Climate Change: Cutting through the Rhetoric
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- The climate is changing
  - Examples from the global cryosphere (snow, sea ice, permafrost, glaciers, ice sheets)

- Causality: Things that push the climate around

- Should we care? What we should be debating
  - Examples of impacts: sea level rise
  - The other side of the coin:
    Can we live with it? Are CO₂ reductions even possible?
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 AVR The climate is changing

❖ Examples from the global cryosphere
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<table>
<thead>
<tr>
<th>Global Top 12</th>
<th>Anomaly °C</th>
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</thead>
<tbody>
<tr>
<td>Warm Years</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>0.62</td>
</tr>
<tr>
<td>2005</td>
<td>0.62</td>
</tr>
<tr>
<td>1998</td>
<td>0.60</td>
</tr>
<tr>
<td>2003</td>
<td>0.58</td>
</tr>
<tr>
<td>2002</td>
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<tr>
<td>2009</td>
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<td>2006</td>
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<td>2007</td>
<td>0.55</td>
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<td>2004</td>
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<td>2001</td>
<td>0.52</td>
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<tr>
<td>2008</td>
<td>0.48</td>
</tr>
<tr>
<td>1997</td>
<td>0.48</td>
</tr>
</tbody>
</table>

http://www.ncdc.noaa.gov/sotc/
Jan-Dec Land & Ocean Surface Mean Temp Anomalies
NCDC/NESDIS/NOAA
Analysis is based upon Smith et al. (2008) methodology.

Global

Northern Hemisphere

Southern Hemisphere
Global Temperature Change
Decade Averages

2000s even warmer. Every year warmer than 1990s average.

1990s even warmer. Every year warmer than 1980s average.

1980s warmest decade on record at the time.
Arctic Amplification
The global glacier mass balance record
albedo

05/09  05/29  06/18  07/08  07/28  08/17
Changes in Greenland

2a. Feedbacks from more melt
Changes in Greenland

Impacts of Ocean Warming
Ice-Sheet and Sea-Level Changes

Richard B. Alley,† Peter U. Clark, Philippe Huybrechts, Ian Joughin

Surface elevation (m)

370 ppm 2000 A.D.

550 ppm 3000 A.D.

750 ppm 3000 A.D.

1000 ppm 3000 A.D.

1000 ppm 4000 A.D.

1000 ppm 5000 A.D.

Summer temperature change (°C)

Year A.D.

Sea level change (m)

Year A.D.
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IPCC (2007) assessment of radiative forcing

Radiative Forcing Components

- **Anthropogenic**
  - CO$_2$
  - CH$_4$
  - Halocarbons
  - Ozone
  - Stratospheric
  - Tropospheric
  - Surface albedo
  - Land use
  - Black carbon on snow
  - Aerosol
  - Cloud albedo effect
  - Linear contrails

- **Natural**
  - Solar irradiance

- Total net anthropogenic

**RF values (W m$^{-2}$)**
- CO$_2$: 1.66 [1.49 to 1.83]
- CH$_4$: 0.48 [0.43 to 0.53]
- Halocarbons: 0.16 [0.14 to 0.18]
- Ozone: -0.05 [-0.15 to 0.05]
- Stratospheric: 0.35 [0.25 to 0.65]
- Tropospheric: 0.07 [0.02 to 0.12]
- Surface albedo: -0.2 [-0.4 to 0.0]
- Land use: 0.1 [0.0 to 0.2]
- Black carbon on snow: -0.5 [-0.9 to -0.1]
- Aerosol: -0.7 [-1.8 to -0.3]
- Cloud albedo effect: 0.01 [0.003 to 0.03]
- Linear contrails: 0.12 [0.06 to 0.30]
- Solar irradiance: 1.6 [0.6 to 2.4]

**Spatial scale**
- Global
- High
- Global
- High
- Continental to global
- Med
- Local to continental
- Med - Low
- Continental to global
- Med - Low
- Continental
- Low
- Global
- Low
On Causality

Lots of things can push the climate around, e.g., solar variability; volcanic & industrial sulphate emissions; , land use changes; greenhouse gases other than CO₂

It is just that nothing other than CO₂ explains the warming over the last 40 years

Flipping things over: given the GHG buildup, it would be strange if the world was not warming
Climate Change: Cutting through the Rhetoric

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Figure 11.9: Ranges of uncertainty for the average rate of sea level rise from 1910 to 1990 and the estimated contributions from different processes.

IPCC (2001)
Figure 11.9: Ranges of uncertainty for the average rate of sea level rise from 1910 to 1990 and the estimated contributions from different processes.

Changing Reality: From IPCC 2001 to IPCC 2007
Contributions to global sea level rise, 1993-2003

Redrawn from IPCC (2007)
Greenland Ice Mass

![Graph showing the mass of Greenland ice from 2003 to 2009. The graph indicates a significant decline in ice mass over the years.]

