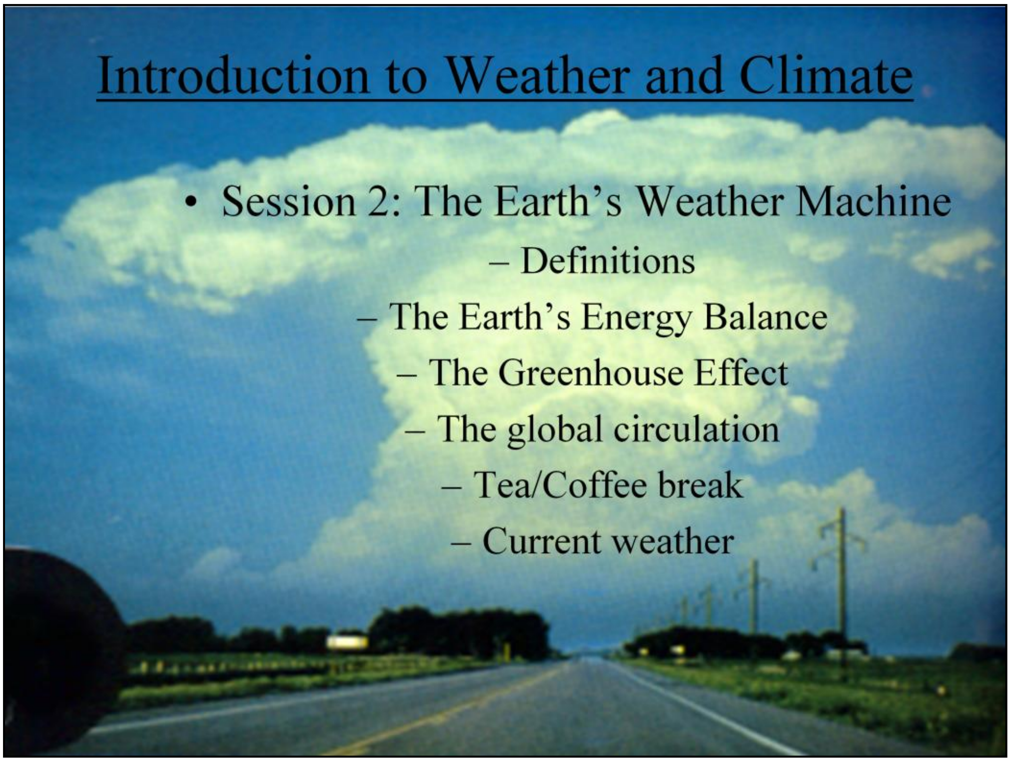

Introduction to Weather and Climate
• Session 2: The Earth's Weather Machine
– Definitions
– The Earth's Energy Balance
– The Greenhouse Effect
– The global circulation
– Tea/Coffee break
– Current weather

Course Structure

- Session 1: Introduction
- **Session 2: The Earth's Weather Machine**
- Session 3: Measuring and the weather
- Session 4: Clouds and Rain
- Session 5: Observing the Weather/Weather Systems
- Session 6: Forecasting the Weather
- Session 7: Climate Change
- Session 8: Extreme Weather 1
- Session 9: UK weather
- Session 10: Extreme weather 2 and Conclusions

- Current Weather Game
- Assignments:
  - Week 1-4 work sheet
  - Week 7: quiz
  - Weather Game

Update this !!!

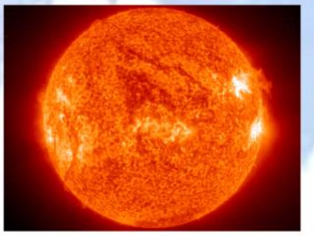
Definitions…

- **Meteorology** (from the Greek for lofty): *"the study of the physical nature of the lower atmosphere and its variability"* or… the study of weather!
- **Climate:** "*meteorological conditions expected for a particular location and season based on observations over a period of decades"*

