Climate change

What lies in the future?

Cormac O'Rafferty (WIT)

Overview

I Global warming

Multiple lines of evidence

II Natural climate cycles

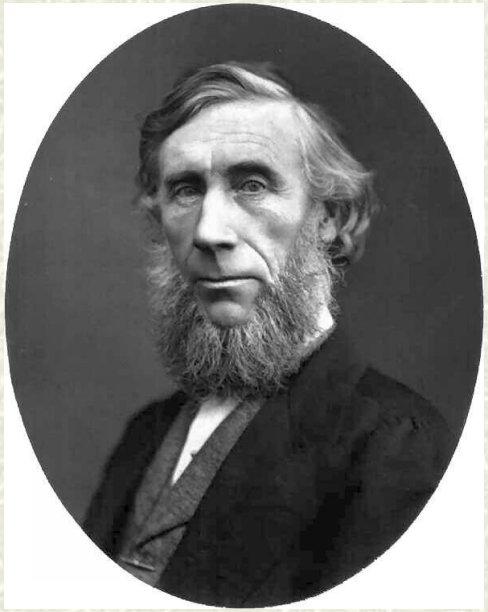
Paleo-climatology

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

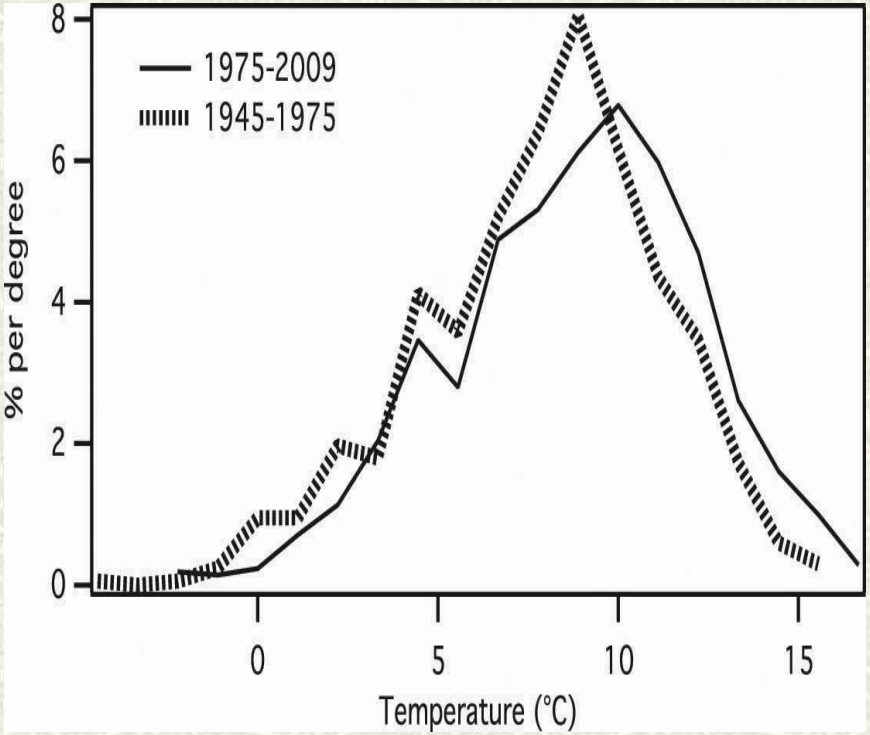
I Climate vs weather

Weather

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

Climate

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



Freq 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

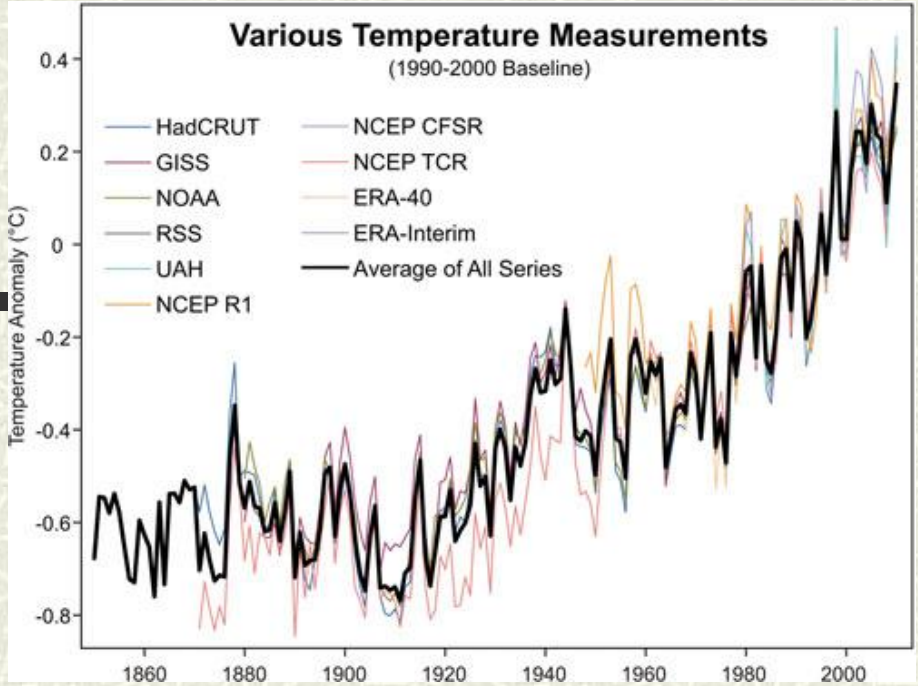
Heat $\neq$ temperature

Do trends in different variables agree?

Climate change?

