Combining Multimodel Numerical Experiments for Climate Change

Douglas Nychka,
Reinhard Furrer, Claudia Tebaldi, Jerry Meehl and
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- What is climate?
- 100 Tb of "data"
- A Bayesian spatial model.
- Heat waves.
- Gaia goes to the powder room.

NCAR

Supported by the National Science Foundation DMS

Climate:

What you expect ...

Climate:

What you expect ...

Weather:

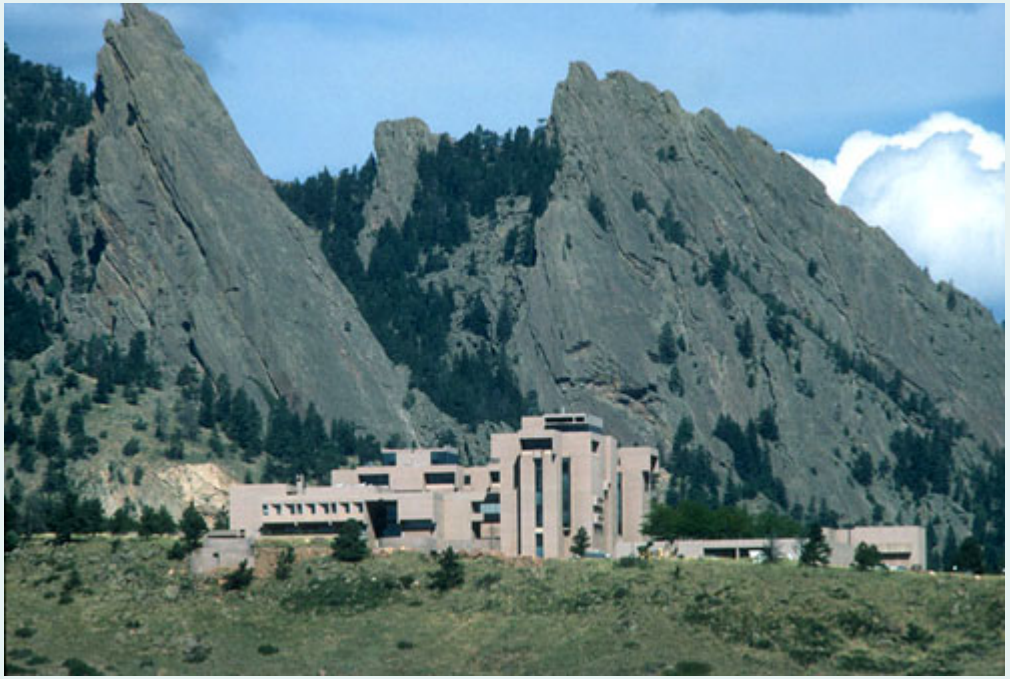
What you get.

Climate:

What you expect ...

Weather:

