Difficulties in Deriving Forecast Probabilities from General Circulation Models and Efforts to Estimate Uncertainty in Future Climate Projections

Dave Stainforth

Grantham Research Institute & Centre for the Analysis of Timeseries, London School of Economics and Political Science

1. Introduction.
2. The difficulties in predicting climate.
3. Domains of possibility.
4. Implications for future experiments.
Introduction

• Climate simulations can:
  – Help us understand the physical system.
  – Help generate plausible storylines for the future.
  – Help us build better models.

• Fundamental issues of how to use scientific information to guide societal development.

• bottom up .vs. top down
  “minimise vulnerability/maximise resilience” .vs. “predict and optimise”

• International adaptation – when is adaptation adaptation and when is it development?

• More uncertainty, please.
Climate Prediction – An Exceptionally Difficult Problem

- A problem of extrapolation:
  - Verification / confirmation is not possible.

- Model deficiencies:
  - Model inadequacy: they don’t contain some processes which could have global impact. (methane clathrates, ice sheet dynamics, a stratosphere, etc.)
  - Model uncertainty: Some processes which are included are poorly represented – e.g. ENSO, diurnal cycle of tropical precipitation.

- Model interpretation:
  - Lack of model independence.

- Metrics of model quality
  - Observations are in-sample.
  - Ensembles are analysed in-sample.
  - Models which are bad in some respects may contain critical feedbacks in others.
  - Non-linear interactions: selecting on a subset of variables denies the highly non-linear nature of climatic interactions.
Types of Climate Uncertainty

- **External Influence (Forcing) Uncertainty**
  What will future greenhouse gas emissions be?

- **Initial Condition Uncertainty** (partly aleatory uncertainty)
  The impact of chaotic behaviour.

- **Model Imperfections** (epistemic uncertainty)
  Different models give very different future projections.
## Uncertainty Exploration

<table>
<thead>
<tr>
<th>Type of Uncertainty:</th>
<th>Response:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forcing Uncertainty</td>
<td>Ensembles of Emission scenarios</td>
</tr>
<tr>
<td>Initial Condition Uncertainty</td>
<td>Initial Condition Ensembles (ICEs). (V. small. Typically max of 4; sometimes 9)</td>
</tr>
<tr>
<td>Model Deficiencies.</td>
<td>Multi-model ensembles e.g. CMIP III – O(10)</td>
</tr>
<tr>
<td></td>
<td>Perturbed-parameter ensembles:</td>
</tr>
<tr>
<td></td>
<td>- O(10000-100000) – climateprediction.net</td>
</tr>
<tr>
<td></td>
<td>- O(100) – in-house teams e.g. MOHC</td>
</tr>
</tbody>
</table>
Climate Prediction – An Exceptionally Difficult Problem

• A problem of extrapolation:
  – Verification / confirmation is not possible.

• Model deficiencies:
  – Model inadequacy: they don’t contain some processes which could have
global impact. (methane clathrates, ice sheet dynamics, a stratosphere,
etc.)
  – Model uncertainty: Some processes which are included are poorly
represented – e.g. ENSO, diurnal cycle of tropical precipitation.

• Model interpretation:
  – Lack of model independence.

• Metrics of model quality
  – Observations are in-sample.
  – Ensembles are analysed in-sample.
  – Models which are bad in some respects may contain critical feedbacks in others.
  – Non-linear interactions: selecting on a subset of variables denies the highly non-linear nature of climatic
interactions.

Centre for
Climate Change
Economics and Policy
Consequences of Lack of Independence

Distribution of Climate Sensitivities

Center for Climate Change Economics and Policy

From Stainforth et al. 2005
Consequences of Lack of Independence 2

See Stainforth et al. 2007, Phil Trans R.Soc A
Climateprediction.net data
An Aside: Emulators Don’t Help Here

- Even the shape of model parameter space is arbitrary so filling it in does not help in producing probabilities of real world behaviour.
An Aside: UK Climate Projections 2009 (UKCP09) - 1

Change in mean summer precip:
10% 90%

Murphy et al, 2004
An Aside: UK Climate Projections 2009: Change in Wettest Day in Summer Medium (A1B) scenario

2080s: 67% probability level: unlikely to be greater than

2080s: 90% probability level: very unlikely to be greater than
An Aside:
A (Very) Basic Summary of My Understanding of the Process

- sample parameters,
- run ensemble,
- “emulate”,
- weight by fit to observations
An Aside: Issues

- Size of ensemble given size of parameter space.
- The ability of the emulator to capture non-linear effects.
- **The choice of prior i.e. how to sample parameter space.**
- The justification for weighting models.
- On what scales do we believe the models have information?
Climate Prediction – An Exceptionally Difficult Problem

• A problem of extrapolation:
  – Verification / confirmation is not possible.

