1) The Science of climate change
2) Coping with the predicted change
3) Avoiding catastrophic change
Is the climate changing?

Temperature change: 30 x faster than expected from natural processes.
To understand what is going on we must start with some basic science........

What drives the Earth’s climate?

Core temperature 15 million degrees K

Core produces 6 x 10^{-6} J per kg

Humans produce about 1.2 J per kg
4.26 million tonnes per second converted to $383 \times 10^{24}$ watts of power

$E = mc^2$

Only 2 billionths of the Sun's radiant energy falls on the Earth (99.998% of the Earth's energy)

Solar constant = 1366 Wm$^{-2}$ at the top of the atmosphere

What are heat and temperature? How can heat be transferred?
How is heat energy radiated through the vacuum of space?

How does the temperature of a body affect the radiation emitted from the body?
The Stefan-Boltzmann Law gives the power radiated from a body at temperature $T$:

$$P = \varepsilon \sigma A T^4 \text{ watts}$$

($\sigma = 5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$ and emissivity $\varepsilon = 1$)

As the temperature of a body increases:

i) It emits more radiation ($T^4$)

ii) The peak emission occurs at a shorter wavelength ($1/T$)
If hot bodies radiate heat and lose energy, how can the temperature of a body remain constant?

Temperature is constant when
Energy in = Energy out
Thermal equilibrium
Can we use conservation of energy to predict the Earth's temperature?

A SIMPLE THERMAL EQUILIBRIUM MODEL

$S(1-\alpha)\pi r^2 = \varepsilon \sigma AT^4$

Assume: Circular orbit, 30% albedo, emissivity of 1 and thermal equilibrium.

If the solar constant is 1366 Wm$^{-2}$, the total solar radiation reaching the Earth is:

$$1366 \times \pi r^2 = 1.7413 \times 10^{17} \text{ Watts}$$

If 30% is reflected back into space, this is reduced to $1.2189 \times 10^{17}$ watts (or 235 Wm$^{-2}$)

If the Earth is in thermodynamic equilibrium, the same amount of power must be radiated back into space.

We can use the Stephan-Boltzmann Law, $P = \sigma AT^4$ to calculate the expected equilibrium temperature of the Earth:

$$T = \frac{4V(P/\sigma A)}{4\pi r^2} = \frac{4V(1.2189 \times 10^{17}/\sigma 4\pi r^2)}{255K}$$

$T_{\text{EARTH}} = -18^\circ C$ !!!!
Why is the Earth’s average surface temperature +14°C rather than -18°C?

The temperature difference is due to the atmospheric greenhouse effect.

This effect causes cloudy nights to be warmer.

Can materials transmit visible light but absorb infrared (heat) radiation?
The Atmosphere

N₂ 78%  
O₂ 21%  
Ar 1%  
CO₂ 0.036%  
Traces of other gases

Light scattered by small particles ($< \lambda/10$) is proportional to $1/\lambda^4$. This is why the sky is blue.

Scattering by larger particles is not wavelength dependent and this is why clouds appear white.
Does scattered by small particles really depend on wavelength?

What about absorption of radiation by gas atoms and molecules in the atmosphere?
Why do some gases absorb IR, while others do not?

Molecular vibrations absorb and emit IR radiation

Driving systems at their natural frequency.

Non-greenhouse gas

Greenhouse gases
If we add the greenhouse effect does our equilibrium model give the correct temperature?

MODIFIED THERMAL EQUILIBRIUM MODEL

\[ S(1-\alpha)\pi r^2 = (1 - \beta)\varepsilon \sigma AT^4 \]

Where \( \beta \) is the proportion of the radiation emitted by the surface that is absorbed by greenhouse gasses and reemitted back to the surface.

At present \( \beta \) is about 0.4 for the earth and this gives a mean surface temperature of 14°C.
But how can we explain the Earth’s increasing temperature?

Energy in > Energy out
Climate forcing → Increasing temperature
(Current net forcing 0.5 - 1.0 Wm⁻²)
What is causing the input energy to increase and/or the output energy decrease?

Is the radiation emitted by the Sun changing?

Past 30 yrs: Solar constant has fluctuated by 0.1%, but no net change.

Past 400 yrs: Only 0.2% variation in the solar constant.
Is the Earth’s orbit changing?

The eccentricity changes from -0.03 to +0.02 with a period of approx. 100,000 yrs

Axial Tilt (obliquity) 41,000 yr period
Precession 26,000yr period
Orbital changes can explain the 100,000 year glacial cycle but not the current warming.

Is the amount of light reflected by the Earth (the albedo) changing?

Water reflects 10%
Land reflects 5-35%
Ice/snow reflect 80-90%

Clouds reflect 20-90%

Solar wind, cosmic rays and albedo

What about particulates in the atmosphere?
Global Dimming would cause the Earth’s temperature to decrease.

Is the strength of the greenhouse effect changing?

36% increase in the past 200yrs.
50% remains in the atmosphere for 100 yrs

Methane is responsible for 20% of forcing (heating effect per kg is 23 X CO₂)

<table>
<thead>
<tr>
<th>Greenhouse Gas</th>
<th>Radiative Forcing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>1.532 W/m²</td>
</tr>
<tr>
<td>Methane</td>
<td>0.48 W/m²</td>
</tr>
<tr>
<td>CFC-12</td>
<td>0.17 W/m²</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>0.15 W/m²</td>
</tr>
</tbody>
</table>

Can we explain the current forcing by combining all these factors?
The greenhouse effect appears to be the most important forcing factor. What feedback mechanisms affect it?

### Negative Feedback and Stability

- Increased low level cloud cover and albedo
- Increased CO₂ take up by oceans
- Faster plant growth
- Reducing water vapour in the the warmer/dryer upper troposphere

### Positive feedback and Tipping Points

- Global Dimming reduced
- Reduced reflection from ice sheets
- Melting permafrost releases methane
- Methane ice (clathrate) releases methane
- Stressed forests begin to emit CO₂ (e.g. Drought could destroy Amazon rain forest)
- Gulf Stream collapses
- Oceans absorb less CO₂ as they heat
Is CO₂ less soluble in warm water?

Can we predict future temperature change?

IPCC Prediction

Likely CO₂ concentration of 550-850 ppm and 2-5°C temperature increase by 2100 (cf 0.6°C increase last century)

What are the implications of global warming?
Implications

• Increasing temperature
• Intensity of storms
• Rising sea levels

• Changes to local climate, droughts/floods
• Rising acidity of the oceans

Does water expand when heated?

Does water become more acidic when it absorbs CO₂?

Basic  Acidic
Implications

• Increasing temperature
• Intensity of storms
• Rising sea levels
• Changes to local climate, droughts/floods
• Rising acidity of the oceans
• Shrinking glaciers and ice caps
• Reduction of biodiversity
• Reduction in world food production and shortage of fresh water

Should we take action to minimise the risk of catastrophic climate change?

“We do not inherit the earth from our ancestors, we borrow it from our children.”
~Native American Proverb