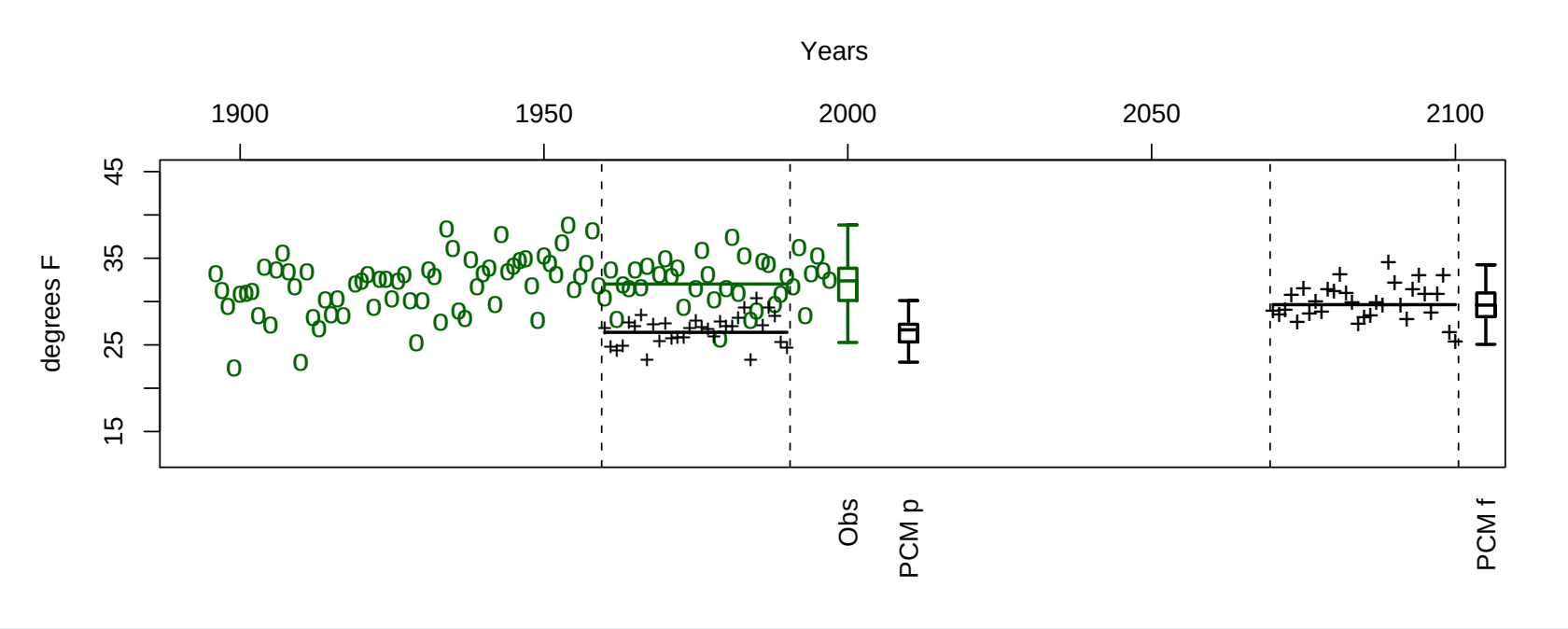
What you get.



Mesa Lab, National Center for Atmospheric Research, Boulder, CO

Observed data and a climate simulation

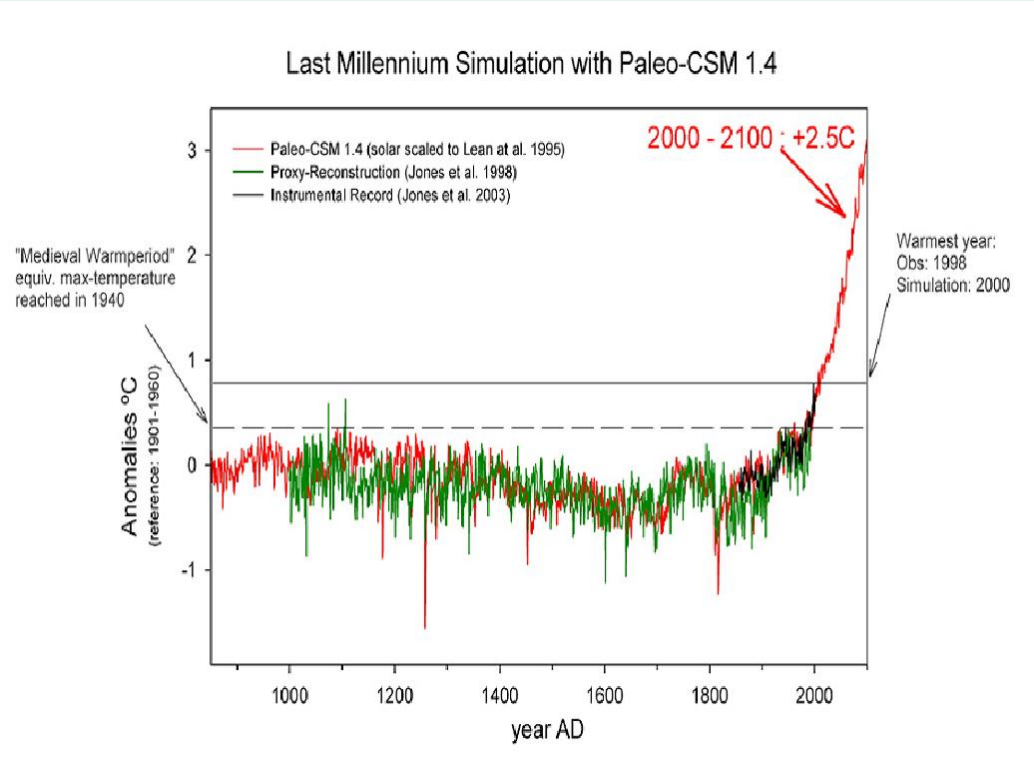
Observed and **simulated** winter temperatures for Boulder (grid box from the NCAR Parallel Climate Model)



