Characterising future climate for application in impact and adaptation studies

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Notice

Colleagues are welcome to incorporate these slides into their own presentations, assuming they are correctly acknowledged. However, the author would also appreciate being informed prior to the extensive use of this material in public meetings.
Outline of lecture

1. Why do we need to characterise future climate?
2. What are climate scenarios?
3. Types of climate scenarios
4. Climate model-based scenarios for IAV analysis
5. Towards probabilistic projections
6. New scenarios for the IPCC AR5
7. Conclusions
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Humans are interfering with the Earth's radiation balance
Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4)
Radiative forcing is the change in the net downward minus upward, irradiance (expressed in $W m^{-2}$) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.

Source: IPCC, 2007 (Glossary)
Factors altering radiative forcing

Natural:

- Solar irradiance
  - Orbital variations
  - Solar output (e.g. sunspot activity)
- Volcanic eruptions
- Continental drift

Anthropogenic:

- Emissions of greenhouse gases and aerosols
- Land use change
Estimate of the Earth’s annual and global mean energy balance (values in Wm⁻²)

Source: Le Treut et al. (2007)
Climate change pioneers

1827: Jean-Baptiste Fourier

Studied the mathematical theory of heat conduction. Used the "greenhouse" analogy.

1863: John Tyndall

Measured the absorption of infrared radiation by CO$_2$ and water vapour; ice age theory.
Climate change pioneers

Roger Revelle (1909-1991)

1957: Warned that humans are conducting a "large-scale geophysical experiment"

Charles Keeling (1928-2005)

1957: Set up first continuous monitoring of CO$_2$ levels in the atmosphere.

Photo: San Diego Historical Society

Photo: NOAA
Changes in greenhouse gas concentrations and radiative forcing during the past 20k years

$\text{CO}_2$, $\text{N}_2\text{O}$, $\text{CH}_4$, Combined

Source: Jansen et al. (2007)
Probability distribution functions (PDFs) for anthropogenic forcing of aerosols (blue), greenhouse gases (red dashed) and combined forcing (red solid) between 1750 and 2005.

Combined PDF also includes surface albedo, contrails and stratospheric water vapour.
Arrhenius, S., 1896: On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine* 41, 237.
### Variation of Temperature caused by a given Variation of Carbonic Acid

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<td>60 to 70</td>
<td>6.0</td>
<td>6.1</td>
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<td>6.05</td>
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<td>50 to 60</td>
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<td>6.1</td>
<td>5.8</td>
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<td>40 to 50</td>
<td>6.1</td>
<td>6.1</td>
<td>5.5</td>
<td>6.0</td>
<td>5.92</td>
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<td>30 to 40</td>
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<td>5.4</td>
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<td>20 to 30</td>
<td>5.6</td>
<td>5.4</td>
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<td>5.2</td>
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<td>10 to 20</td>
<td>5.2</td>
<td>5.0</td>
<td>4.9</td>
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<td>0 to 10</td>
<td>5.0</td>
<td>5.0</td>
<td>4.9</td>
<td>4.9</td>
<td>4.95</td>
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<tr>
<td>-10 to 0</td>
<td>4.9</td>
<td>4.0</td>
<td>5.0</td>
<td>5.0</td>
<td>4.97</td>
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<tr>
<td>-20 to -10</td>
<td>5.0</td>
<td>5.0</td>
<td>5.2</td>
<td>5.1</td>
<td>5.07</td>
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<td>-30 to -20</td>
<td>5.2</td>
<td>5.3</td>
<td>5.5</td>
<td>5.4</td>
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<td>-40 to -30</td>
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<td>5.62</td>
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<td>-50 to -40</td>
<td>5.8</td>
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<td>-60 to -50</td>
<td>6.0</td>
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</table>

"...... I have calculated the mean alteration of temperature that would follow if the quantity of carbonic acid varied from its present mean value (K=1) to another, viz. to K=0.67, 1.5, 2, 2.5, and 3 respectively*."