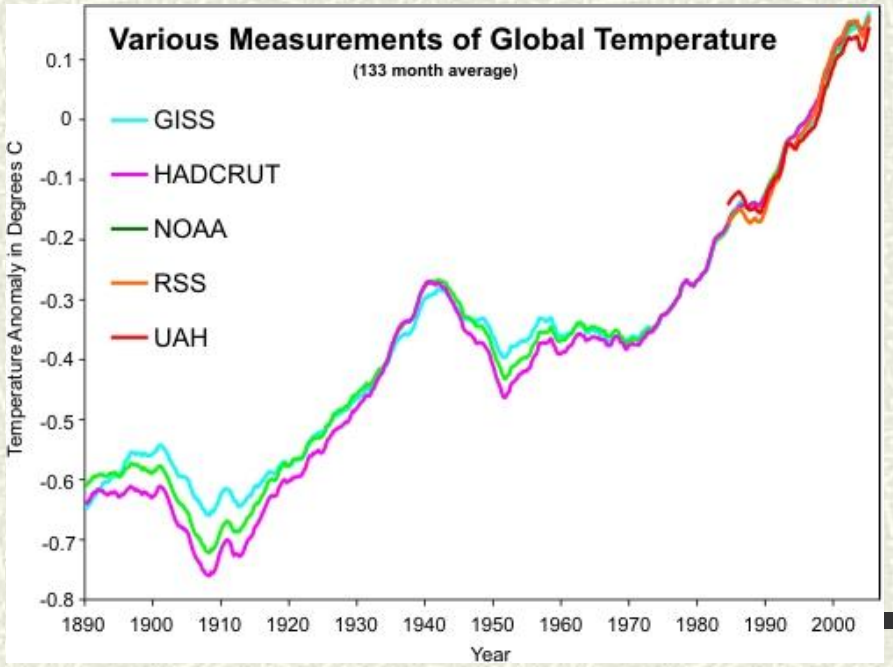
1. Surface temperature record

- *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*

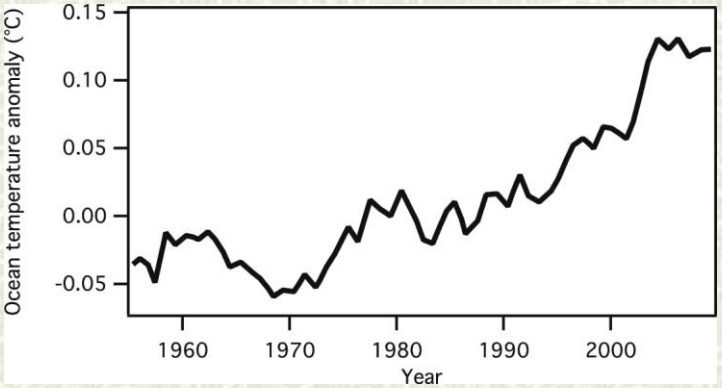


1906 -2005: + 0.74 °C/century

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**

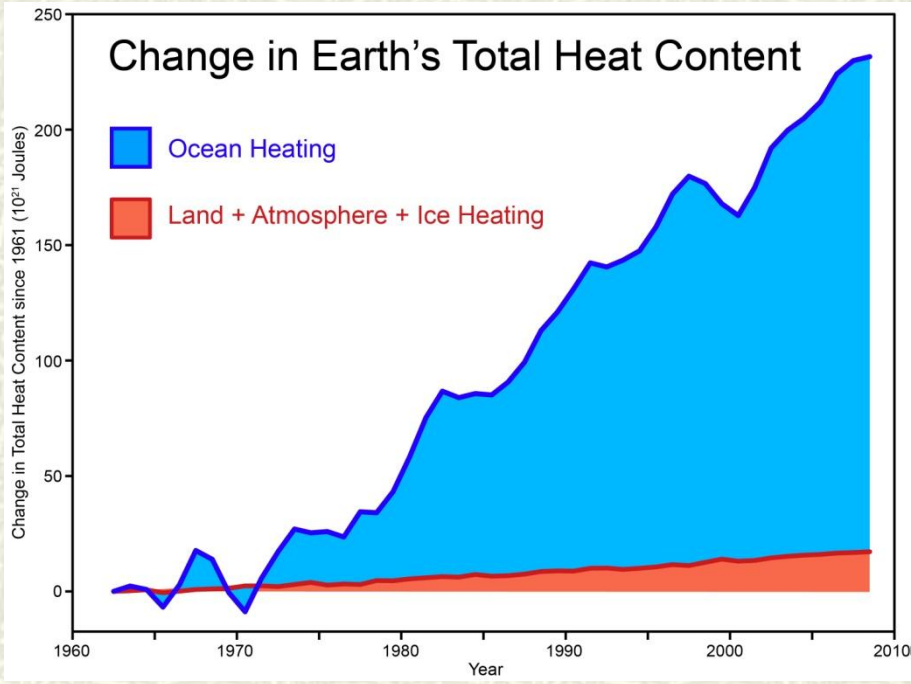
  Small rise

  Large heat capacity of water

  Large oceans

- **Most warming occurs in oceans**

- **No slowing in temp rise**



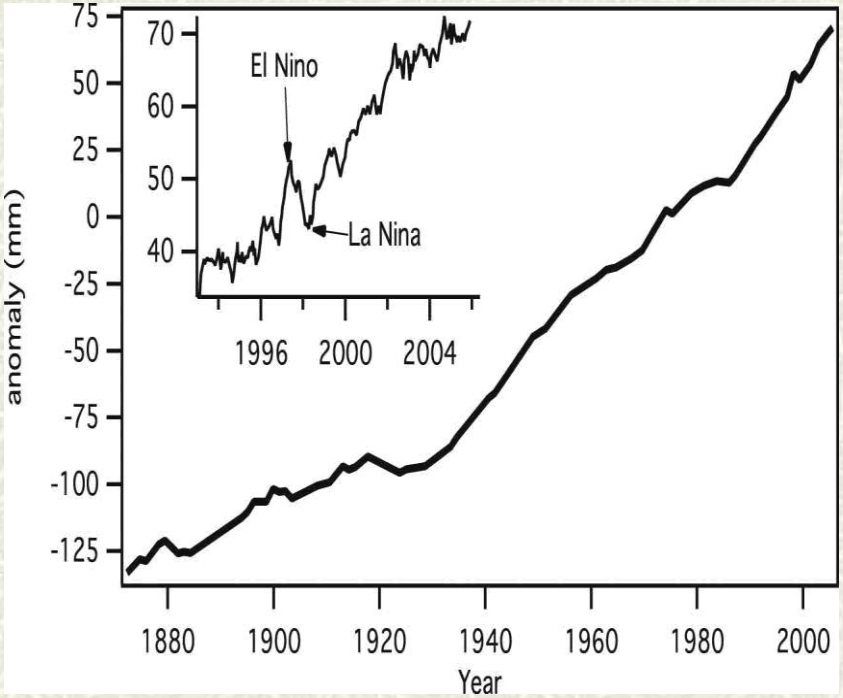
Sea levels

Test for sea level rise:

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

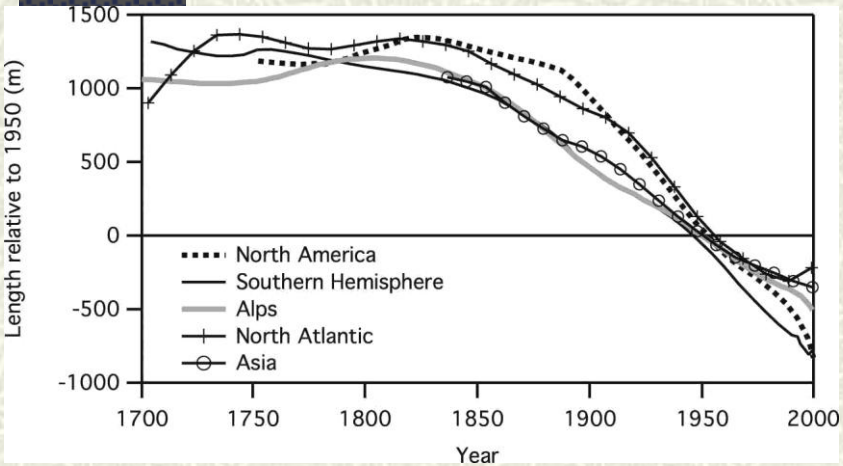
Results

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

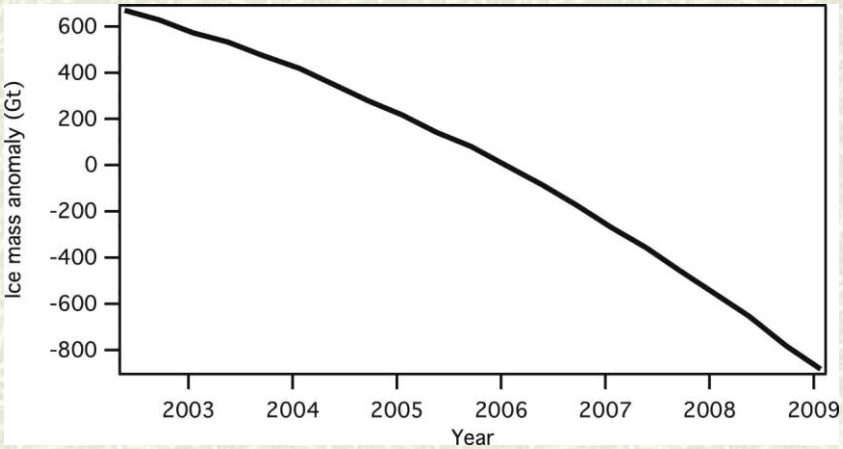


Global annual average sea-level anomaly

Ice-melt (land and sea)



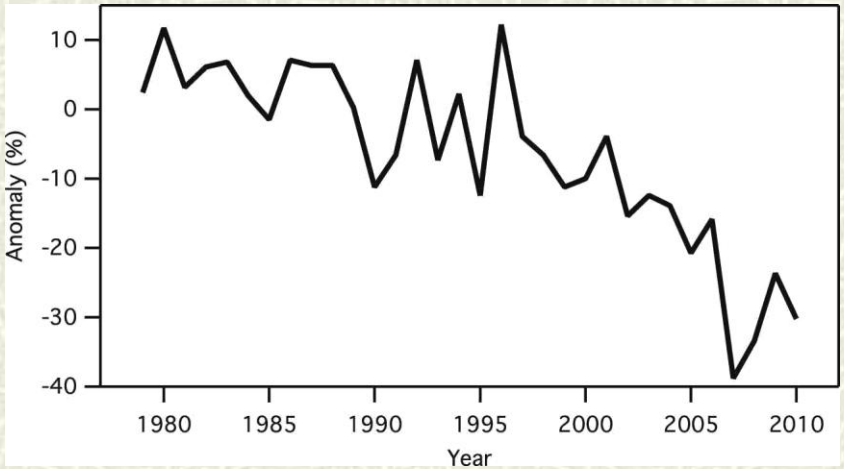
Glacier melt



Greenland ice sheet melt

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

Total melt → sea level rise 100m



Arctic sea-ice melt

Conclusions

Global warming (1900-2010)

