Climate Variability and Climate Change

1. Definitions
   • The Climate System; Natural and Forced Variability

2. Natural Variability
   • North Atlantic Oscillation, El Nino/Southern Oscillation

3. Forced Change (natural)
   • Volcanic Eruptions (scattering particles)
   • Changes in the Solar Luminosity

4. Forced Change (human)
   • Burning of fossil fuels (increasing GH gases)
   • Burning of biomass (scattering particles)

Forced Change: Changes in the Sun’s output

• Sunspots are associated with a small increase in energy coming from the Sun
  – Sunspot numbers vary (11 year cycle, and other poorly understood time scales)
• Direct estimates of the change in insolation since 1978
  – The solar constant varies by +/- 0.05% over the sunspot cycle, or about +/- 0.5W/m², or about +/-0.125 W/m² averaged over the whole Earth
• Changes are too small to explain correlated variability in global temperature (so proponents of solar forcing offer exotic ideas -- often involving cosmic rays and clouds -- to amplify the impact):
  – Expect ~0.05°C changes in global temperature
"one of the most powerful solar flares in years... erupted from sunspot 486."

www.spaceweather.com

The Solar Constant

Direct measurements of Solar luminosity since 1978
The Solar Constant

Sunspot cycle #22

Sunspot observations

25 BC: First sunspot records in China
1611: Sunspots discovered by Europeans (with telescopes)
How to view sunspots

NO !!!

Yes

Focus solar image onto a screen

Sunspot Evolution

Cycle is on average 10.55 yrs (range is 9 to 14 yr)
Sunspot Numbers

The Solar Constant in the past

History of Sun’s luminosity is revised downward (to brown curve)

Estimate comes from: (i) extrapolating direct insolation-sunspot number relationship; (ii) modeling of the solar magnetic flux; $^{14}$C and $^{10}$Be measurements in trees (cosmogenic flux); (iii) observing range of luminosity in other Sun-like stars.

IPCC 2007 Fig 6.14
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Forced Change: Three Important GH gases influenced by human activity

**FAQ 2.1, Figure 1.** Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample. (Data combined and simplified from Chapters 6 and 2 of this report.)

IPCC 2007
Human Forcing: Changes in GH gases

Grey bar = maximum range seen over glacial cycles

Forced Change: Three Important GH gases influenced by human activity

Figure TS.1. Variations of deuterium (δD) in antarctic ice, which is a proxy for local temperature, and the atmospheric concentrations of the greenhouse gases carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) in air trapped within the ice cores and from recent atmospheric measurements. Data cover 650,000 years and the shaded bands indicate current and previous interglacial warm periods. (Adapted from Figure 6.3)
The Carbon Cycle is complex

Where is the carbon circa 1990AD?
Ocean (non-biota) 38,150 + 118 Gt
Land Biosphere 2300 - 39
Fossil Fuels 3700 - 244

The Carbon Cycle is complex

Where is the carbon circa 2005AD?
Ocean (non-biota) 38,150 + 118 + 145 Gt
Land Biosphere 2300 - 39 - 28
Fossil Fuels 3700 - 244 - 323
How do we know the increase in CO₂ is due to human activity?

- Inventory industry and government: how much coal and oil is sold each year?
- Look at isotopes of carbon in the atmosphere carbon dioxide
  - Cosmic rays create a little bit of C¹⁴ in the atmosphere, and plants take this in along with lots of normal carbon (C¹²)
  - Fossil fuels have no C¹⁴ because it is old (all C¹⁴ has decayed to C¹²)
  - So adding CO₂ to the atmosphere from burning fossil fuels will cause the atmospheric C¹⁴/C¹² ratio to decrease over time.
- Look at how oxygen in atmosphere has changed in the atmosphere
- Inventory industry: how much cement is produced each year?
## Human Forcing: Carbon Dioxide

### Sources and Sinks of Carbon to the Atmosphere

<table>
<thead>
<tr>
<th>Source/Sink</th>
<th>1980s</th>
<th>1990s</th>
<th>2000-2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric increase</td>
<td>3.3 ± 0.1</td>
<td>3.2 ± 0.1</td>
<td>4.1 ± 0.1</td>
</tr>
<tr>
<td>Fossil carbon dioxide emissions</td>
<td>5.4 ± 0.3</td>
<td>6.4 ± 0.4</td>
<td>7.2 ± 0.3</td>
</tr>
<tr>
<td>Net ocean-to-atmosphere flux</td>
<td>-1.9 ± 0.8</td>
<td>-2.2 ± 0.4</td>
<td>-2.2 ± 0.5</td>
</tr>
<tr>
<td>Net land-to-atmosphere flux</td>
<td>-0.3 ± 0.9</td>
<td>-1.0 ± 0.6</td>
<td>-0.9 ± 0.6</td>
</tr>
</tbody>
</table>

**Partitioned as follows**

<table>
<thead>
<tr>
<th>Flux Type</th>
<th>1980s (range)</th>
<th>1990s (range)</th>
<th>2000-2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use change flux</td>
<td>1.6</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Residual land sink</td>
<td>-1.7</td>
<td>-2.6</td>
<td>NA</td>
</tr>
</tbody>
</table>

### Notes

1. Fossil CO$_2$ emissions include those from the production, distribution and consumption of fossil fuels and from cement production. Emission of 1 GtC corresponds to 3.67 GtCO$_2$.
2. As explained in Section 7.3, uncertainty ranges for land use change emissions, and hence for the full carbon cycle budget, can only be given as 68% confidence intervals.

### Units

- Giga tonnes of Carbon per year
  
  $(1 \text{ Gt} = 10^9 \text{ tonnes}; 1 \text{ tonne} = 2200 \text{ lbs})$

### Human input

(burning of fossil fuel) is increasing