*Carbonic acid = 2

Source: Arrhenius, S. (1896)
Global climate is changing
Patterns of Global Temperature Change

°C Temperature anomalies from the period 1961-1990

Climatic Research Unit, University of East Anglia  http://www.cru.uea.ac.uk/cru/demos/#temrec
Linear trend of annual temperatures, 1979-2005 (°C/decade)
White + marks: significant at the 5% level

Trenberth et al. 2007
"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level"
Simulation of continental-scale temperature changes (IPCC AR4 WG1 Fig. SPM.4)

Simulations with anthropogenic + natural forcing
Simulations with only natural forcing

"It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica"
”It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica”
Recent climate change has been affecting natural and human systems
Glaciers are retreating globally

Source: Oerlemans

Source: EEA, 2004
Summer minimum arctic sea ice extent: 1979-2008

National Snow and Ice Data Center, Boulder CO
Map 5.40  Rate of change of crop growing season length 1975–2007

Note: The rate of change (number of days per year) of the duration of the growing season (defined as total number of frost-free days per year) as actually recorded during the period 1975–2007.

Source: EEA, 2008
Mean sowing dates for potato in Finland, 1965-1999
Upper line: latest sowings; lower line: earliest sowings

Day

Hildén et al., 2005
Kaukoranta and Hakala, 2008
Future impacts are of concern
Coping range and risk of exceedance

Based on Willows and Connell, 2003
UN Framework Convention on Climate Change

Article 2

OBJECTIVE

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.
Potential future tipping elements in the climate system

<table>
<thead>
<tr>
<th>Tipping element</th>
<th>Feature of system, $F$ (direction of change)</th>
<th>Control parameter(s), $\rho$</th>
<th>Critical value(s), $\rho_{crit}$</th>
<th>Global warming, $T$</th>
<th>Transition timescale, $T$</th>
<th>Key impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic summer sea-ice</td>
<td>Areal extent (−)</td>
<td>Local $\Delta T_{air}$, ocean heat transport</td>
<td>Unidentified</td>
<td>+0.5−2°C</td>
<td>∼10 yr (rapid)</td>
<td>Amplified warming, ecosystem change</td>
</tr>
<tr>
<td>Greenland Ice sheet (GIS)</td>
<td>Ice volume (−)</td>
<td>Local $\Delta T_{air}$</td>
<td>+∼3°C</td>
<td>+1−2°C</td>
<td>&gt;300 yr (slow)</td>
<td>Sea level +2−7 m</td>
</tr>
<tr>
<td>West Antarctic Ice sheet (WAIS)</td>
<td>Ice volume (−)</td>
<td>Local $\Delta T_{air}$, or less $\Delta T_{ocean}$</td>
<td>+∼5−8°C</td>
<td>+3−5°C</td>
<td>&gt;300 yr (slow)</td>
<td>Sea level +5 m</td>
</tr>
<tr>
<td>Atlantic thermohaline circulation (THC)</td>
<td>Overturning (−)</td>
<td>Freshwater Input to N Atlantic</td>
<td>+0.1−0.5 Sv</td>
<td>+3−5°C</td>
<td>∼100 yr (gradual)</td>
<td>Regional cooling, sea level, ITCZ shift</td>
</tr>
<tr>
<td>El Niño–Southern Oscillation (ENSO)</td>
<td>Amplitude (+)</td>
<td>Thermocline depth, sharpness in EEP</td>
<td>Unidentified</td>
<td>+3−6°C</td>
<td>∼100 yr (gradual)</td>
<td>Drought in SE Asia and elsewhere</td>
</tr>
<tr>
<td>Indian summer monsoon (ISM)</td>
<td>Rainfall (−)</td>
<td>Planetary albedo over India</td>
<td>0.5</td>
<td>N/A</td>
<td>∼1 yr (rapid)</td>
<td>Drought, decreased carrying capacity</td>
</tr>
<tr>
<td>Sahara/Sahel and West African monsoon (WAM)</td>
<td>Vegetation fraction (+)</td>
<td>Precipitation</td>
<td>100 mm/yr</td>
<td>+3−5°C</td>
<td>∼10 yr (rapid)</td>
<td>Increased carrying capacity</td>
</tr>
<tr>
<td>Amazon rainforest</td>
<td>Tree fraction (−)</td>
<td>Precipitation, dry season length</td>
<td>1,100 mm/yr</td>
<td>+3−4°C</td>
<td>∼50 yr (gradual)</td>
<td>Biodiversity loss, decreased rainfall</td>
</tr>
<tr>
<td>Boreal forest</td>
<td>Tree fraction (−)</td>
<td>Local $\Delta T_{air}$</td>
<td>+∼7°C</td>
<td>+3−5°C</td>
<td>∼50 yr (gradual)</td>
<td>Biome switch</td>
</tr>
</tbody>
</table>

