Dealing with Uncertainty in Climate Change Adaptation and Mitigation

Dr. Marc Neumann, BC3
a, b, Statistical distribution of mean summer temperatures at a grid point in northern Switzerland.

c, Change in average

d, Change in variability (relative change in standard deviation)

Schär et al. 2004, Nature
Mean annual streamflow

Multi-model mean change across 5 General Circulation Models (GCMs) and 11 Global Hydrological Models (GHMs); saturation shows the agreement on the sign of change across all 55 GHM–GCM combinations (for a global mean temperature rise of 2°C above 1980–2010).

[source: WGII AR5 Fig 3.4]
Change in mean monthly runoff across **seven climate models**, with a 2°C increase in global mean temperature above 1961-1990. HadCM3 is highlighted separately, showing changes with both a 2°C increase (dotted line) and a 4°C increase (solid line). [source: WGII AR5 2014, Fig.3-5]
Change in mean monthly runoff across seven climate models, with a 2°C increase in global mean temperature above 1961-1990. HadCM3 is highlighted separately, showing changes with both a 2°C increase (dotted line) and a 4°C increase (solid line). [source: WGII AR5 2014, Fig.3-5]
1. Emission scenario
2. Global climate model
3. Downscaling to regional level
4. (Local weather patterns)
5. Impact models
6. Economic valuation of impacts
Types of Uncertainty

• Epistemic uncertainty
  – lack of knowledge, partially reducible by further investigation

• Aleatory uncertainty (natural variability)
  – spread of values from a well specified population, irreducible, frequency distribution

• Ambiguity/Vagueness
  – Capability of being understood in two or more ways; double or dubious signification
Risk vs. uncertainty

• Civil Engineering:
  \[ \text{Risk} = \text{Probability}(\text{Flood}) \times \text{Cost}(\text{Flood}) \]

• Intergovernmental Panel on Climate Change (IPCC - AR5):
  \[ \text{Risk} \leftarrow \text{Hazard} \times \text{Exposure} \times \text{Vulnerability} \]
## Interpretation of uncertainty

<table>
<thead>
<tr>
<th>Term</th>
<th>Likelihood scale (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtually certain</td>
<td>Likelihood of the outcome</td>
</tr>
<tr>
<td>Very likely</td>
<td></td>
</tr>
<tr>
<td>Likely</td>
<td></td>
</tr>
<tr>
<td>About as likely as not</td>
<td></td>
</tr>
<tr>
<td>Unlikely</td>
<td></td>
</tr>
<tr>
<td>Very unlikely</td>
<td></td>
</tr>
<tr>
<td>Exceptionally unlikely</td>
<td></td>
</tr>
</tbody>
</table>

**A:** For each term provide **single estimate** on a scale from 0 to 100%

**B:** For each term provide a **range (from – to)** on a scale from 0 to 100%
IPCC – AR5 Treatment of Uncertainty

Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties

IPCC Cross-Working Group Meeting on Consistent Treatment of Uncertainties Jasper Ridge, CA, USA, 6-7 July 2010

IPCC – AR5 Treatment of Uncertainty

“Each key finding is based on an author team’s evaluation of associated evidence and agreement. The confidence metric provides a qualitative synthesis of an author team’s judgement about the validity of a finding, as determined through evaluation of evidence and agreement. If uncertainties can be quantified probabilistically, an author team can characterize a finding using the calibrated likelihood language or a more precise presentation of probability.”
Figure 1: A depiction of evidence and agreement statements and their relationship to confidence. Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence.
# IPCC AR5 - calibrated likelihood language

<table>
<thead>
<tr>
<th>Term*</th>
<th>Likelihood of the Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtually certain</td>
<td>99-100% probability</td>
</tr>
<tr>
<td>Very likely</td>
<td>90-100% probability</td>
</tr>
<tr>
<td>Likely</td>
<td>66-100% probability</td>
</tr>
<tr>
<td>About as likely as not</td>
<td>33 to 66% probability</td>
</tr>
<tr>
<td>Unlikely</td>
<td>0-33% probability</td>
</tr>
<tr>
<td>Very unlikely</td>
<td>0-10% probability</td>
</tr>
<tr>
<td>Exceptionally unlikely</td>
<td>0-1% probability</td>
</tr>
</tbody>
</table>
Example heat waves (Table TS.2)

Observed:

*Very likely* decrease in the number of cold days and nights and increase in the number of warm days and nights, on the global scale between 1951 and 2010. [WGI AR5 2.6.1]

*Medium confidence* that the length and frequency of warm spells, including heat waves, has increased globally since 1950. [WGI AR5 2.6.1]