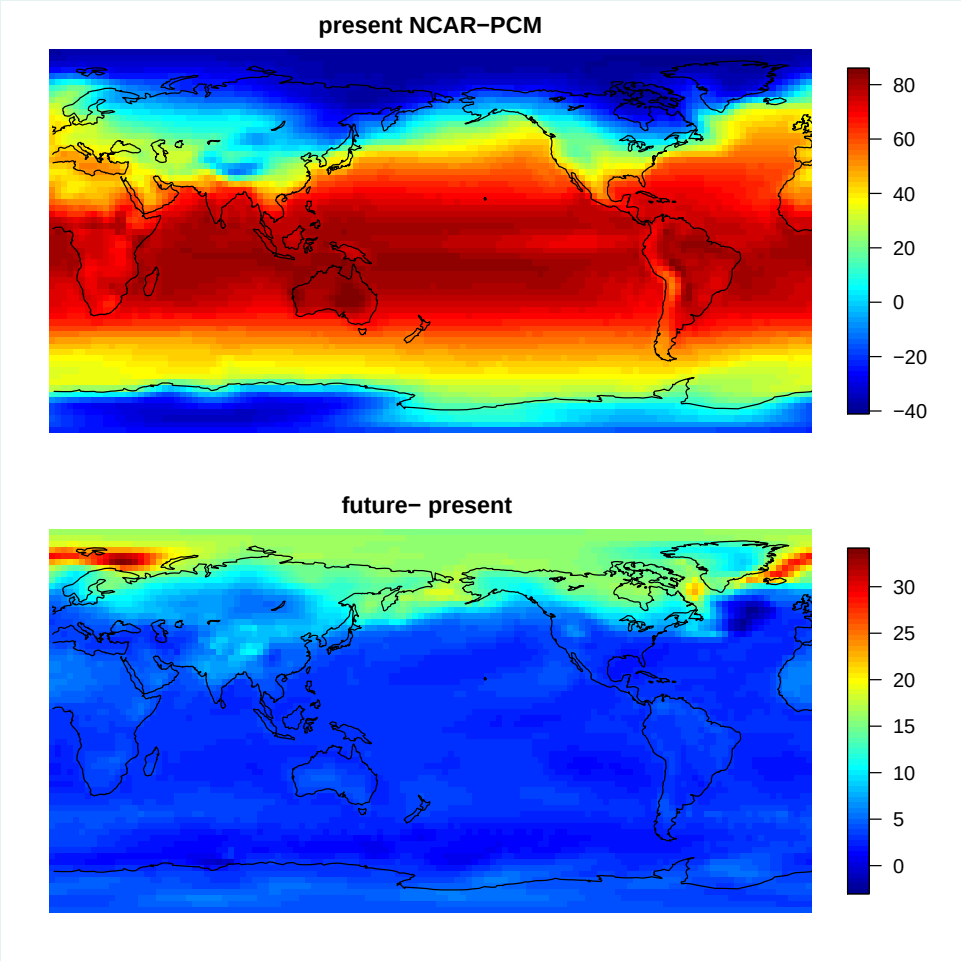
Climate is estimated by simulating weather and averaging.