Lenton et al., 2008
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What are scenarios?

"A scenario is a coherent, internally consistent and plausible description of a possible future state of the world” (IPCC, 1994)

Scenarios are:

• alternative images of how the future can unfold

• not forecasts

• important tools for assessing future developments in complex systems with high uncertainties
What are climate scenarios?

"A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change. Climate scenarios often make use of climate projections (descriptions of the modelled response of the climate system to scenarios of greenhouse gas and aerosol concentrations), by manipulating model outputs and combining them with observed climate data."

Mearns et al. (2001)
Scenarios for climate impact, adaptation and vulnerability assessment

Socio-economic changes

Land-use and land-cover change

Other environmental changes

Climate change

Sea-level rise

Vulnerability, exposure to stimuli and adaptive capacity

Cross cutting

Reference conditions

Consistency

Interactions & feedbacks

Carter et al. (2001)
Who needs climate scenarios?
Use of climate information by researchers for CCIAV*

Two alternative approaches:

- Prognostic approach
- Diagnostic approach

*CCIAV = Climate change impacts, adaptation and vulnerability
Prognostic approach

- Select one or more projections of the future for assessing impacts

- Question: "If the environment changes like this, what will the impacts be?"

- Conventional "top-down" approach - results are highly dependent on the specific scenarios selected.
"If you wanna know the impacts then tell me how the climate will change"

Dessai and Hulme (2003)
Diagnostic approach

- Select a wide range of projections for conducting sensitivity analyses

- Question: "What types of changes are needed to produce a given impact?"

- Less common, "bottom-up" approach - accounts for a range of uncertainties in projections; can provide insights into policy questions
"No scenarios please, we're vulnerable"

Dessai and Hulme (2003)

Bottom-up approach

Past Present Future

Adaptive capacity

Vulnerability (social)

Indicators based on:
- Economic resources
- Technology
- Infrastructure
- Information & skills
- Institutions
- Equity

Global

Local

"No scenarios please, we're vulnerable"
Dessai and Hulme (2003) Global Local Impacts
Regionalisation Global climate models
Vulnerability (physical)
World development
Global greenhouse gases
Regionalisation
Impacts
Vulnerability (physical)
Adaptive capacity
Indicators based on:
Economic resources Technology
Infrastructure Information & skills
Institutions Equity

Past Present Future
Climate adaptation policy

Top-down approach

Bottom-up approach

Past Present Future

Indicators based on:
Adaptive capacity Vulnerability (social)

Dessai and Hulme (2003)
Climate scenarios for assessing knowledge

**Examples:**

- IPCC, ACIA, ACACIA, national assessments

**Function:**

- To facilitate a consistent treatment of future conditions
- To provide a reference for assessors to interpret published results

Sometimes referred to as *characterisations*
The SRES* driving forces and storylines

*SRES: Special Report for Emissions Scenarios

Nakicenovic et al., 2000

METIER Graduate Training Course No. 7, Environmental Scenario Analysis
16-22 April 2009, Roskilde, Denmark
CO₂ concentrations projected for the 21st century

Scenarios
- A1B
- A1T
- A1FI
- A2
- B1
- B2
- IS92a

CO₂ concentration (ppm)

Year

IPCC, 2001
Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.

