Climate change

What lies in the future?

Cormac O’Rafferty (WIT)
Overview

I  Global warming
   *Multiple lines of evidence*

II  Natural climate cycles
   *Paleo-climatology*

III  The contribution of man
   *The enhanced greenhouse effect*

IV  What lies in the future
   *Projections, fixes and skepticism*

John Tyndall (1820-1893)
*Greenhouse gases*
I  Climate vs weather

Weather
- State of the atmosphere
- Short-term variation
- Regional variation

Climate
- Long-term trends (min. 30-yr)
- Large regions
- Global trends

Frequency of min. August temp., Texas

Variables: Air and water temperature, precipitation, snowfall
Climate change?

- **Long-term variation in climate elements**
  - *Is the global climate of 1900-1950 different from 1950-2010?*

- **Parameters**
  - Air temperature (land, sea)
  - Ocean temperature
  - Ice-melt (land, sea)
  - Sea level

- *Heat ≠ temperature*

**Do trends in different variables agree?**
1. Surface temperature record
- one test of climate change
- oldest measurements, largest dataset
- average of many stations around globe

Relative measurement
- measure relative to benchmark
- temperature anomaly
- ground data + satellite data

1906-2005: + 0.74 °C/century
1950-2005: + 1.3 °C/century

acceleration
Ocean temperatures

2. Ocean temp record
   1-4 km depth
   Mixed layer and deep ocean

   - Rising over the past few decades
     Small rise
     Large heat capacity of water
     Large oceans

   - Most warming occurs in oceans

   - No slowing in temp rise
Sea levels

Test for sea level rise:

- Melting of land ice
- Thermal expansion of water
- Changes in water stored on land

Results

- Sea level risen by + 15 cm/cent
- Past 40 years: + 1.8 cm/decade
- Past 10 years: + 3.1 cm/decade

Global annual average sea-level anomaly
Ice-melt (land and sea)

- Glacier melt
- Ice sheet melt (both poles)
- Sea-ice melt (arctic)

Total melt → sea level rise 100m
Conclusions

Global warming (1900-2010)

- Surface temperature (land, sea): up
- Ocean temperature: up
- Ice melt (land): up
- Ice melt (sea): up
- Sea level: up

Different datasets
Different uncertainties/errors
Independent lines of evidence

Clear trend in different variables

Global Warming (1900-2010)

Five Year Average

Annual Average
II Natural climate cycles

- Climate has changed in the past
  Both warmer and cooler
  Ice cores and ocean sediments

- Ice ages and interglacials
  Ice age temp only 5 °C colder

- Warming faster than cooling
  Sawtooth function
  Positive feedbacks
  Note correlation with CO2
Natural cycles (1): tectonics

- **Tectonic motion**
  
  Motion of the continents

- **Affects the earth’s albedo**
  
  Affects the ice sheets
  Varies the distribution of solar energy

- **Affects ocean circulation**
  
  North Atlantic Drift

*Mismatch: timeframe = millions of years*
Natural cycles (2): solar activity

- **Solar sunspots/storms**
  
  Variation of 0.1% every 11 years
  
  Current max smaller than expected

- **Small effect on climate**
  
  Rapid effect, slow response
  
  Possible trigger for mini-ice ages
  
  Longer cycles not known

**Mismatch: short timeframe, cooling effect**

Solar output (1985-2020)
Natural cycles (3): earth’s orbit

- **Orbit cycles**
  *Eccentricity of earth’s orbit changes*
  *Change in earth-sun distance*
  *100,000 year cycle*

- **Explanation for ice ages**
  *Correlates well with ice-age cycles*
  *Contributing factor*
  *Amplified by greenhouse effect*

**Mismatch: timeframe too long**

Earth's orbit over 100,000 years
Milankovitch cycles
Natural cycles (4): internal

Climate change from internal factors

- **El Nino**
  - **Duration**: one year
  - **Frequency**: every few years
  - **Warming**: a few tenths of a degree

- **La Nina**

- **Similar timeframe**
  - **Cooling effect**

**Mismatch**: timeframe too short
III The contribution of man

- **Earth receives energy from the sun**

  Solar constant \( S = 1360 \text{ W/m}^2 \)

  Subtract albedo \( \alpha = 0.3 \)

- **Warm earth radiates energy back to space**

  \[
  E_{\text{out}} = E_{\text{in}} \]

  \[
  S(1-\alpha)/4 = \sigma T^4 \]

  \[
  T = -15 \degree \text{C} \]