Projected:

*Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase, for events defined as extremes on both daily and seasonal time scales. [WGI AR5 12.4.3]
Uncertainty in modelling

• Parameter uncertainty
  – Bayesian
    • Random variables
    • Prior distributions (expressing degrees of belief)
    • Learning with data $\rightarrow$ posterior distributions
  – Frequentist
    • Error estimates (co-variance) obtained from statistical regression (mapping of random measurement error to parameters)

• Model structure uncertainty
Parameter uncertainty
Uncertainty analysis

• Identifying sources of uncertainty
• Quantifying uncertainty
• Propagating uncertainty
• Assessing uncertainty of outcomes
• Assessing sensitivity
Identifying sources of uncertainty

Quantifying uncertainty

Fossil fuels RURRs

cumulative probability vs. EJ

- Conventional oil
- Unconventional oil
- Conventional gas
- Unconventional gas
- Coal
Uncertainty propagation

- Monte Carlo simulation

1. Draw a random sample for each parameter
2. Run simulation
3. Store output

Repeat \( n \) times

Analyse output:
- mean, standard deviation, quantiles
- histogram, empirical cumulative distribution function
Cumulative CO₂ emissions

Total cumulative CO₂ emissions (GtC)

- 50% probability range
- 90% probability range
- 100% probability range

IPCC-AR5 range of baseline scenarios

Carbon budget
CO₂ cumulative emissions 2100

IPCC-AR5 review
(50% confidence interval)

50% confidence interval
Temperature change

<2°C threshold
Temperature change in 2100

**IPCC-AR5 review**
(50% confidence interval)
Sensitivity analysis

Many sensitivity analyses are based on changing one parameter at a time (local sensitivity analysis), often assessing the impact of a small perturbation to that parameter.

Global sensitivity analysis relaxes these assumptions by looking at the effect of varying a parameter:

i) while all others are also varying and
ii) across the entire distribution.
Global Sensitivity Analysis  
(Standardised Regression Coefficients)

\[ y = \sum b_i \cdot x_i + a \]

\[ \beta_i = b_i \cdot \frac{\sigma_{x_i}}{\sigma_y} \]

\[ \beta_i^2 \text{ Variance contribution of } x_i \text{ to } y \]

\( R^2 > 0.7: \text{Saltelli et al. (2004)} \)
Global Sensitivity Analysis

**Table 2** Fraction of variance in climate outcomes for the year 2100 explained by the main inputs (squared standardized regression coefficients, SRC$^2$)

<table>
<thead>
<tr>
<th></th>
<th>Total cumulative CO$_2$ emissions</th>
<th>Total radiative forcing</th>
<th>Temperature change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional oil RURR</td>
<td>0.014</td>
<td>0.020</td>
<td>0.003</td>
</tr>
<tr>
<td>Unconventional oil RURR</td>
<td>0.003</td>
<td>0.007</td>
<td>0.002</td>
</tr>
<tr>
<td>Natural gas RURR</td>
<td>0.022</td>
<td>0.043</td>
<td>0.012</td>
</tr>
<tr>
<td>Coal RURR</td>
<td>0.730</td>
<td>0.676</td>
<td>0.138</td>
</tr>
<tr>
<td>ECS</td>
<td>—</td>
<td>0.017</td>
<td>0.702</td>
</tr>
<tr>
<td>Other inputs</td>
<td>0.004</td>
<td>0.005</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Total ($R^2$)</strong></td>
<td><strong>0.774</strong></td>
<td><strong>0.766</strong></td>
<td><strong>0.857</strong></td>
</tr>
</tbody>
</table>

For total cumulative CO$_2$ emissions and total radiative forcing, the coal RURR explains 73% and 68% of the uncertainty respectively, whereas for the temperature change, coal RURR explains only 14%, with equilibrium climate sensitivity (ECS) explaining 70%. Total ($R^2$) represents the coefficient of determination of the total multivariate regression.
Caveat

Models are concepts, i.e. thought experiments!

Including uncertainty can either reduce or increase our overconfidence in our models

➔ Be explicit about assumptions and limitations
➔ Study of limitations as a continuous process
Climate Change

• System of systems
  – Complexity
  – Feedbacks
  – Non-linearity

• Emergence of new properties, structures, processes, knowledge, values, rules

→ Limits of predictability
Adaptation – look for

• **Satisficing** for a wide range of possible futures
• **Flexible and adaptive**
• **Low-regret**
• Address issues of the **present**
• With **co-benefits** to other sectors
• **Source control: Mitigation** [Precautionary principle]