Source: IPCC (2007)
Climate scenarios for policy

Policy makers may need climate scenarios:

- As general background information
- To appraise the risk of the impacts
- To assist in formulating response strategies

Scenarios may be normative (i.e. targeted)
2°C EU limit on global mean warming

"The first principle, preservation of Creation, is defined within this scenario in the form of a tolerable “temperature window”. This window is derived from the range of fluctuation for the Earth’s temperature in the late Quarternary [sic] period. This geological epoch has shaped our present-day environment, with the lowest temperatures occurring in the last ice age (10.4°C) and the highest temperatures during the last interglacial period (16.1°C) (Schönwiese, 1987). If this temperature range is exceeded in either direction, radical changes in the composition and function of today’s ecosystems can be expected. If we extend the tolerance range as a precaution by a further 0.5 °C at either end, then the tolerable temperature window extends from 9.9 °C to 16.6 °C. Today’s global mean temperature is 15.3 °C, which means that the temperature span to the tolerable maximum is currently 1.3 °C."

WBGU (German Advisory Council on Global Change), 1995
World in Transition: Ways Towards Global Environmental Solutions
Climate scenarios for stakeholders

Diverse stakeholder needs, including:

- To inform strategic decisions (e.g. investment in new infrastructure)
- To assist in designing adaptation measures (e.g. strengthening or heightening dams)
- To inform planning (e.g. accounting for changing flood risk in the spatial planning of housing)
- To modify regulations and standards (e.g. building regulations)
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Types of climate scenarios

1. Incremental scenarios

2. Analogue-based
   - Palaeoclimatic analogues
   - Historical instrumentally-based analogues
   - Spatial analogues

3. GCM-based
   - Direct GCM outputs
   - Statistical downscaling
   - High resolution models

4. Other types (e.g. expert judgement)
Incremental or "synthetic" scenarios

Systematic but arbitrary adjustments to baseline climate data

Adjustments may be:

- for single variables or combinations
- for means or variance
- at different time resolutions
- based on unknown or anticipated changes (guided sensitivity analysis)
Modelled spring wheat yield response to temperature and CO$_2$ concentration in S. Finland

Carter et al. (2000)
Incremental scenarios

Advantages:

- Easy to design and apply
- Allows impact response surfaces to be created

Disadvantages:

- Variables may be poorly resolved in space and time
- Not related to greenhouse gas forcing
Analogue scenarios

Observed or reconstructed information on climate that might serve as an analogue for future climatic conditions taken from:

- Other regions - spatial analogues
- Previous time periods - temporal analogues
Spatial analogues

Present-day climate in another region that resembles the future climate anticipated in the study area
Some present day spatial analogues of the GISS 2 x CO₂ climate

Parry and Carter (1988)
Present-day spatial analogues of the climates projected for selected European cities by the HadRM3 model for 2071-2100

Background shows observed 1961-1990 mean annual temperature

Hallegatte et al. (2007)
Spatial analogues

Advantages:
- Testing system sensitivity
- Identifying key climate thresholds
- Effective communication tool

Disadvantages:
- Not related to greenhouse gas forcing
- Often physically implausible
- No appropriate analogues may be available
Temporal analogues

Three types:

- Palaeoclimatic analogues
- Instrumentally-based analogues
- Event-driven analogues
Palaeoclimatic analogues

Three main periods:

- Pliocene (3.3 - 3.0 million years BP)
- Eemian interglacial (125,000 years BP)
- Mid-Holocene (6 - 10,000 years BP)
Variations of deuterium ($\delta$D), a proxy for temperature, and atmospheric concentrations of $CO_2$, methane and nitrous oxide in air trapped within ice cores and from recent atmospheric measurements

Shaded bands: current and previous interglacial warm periods

Source: IPCC (2007)
Palaeoclimatic analogues

Advantages:

- Physically plausible - actually occurred
- Similar magnitudes of change to those predicted for ~2100

Disadvantages:

- Variables may be poorly resolved in space and time
- Related to orbital variations not greenhouse gas forcing
Instrumentally-based analogues

