Emission pathways reducing the risk of dangerous climate change

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Outline

• What is “dangerous climate change”?
• The UVic Earth System Climate Model
• Experimental design
• Results: CO₂ emissions compatible with specified temperature targets
• Conclusions
UNFCCC Article 2

“The ultimate objective of this convention … is to achieve … 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.”
What is “dangerous”? 

Interpretation of Article 2 involves

• Scientific assessment of what impacts might be associated with different levels of greenhouse gas concentrations or levels of climate change.

• Normative evaluation by policy-makers of which impacts and associated likelihoods constitute “dangerous anthropogenic interference”.

IPCC’s reasons for concern

IPCC, TAR, Synthesis Report, 2001

CRG Workshop, 21-23 July 2008
Motivation

• Recent international climate policy discussions framed around limiting global mean temperature increase to 2°C relative to pre-industrial times.
• Earlier studies have linked specific CO₂ concentration levels with the probability of meeting the 2°C target.
• Probability of meeting that target is ‘likely’ (p<0.33) at CO₂ equivalence concentration levels below 450 ppmv.
• Link to allowable CO₂ emissions usually provided by integrated assessment models including highly simplified representation of the carbon cycle.
• Scope of this study: Consistently derive cumulative emissions compatible different temperature targets using state-of-the-art climate-carbon cycle model.
The UVic Earth System Climate Model

• “Intermediate complexity” model.
• Suited for climate studies on decadal to millennial time-scales.
• Computationally efficient (~160 model years in 1 day).
The UVic Earth System Climate Model

Ocean General Circulation Model
MOM 2
19 vertical layers
The UVic Earth System Climate Model

Ocean General Circulation Model

Dynamic-Thermodynamic Sea Ice Model
The UVic Earth System Climate Model

Ocean General Circulation Model

Sea Ice Model

Land Surface Scheme
The UVic Earth System Climate Model

Energy/Moisture Balance

Atmospheric Model

Sea Ice Model

Ocean General Circulation Model

Vegetation Model

Land Surface Scheme
The UVic Earth System Climate Model

- Energy
- Water

Atmospheric Model

Sea Ice Model

Ocean General Circulation Model

Vegetation Model

Land Surface Scheme
The UVic Earth System Climate Model

- Atmospheric Model
- Ocean General Circulation Model
- Sea Ice Model
- Vegetation Model
- Land Surface Scheme
- Inorganic Carbon Cycle
- Organic Carbon Cycle
- Marine sediment model
The UVic Earth System Climate Model

- **Energy**
- **Water**
- **Carbon**

**Components:***

- **Atmospheric Model**
- **Sea Ice Model**
- **Ocean General Circulation Model**
  - Inorganic Carbon Cycle
  - Organic Carbon Cycle
- **Land Surface Scheme**
- **Vegetation Model**
- **Marine sediment model**

Each component has a resolution of 3.6°x1.8°
The UVic Earth System Climate Model

- Ocean General Circulation Model
  - Inorganic Carbon Cycle
  - Organic Carbon Cycle
- Atmospheric Model
- Sea Ice Model
- Land Surface Scheme
- Vegetation Model
- Marine sediment model

Externally driven by:
- insolation, winds, greenhouse gases...

Each component has a resolution of $3.6^\circ \times 1.8^\circ$
Model evaluation: Historical temperature change

Data: Jones et al. (2006)
Model evaluation:
Historical CO$_2$ change

Data: Keeling et al., 2005
Experiment design

- Over the historical period (1800-2000) the model is driven by known forcings (greenhouse gases, sulphates, solar irradiance, volcanoes, land cover change).
- From 2000 on the model computes the CO$_2$ emissions consistent with a specified temperature profile ("temperature tracking"). Most non-CO$_2$ forcing agents are hold constant at year-2000 levels.
- Proportional control:
  \[ E(t) = k(\Delta T^{DATA}(t) - \Delta T(t)) \]

  E - CO$_2$ emissions
  k - constant
  $\Delta T^{DATA}$ - prescribed temperature anomaly
  $\Delta T$ - modelled temperature anomaly
Temperature tracking

Temperature vs. Calendar year

CO₂ (ppmv) vs. Calendar year
Cumulative emissions meeting 2°C target

Cumulative emissions in 2500 independent of specified temperature trajectory

> Cumulative emissions in 2500 independent of specified temperature trajectory
Variation of climate sensitivity

Cumulative emissions (PgC) strongly dependent on assumed value of climate sensitivity.
PDFs for climate sensitivity

IPCC 2007, WG I, Ch 10
Probability of exceeding temperature target

Given $E(cs^0, \Delta T^{GOAL})$

$$P(\Delta T(E) \geq \Delta T^{GOAL}) = \int_{cs^0}^{\infty} P(cs = x) \, dx$$

$$= P(cs \geq cs^0)$$

$\Delta T^{GOAL}$ - Temperature target

$cs$ - Equilibrium climate sensitivity

$P(cs = \Delta T)$ - Climate sensitivity PDF

$P(cs \geq \Delta T)$ - Climate sensitivity CDF
Probability of exceeding 2°C target
Conclusions

• Cumulative CO$_2$ emissions compatible with 2°C target independent of path taken to stabilization.

• To limit global mean temperature rise to 2°C above pre-industrial with a probability of 0.33 cumulative emissions after 2000 must not exceed 640 PgC (range: 280-930 PgC).

• We suggest shift in focus from allowable greenhouse gas concentrations to total allowable emissions.

• Path independency may facilitate international climate policy negotiations: Countries are allocated total emissions shares. No need to agree on common time-line.
Thank you for your attention!

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