Surface temperature (land, sea): up

Ocean temperature : up

Ice-melt (land): up

Ice-melt (sea): up

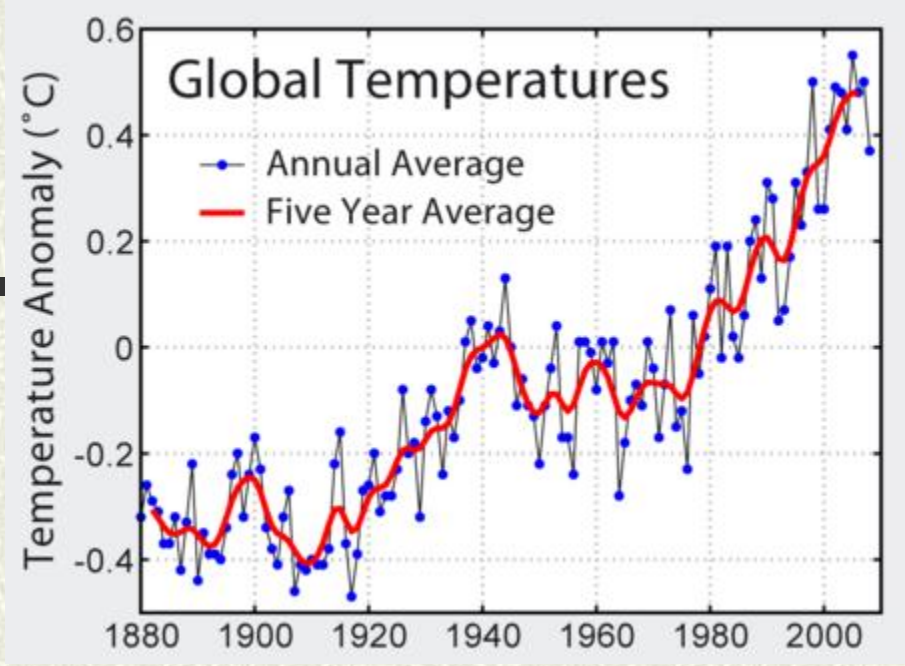
Sea level: up

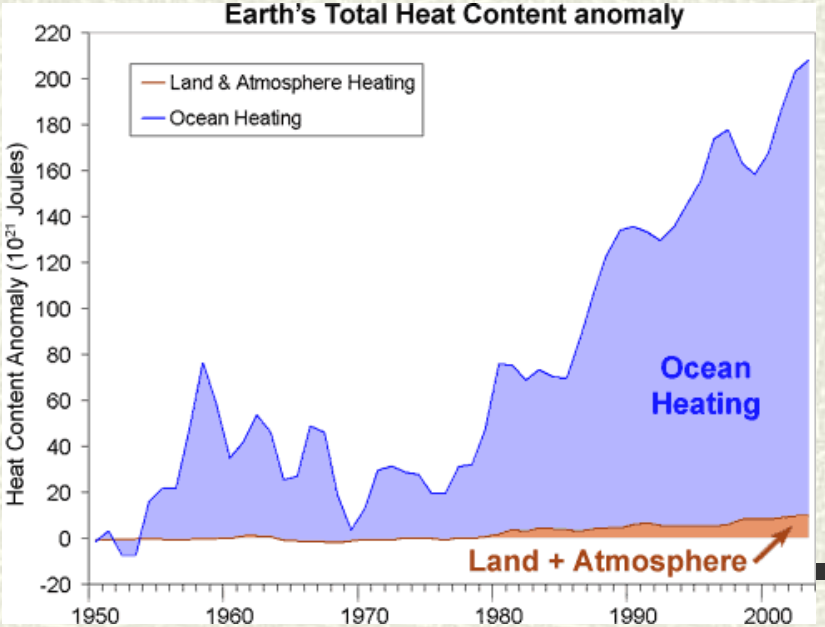
Clear trend in different variables

Independent lines of evidence

Different datasets

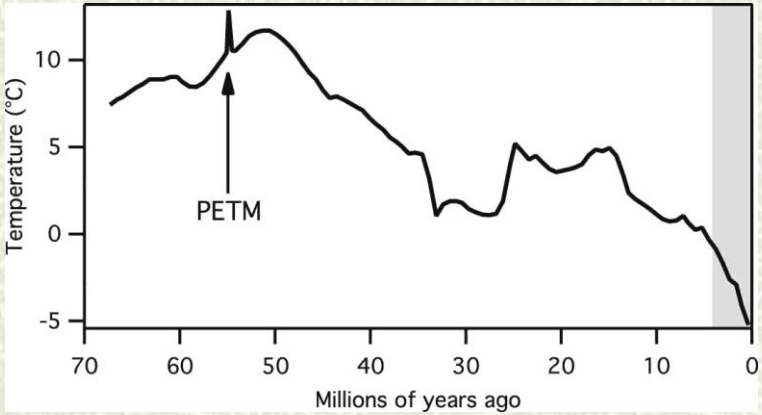
Different uncertainties/errors

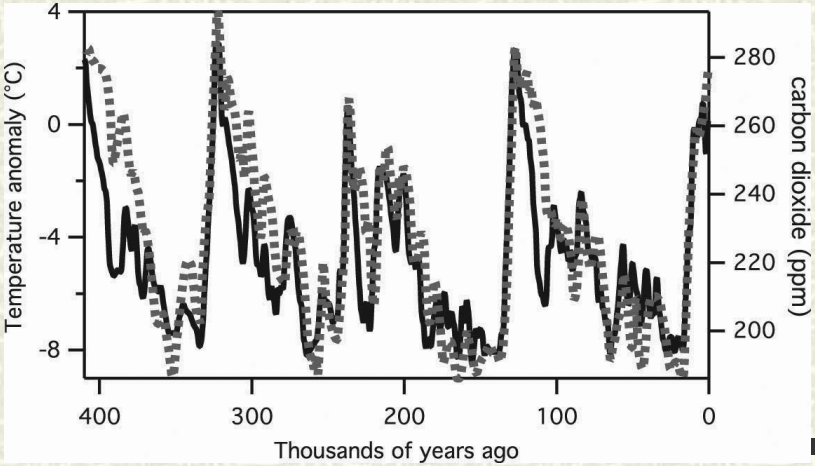




II Natural climate cycles

- **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

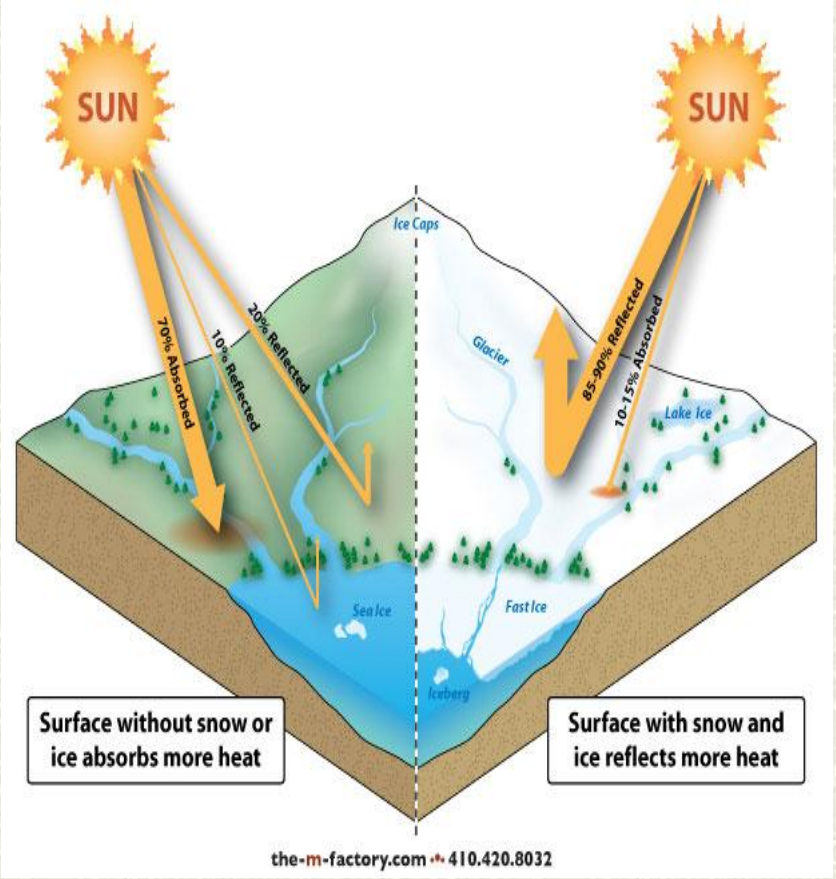
- **Affects the earth's albedo**

  Affects the ice sheets

  Varies the distribution of solar energy

- **Affects ocean circulation**

  North Atlantic Drift



The albedo effect

Mismatch: timeframe = millions of years

Natural cycles (2): solar activity

- **Solar sunspots/storms**

  Variation of 0.1% every 11 years

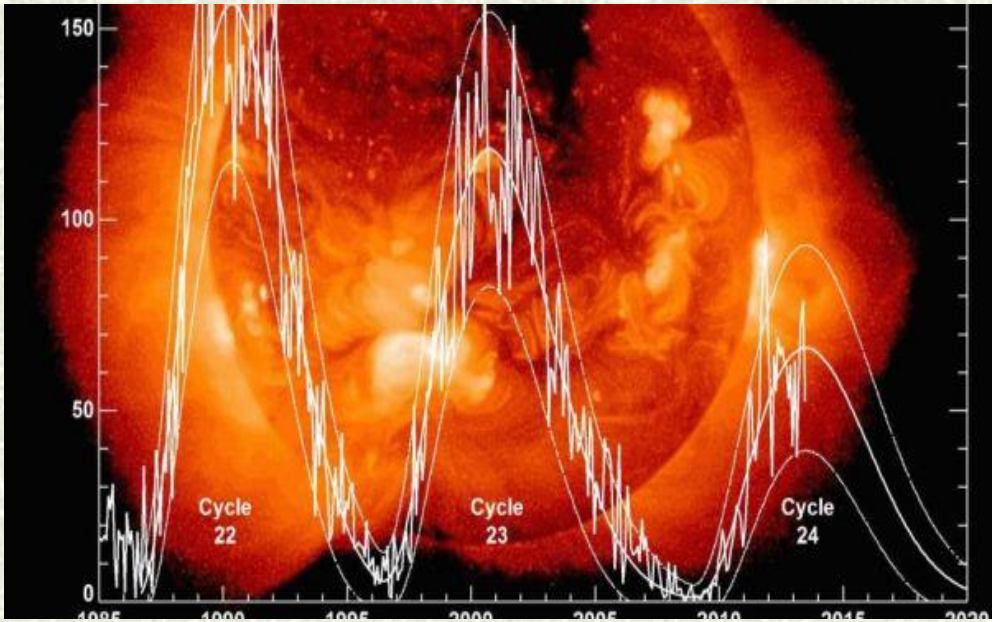
  Current max smaller than expected

- **Small effect on climate**

  Rapid effect, slow response

  Possible trigger for mini-ice ages

  Longer cycles not known

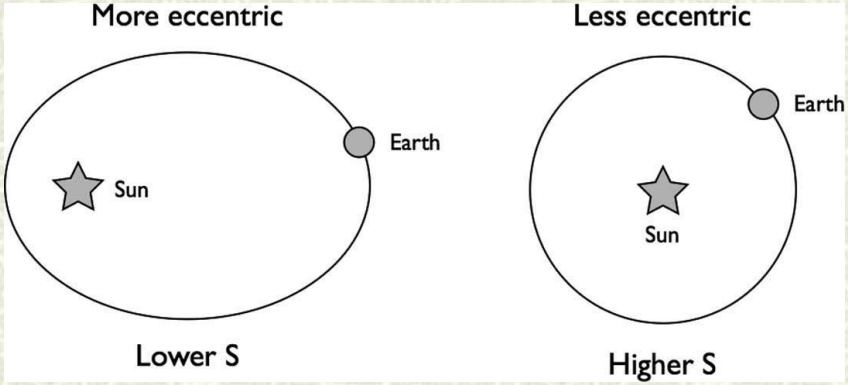


Solar output (1985-2020)