Climate during periods or composite years from the historical climate record that may serve as an analogue of future conditions

Types:

- Warm periods (e.g. the Dust Bowl years in USA)
- Warmest years (composite)
- Regression based techniques
Example: Differences in England and Wales rainfall between warm and cool periods

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<td>DJF</td>
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<td>-0.03</td>
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<td>MAM</td>
<td>-0.37</td>
<td>0.11</td>
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<td>JJA</td>
<td>-0.27</td>
<td>-0.44</td>
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<td>SON</td>
<td>-0.41</td>
<td>0.29</td>
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<tr>
<td>Annual</td>
<td>-0.05</td>
<td>-0.02</td>
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Differences are in standard deviation units

Hulme and Jones, 1988
Arnell et al., 1990
Example: Differences in average annual runoff (%) between warm and cool periods in England

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<tr>
<td>Eden</td>
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<td>8</td>
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<tr>
<td>Wye</td>
<td>-3</td>
<td>0</td>
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Arnell et al. (1990)
Instrumentally-based analogues

Advantages:
- Physically realistic changes
- Rich, well-resolved, internally consistent variables
- Data readily available

Disadvantages:
- Not necessarily greenhouse gas forced
- Climate changes usually quite small
- Suitable analogues may not be available
Event-driven analogues

Past impact-relevant climate or weather events

Types:

- climate events identified as extreme meteorologically (e.g. windstorms, droughts)
- climate events identified on the basis of anomalous impacts (e.g. eroding winds, ice storms, ENSO)
- climate events serving as benchmarks for impacts/adaptation (e.g. 100-year flood, 1-in-10 drought)
Daily mortality in Paris during the August 2003 heatwave compared with the four-year average for 1999-2002

Source: van den Torren, 2004
2003 compared to Swiss summer (June-August) temperatures for 1864–2000

Fitted gaussian distribution is indicated in green. Values in the lower left corner of each panel are the standard deviation (σ) and the 2003 anomaly normalized by the 1864–2000 standard deviation (T/σ)

σ = 0.94 °C
T/σ = 5.4

Schär et al. (2004)
Event-driven analogues

Advantages:

- Physically realistic
- Rich, well-resolved, internally consistent variables
- Data readily available
- Impacts/adaptation-relevant

Disadvantages:

- Not necessarily greenhouse gas forced
- May be unsuitable as analogues of future events (e.g. unique, non-climate factors different)
Climate model-based scenarios

- Numerical models of the climate system
- The most credible, physically-based method of simulating future climate
- Different types of models:
  - Simple energy balance models
  - EMICs (Earth System Models of Intermediate Complexity)
  - Atmosphere-Ocean General Circulation Models (AOGCMs)
  - Earth System Models
  - Regional climate models (RCMS)
- Regional scenarios obtained by downscaling
General circulation models (GCMs)

The earth is represented by a grid of boxes, typically 150 km across or smaller.

The atmosphere and oceans are divided into vertical slices of varying depths.

Together this provides a 3-dimensional picture of the circulation of the atmosphere and oceans.

Slingo, 2006
Mid-1970s

CO₂

Rain

Source: Le Treut et al. (2007)
Source: Le Treut et al. (2007)
SAR 1995

Volcanic Activity

Sulphates

Ocean

Source: Le Treut et al. (2007)
Source: Le Treut et al. (2007)
Geographical resolution of global climate models over northern Europe reported in successive IPCC assessments

Source: Le Treut et al. (2007)
1983
Villach, Austria

Climatic Change, 1985, Vol 7 (1)

4 x CO₂ climate (Manabe & Stouffer, 1980) / 2

METIER Graduate Training Course No. 7, Environmental Scenario Analysis
16-22 April 2009, Roskilde, Denmark
Holdridge: Observed climate

Holdridge: 2 x CO₂ climate

Climatic Change, 1985, Vol 7 (1)

1983
Villach, Austria

Holdridge: Observed climate

Holdridge: 2 x CO₂ climate

Climatic Change, 1985, Vol 7 (1)
Climate Modelling and Prediction requires huge supercomputers

