Ensembles, Uncertainty and Climate Projections

Chris Brierley
(Room 117)
Definitions

- **Ensemble**: group of model simulations
- **Uncertainty**: doubt and ambiguity about future conditions
- **Climate Projection**: modeled climate state under a specified scenario
Uncertainty

• We do not know exactly what will happen in the future.

• We do have rough idea of the chance of an event happening.

• Formalize that rough idea (quantifying the uncertainty) to produce a probability
Adaptation and Mitigation

- Two responses to climate change require different knowledge of the future.
  - Mitigation (prevention) needs an “if … then… will happen”
  - Adaptation (coping with) needs a more definite “… will happen”
- Only the first kind of forecast is routinely performed for long-time scale climate change
Adaptation: Example

- Suppose we want to build coastal defenses for New Haven to last 100 years.
- What information would you want?
  - What is the sea-level rise going to be at New Haven in 2100?
Coastal Defenses II

- Cost of build up to a certain height
- Possible losses if you don’t build up to a certain height
- Other solutions and their cost/loss => Risk Analysis
- What information is provided by climate scientists to help us with our decision?
- Let’s look in the IPCC’s most recent report....
Figure 10.33. Projections and uncertainties (5 to 95% ranges) of global average sea level rise and its components in 2090 to 2099 (relative to 1980 to 1999) for the six SRES marker scenarios. The projected sea level rise assumes that the part of the present-day ice sheet mass imbalance that is due to recent ice flow acceleration will persist unchanged. It does not include the contribution shown from scaled-up ice sheet discharge, which is an alternative possibility. It is also possible that the present imbalance might be transient, in which case the projected sea level rise is reduced by 0.02 m. **It must be emphasized that we cannot assess the likelihood of any of these three alternatives, which are presented as illustrative. The state of understanding prevents a best estimate from being made.**
Probability

- Obviously, this information is not the most useful.
- Probabilities are essential for risk-analysis
- Probabilities are provided for weather forecasts
Ensemble Weather Prediction

- Many different simulations of the same model with slightly different initial conditions
- Samples “Natural Variability”
- Can we use the same methodology to provide probability for climate predictions?
Natural Variability - The Butterfly Effect

- There is a limit to the predictability of a chaotic system.
- Arises from **uncertainty in the initial conditions** of the atmosphere.
- Other aspect of the climate system can also have uncertain initial conditions.
  - Upper ocean on seasonal timescales
  - Cryosphere (ice) and deep ocean on longer timescales
Scenarios

• What, if anything, will we do to reduce CO$_2$ emissions in the future?
• Will a series of big volcanoes go off?
• Will effect the climate system, but are external to it.
• Requires expertise of vast amount of fields
Model Uncertainty

- How can we model the whole climate?
- We have to make choices:
  - What to exclude?
  - What scale do we need?
  - How do we include important things that happen below that scale?
3 Uncertainties = 1 Big Problem

- What is relative importance of these factors?
- No-one really knows, but all agree scenario uncertainty dominates at about 50 years

Cox and Stephenson (2007)
How do we cope with this?

- Two approaches:
  - Reduce the uncertainties to make more accurate
  - Accept the uncertainty and produce probabilistic forecast

- We need to do both, but the latter has been mainly ignored.
Doing a probabilistic climate forecast

• Need to sample all 3 uncertainties in a systematic manner

• Probability In -> Probability Out
  • Compare initial conditions to observations
  • Question politicians and economist for scenario probabilities
  • How do we even sample model uncertainty?
Model Uncertainty II

- **Structural** - Resolution, Numerical choices, Dynamic vegetation, Interactive sulfur cycle?
- **Parameter** - Values of constants in parameterization not well constrained by observations
The Uncertaintree

- Total Uncertainty
  - Initial Condition
    - Ocean
    - Atmosphere
  - Scenario
  - Model
    - Parameter Uncertainty
    - Structural Uncertainty
My Work

- Set out to make an initial investigation into ocean parameter uncertainty
  1. What parameters are uncertain and by how much?
  2. How big/important is it?
  3. Do we need to include in future predictions?
Expert Consultation

• Ask lots of experts in ocean modelling, what the most important parameters are.