Mismatch: short timeframe, cooling effect

Natural cycles (3): earth's orbit

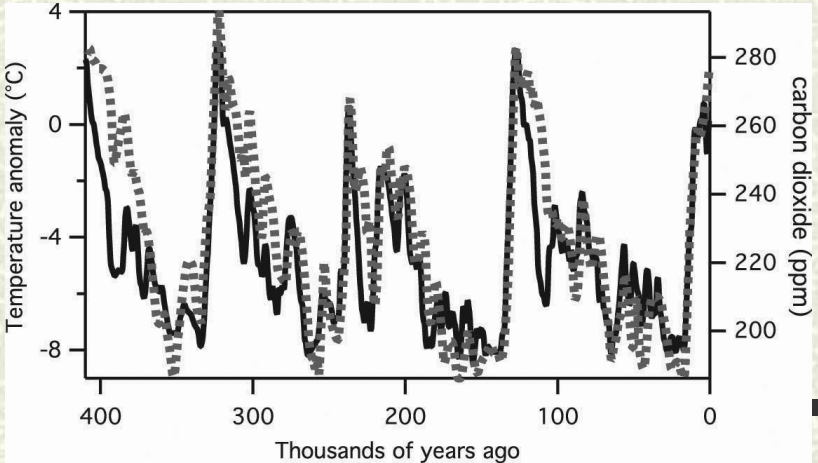
- **Orbit cycles**
  Eccentricity of earth's orbit changes
  Change in earth-sun distance
  100,000 year cycle



Earth's orbit over 100,000 years

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

Milankovitch cycles



Mismatch: timeframe too long

Natural cycles (4): internal

Climate change from internal factors

- *El Nino*

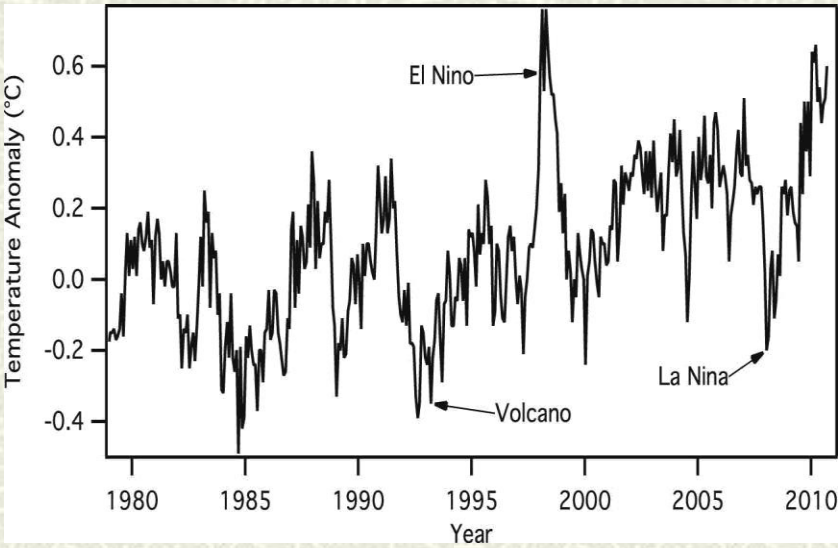
  Duration: one year

  Frequency: every few years

  Warming: a few tenths of a degree

- *La Nina*
- *Similar timeframe*

  Cooling effect

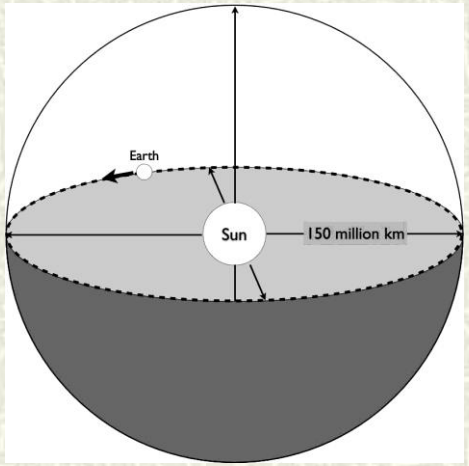


El Nino and *La Nina*

Mismatch: timeframe too short

III The contribution of man

- **Earth receives energy from the sun**

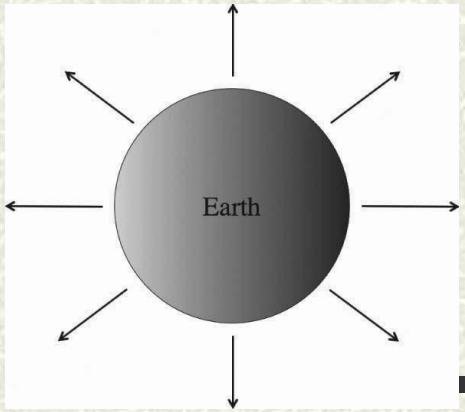


Solar constant (S = 1360 W/m^2)
Subtract albedo (α = 0.3)

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

E_{in} = 1360 W/m^2

If E_{out} = E_{in}
$S(1-\alpha)/4 = \sigma T^4$
T = - 15 °C



What is missing?

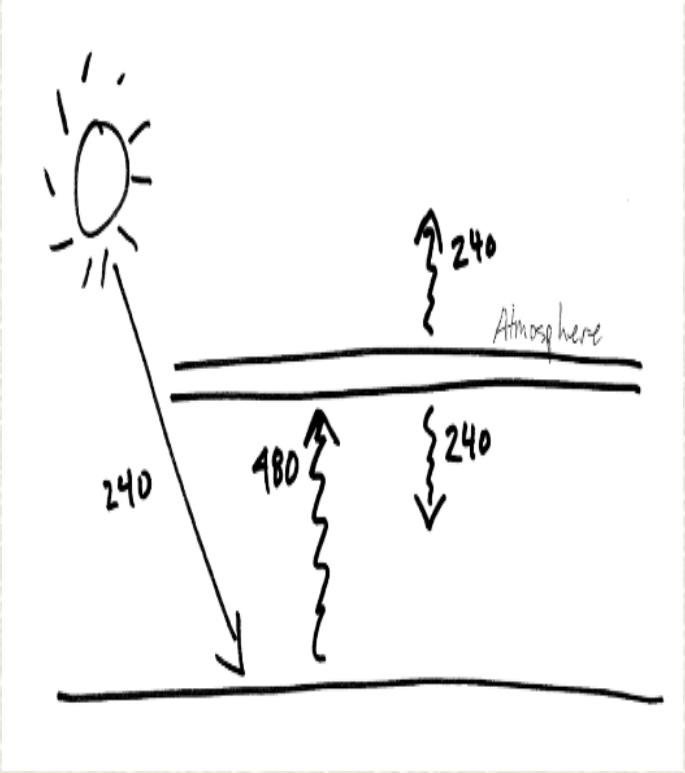
The role of the atmosphere

- Atmosphere is transparent to solar radiation but absorbs infra-red
- Radiation from earth <u>absorbed</u>

  Re-emitted towards earth
- Atmosphere acts as blanket

  Earth is warmed by sun + atmos

<u>The greenhouse effect</u>



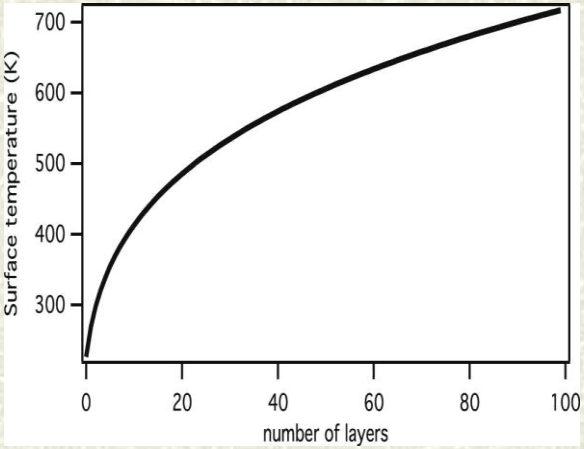
The greenhouse effect and the planets

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 4.1 Data on the four inner planets in our solar system

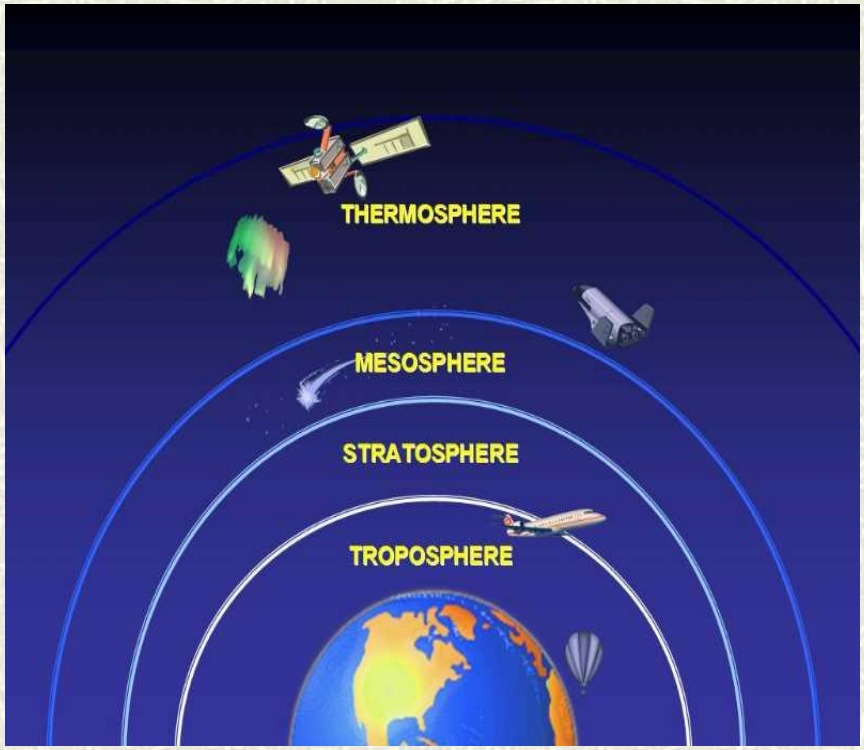
Planet	Solar constant (W/m^2)	Albedo	Observed surface temperature (K)	Inferred *n*
Mercury	10,000	0.1	452	0.052
Venus	2,650	0.7	735	82
Earth	1,360	0.3	289	0.65
Mars	580	0.15	227	0.22

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?

