Tipping the atmospheric scales: the Earth's energy balance

The temperature of the Earth's surface, and the atmosphere above it, are governed by the intricate exchange of energy between the different components of the climate system – atmosphere, **cryosphere**, oceans and land. If this exchange of energy, called the Earth's radiation budget, is in balance, the temperature stays the same. However, if anything happens to tip the balance – such as an increase in the amount of greenhouse gases in the atmosphere, the temperature has to change. Climate and climate change are common themes in all the geography specifications.

Incoming solar radiation
Almost all of the energy in the atmosphere ultimately comes from the electromagnetic radiation emitted by the sun. The amount of incoming solar radiation depends on things like:

- How active the sun is – how many sunspots there are. After a period of relatively high activity at the end of the 20th Century, the sun has recently been fairly inactive.
- Where in the 11-year solar cycle we are. Changes in the amount of incoming solar radiation through an 11-year cycle are typically less than 0.1%, with an estimated global average temperature response of less than 0.03ºC. Some correlation has been noted with droughts, temperature, ozone, etc. and some mechanisms to link solar activity with climate change have been identified.
- How far the Earth is from the Sun. The combined gravitational pull of the Sun, Saturn, Jupiter and other planets cause the shape of the Earth's orbit to vary from its most elliptical to almost circular on a 110,000 year time scale. The Earth is currently closer to the Sun in Northern Hemisphere winter than in Southern Hemisphere winter. This results in changes in the incoming solar radiation; the current seasonal variation is 6.8%.

Reflected solar radiation
This is the combined radiation reflected by the atmosphere, clouds, small particles in the atmosphere ('aerosol') and the surface of the Earth.

Anything that makes the Earth look white from Space is reflecting the Sun's energy back (see figure 3). The proportion of energy reflected is called the **albedo**. Albedo varies between 0 and 1; typical values are given in table 1:

	albedo
Clouds	0.15-0.8
Snow & ice	0.8-0.9
Forests & cities	0.1-0.2
Desert	0.35
Water	0.05-0.5

Huge explosive volcanic eruptions in the Tropics, energetic enough to push sulphur gases up into the relatively stable stratosphere where they condense into **aerosol**s, can have a cooling effect on climate by increasing the albedo. This effect can last a couple of years. The combined eruptions of La Soufrière (1812), Mayon (1814) and Tambora (1815) had catastrophic global effects, leading to a 'year with no summer' in 1816. The eruption of Ejafjallajökull in 2010 did not have any lasting effects on the climate – the ash it produced did not make it up into the stratosphere, the reduced number of contrails caused by the grounding of flights did not have a noticeable impact on the weather and the amount of carbon dioxide released by the volcano was much less than the emissions saved by the reduction in the number of flights – a tiny proportion of annual emissions.
Changes in the albedo are a major source of feedbacks in the climate: for example, if the atmosphere warms, causing ice and snow on the Earth's surface to melt and reducing the

amount of reflected solar radiation, more radiation will be absorbed by the Earth's surface, ultimately leading to further warming.

Changing the Earth's albedo to combat climate change
Several people have proposed ways to artificially 'engineer' the climate to combat man-made climate change by increasing the Earth's albedo. One way involves having a fleet of 1,500 wind-driven ships pumping a fine spray of salt water into the atmosphere. This would make cloud droplets smaller and more reflective, increasing the amount of solar radiation reflected back out into space by about 10%. Figure 5 shows some of the arguments for and against the scheme.
For discussion: Do you think climate engineering is worth a try?
The UN has recently banned any climate engineering scheme which

Radiation absorbed by the Earth's surface

All the solar radiation that reaches the surface of the Earth without being reflected or absorbed, as well as the radiation that is emitted back towards the surface of the Earth by the atmosphere, is absorbed by the surface. This warms the ground and the oceans.

Thermals, evapotranspiration and surface radiation

The warm surface of the Earth returns energy to the atmosphere by:

- Warming the air directly above it;
- The evaporation of water from oceans, lakes, etc;
- Plants transpiring. When water vapour condenses to form cloud droplets, the energy is released (**latent heat**), warming the atmosphere.
- The Earth itself radiates energy upwards, but because the Earth is considerably colder then the Sun (288K compared to 6000K) the radiation is longer wavelength – it mainly takes the form of heat (**infra red**) rather than the visible and ultraviolet radiation we get from the sun.