Recent warming appears unusual from the proxy records of global temperatures ...

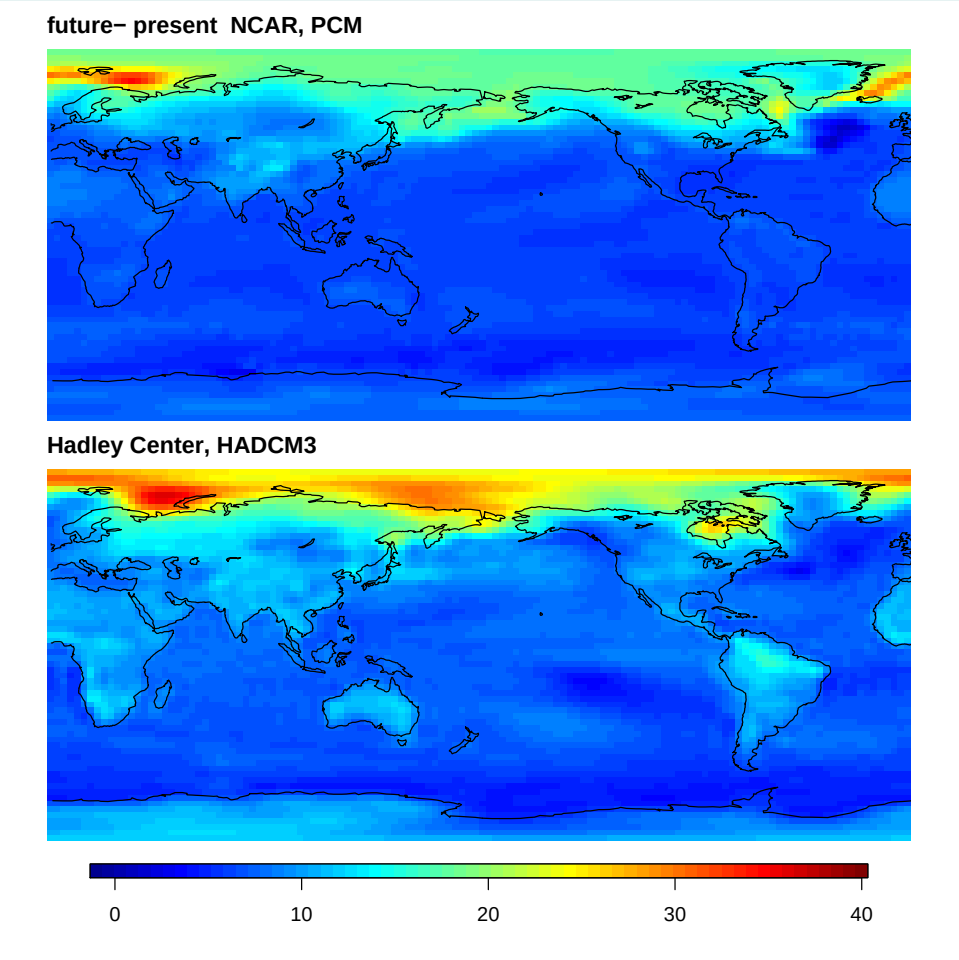
and is reproduced by numerical climate models.



Global results for NCAR Paralell Climate Model



Comparison with the Hadley Center Model



The IPCC and Climate Experiments

The Intergovernmental Panel on Climate Change (IPCC) is a United Nations sponsored effort to regularly evaluate the state of climate science and provide projections and analysis of future climate.