The atmosphere

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)

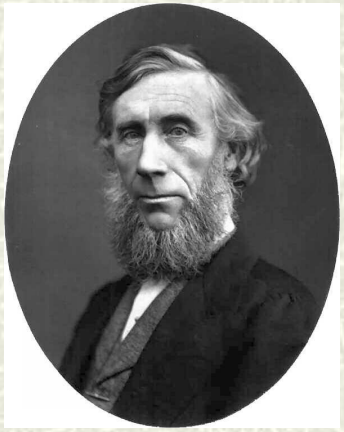
Fertilizer and natural sources

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)

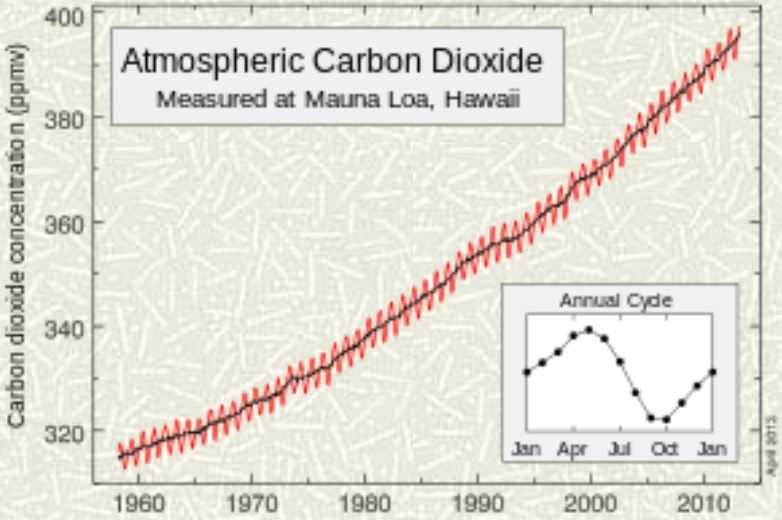


John Tyndall (1820-1893)

CO_2 = most abundant non-condensing GHG

Monitoring carbon dioxide

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

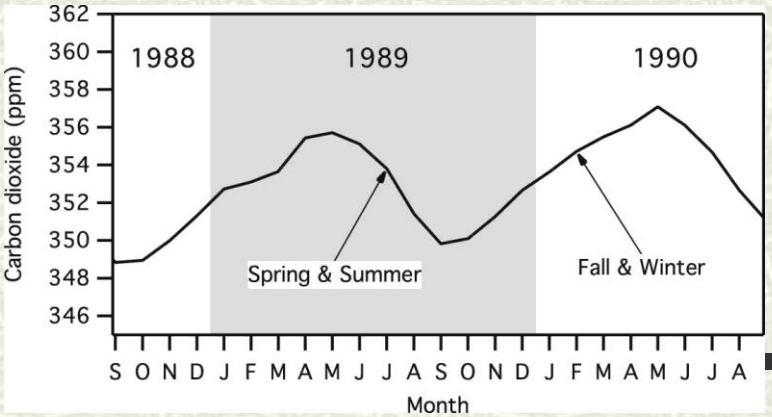


Systematic increase (1958 -)

- **The carbon cycle**

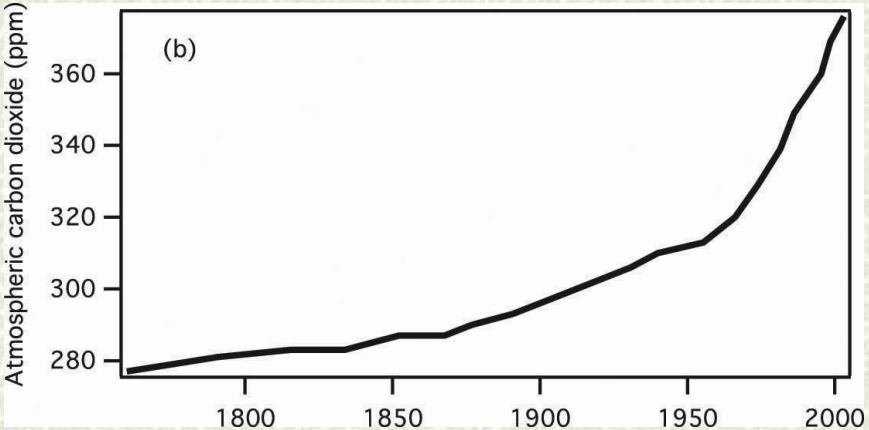
  Photosynthesis
  Plants absorb CO_2 from atmos
  $CO_2 + H_2O$ + sunlight -> $CH_2O + O_2$

  Respiration
  Animals, bacteria consume plants
  $CH_2O + O_2$ -> $CO_2 + H_2O$ + energy



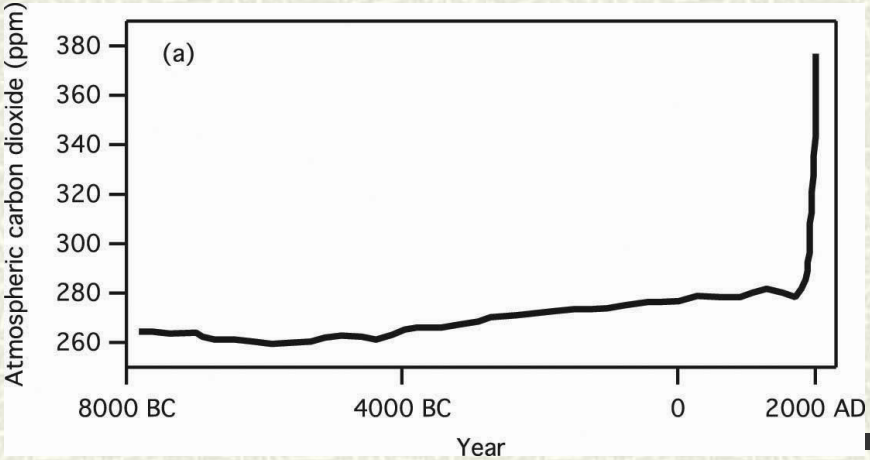
CO_2 and fossil fuels

- 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 CO_2 into atmos.



Flux from fossil fuels: 6 GtC/yr

- Much larger than volcano cycle
- Buildup of CO_2 in atmos.
- **Increase of 40% from 1850**



The smoking gun

- **Compare CO_2 rise with fossil fuel use**

  Strong correlation

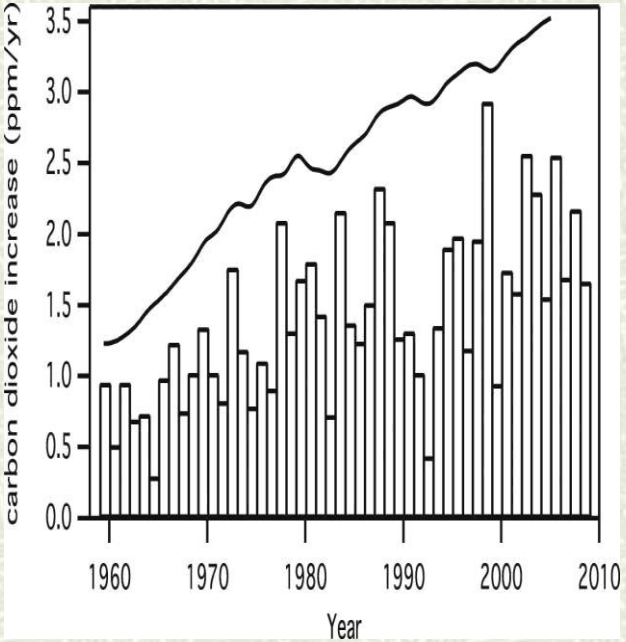
- **<u>Identify</u> age of CO_2**

  Radioactive dating using C13 and C14

  Significant portion millions of years old

- **<u>Conclude CO_2 rise from fossil fuels</u>**

Note: 50% of CO_2 added to atmos. stays there



Emissions output with CO_2 overlay

Other factors

- Other GHGs (warming)

  CO_2 *presently dominates*

- Clouds (dynamic)