Radiation absorbed by the atmosphere

Some incoming solar radiation is absorbed by the atmosphere. Most importantly for us, stratospheric ozone absorbs much of the incoming ultraviolet radiation, protecting all living things from potential damage.
In 1859, John Tyndall's laboratory experiments showed that water vapour and carbon dioxide absorb infra-red radiation and that they could therefore affect the climate of the Earth. In fact, greenhouse gases absorb much of the long-wave radiation emitted by the surface of the Earth. These gases include water vapour (the most important), carbon dioxide, methane and nitrous oxide. Without them, the surface of the Earth would be about 33℃ cooler. There are greenhouse gases on other planets too: Mars is kept about 10℃ warmer, Venus about 500℃! However, man-made or anthropogenic emissions of greenhouse gases since the industrial revolution in the mid 18th century have led to a rapid rise in the concentration of greenhouse gases in the atmosphere. In 1896, Arrhenius estimated that a doubling of carbon dioxide would lead to a warming of 5-6 ºC. The observed concentration of atmospheric carbon dioxide has increased from 280ppm (parts per million) to well over 390ppm in 2008 and is rising by about 2ppm per year (figure 2).

The warm atmosphere radiates energy in two directions – upwards, so that it is lost to space, and downwards, back towards the surface of the Earth (back radiation). Because of the enhanced greenhouse effect, the amount of energy emitted by the atmosphere has reduced, and the amount of back radiation has increased.

Atmospheric window

Some wavelengths of outgoing radiation are not absorbed by any atmospheric gas, and therefore escape to space unhindered. Because of the enhanced greenhouse effect, the amount of energy that goes out through the atmospheric window has fallen.

Outgoing long-wave radiation

This is the amount of energy the Earth loses to space. In figure 1:

reflected solar radiation + outgoing long-wave radiation = incoming solar radiation

This would suggest that Earth's atmosphere is in balance and you would not expect there to be a long-term change in temperature. This is no longer the case. At the moment:

reflected solar radiation + outgoing long-wave radiation < incoming solar radiation

implying that energy is accumulating in the climate system, heating it up. This will produce a new equilibrium at a higher temperature.

Key points

- Radiation in the Earth's atmosphere can be ultraviolet, visible or infra-red.
- The Earth's radiation budget is constantly changing, as day turns to night, season follows season, the composition of the atmosphere changes or the Earth's albedo changes.
- As a result, no component of the climate system – air, ocean, ground, ever reaches a constant temperature, but is constantly adjusting.
- Since the pre-industrial period, the Earth's temperature has risen by about 0.75 ºC, and is now rising more rapidly than at any other time since industrialisation started.
- By changing the amount of greenhouse gases in the atmosphere, people have unintentionally altered the climate. Now, schemes are being proposed to purposefully engineer the climate to prevent catastrophic climate change.

Further reading:

Links to a wealth of weather and climate information can be found at the Royal Meteorological Society's website http://www.Metlink.org

The IPCC's frequently asked questions are also very helpful:

http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faqs.html

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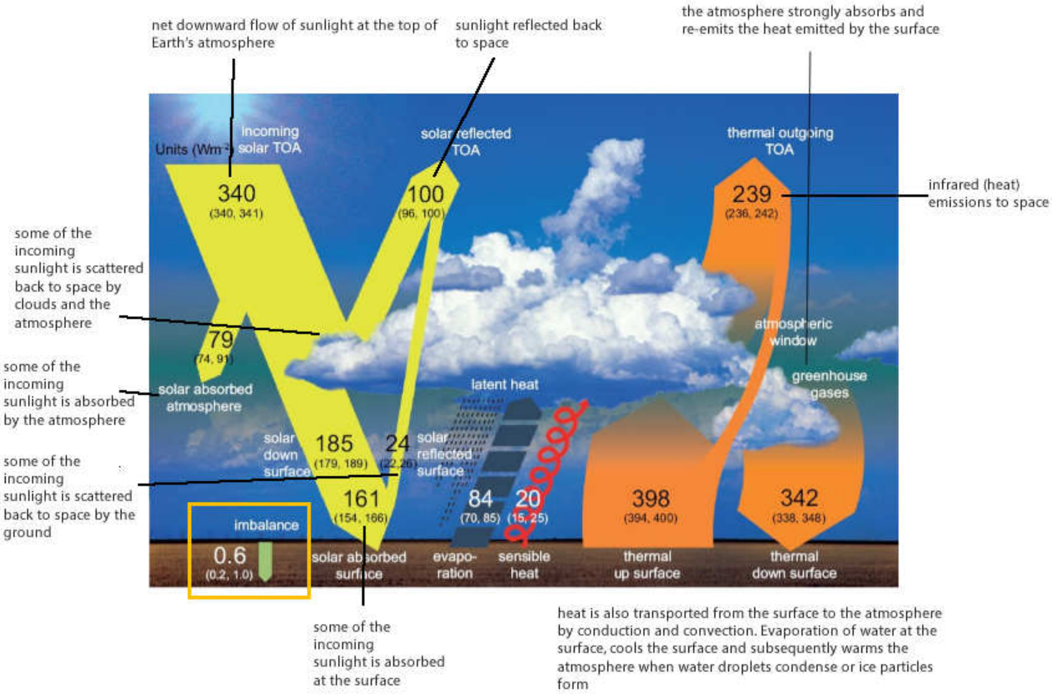