There have been three reports each involving hundreds of scientists and extensive numerical model simulations.

The current report Assessment Report Four (AR4) due in 2007 integrates the climate simulations from more than twenty modeling centers.

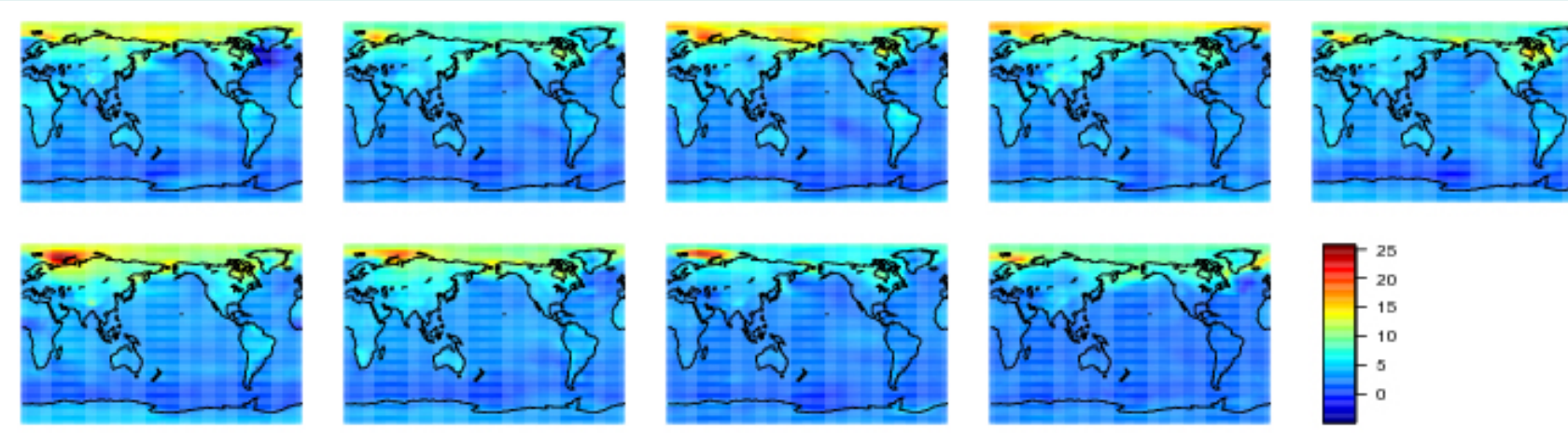
This is big science.

NCAR Community Climate System Model:

- 1000's of person/years of development
- Requires massively parallel supercomputers.
- IPCC numerical experiments generated 100 Tb of output, 10,800 total years.

How can the results of several models be combined?

Use a Bayesian hierarchical model where the IPCC models are considered as samples from a model superpopulation.



Goal: Draw an inference about the mean of the superpopulation.

Data Level

[data | process, parameters]

$\mathbf{D_i}$ = future - present climate for the i^{th} model.

$$\boldsymbol{D}_i = \boldsymbol{\mu}_i + \boldsymbol{\epsilon}_i$$

$\boldsymbol{\epsilon}_i$ a spatial process on the sphere, $\boldsymbol{\epsilon}_i \sim MN(0, \phi_i \Sigma)$

Process Level

[process | parameters]

$$\boldsymbol{\mu}_i = M\boldsymbol{\theta}_i \quad \boldsymbol{\theta}_i \sim MN(\boldsymbol{\nu}, \psi_i \Omega)$$

and M is a matrix of carefully chosen basis functions.

Parameter (or Prior) Level

[parameters]

Usually conjugate and uninformed.