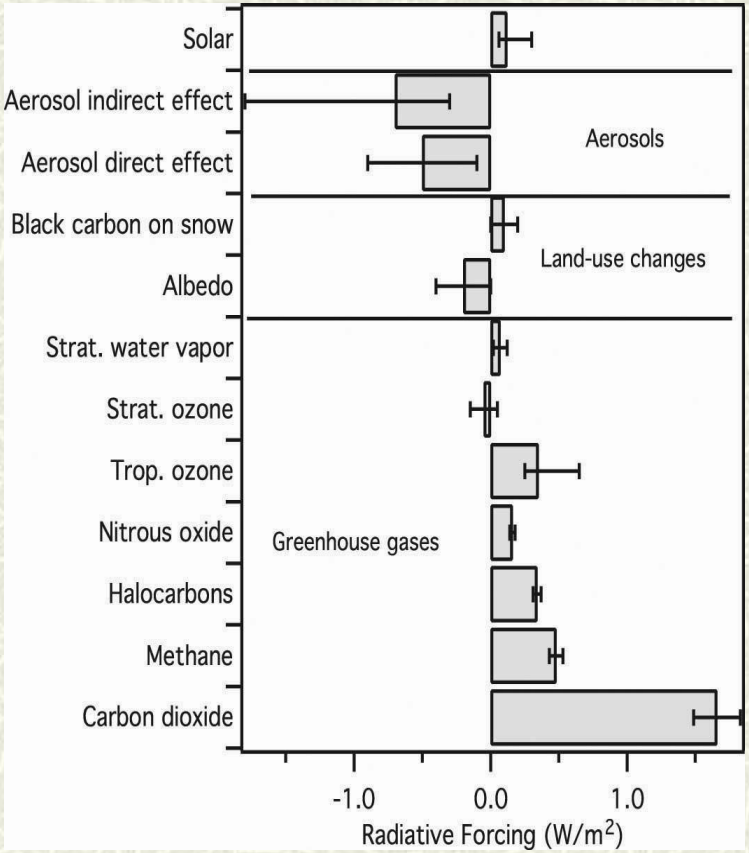
  Warming and cooling

  Net cooling

- Pollution (cooling)

  The china syndrome

- Land use (deforestation)



Radiative forcing

More evidence

1. **Measure E_{out} of atmosphere**

   Function of wavelength, time

   Satellite measurements (1970 -)

   Clear dip in microwave region

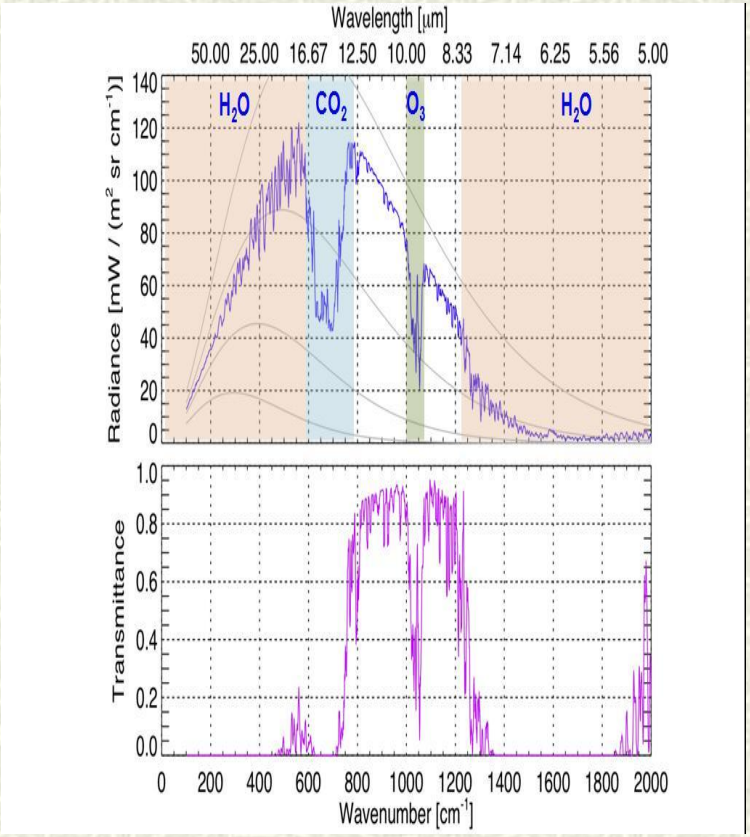
   Clear increase in dip over 4 decades

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**

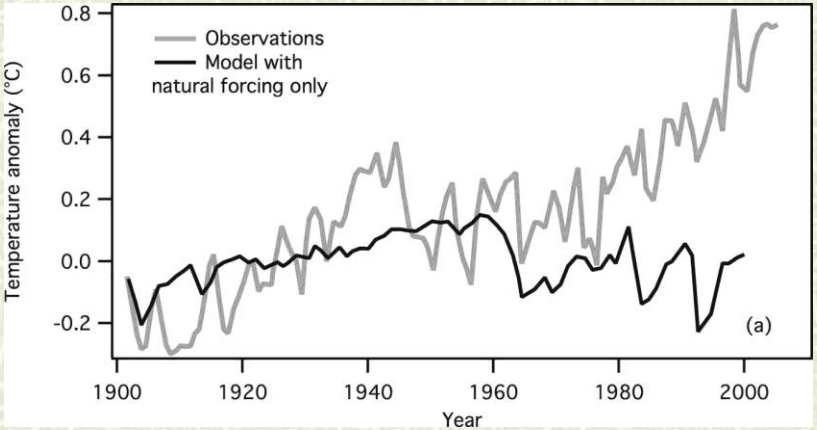
   Surface temps, ocean temps, sea-level rise, ice melt

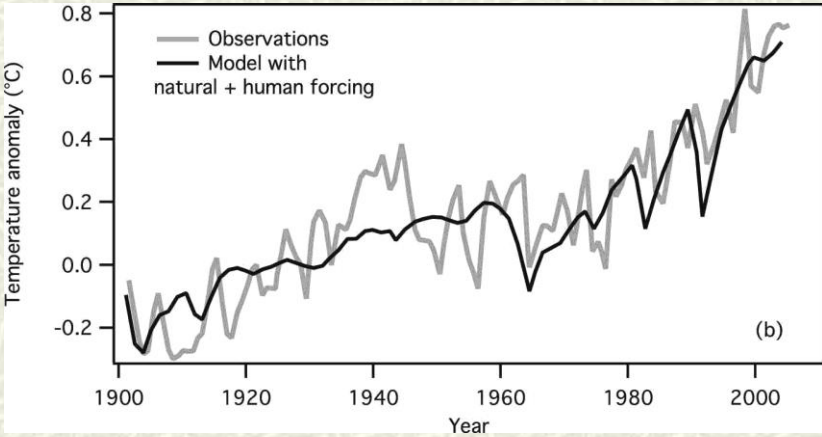
2. **Multiple lines of evidence for enhanced GHG effect**

   CO_2 *increase, radioactive dating, wavelength of absorbed radiation, stratospheric cooling*