Figure 1: The Earth's radiation budget.

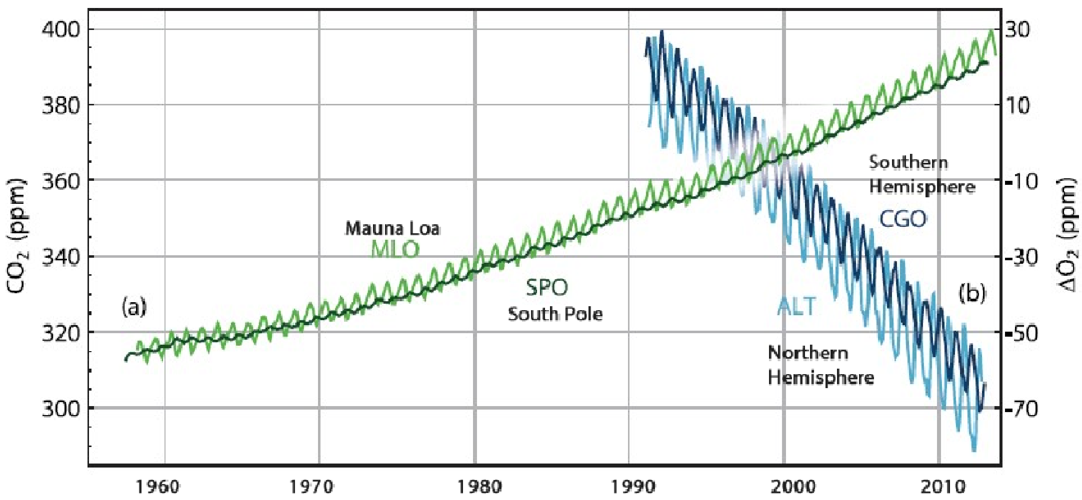

Figure 2: The concentration of carbon dioxide in the atmosphere recorded at Mauna Loa observatory, Hawaii. Note the annual cycle: carbon dioxide tends to be released by plants in the autumn and taken up in the spring. As there is more land and therefore vegetation in the Northern Hemisphere than the Southern Hemisphere, we see more carbon dioxide in the atmosphere in Northern Hemisphere winter than summer.

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Figure 3: A satellite image of the Earth, from 12UTC on the 7th January 2010 - a day the UK was completely snow covered! This image was taken using visible wavelengths, so, the whiter the image, the more of the Sun's visible radiation is being reflected. What surfaces other than cloud and snow are reflecting a lot of radiation? What surfaces are hardly reflecting any radiation at all? (copyright Dundee University Satellite Receiving Station)