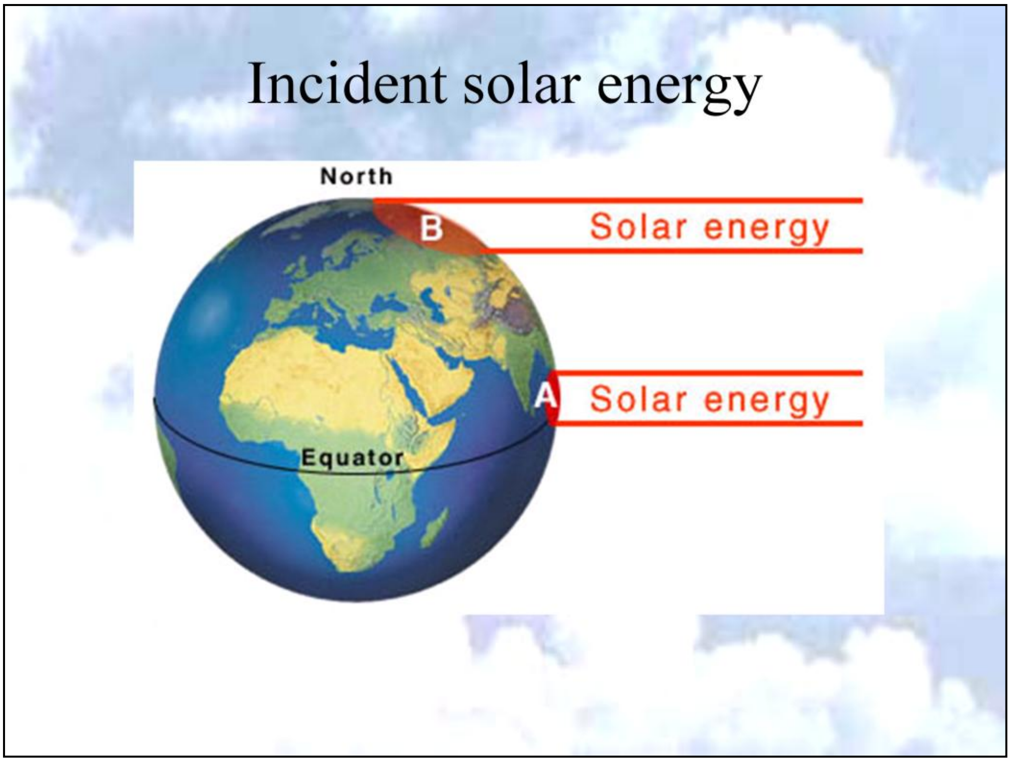
- *"climate is what we expect, weather is what we get"*
- ***What determines our weather and climate?***

What measures climate? A variety of variables including their variability and extreme values determine climate for a particular location. Ecosystems are finely tuned to survive in their climatic zone; this includes their ability to survive fluctuations in climate as well as prosper in optimum conditions. Typical variables to consider are temperature (maximum, miniumum), precipitation (includes rain, sleet, snow, hail, etc), sunlight/cloudiness, wind, humidity, ice cover, sea temperature, etc… Many of the variables are linked: for example more cloud leads to less sunlight, and a smaller range in temperature over the day (warmer nights but cooler days) and is likely to coincide with higher humidity and precipitation.