**Velicogna (2009), GRL**
Contributions to global sea level rise, 1993-2009

Observations

Total

Thermal expansion

Greenland

Antarctica

Glaciers & Ice Caps

Prospects for IPCC (2013) ??

3.3 mm/yr
Concerns about sea level rise

A bit of a wild card: Published estimates vary from 20-160 cm of global eustatic sea level rise by 2100.

Impacts: Very global, and most serious for tropical developing countries.

* 150 of the world’s 192 sovereign nations border the ocean.
* The world’s 98 largest coastal cities (population > 2 million) constitute 664 million people.
Potential impact of sea-level rise on Bangladesh

Today
Total population: 112 Million
Total land area: 134,000 km²

1.5 m - Impact
Total population affected: 17 Million (15%)
Total land area affected: 22,000 km² (16%)

Source: UNEP/GRID Geneva; University of Dacca; JRO Munich; The World Bank; World Resources Institute, Washington D.C.
Modelled Ocean Warming, Zonally-Averaged

CCCmA simulation, A1b scenario

Depth (m)

Ocean Temperature Change (°C)

Latitude

2100-1800 AD
Implications for Sea Level Rise Commitment

CCCmA simulation, ‘drop dead @ 2100’ scenario

Ocean Temperature Change (°C)

Latitude

Depth (m)

2500-2100 AD
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Climate Change Policy

1997: COP 3, Kyoto

Mandatory targets on greenhouse-gas emissions for the world's leading economies.

Targets range from –8% to +10% of countries’ individual 1990 emissions levels

“with a view to reducing their overall emissions of such gases by at least 5 per cent below existing 1990 levels in the commitment period 2008 to 2012"
Changes in GHG emissions excluding LULUCF (%)

<table>
<thead>
<tr>
<th>Country</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>42.9</td>
</tr>
<tr>
<td>Iceland</td>
<td>42.3</td>
</tr>
<tr>
<td>Spain</td>
<td>32.2</td>
</tr>
<tr>
<td>Portugal</td>
<td>31.4</td>
</tr>
<tr>
<td>Australia</td>
<td>24.1</td>
</tr>
<tr>
<td>Canada</td>
<td>23.1</td>
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<tr>
<td>Greece</td>
<td>23.0</td>
</tr>
<tr>
<td>Ireland</td>
<td>22.7</td>
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<tr>
<td>New Zealand</td>
<td>14.7</td>
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<tr>
<td>Liechtenstein</td>
<td>13.3</td>
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<tr>
<td>United States</td>
<td>10.8</td>
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<tr>
<td>Austria</td>
<td>8.0</td>
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<tr>
<td>Norway</td>
<td>5.2</td>
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<tr>
<td>Slovenia</td>
<td>4.7</td>
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<tr>
<td>Italy</td>
<td>3.6</td>
</tr>
<tr>
<td>Japan</td>
<td>1.0</td>
</tr>
<tr>
<td>Switzerland</td>
<td>-0.5</td>
</tr>
<tr>
<td>Finland</td>
<td>-0.9</td>
</tr>
<tr>
<td>Croatia</td>
<td>-2.4</td>
</tr>
<tr>
<td>Netherlands</td>
<td>-4.8</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>-6.1</td>
</tr>
<tr>
<td>France</td>
<td>-7.1</td>
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<td>Denmark</td>
<td>-7.1</td>
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<tr>
<td>Belgium</td>
<td>-11.0</td>
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<td>European Union</td>
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<tr>
<td>Monaco</td>
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<tr>
<td>Sweden</td>
<td>-11.7</td>
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<td>United Kingdom</td>
<td>-18.5</td>
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<tr>
<td>Germany</td>
<td>-22.2</td>
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<td>Czech Republic</td>
<td>-27.5</td>
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<tr>
<td>Poland</td>
<td>-29.0</td>
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<tr>
<td>Russian Federation</td>
<td>-32.9</td>
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<td>Slovakia</td>
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<td>Belarus</td>
<td>-55.1</td>
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<td>Hungary</td>
<td>-56.1</td>
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<tr>
<td>Bulgaria</td>
<td>-55.6</td>
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<tr>
<td>Romania</td>
<td>-56.1</td>
</tr>
<tr>
<td>Estonia</td>
<td>-50.4</td>
</tr>
<tr>
<td>Lithuania</td>
<td>-51.1</td>
</tr>
<tr>
<td>Ukraine</td>
<td>-53.9</td>
</tr>
<tr>
<td>Latvia</td>
<td>-58.6</td>
</tr>
</tbody>
</table>

Changes in GHG emissions 1990 to 2008

- U.S.A.
- Canada
Changes in GHG emissions excluding LULUCF (%)

