A small statistical contribution towards a global picture

Reinhard Furrer

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Outline of the Talk

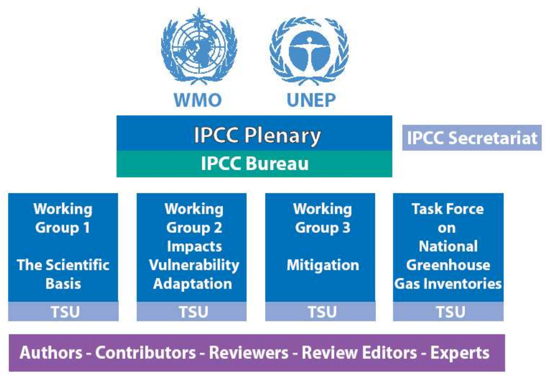
- Introduce IPCC, its mission and contributions
- Outline the framework of the statistical analysis for an IPCC publication
- Develop a multivariate Bayesian analysis of Atmosphere-Ocean General Circulation Models

IPCC: 101

Intergovernmental Panel for Climate Change (IPCC)

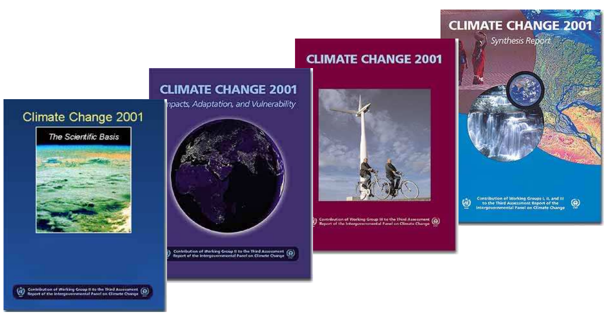
- established in 1988 by the World Meteorological Organization and the United Nations Environment Program
- assesses scientific information relating to climate change
- formulates realistic response strategies

IPCC: Structure



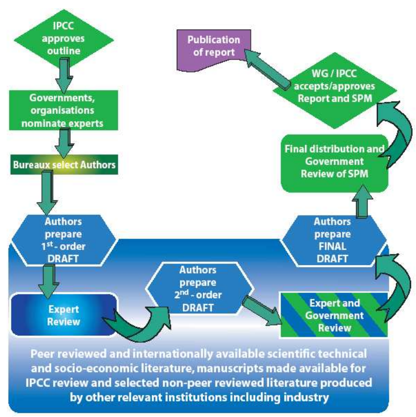
IPCC: Assessment Reports

Major assessment reports: 1990, 1996, 2001



Fourth Assessment Report (AR4) is planned for 2007.

IPCC: Publication Procedures



WG1: The Scientific Basis

Working group 1 is concerned with the scientific aspects of the climate system itself and climate change in particular.

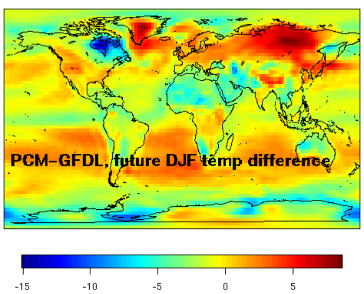
- Observations
- Paleoclimate
- Climate Models and their Evaluation
- Understanding and Attributing Climate Change
- Global Climate Projections
- Regional Climate Projections

Study Climate with AOGCMs

AOGCM: Atmosphere-Ocean General Circulation Models

Numerical models that calculate the precise large-scale motions of the atmosphere and the ocean explicitly from hydrodynamical equations.

Models Do Not Agree



Example: Atmospheric Model

Input
- External forcings (radiation, volcanos, . . .)
- Anthropogenic forcings (GHG, aerosols, . . .)
- Initial conditions

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- Flow dynamics, PDEs
- Discretization and simplifications
- Parametrization

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Output
- Temperature and precipitation
- Pressure, wind, . . .

Quantifying Uncertainty

- Variability of global temperature increase across 16 models. MAGICC/SCENGEN program (Wigley, 2003).
- Probabilistic description of regional climate changes. (Tebaldi et al. 2005).
- Gridded, global, spatial approach . . .

Bayesian Approach

Synthesizing temperature and precipitation climate projections from the outputs of several AOGCMs' with a hierarchical Bayesian approach.

In collaboration with: Stephan Sain - CU at Denver
Claudia Tebaldi - NCAR
Doug Nychka - NCAR

Jerry Meehl - NCAR
Linda Mearns - NCAR
Tom Wigley - NCAR
Reto Knutti - NCAR

Data

Data provided for the Fourth Assessment Report of IPCC:

- 19 models (CCSM, GFDL, HADCM, PCM, ...)
- At least $2.8^\circ \times 2.8^\circ$ resolution (8192 data points, T42)
  aggregate to $5^\circ \times 5^\circ$
- Different scenarios (A2: "business as usual", A1B, B1)
- Temperature, precipitation, pressure, winds...
  seasonal averages over years 1980–1999 and 2080–2099, ...
- NCEP reanalysis as "observations"

Hierarchical Statistical Model

For models $i = 1, \dots, N$, stack the gridded output into vectors:

$$\mathbf{X}_i = \text{simulated present climate}_i$$
$$\mathbf{Y}_i = \text{simulated future climate}_i$$

Objective:

Probabilistic description of simulated climate change

Hierarchical Statistical Model

Data level:

$$\begin{aligned}\mathbf{D}_i = \mathbf{Y}_i - \mathbf{X}_i &= \text{simulated climate change}\\ = \mathbf{Y}_i - \mathbf{X}_i &= \text{large scale structure} + \text{small scale structure}\\ = \mathbf{Y}_i - \mathbf{X}_i &= \mathbf{M}\boldsymbol{\theta}_i + \varepsilon_i, \qquad \text{with } \varepsilon_i \sim \mathcal{N}(\mathbf{0}, \phi_i \Sigma)\end{aligned}$$

Process level:

$\boldsymbol{\theta}_i \sim \mathcal{N}(\boldsymbol{\mu}, \psi_i \mathbf{I})$ (projection coefficients)

Prior level:

$\phi_i \sim \mathrm{I}\Gamma(\xi_1, \xi_2)$ (small scale variability)
$\psi_i \sim \mathrm{I}\Gamma(\xi_3, \xi_4)$ ("model" variability)
$\boldsymbol{\mu} \sim \mathcal{N}(\mathbf{0}, \xi_5 \mathbf{I})$ (unknown large scale)

Basis Functions M

We need a "rich" truncated basis set **M**.

Current candidate:

- Harmonic functions on the sphere
- Indicators for continents, sea ice, ...
- Patterns of current climate from NCEP reanalysis

Covariance Matrix Σ

Examples of positive definite functions on the sphere:

1. representation using an infinite series of Legendre polynoms
$$c(h; \sigma, \tau) = \sigma\big(1 - 2\tau\cos(h) + \tau^2\big)^{-3/2}$$
2. restriction of a positive definite function on $\mathbb{R}^3$ to the sphere
$$c(h; \sigma, \tau) = \sigma\exp\big(-\tau\sin(h/2)\big)$$

We only parameterize the scale σ of the covariance matrix Σ.

The "range" τ is choosen according an "empirical Bayes" approach.

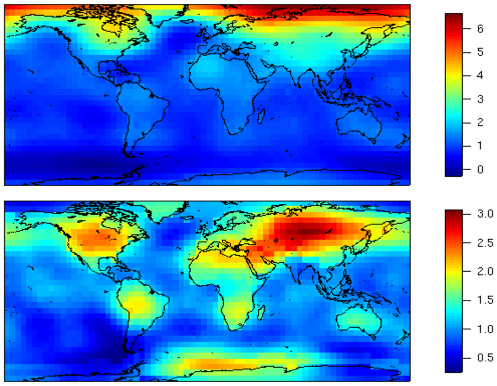
Gibbs Sampler

Distribution of $\boldsymbol{\mu}$ given the AOGCM outputs.

- Full conditionals for the parameters are available
- Gibbs sampler programmed in R
- Run many iterations:
  5000 burn-in, keep every 10th
- Assessing convergence with:
  trace plots, different starting values, ...

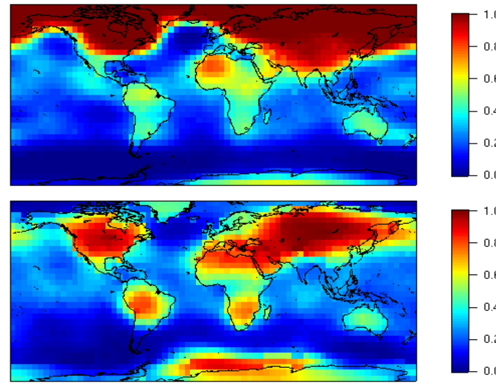
Posterior Climate Change

Posterior 20% quantile of synthesized, modeled temperature change



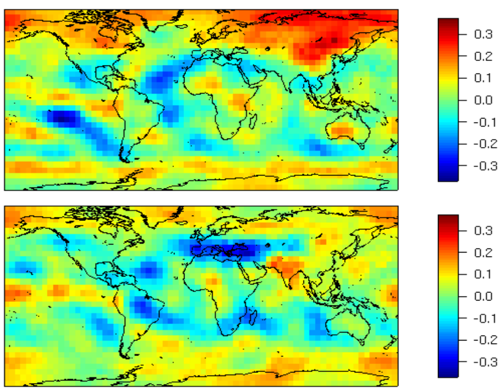
Posterior Climate Change

Probability that we observe at least a 2°K modeled temperature increase

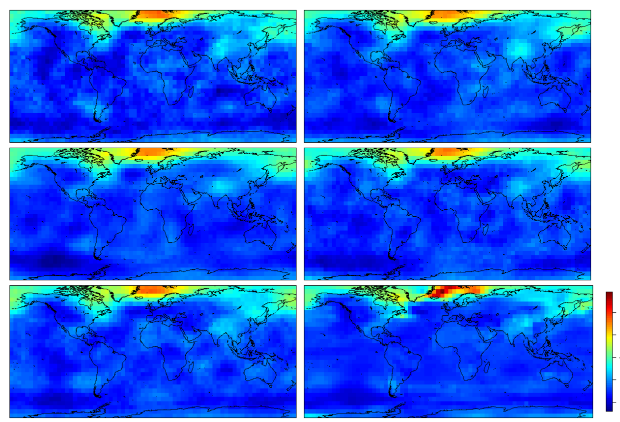


Posterior Climate Change

Posterior median of synthesized, modeled precipitation change



Posterior PCM Model Realisations



Discussion and Further Work

- Simple statistical model
- Provides probabilistic answers to climatologist's questions
- Implement ensemble runs
- Generalize covariance parametrization
- Extend to multivariate setting