Slingo, 2006
Inside the Earth Simulator

Capable of performing $35 \times 10^9$ sums per second

Slingo, 2006
Multi-model mean changes in surface air temperature (°C) by 2011-2030, 2046-2065 and 2080-2099 relative to 1980-1999 for the SRES B1, A1B and A2 scenarios.
Multi-model mean changes in precipitation (%) by 2090-2099 relative to 1980-1999 based on the SRES A1B scenario

Changes plotted only where more than 66% of the models agree on the sign of the change
Stippling: areas where more than 90% of the models agree on the sign of the change

Source: IPCC (2007)
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Conventional approach to climate change impact assessment

Impacts estimated as the difference between:

- Conditions in the absence of climate change (future baseline), and
- Conditions with climate change
Baseline/reference climate

Roles:

- To provide a reference or benchmark against which to evaluate future changes
- To characterise the climatic conditions to which systems are exposed at the present-day
- To provide the initial conditions for modelling future changes
Scenario time horizon

Choice influenced by:

- Relevance to the system/sector under study
- Signal:noise considerations
- Importance of lags in response
- Availability of projections
Scenario resolution

Depends on:

- Spatial scale of the exposure unit
- Availability of scenario information
- Ability to "scale" to the resolution of interest
Scenario application

- Direct model outputs are commonly biased
- "Delta change" approach often favoured for monthly climate scenarios:
  - Baseline climate described using observations
  - Future climate computed as change ($\Delta$) between modelled baseline and modelled future applied to observed baseline
  - Difference (e.g. temperature) or ratio (%) (e.g. precipitation)
- Direct model outputs or weather generator often used for daily/sub-daily climate scenarios (commonly downscaled from GCMs)
Regionalization

Goal: To obtain region-specific information at a finer resolution than offered by GCMs

Two main types:

1. Fine resolution modelling, using:
   - variable resolution global models
   - global model time slice experiments
   - nested regional climate models (RCMs)

2. Statistical downscaling
Regional climate models (RCMs)

- Offer information at a higher spatial (appr. 50 km) and temporal (daily) resolution than AOGCM outputs
- Provide the possibility to account for changes in both the mean climate and climate variability
- But: cover only a limited range of uncertainty in climate change
<table>
<thead>
<tr>
<th>Institute/Contact</th>
<th>Scenario</th>
<th>Driving GCM</th>
<th>Model</th>
<th>Resolution</th>
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</table>
Statistical downscaling

- Complementary technique to RCMs
- Derives relationships linking large-scale atmospheric variables (predictors) and local/regional climate variables (predictands)
- Applies relationships to equivalent predictors from AOGCM simulations to obtain local estimates
- Techniques include:
  - linear and non-linear regression-type models
  - weather generators for generating synthetic sequences of local variables
  - weather classification techniques to simulate circulation patterns
  - statistical-dynamical downscaling, combining weather classification with RCM simulations
Annual precipitation change in Norway (% per decade) relative to 1961-1990 statistically downscaled from the ECHAM4 model

Hanssen-Bauer et al., 2001
Web portals for Climate Data Access and Statistical Downscaling

One of the ENSEMBLES project's aims is maximizing the exploitation of the results by linking the outputs of the ensemble prediction system to a range of applications, including agriculture, health, food security, energy, water resources, and insurance, which use high resolution climate inputs to feed their models. The data access portal allows end-users to interact with seasonal and climate model simulations to local points of interest, obtaining the requested data in simple formats (e.g., text files). Moreover, the statistical downscaling portal allows to calibrate/adapt the coarse model outputs in the region of interest using historical observed records.

The Data Access portal provides access to observations, reanalyses and seasonal and climate simulations [see the common list of variables available for all models in the portal].

This Statistical Downscaling portal provides user-friendly web access to different statistical downscaling techniques.

