Example of Work on Uncertainty Measure
Incorporating Model Bias and Projection Convergence

Claudia Tebaldi (RAP/NCAR)

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Motivation

- Different General Circulation Models (GCM) produce different climate change projections, especially when these are evaluated on a regional (subcontinental) scale.

- Analyses of climate change have to recognize these differences, no model is the ”true” model.

- Perceived criteria of reliability:
  - Bias
  - Convergence
  - Sensitivity
  - ...

- Need formalization/quantification.
Giorgi and Mearns’ Reliability Ensemble Average (1)

- *Journal of Climate*, May 2002: Calculation of Average, Uncertainty Range and Reliability of Regional Climate Change from AOGCM Simulations (...)

- Summary measures of regional climate change, based on a **WEIGHTED AVERAGE** of different GCMs’ responses.

- Weights take into account model performance (i.e. **BIAS**) and model agreement (i.e. **CONVERGENCE**).
Giorgi and Mearns’ Reliability Ensemble Average (2)

- 9 GCMs;
- 2 Scenarios;
- 22 Regions;
- 2 Seasons;
- Simulated Temperature values in 30-years averages (1961-1990; 2071-2100);
Giorgi and Mearns’ Reliability Ensemble Average (3)

Given the single GCM responses:

\[ \{ \Delta T_i \}_{i=1,\ldots,9} \]

The summary is given by a weighted average:

\[
\Delta \tilde{T} = \sum_i \frac{R_i \Delta T_i}{\sum_i R_i}
\]

where the weights are iteratively recomputed, since they include \( \Delta \tilde{T} \) itself, the target of the estimation:

\[
R_i = \left( \frac{1}{|B_i|} \cdot \frac{1}{|\Delta T - \Delta T_i|} \right) \frac{1}{m \times n}
\]

\((B_i)\) is the bias of the model)
Robust Estimation

Giorgi and Mears’ loss function turns out to be:

$$\sum_{i} \frac{1}{m} \left( \frac{|\tilde{T} - T_i|}{m \times n} \right)^{2 - \frac{n}{m \times n}}$$

If $m = n = 1$, this is the (weighted) $L_1$ norm, and $\tilde{T}$ is optimally estimated by the weighted median of the 9 GCM responses.
A possible alternative way to attack the same data set:

Mixed effects model

- Fixed Effects: season*region+scenario
- Weights: inverse of the absolute bias
- Random effects: model
Statistical Analysis of GCM output

- **ANOVA** can explore **relevant factors** (region, season, scenario) and **interactions** among factors (region:season, model:region).

- **ROBUST REGRESSION** handles **outliers** and favors model convergence.

- **MIXED EFFECTS MODELS** treat GCMs as ”draws” from a superpopulation of models and allow to distinguish **within and between model variability**.

- **BAYESIAN THEORY** naturally allows to model **uncertainty** at different levels of a **hierarchy** (model, scenario, spatial scale), exploiting when available **domain knowledge** and **subjective evaluations** of uncertainty.
Statistical Analysis of GCM output (cont’d)

- **SPATIAL MODELS** account for correlation between regional responses at similar latitude; may assess the robustness of results to different spatial scales of aggregation.

- **TIME SERIES ANALYSIS** looks at the process of climate change in its temporal evolution rather than by summary over decades.

- **THEORY OF EXTREMES** focuses the modeling effort on the tails of a distribution.

- **EXPERIMENTAL DESIGN** can guide the choice of models’ or scenarios’ parameters for efficient exploration of the space of possible settings.
Regional Climate Change assessment

DJF, A2

Temperature Change

ALM AMZ CAM CAS CNA EAF EAS ENA GRL MED NAS NAU NEU SAF SAH SAS SAU SEA SSA TIB WAF WNA

lm rlm mean median mixef

regions
Feedback Value of Statistical Analysis

• We model for the sake of
  - optimal description, summary, prediction,
  - uncertainty evaluation.

• In addition, statistical analysis can unveil aspects of the climate model output worth further investigation by the climate modeling research community:
  - peculiar model:region interactions,
  - ranking of factors’ relevance,
  - sensitivity analysis to parameterization.

• Once the machinery is in place, an active role in choosing experimental settings makes sense.