<u>Conclude :</u> (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

CO_2 emitted = pop x affluence x tech

IPAT

- **P x A = energy required**

  Population growth

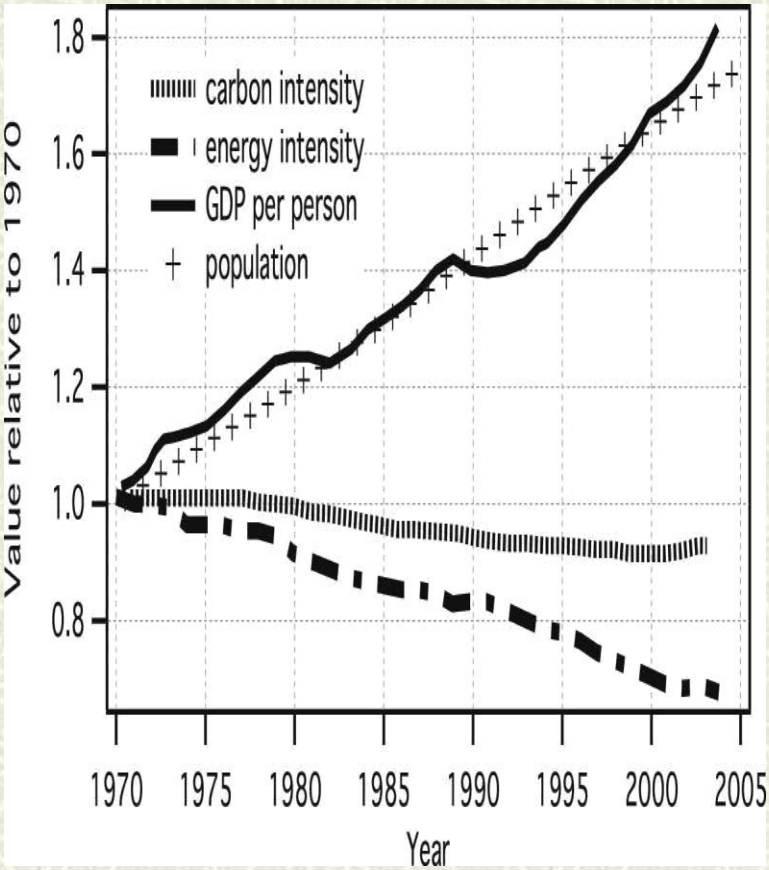
  Affluence growth

- **Technology = GHG emitted/$**

  Carbon intensity x energy intensity

  Tends to decrease

Net effect: large increase in emissions



IPCC scenarios

- **Continued emissions**

  Four emissions scenarios

- **Committed warming**

  Already in the pipeline

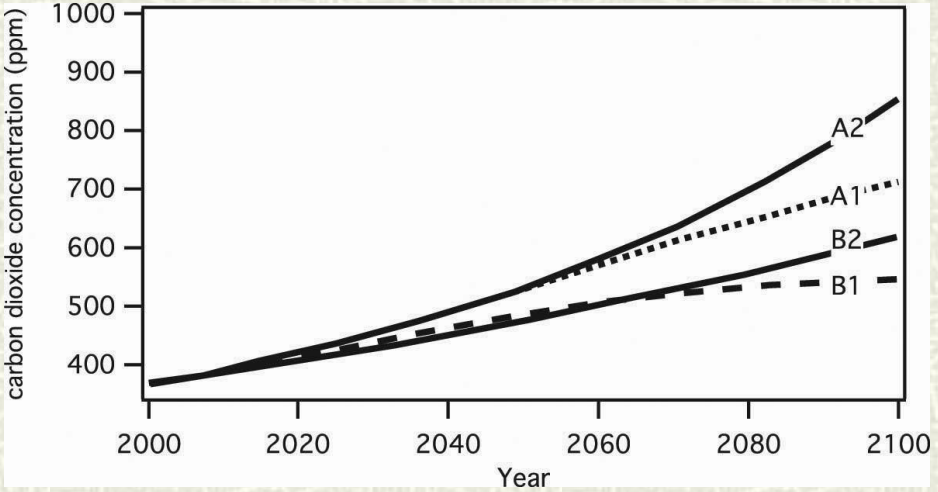
- **Future warming**

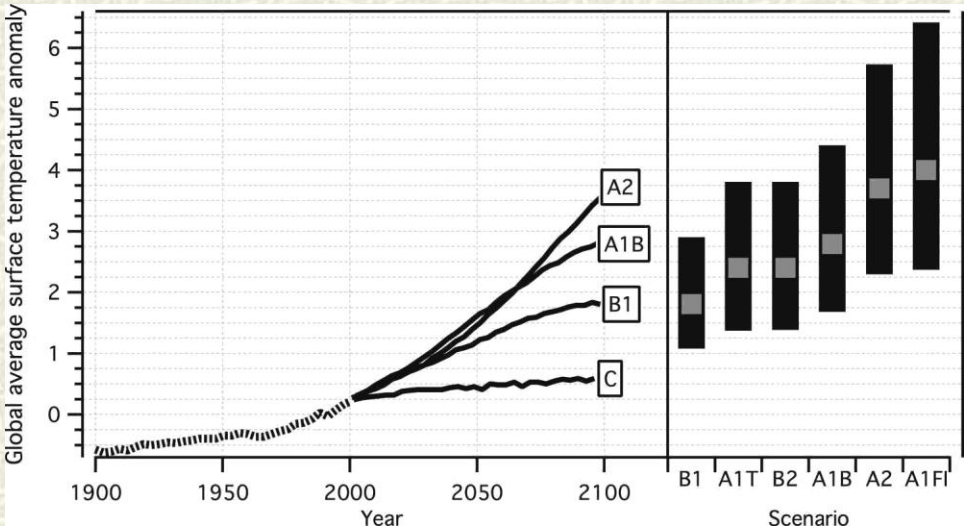
  2-6 °C by 2050

  Worst case scenarios

- **Actually worse again**

  Feedbacks and tipping points





Climate feedbacks

- **Reduced albedo**

  Melting of ice sheets reduces reflectivity

- **Reduced permafrost**

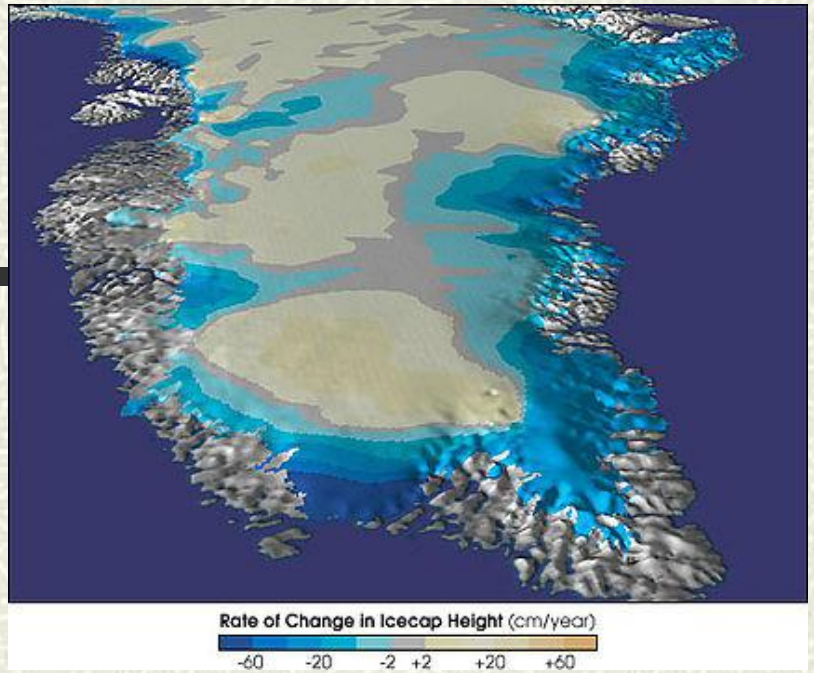
  Releases methane and CO2

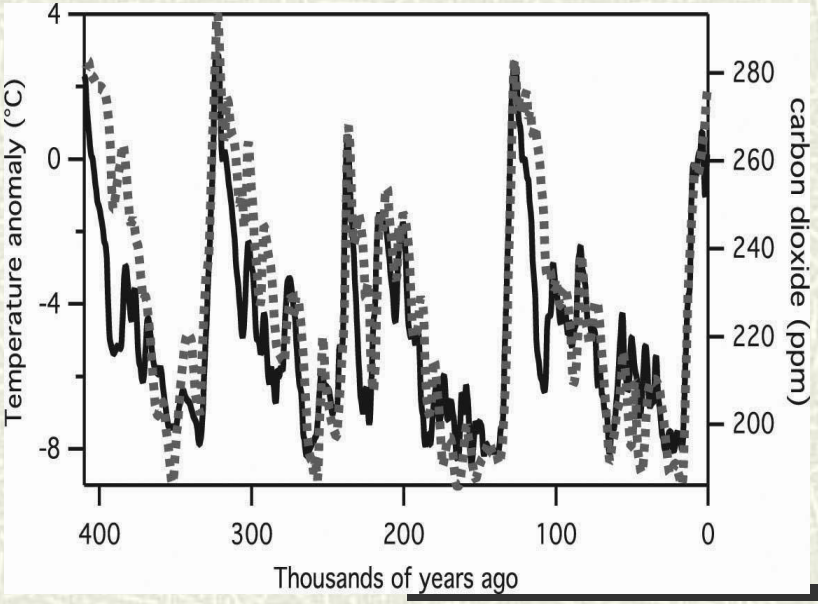
- **Ocean vents**

  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**

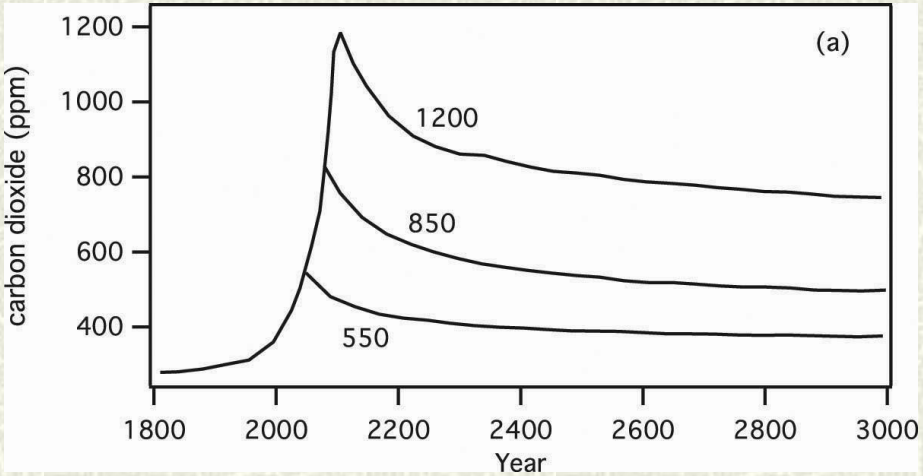
  Fossil fuels finite: peak around 2100

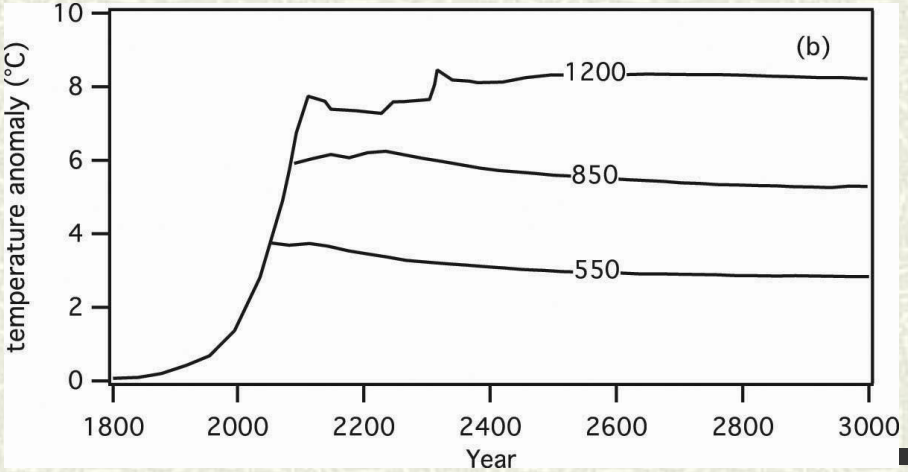
  Some delay due to fracking

  Major new threat to climate

- **Future warming**

  Climate for the next thousand years



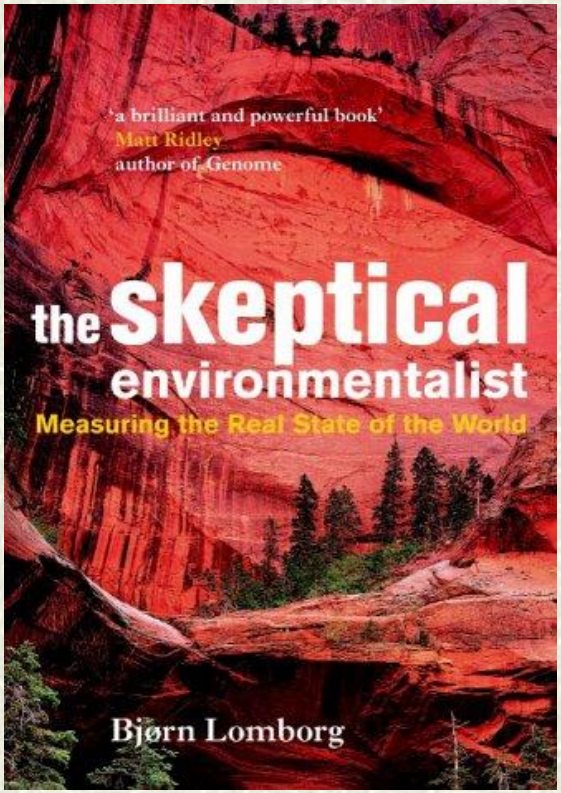


Consequences

- **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

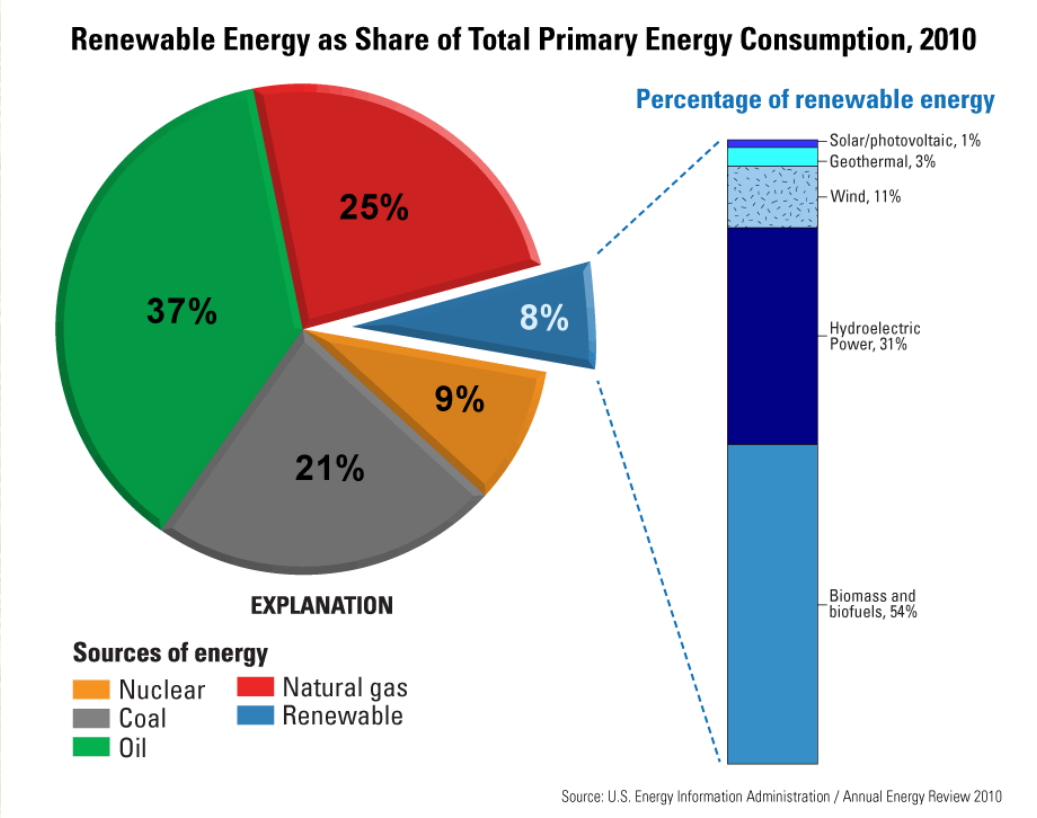
- **Reduce GHG emissions**
  - *Reduce fossil fuel use*
  - *Remove fossil fuel subsidies*