• Find a range for those parameters (either from the observational studies or asking experts).

• Prioritise the parameters by their expected effect on transient climate change.
Vertical Diffusion

- Small compared to horizontal mixing.
- However all mixing is small vertically, due to stratification.
- Diffusivity varies with depth.

Molecular Diffusion  Eddy Diffusion
Isopycnal diffusion

- Parameterises effects of Mesoscale Eddies
- Mainly horizontal
- Vertical transfers possible at high latitudes
- Largest in Southern Ocean
Mixed Layer

- Parameterise the mixed layer by working out the mixed layer depth and then mixing above (Kraus-Turner).
- Mixed Layer Depth is when turbulent energy runs out.
- Scheme has 2 parameters - fraction and a decay length.
## 7 Ensemble Members

<table>
<thead>
<tr>
<th></th>
<th>Isopycnal Diffusivity (m²s⁻¹)</th>
<th>Background Vertical Diffusivity profile (x10⁻⁵ m²s⁻¹)</th>
<th>Mixed Layer Parameters, fraction, depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>1000</td>
<td>1-15</td>
<td>0.7                          100</td>
</tr>
<tr>
<td>Low ISO</td>
<td>200</td>
<td>1-15</td>
<td>0.7                          100</td>
</tr>
<tr>
<td>High ISO</td>
<td>2000</td>
<td>1-15</td>
<td>0.7                          100</td>
</tr>
<tr>
<td>Low VDiff</td>
<td>1000</td>
<td>0.5-4</td>
<td>0.7                          100</td>
</tr>
<tr>
<td>High VDiff</td>
<td>1000</td>
<td>2-50</td>
<td>0.7                          100</td>
</tr>
<tr>
<td>Low LAM</td>
<td>1000</td>
<td>1-15</td>
<td>0.3                          100</td>
</tr>
<tr>
<td>Med LAM</td>
<td>1000</td>
<td>1-15</td>
<td>0.5                          50</td>
</tr>
</tbody>
</table>
• The grey bar marks the beginning of the experiment, and dotted lines are the increasing CO₂ runs
- Ensemble spread (range) in surface temperature climate change signal.
Ensemble spread (range) in surface temperature climate change signal, as a percentage of the ensemble mean signal.
Aside: Other Results

- Can’t detect changes in thermohaline circulation behavior from ocean model uncertainty in these runs
- Atmospheric differences dominate ocean heat uptake differences
- Climate sensitivity may be sensitive to current climate
The Bigger Context

- So I’ve shown that ocean parameter uncertainty can have detectable results that are important in some localities, but so what?
- How does it compare to other sources of uncertainty?
Comparison of TCR Ranges

Note: Using standard deviation instead of range gives a substantively similar plot
Importance

• So uncertainty related to the ocean parameters exists.

• Less important on the global scale than other modeling uncertainties.

• It is important locally though, so should be included in probabilistic climate prediction.
Other ingredients

- Systematic sampling - multiple perturbations
- Assigning probabilities
- Getting enough computer power to run it.
Multiple Perturbations

- Single parameter - 53 members (Murphy et al., 2004)
- Multi parameter - 128 members (Webb et al., 2006)
- Multi parameter - 1148 (Stainforth et al., 2005)
Weighting for Simulation Quality

The graph shows two probability density functions (PDFs) for climate sensitivity in °C. The blue line represents the unweighted PDF, and the red line represents the weighted PDF. The x-axis represents climate sensitivity, and the y-axis represents the relative probability. The weighted PDF is shifted to the right compared to the unweighted PDF, indicating a higher probability of higher climate sensitivities after weighting.
Distributed Computing

- ClimatePrediction.net is a version of the UK Met Office’s climate model
- Downloadable as a screensaver
- BBC experiment
Take Home Messages

I. Climate prediction contains much uncertainty
II. Some of it comes from the models themselves
III. Probabilistic forecasts provide more information than a single prediction
IV. Probabilistic forecasts need “grand” ensembles
V. We are moving towards creating these ensembles
Climate Sensitivity

10% chance of very dangerous sensitivity

Direct Obs.
Proxy Obs.
AOGCM
QUMP/CPDN