References:


Regionalization

Advantages:

- Resolves sub-GCM-scale features and hence *may* provide more reliable information on regional climate change
- Resolves higher temporal/spatial resolution weather events than GCMs, hence *may* provide useful information on changes in climatic variability and extreme events
Hurricane Katrina, 23:32 UTC, 28 August 2005
Max'm sustained wind: 258 kph; Central pressure: 904 mb; Category 5
Regionalization

Advantages:
- Resolves sub-GCM-scale features and hence may provide more reliable information on regional climate change
- Resolves higher temporal/spatial resolution weather events than GCMs, hence may provide useful information on changes in climatic variability and extreme events

Disadvantages:
- Scenarios dependent on bounding GCM (nested RCMs and statistical downscaling)
- High resolution processes have their own uncertainties
- Samples only a small part of the climate change uncertainty range
Outline of lecture

1. Why do we need to characterise future climate?
2. What are climate scenarios?
3. Types of climate scenarios
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7. Conclusions
Sources of uncertainty in climate projections

- Natural variability
- Future radiative forcing
- Process uncertainty
- Model parameter uncertainty
- Model structural uncertainty
- Downscaling

Of course, impacts are uncertain too!
Natural variability (ensembles)

Source: Glen Harris, Met Office Hadley Centre

HadCM3

Source: Glen Harris, Met Office Hadley Centre
Future radiative forcing (SRES) HadCM3 projections

Source: Meehl et al., 2007
Model parameter uncertainty

Perturbed physics experiment (PPE)

Source: Glen Harris, Met Office Hadley Centre
Model structural uncertainty

Multi-model AR4 experiments
Model structural uncertainty

Multi-model AR4 experiments

A2(17)

A2
Model structural uncertainty

Multi-model AR4 experiments

Source: Meehl et al., 2007
Comparing parameter uncertainty (HadCM3) and structural uncertainty (AR4-A1B-21)
Carbon cycle feedbacks

A2 scenario

Source: Meehl et al., 2007
Comparing modelled carbon cycle with structural uncertainties

Source: Meehl et al., 2007
Downscaling (dynamical, SD)

Temperature Change(°C)

HadCM3

A2

PRUDENCE

HadAM3

9 RCMs
Comparing RCM and GCM uncertainties

Source: Fronzek and Carter, 2007, PRUDENCE
Methodology for the production of probabilistic projections of future climate change for the United Kingdom (UKCP09) from physics perturbation experiment (PPE) simulations using various configurations of the HadCM3 climate model and information from the IPCC AR4 multi-model ensembles (Box K).

Source: Murphy et al. (2007)
UK Climate Projections 2009

The next package of climate change scenarios for the UK have the full title of UK Climate Projections and will be known as UKCP09 or the Projections for short.

The information provided on these pages is intended to support the development of the UKCP09 scenarios between now and their launch in early 2009.

About UKCP09 provides a starting point for learning about UKCP09. The page also contains the latest news about the development of UKCP09 and explains what is being done.

UKCP09 in context discusses why UKCP09 will take the form it will, including consideration of past UK climate change scenarios, current user requirements and recent advances in climate science.

What information will be provided by UKCP09? examines what information UKCP09 can be expected to provide. A technical briefing section gives more detail about the science behind UKCP09 and the methods used.

Using UKCP09 looks at UKCP09 from a user perspective, including how the information will be provided and what outputs can be expected. Also provided here are details of the planned training and guidance to support use of UKCP09, information about the UKCP09 Users' Panel, FAQs and a glossary of terms.

Finding out more offers suggestions of where to go for more information about UKCP09, including web-links, downloads and publications.

UKCP09 remains work in progress and the information provided here is provisional and is liable to change.

