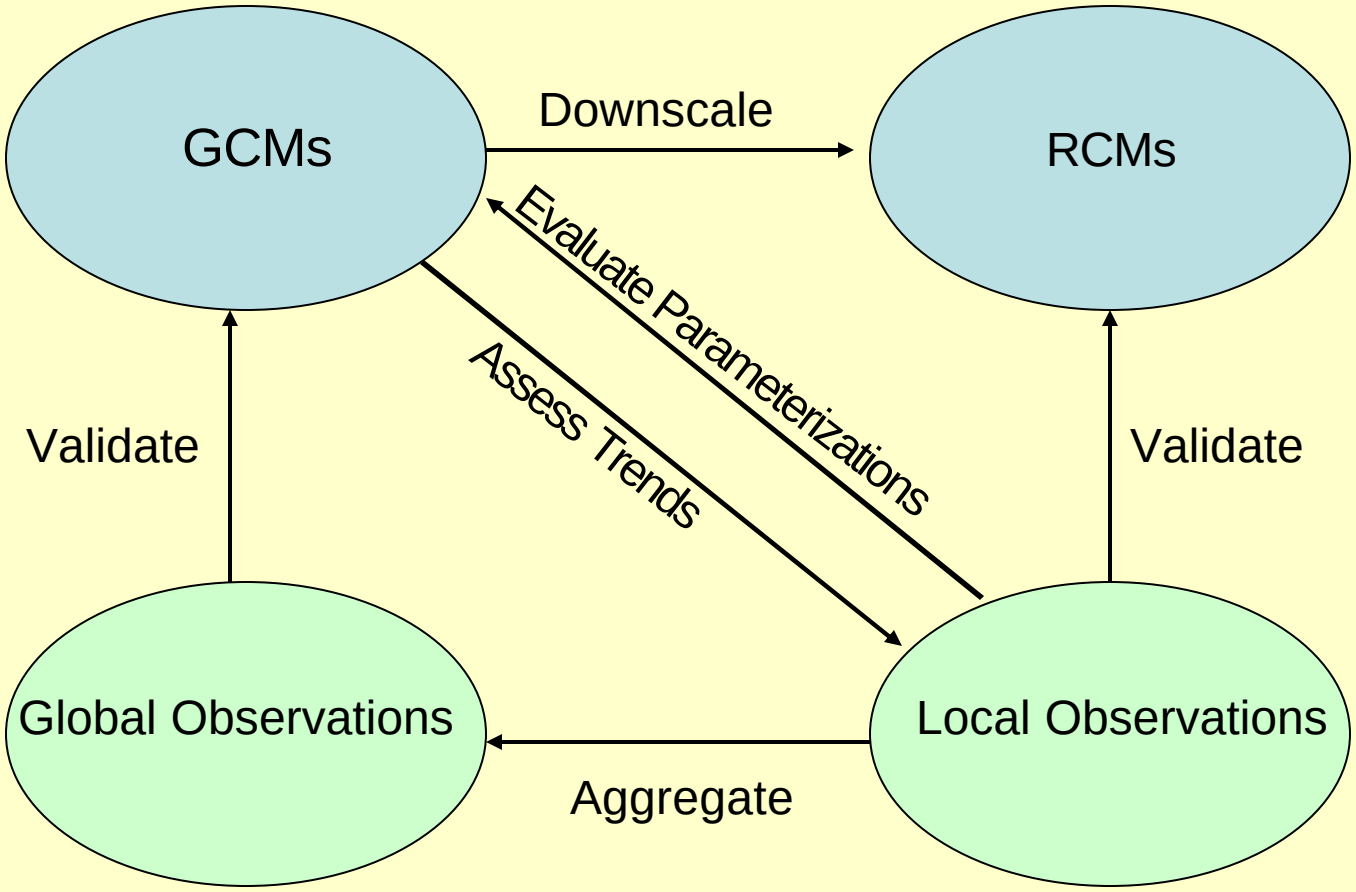
Summary

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