  **What is missing?**
The role of the atmosphere

- Atmosphere is transparent to solar radiation but absorbs infra-red
- Radiation from earth absorbed
  Re-emitted towards earth
- Atmosphere acts as blanket
  Earth is warmed by sun + atmos

*The greenhouse effect*
The greenhouse effect and the planets

**Mercury**: close to the sun but no atmosphere

**Venus**: much further away but much hotter

**Mars**: little atmosphere, much colder

**Earth**: between Mars and Venus

*The moon is cold!*

<table>
<thead>
<tr>
<th>Planet</th>
<th>Solar constant (W/m²)</th>
<th>Albedo</th>
<th>Observed surface temperature (K)</th>
<th>Inflected n</th>
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</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>10,000</td>
<td>0.1</td>
<td>452</td>
<td>0.052</td>
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<tr>
<td>Venus</td>
<td>2,650</td>
<td>0.7</td>
<td>735</td>
<td>82</td>
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<td>Earth</td>
<td>1,360</td>
<td>0.3</td>
<td>289</td>
<td>0.65</td>
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<tr>
<td>Mars</td>
<td>580</td>
<td>0.15</td>
<td>227</td>
<td>0.22</td>
</tr>
</tbody>
</table>
The chemistry of the atmosphere

Nitrogen ($N_2$): 78% (inert)
Oxygen ($O_2$): 21% (unique)
Argon (Ar): 1% (inert)

- Do not absorb in UV or IR
- Do not warm surface
- Not greenhouse gases
- Play little role in climate

What gases cause the greenhouse effect?
Earth’s greenhouse gases

1. **Water vapour** \((H_2O)\): [0.2 – 4.0 %] at surface
   - Evaporation from oceans, decreases rapidly with height

2. **Carbon dioxide** \((CO_2)\): 0.039% in 2010 (390 ppm)
   - Animal and plant exhalation, emissions from fossil fuels

3. **Methane** \((CH_4)\): 1.8 ppm (2010)
   - From wetlands, animals, agriculture, fossil fuels

4. **Nitrous oxide** \((N_2O)\): 0.3 ppm (2010)
   - Fertilizer and natural sources

5. **Ozone** \((O_3)\): 10 ppb (surface)– 10 ppm (stratosphere)
   - UV protection in high atmosphere, pollutant at low atmosphere

6. **Halocarbons** (CFC, HCFCs): 10 ppb
   - Synthetic industrial chemicals (refrigerants etc)

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**John Tyndall** (1820-1893)

\(CO_2 = \text{most abundant non-condensing GHG}\)
Monitoring carbon dioxide

- **Keeling Curve (1950 - )**
  
  $CO_2$ from industry?
  
  Direct measurement (Mauna Loa)

- **The carbon cycle**
  
  *Photosynthesis*
  
  Plants absorb $CO_2$ from atmos
  
  $CO_2 + H_2O + $ sunlight $\rightarrow CH_2O + O_2$

  *Respiration*
  
  Animals, bacteria consume plants
  
  $CH_2O + O_2 \rightarrow CO_2 + H_2O + $ energy
CO₂ and fossil fuels

- Fossils formed when plants buried before respiration
- Stored in rock reservoirs; subject to intense heat and pressure
- Digging up and burning fossilized carbon releases energy
- Also releases CO₂ into atmos.

Flux from fossil fuels: 6 GtC/yr

- Much larger than volcano cycle
- Buildup of CO₂ in atmos.
- Increase of 40% from 1850
The smoking gun

- **Compare CO$_2$ rise with fossil fuel use**
  - *Strong correlation*

- **Identify age of CO$_2$**
  - *Radioactive dating using C13 and C14*
  - *Significant portion millions of years old*

- **Conclude CO$_2$ rise from fossil fuels**

  *Note: 50% of CO$_2$ added to atmos. stays there*

Emissions output with CO$_2$ overlay
Other factors

- Other GHGs (warming)
  - CO₂ presently dominates

- Clouds (dynamic)
  - Warming and cooling
  - Net cooling

- Pollution (cooling)
  - The china syndrome

- Land use (deforestation)
More evidence

1. Measure $E_{out}$ of atmosphere
   - Function of wavelength, time
   - Satellite measurements (1970 - )
     - Clear dip in microwave region
     - Clear increase in dip over 4 decades

