Global Warming:
Science, Projections and Uncertainties

An overview of the basic science

1. A Brief History of “Global Warming”
2. Climate Change: 1850-2007
3. Projections of Climate Change: 2100 and beyond
4. What’s new in Climate Science?
5. Conclusions

Greenhouse Effect: not a new problem

Joseph Fourier, 1827:
Recognized the earth (not the atmosphere) is mainly heated by the Sun, and gases in the atmosphere slow the heat loss to space and make the surface of the planet warmer than it would otherwise be.

John Tyndall, 1860s:
Recognized water vapor and carbon dioxide are greenhouse gases.

Tyndall’s thermopile
Global Warming: not a new problem

Svante Arrhenius, 1896

- In 1894, Hogbom calculated the amount of carbon dioxide added to the atmosphere due to burning coal
- In 1896, Arrhenius:
  - estimated that it would take 3000 years for humans to double atmospheric carbon dioxide
  - calculated that doubling atmospheric carbon dioxide would increase the global temperature by 5-6 degrees C.

Atmospheric Carbon Dioxide

- Carbon Dioxide is increasing because of the burning fossil fuels (85%) and deforestation (15%)
  - 25% increase in the past 50 years; 10% increase since 1990;
• Carbon dioxide increased by 1/3 since 1750 because of the burning fossil fuels (75%) and deforestation (25%)
  – Fate: 40% in atmosphere, 35% in land and 25% in ocean
• The rate of increase is 100-1000 times faster than Nature can change CO₂

2. Climate Change: 1850-2007
• Intergovernmental Panel on Climate Change (IPCC)
  – A consensus report with contributions from more than 1000 scientists
• Greenhouse gases (carbon dioxide, methane, nitrous oxide) have been increasing since 1750 because of human activity.
• The Earth has warmed by 0.8 ± 0.2°C since 1900.
• The IPCC concludes:
  – “Most of the observed warming over the past 50 years is likely to have been due to the increase in greenhouse gas concentrations.” (2001)
  – “Most of the observed increase in global average temperature since the mid-20th century is very likely [≥90% chance] due to the observed increase in anthropogenic greenhouse gas emissions” (2007)
  – Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns” (2007)
Most glaciers are receding.

Climate Models are used to understand the cause of the observed climate change, and to project the future.

Climate Models are based on the laws of physics and chemistry, and used for ~40 years for various problems.
Modeled and Observed Temperature Change 1900-2000

Why has the global average temperature increased? It's more than just CO$_2$
Climate changes (1900 to 2000) due to human activity

<table>
<thead>
<tr>
<th>Phenomenon and direction of trend</th>
<th>Likelihood that trend occurred in late 20th century (typically post 1960)</th>
<th>Likelihood of a human contribution to observed trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warmer and fewer cold days and nights over most land areas</td>
<td>Very likely</td>
<td>Likely</td>
</tr>
<tr>
<td>Warmer and more frequent hot days and nights over most land areas</td>
<td>Very likely</td>
<td>Likely (night)</td>
</tr>
<tr>
<td>Warm spells/heat waves. Frequency increases over most land areas</td>
<td>Likely</td>
<td>More likely than not</td>
</tr>
<tr>
<td>Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas</td>
<td>Likely</td>
<td>More likely than not</td>
</tr>
<tr>
<td>Area affected by droughts increases</td>
<td>Likely in many regions since 1970</td>
<td>More likely than not</td>
</tr>
<tr>
<td>Intense tropical cyclone activity increases</td>
<td>Likely in some regions since 1970</td>
<td>More likely than not</td>
</tr>
<tr>
<td>Increased incidence of extreme high sea level (excludes tsunamis)</td>
<td>Likely</td>
<td>More likely than not 1)</td>
</tr>
</tbody>
</table>

Virtually certain > 99%
Very likely >90%
Likely >66%
More likely than not > 50%

Probability “based on quantitative analysis or an elicitation of the expert views”

IPCC 2006

3. Projections of Climate Change: 2100 and beyond

- Projections taken from the most recent consensus report from Intergovernmental Panel on Climate Change.
- Focus on those changes that are “very likely” (i.e., those that are either deemed to have a greater than 90% chance to occur “based on quantitative analysis or an elicitation of the expert views”)
How much Carbon Dioxide will be released into the atmosphere?

Scenarios provided by economists, policy makers, etc.

Estimates depend on population and economic projections, future choices for energy, governance/policy options in development (e.g., regional vs. global governance)

How much Carbon Dioxide will go into the atmosphere?

Scenarios
- A1B
- A2
- B1
- IS92a

CO₂ concentration (ppm)

1980 2000 2020 2040 2060 2080 2100

300 400 500 600 700 800 900 1000 1100 1200 1300
Climate change due to increasing greenhouse gases

Changes that are *highly likely* over the next 100 years include:

- the planet will warm, more so in middle and high latitudes than in the tropics
- the hydrologic cycle will speed up
- the area covered by snow and sea ice in winter will decrease
- the interior of continents will be drier in the summertime
- the sea level will rise
- the surface ocean will become 2-3 times more acidic

These changes will be much, much greater than the changes seen over the past 150 years that have been attributed to increased greenhouse gases and aerosols.