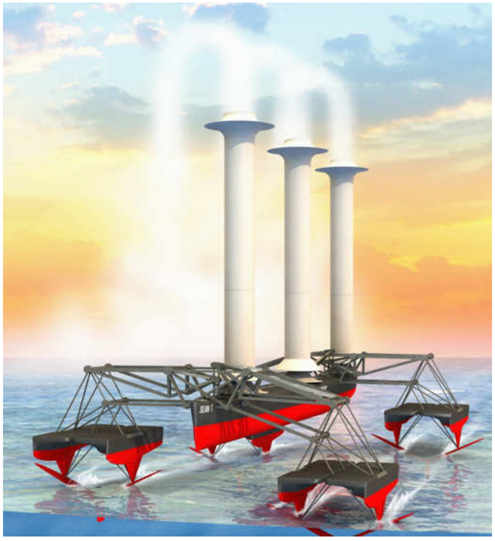

Figure 4 Salter's cloud-seeding ships, an artist's impression

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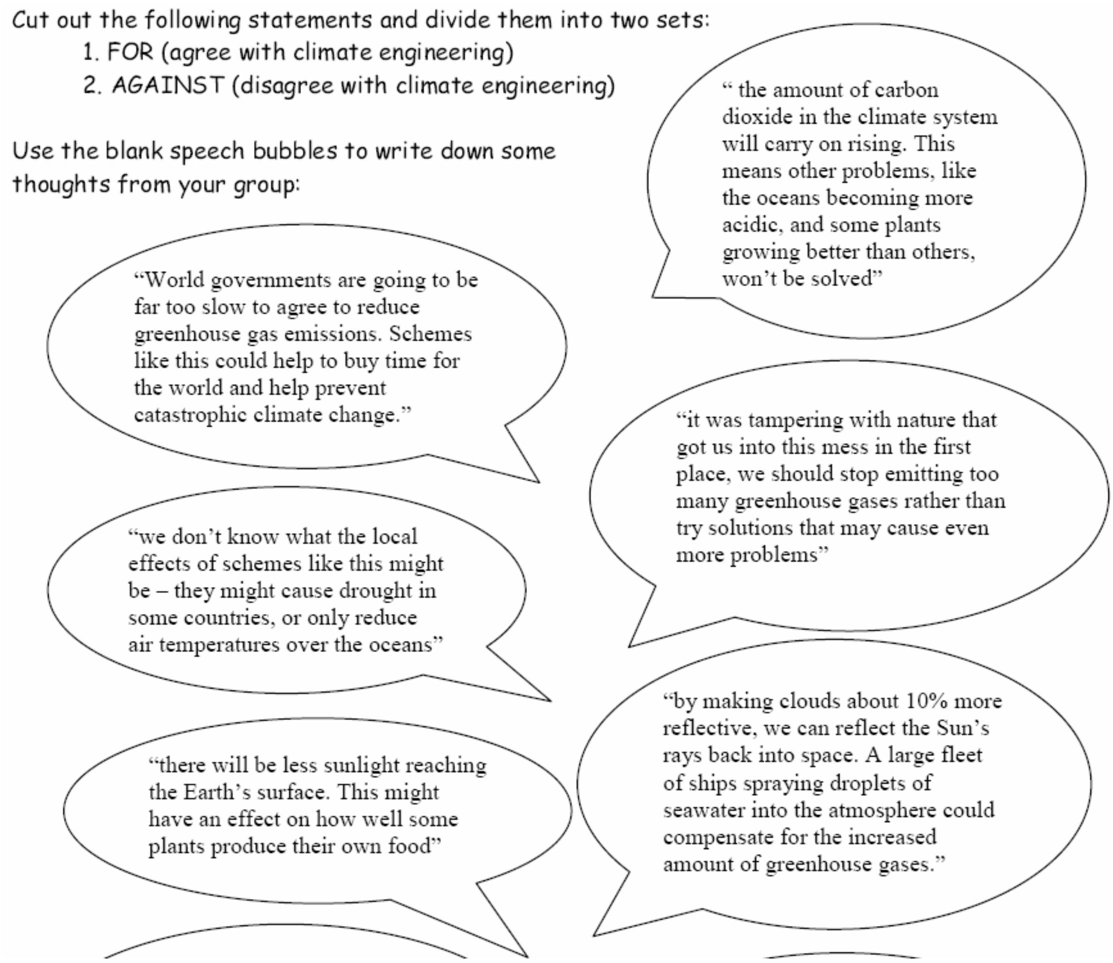

Figure 5 Some arguments for and against a climate engineering scheme

Glossary

Aerosol

Albedo The proportion of the Sun’s radiation which is reflected back into space. The closer the albedo is to 1, the more radiation is reflected.

Cryosphere

Latent heat

Infra red

Ultra violet

Visible light