2. Measure $T$ of atmosphere
   - Function of height
   - Stratosphere cooling
     - Clear signals of greenhouse effect

Radiation from earth
Conclusions

1. Multiple lines of evidence for warming
   Surface temps, ocean temps, sea-level rise, ice melt

2. Multiple lines of evidence for enhanced GHG effect
   CO$_2$ increase, radioactive dating, wavelength of absorbed radiation, stratospheric cooling

Conclude: (IPCC 2007)
Most of the warming since 1950 very likely (90% prob) due to increase in GHG conc
Expect rise of 2-6 °C by 2050
IV The future

\[
\text{CO}_2 \text{ emitted} = \text{pop} \times \text{affluence} \times \text{tech}
\]

\[ IPAT \]

- \( P \times A = \text{energy required} \)
  - Population growth
  - Affluence growth

- Technology = GHG emitted/$
  - Carbon intensity \times \text{energy intensity}
  - Tends to decrease

Net effect: large increase in emissions
IPCC scenarios

- **Continued emissions**
  *Four emissions scenarios*

- **Committed warming**
  *Already in the pipeline*

- **Future warming**
  *2-6 °C by 2050*  
  *Worst case scenarios*

- **Actually worse again**
  *Feedbacks and tipping points*
Climate feedbacks

- **Reduced albedo**
  
  *Melting of ice sheets reduces reflectivity*

- **Reduced permafrost**
  
  *Releases methane and CO₂*

- **Ocean vents**
  
  *Release of methane from ocean vents*

- **Tipping points**
  
  *Past climates show accelerated warming*
The longterm future

- **Continued emissions**
  
  Slow removal of CO$_2$ from atm/bios/ocean system

- **Peak warming**
  
  Fossil fuels finite: peak around 2100
  Some delay due to fracking
  Major new threat to climate

- **Future warming**
  
  Climate for the next thousand years
Consequences

- **Prolonged drought, desertification**
  
  *Africa, USA, Australia*

- **Chronic flooding**
  
  *China, India, Bangladesh, Tuvulu*
  
  *Poorest worst affected*

- **War**
  
  *Longterm conflicts over resources*

- **Frequent extreme events**
  
  *Warmer air holds more moisture*
Fixing climate

- **Reduce GHG emissions**
  - Reduce fossil fuel use
  - Remove fossil fuel subsidies
  - Reduce hydraulic fracking

- **Impose international targets**
  - Developed vs developing nations
  - Concerted global action

- **Invest in renewable energy**
  - Increase subsidies for renewables
  - Create climate of investment
  - Economics based on sound science
Renewables

- **Biofuels** 2\textsuperscript{nd}, 3\textsuperscript{rd} generation
- **Hydroelectric**
- **Wind energy**
- **Solar energy**
- **Tidal energy**
  - Longterm promise?
- **Nuclear energy**
  - Pebble reactors

![Renewable Energy as Share of Total Primary Energy Consumption, 2010](image)

Source: U.S. Energy Information Administration / Annual Energy Review 2010
Climate skepticism

- ‘It’s just a theory’
  
  *Role of evidence misunderstood*

- Media discussions poor/biased
  
  *Expertise vs opinion or vested interest*

- Opposition from ff industry
  
  *Lobbyists, propagandists*

- Resistance from politics
  
  *Conservative values*

*Figures of influence*
Climate controversy

- **Hockey-stick controversy**
  - Medieval warm period inaccurate?
  - Contested by conservative think tanks

- **Complex science**
  - Ice cores, tree rings, ocean sediments
  - Vindicated by many studies

- **Climategate controversy**
  - Hacked emails - fake controversy
  - Exploited by conservative media
  - Prevented agreement at COP 2009
Climate and tobacco

- Dangers of smoking understood early on
  *Research results clear from 1950s*

- Strongly contested by tobacco industry
  *Industry experts, scientists*

- Media wars, PR wars
  *Doubt is our product*

- Same tactics for climate science
  *Heartland Institute*

*Conservative politics*
Summary

- **A clear and present danger**
  
  *Action required*

- **Understood by scientists**
  
  *Clear solution (difficult)*

- **Not understood by society**
  
  *Lack of knowledge or trust in science*
  
  *Influence of politics, lobbyists and the media*

- **Prognosis poor**
  
  *No solution without acceptance*