• Model deficiencies:
  – Model inadequacy: they don’t contain some processes which could have global impact. (methane clathrates, ice sheet dynamics, a stratosphere, etc.)
  – Model uncertainty: Some processes which are included are poorly represented – e.g. ENSO, diurnal cycle of tropical precipitation.

• Model interpretation:
  – Lack of model independence.

• Metrics of model quality
  – Observations are in-sample.
  – Ensembles are analysed in-sample.
  – Models which are bad in some respects may contain critical feedbacks in others.
  – Non-linear interactions: selecting on a subset of variables denies the highly non-linear nature of climatic interactions.
Domains of Possibility 1

Distribution of Climate Sensitivities

Simulated Climate Sensitivity (K)

Normalized Frequency (%/degree)
Domains of Possibility 2

See Stainforth et al. 2007, Phil Trans R.Soc A
Climateprediction.net data
Climate Prediction – An Exceptionally Difficult Problem

• A problem of extrapolation:
  – Verification / confirmation is not possible.

• Model deficiencies:
  – Model inadequacy: they don’t contain some processes which could have global impact. (methane clathrates, ice sheet dynamics, a stratosphere, etc.)
  – Model uncertainty: Some processes which are included are poorly represented – e.g. ENSO, diurnal cycle of tropical precipitation.

• Model interpretation:
  – Lack of model independence.

• Metrics of model quality
  – Observations are in-sample.
  – Ensembles are analysed in-sample.
  – Models which are bad in some respects may contain critical feedbacks in others.
  – Non-linear interactions: selecting on a subset of variables denies the highly non-linear nature of climatic interactions.
Interpretational Approaches

• Domains of possibility – a non-discountable envelope.
• Deduce subjective probabilities.
• Maximum consistency / maximum likelihood / non-probabilistic odds approaches.
• Transfer Functions
Relationship with Global Mean Temperature

DJF Regional Delta T (Northern_Europe) Against Global Delta T

Regional Temperature Change (K) vs Global Temperature Change (K)

Centre for Climate Change Economics and Policy
Climateprediction.net data
A Trick?

• Try to remove internal variability / initial condition uncertainty.
• Treat all model versions as providing a domain of possibility.
• Add internal variability back in.
Correlations with Global Mean Temperature

DJF Regional Delta T (Northern Europe) Against Global Delta T

Regional Temperature Change (K)

Global Temperature Change (K)
Correlations with Global Mean Temperature

DJF Regional Delta T (Northern Europe) Against Global Delta T

Regional Temperature Change (K) vs Global Temperature Change (K)

Climateprediction.net data
Combine With Predictions of Global Mean Temperature and Atmospheric CO₂ Concentrations

Conditional PDFs of Northern Europe DJF Temp Change

Regional Temperature Change (K)

Decade: 2020-30, 2050-60, 2090-2100

Centre for Climate Change Economics and Policy
And again with precipitation
Best Information Today / Best Ensemble Design For Tomorrow

• For tomorrow:
  Design ensembles to push out the bounds of possibility.

• For today:
  Use the best exploration of model uncertainty combined with the best global constraints.
Final Thoughts

- The focus on reducing uncertainty on regional scales is premature.
- We must communicate what we understand. Sometimes we cannot provide information asked for by policy makers. Sometimes they are simply asking currently unanswerable questions.

- Models may not be reliable prediction tools for multi-decadal predictions at local scales for some time. Waiting for that would be ridiculous. Not using the information they contain – along with understanding of the physical processes – seems foolish.
Really Final Thoughts

What do we need to do now?

• Define/design models and experiments to be useful.
• Use models and understanding together to paint plausible futures.
• Develop procedures for identifying when and where climate models are potentially informative about specific problems.
• Integrate scientific information with other decision drivers.
Let's Be Careful Out There