Back to top
1. Impact approach (conventional)

CLIMATE
Scenario 1
Scenario 2
Scenario 3

Mean & range of climate change

IMPACT MODEL

IMPACTS
Impact 1
Impact 2
Impact 3

Mean & range of impacts

Interpretation of vulnerability
Modelled change in water-limited wheat yield (T ha\(^{-1}\)) by 2050 relative to the baseline climate

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<th>Region</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
<th>HadCM2</th>
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<td>2.1</td>
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Source: Harrison and Butterfield, 2000

EU CLIVARA Project
Ensemble of opportunity

Advantages:
- AOGCM outputs are readily available
- Scenarios are physically plausible

Disadvantages:
- Scenarios only sample part of the uncertainty range
- Impacts are wholly based on only a few representations of future climate
2. Risk-based inverse approach (ENSEMBLES)

CLIMATE
- Scenario 1
- Scenario 2
- Scenario 3
- Scenario 4
- Scenario 5
- Scenario 6
  ...  
  ...  
  ...  
- Scenario n

Probabilistic climate change

IMPACT MODEL

IMPACTS
- Threshold exceeded?
  - Scenario 1
  - Scenario 2
  - Scenario 3
  - Scenario 4
  - Scenario 5
  - Scenario 6
  ...  
  ...  
  ...

Probabilistic impacts

Our challenge

Determination of impact threshold
Distribution of modelled precipitation and temperature for Northern Europe (Sep-Nov) and East Africa (Mar-May) from climateprediction.net. (a,b) Crosses: control climate for the second half of the 20th century with pre-industrial CO$_2$; Dots: mean response for doubled CO$_2$. (c,d) Response to doubled CO$_2$ for each simulation (delta change).
Change in simulated median daily flow of the Thames at Teddington, London using the CATCHMOD hydrological model for doubled CO$_2$ climates simulated in a climateprediction.net (CP.net) ensemble.

Source: New et al. (2007)
The use of probabilistic climate projections for estimating risks of palsa mire disappearance

Observed spatial distribution of palsa mires

Impact response surface and climate PDF (A1B)

The projections are probabilistic, therefore they are not scenarios

Source: Fronzek et al. (in press)
Should we assign probabilities to alternative future worlds?

• Yes – “Policy analysts need[ed] probability estimates to assess the seriousness of the implied impacts; otherwise they would be left to work out the implicit probability assignments for themselves”  
(Schneider, 2001)

• No – ”..... there are no independent observations and no repeated experiments: the future is unknown, and each future is ‘path-dependent’ ......There is a danger that Schneider’s position might lead to a dismissal of uncertainty in favour of spuriously constructed ‘expert’ opinion.”  
(Grübler and Nakicenovic, 2001)
Uncertainties in global-mean warming for: 1990-2030 (dots), 1990-2070 (crosses) and 1990-2100 (bold)

Outline of lecture

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METIER Graduate Training Course No. 7, Environmental Scenario Analysis
16-22 April 2009, Roskilde, Denmark

(a) Sequential approach

1. Emissions & socio-economic scenarios (IAMs)
2. Radiative forcing
3. Climate projections (CMs)
4. Impacts, adaptation & vulnerability (IAV)

(b) Parallel approach

1. Representative concentration pathways (RCPs) and levels of radiative forcing
2a. Climate, atmospheric & C-cycle projections (CMs)
2b. Emissions & socio-economic scenarios (IAMs)
3. Impacts, adaptation, vulnerability (IAV) & mitigation analysis
Some features of the Representative Concentration Pathways (RCPs)

- CO2 Emissions
- CO2 Concentrations
- Radiative forcing
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Characterisations of the future

- Implausible futures: Zero or negligible likelihood
- Plausible futures: Without ascribed likelihood
- Proximal futures: With ascribed likelihood

Carter et al. (2007)
Conclusions

1. Climate scenarios have an important role in impacts research, policy making and adaptation planning
2. Several types of scenarios have been adopted in IAV studies: incremental scenarios, analogues and climate model-based
3. Different sources of uncertainty in projections of future climate need to be represented in scenarios
4. Probabilistic climate projections offer an opportunity to examine risks of future impacts
5. New climate model simulations will be conducted in preparation for the IPCC AR5
CHARACTERISING FUTURE CLIMATE FOR APPLICATION IN IMPACT AND ADAPTATION STUDIES

Lecturer: Timothy Carter, Finnish Environment Institute

Selected reading