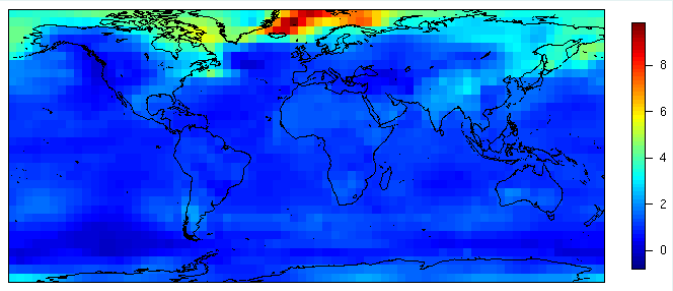
Some Details

- Choice of basis is crucial, involves spherical harmonics, indicators for land masses and *present climate*.
- Spatial processes are assumed stationary.
- Use MCMC to sample posterior.
- Can compare predictive distributions of individual climate models for (statistical) model checking

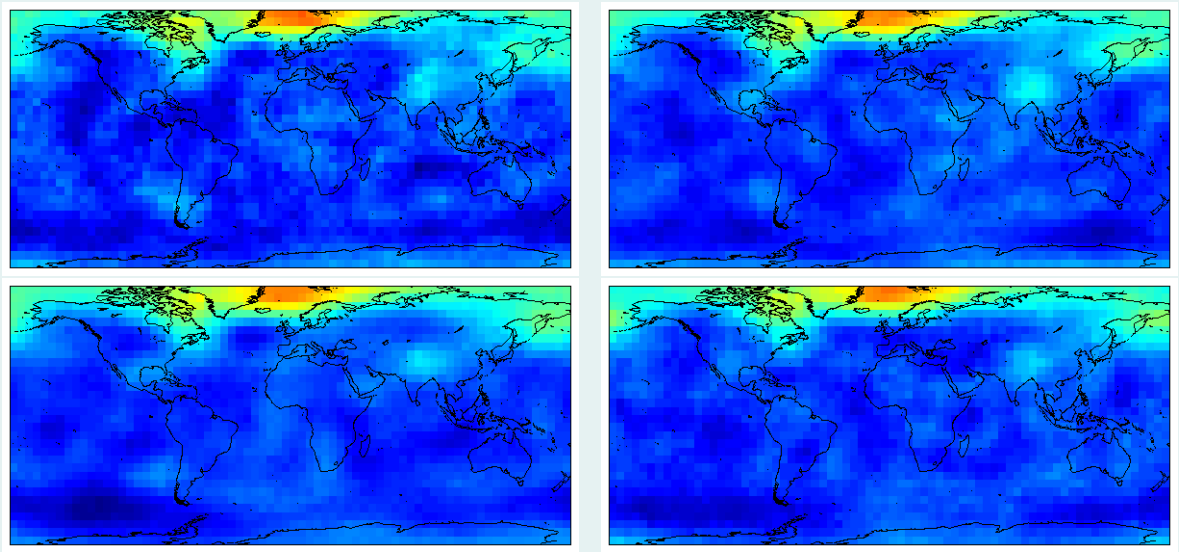
A more complicated model:
Separate present and future responses and include observed climate as an additional data set to estimate model bias for present climate.

Smith et al. (2005)