  - *Reduce hydraulic fracking*
- **Impose international targets**
  - *Developed vs developing nations*
  - *Concerted global action*
- **Invest in renewable energy**
  - *Increase subsidies for renewables*
  - *Create climate of investment*
  - *Economics based on sound science*



Unsound science

Renewables

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



Climate skepticism

- ‘It’s just a theory’

  Role of evidence misunderstood

- Media discussions poor/biased

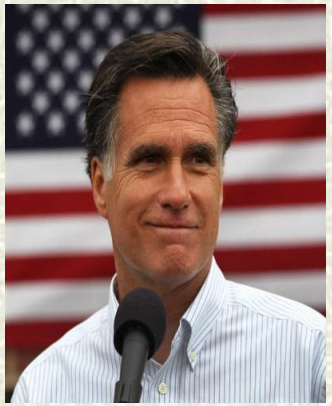
  Expertise vs opinion or vested interest

- Opposition from ff industry

  Lobbyists, propagandists

- Resistance from politics

  Conservative values

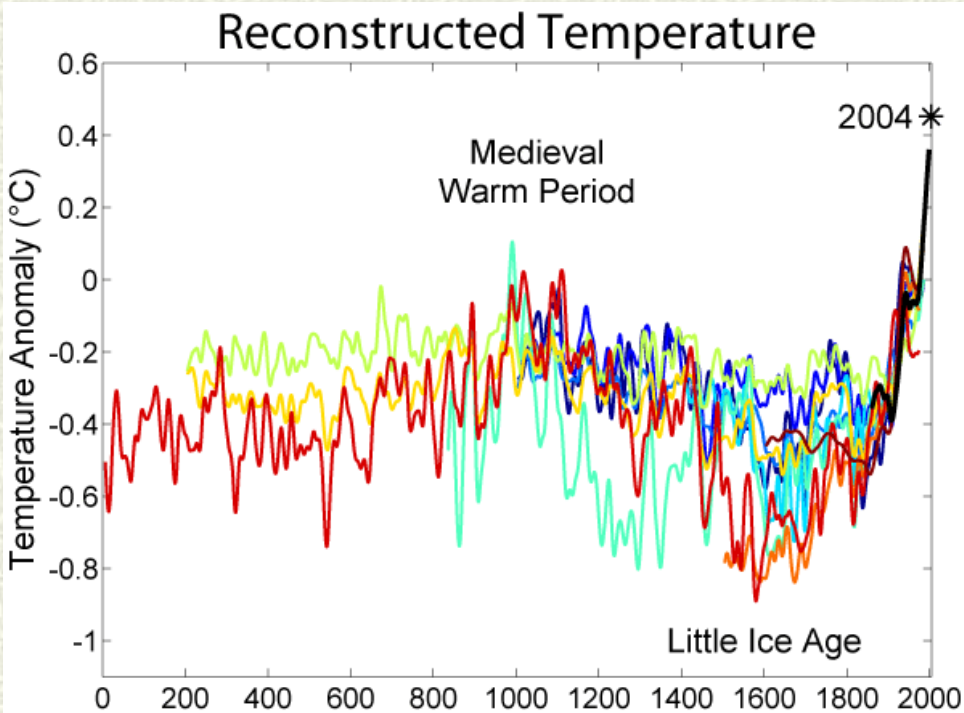


Figures of influence

Climate controversy

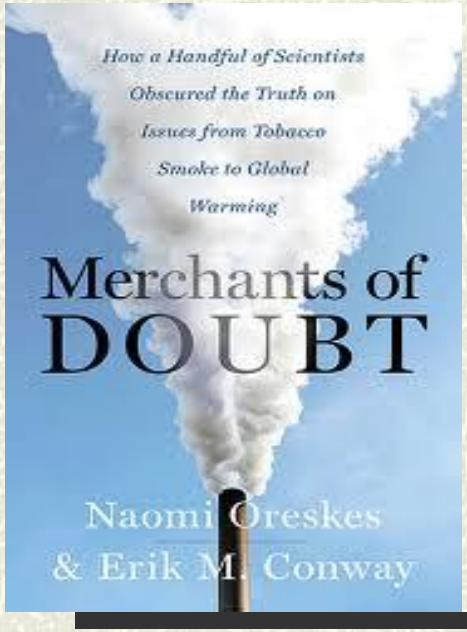
- **Hockey-stick controversy**
  - *Medieval warm period inaccurate?*
  - *Contested by conservative think tanks*
- **Complex science**
  - *Ice cores, tree rings, ocean sediments*
  - *Vindicated by many studies*
- **Climategate controversy**
  - *Hacked emails - fake controversy*
  - *Exploited by conservative media*
  - *Prevented agreement at COP 2009*

COP15
COPENHAGEN
UN CLIMATE CHANGE CONFERENCE 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)

The Venus syndrome

- **Not understood by society**

  Lack of knowledge or trust in science

  Influence of politics, lobbyists and the media

- **<u>Prognosis poor</u>**

  No solution without acceptance