- Turkey: 96.0%
- Iceland: 42.9%
- Spain: 42.3%
- Portugal: 32.2%
- Australia: 31.4%
- Canada: 24.1%
- Greece: 23.1%
- Ireland: 23.0%
- New Zealand: 22.7%
- Liechtenstein: 14.7%
- United States: 13.3%
- Austria: 10.8%
- Norway: 8.0%
- Slovenia: 5.2%
- Italy: 4.7%
- Japan: 1.1%
- Switzerland: -0.8%
- Finland: -0.2%
- Croatia: -0.9%
- Netherlands: -2.4%
- Luxembourg: -4.8%
- France: -6.1%
- Denmark: -7.1%
- Belgium: -7.1%
- European Union: -11.3%
- Monaco: -11.4%
- Sweden: -11.7%
- United Kingdom: -18.5%
- Germany: -22.2%
- Czech Republic: -27.5%
- Poland: -29.9%
- Russian Federation: -32.9%
- Slovakia: -33.9%
- Belarus: -35.1%
- Hungary: -36.1%
- Bulgaria: -41.9%
- Romania: -46.9%
- Estonia: -50.4%
- Lithuania: -51.1%
- Ukraine: -53.9%
- Latvia: -55.6%

Changes in GHG emissions 1990 to 2008
**Fossil CO₂ Emissions**

Emissions (GtCO₂/yr)

- Possible Future without Climate Policy
- 1000 GtCO₂ until 2050

**Global Warming**

- Probability of exceeding 2°C
  - No climate policy: 100%

- Emission budget of 1000 GtCO₂ until 2050: 25%

- Possible Future without Climate Policy

**Global Mean Surface Warming**

Max +2°C

Past observed Temperatures

- 1900
- 1920
- 1940
- 1960
- 1980
- 2000
- 2020
- 2040
- 2060
- 2080
- 2100

Adapted from Meinshausen et al. 2009

Source: Adapted from Meinshausen et al. 2009
Potential ‘tipping elements’ in Earth’s climate

Lenton et al., 2008
General Comments On Climate Models

Like weather forecasts,
“Too speculative to trust, but too good to ignore”

A few important points:

- Good at certain things, lousy at others
- Forecasting the mean climate state is a much simpler problem than a weather forecast
- Not about the internal redistribution of energy, but the balance:
  \[ \rho c \frac{\partial T}{\partial t} = \text{Energy In} - \text{Energy Out} \]
Climate Change: Hedging our Bets

We don’t know exactly what is ahead:

- natural forcings could make it warmer or colder than the simple GHG-driven trajectory we are on
- there are feedbacks that can go either way

But: What we *do* know about the climate system is that the basic thermodynamics make warming a good bet, and that feedbacks in the system are mostly positive.

The conservative, rational thing to do is to play the odds and minimize our risks and negative impacts.
Climate Change: Cutting through the Rhetoric

Can we reframe the question to:

“What kind of world do we want?”
Thanks.... Questions?
Spare slides
Periodic variation in sunspot number

Duhau and Jager, 2010
### Summary, Primary Climate Forcings (W/m²)

<table>
<thead>
<tr>
<th></th>
<th>0-2000 AD (W/m²)</th>
<th>1900-2000 (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volcanic</td>
<td>−0.21</td>
<td>−0.27</td>
</tr>
<tr>
<td>Aerosol</td>
<td>−0.03</td>
<td>−0.50</td>
</tr>
<tr>
<td>Solar</td>
<td>+0.04</td>
<td>+0.41</td>
</tr>
<tr>
<td>Greenhouse gases</td>
<td>+0.01</td>
<td>+1.10</td>
</tr>
</tbody>
</table>
Canada’s Policy-as-usual Emissions Projection and the Kyoto Protocol

- 601 (1990)
- 682 (1995)
- 694 (2000)
- 764 (2010)

199 Mt or 26%

Kyoto Protocol: 565 Mt
Carbon Dioxide Stabilization

CO₂ Concentration (ppmv)

CO₂ Emissions (GtC/yr)

1900 2000 2100 2200 2300
Observed sea level rise

20th century: $1.7 \pm 0.2$ mm/yr
1993-2009: $3.3 \pm 0.4$ mm/yr

Satellite altimetry since 1993 (Poseidon, Jason I, Jason II)

Tide gauges

IPCC (2007)
Wet base = potential speedup
Climate Change Policy

1997: COP 3, Kyoto

Required ratification from at least 55 parties to the Convention, representing at least 55% of global CO$_2$ emissions, to come into effect

Stalled for several years. Canada (3.3%) ratified in 2002. Russia (17.6%) ratified November, 2004.

Legally came into effect, February 16, 2005

156 of 162 countries accepted, representing 61.6% of global emissions