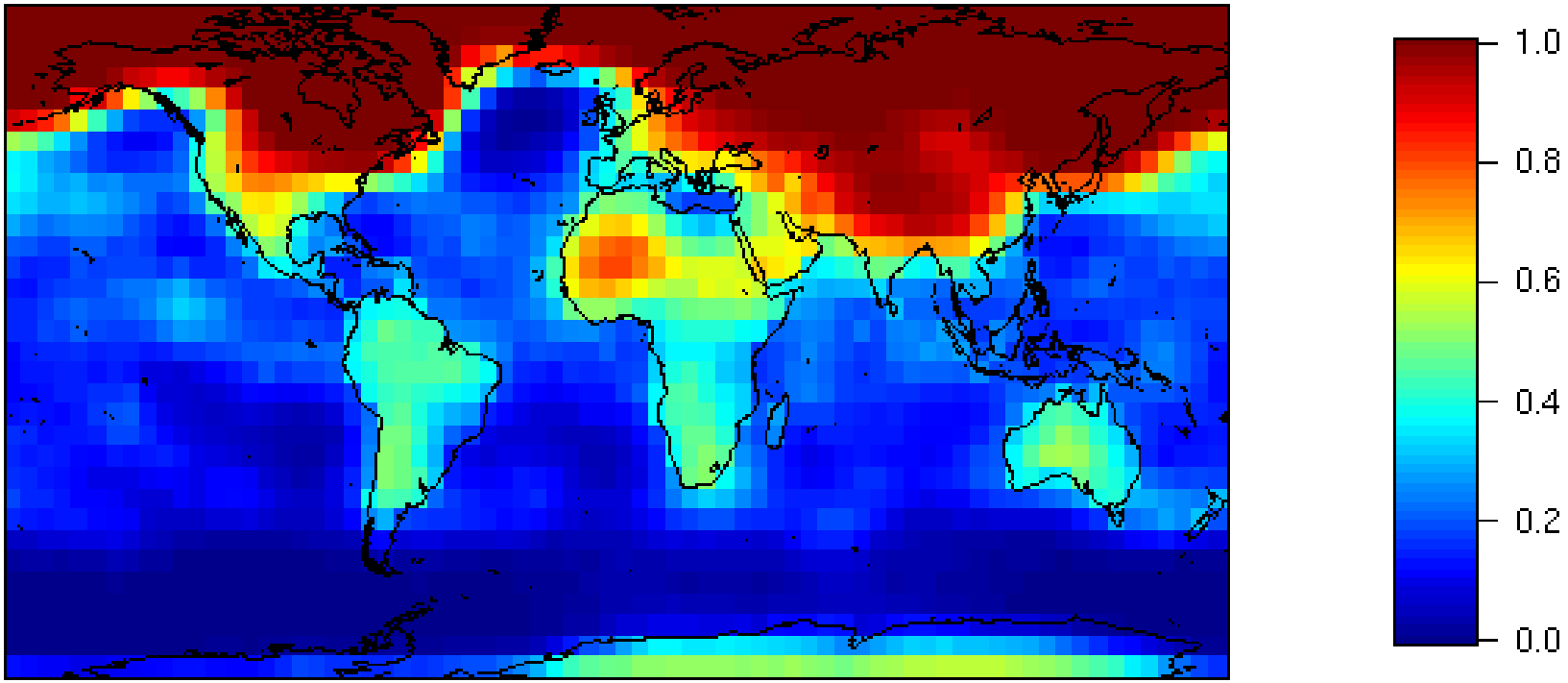
NCAR-Parallel Climate Model DJF temperature



Four draws from posterior:



Posterior probability of exceeding a difference 1 degree C for winter (A2 scenario) based on 9 models.



What about heat waves?

The AOGCMs have a resolution on the order of 150-300 km and the simulated temperature will not match point locations.

Downscaling approach of Tebaldi et. al 2004

- Aggregate observed temperatures to reflect a grid box average (NCEP reanalysis)
- Pair observed heat waves (e.g. consecutive days above a threshhold) with grid box averages.
- Find the implied threshhold for a heat wave for the aggregated data.
- Apply this same definition to the grid box values based on model simulations.

Issues of interpretation: A panel of experts

You have group of the experts gathered in a room.

However, unfortunately one of the experts, Gaia, temporarily leaves. Your task is to predict her opinion when she returns based on the other experts.

Gaia is the earth ...

The remaining experts are climate models.

There will be a component of error that will not decrease with the number of experts (models).

Summary

- Climate model experiments produce data that is important to analyze and provokes interesting spatial models.
- Nonstationary models for spatial fields on the sphere.
- Multivariate responses (max/min temperature, precip.)
- Downscaling of results to regional and local climate change.