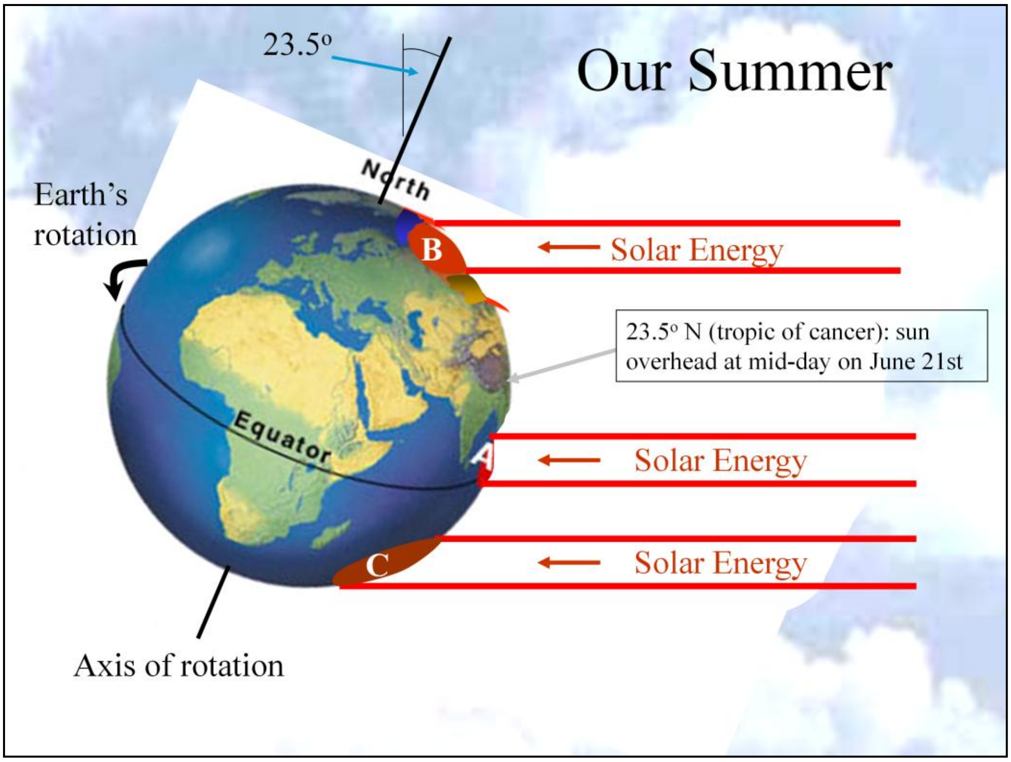
The sun drives our weather and climate



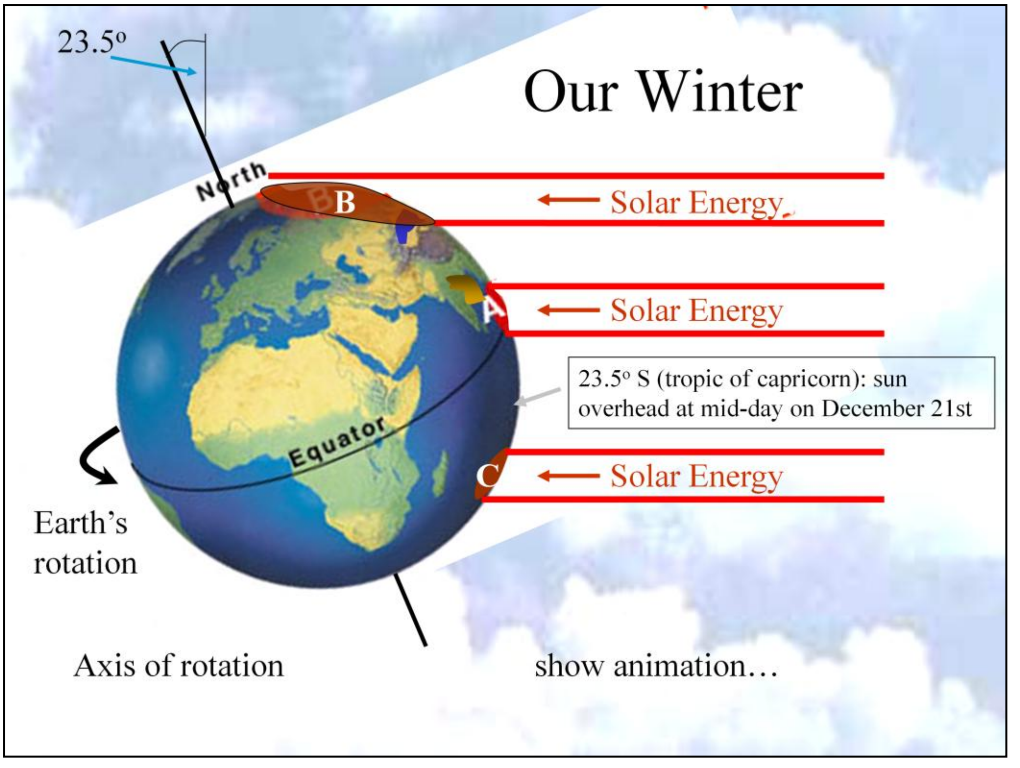
- *"the weather is a series of incidents in the working of a vast natural engine"*
  - Sir Napier Shaw
- The sun provides the energy for this engine
- Obvious effects of the sun on weather and climate over the course of a day/night and over seasons



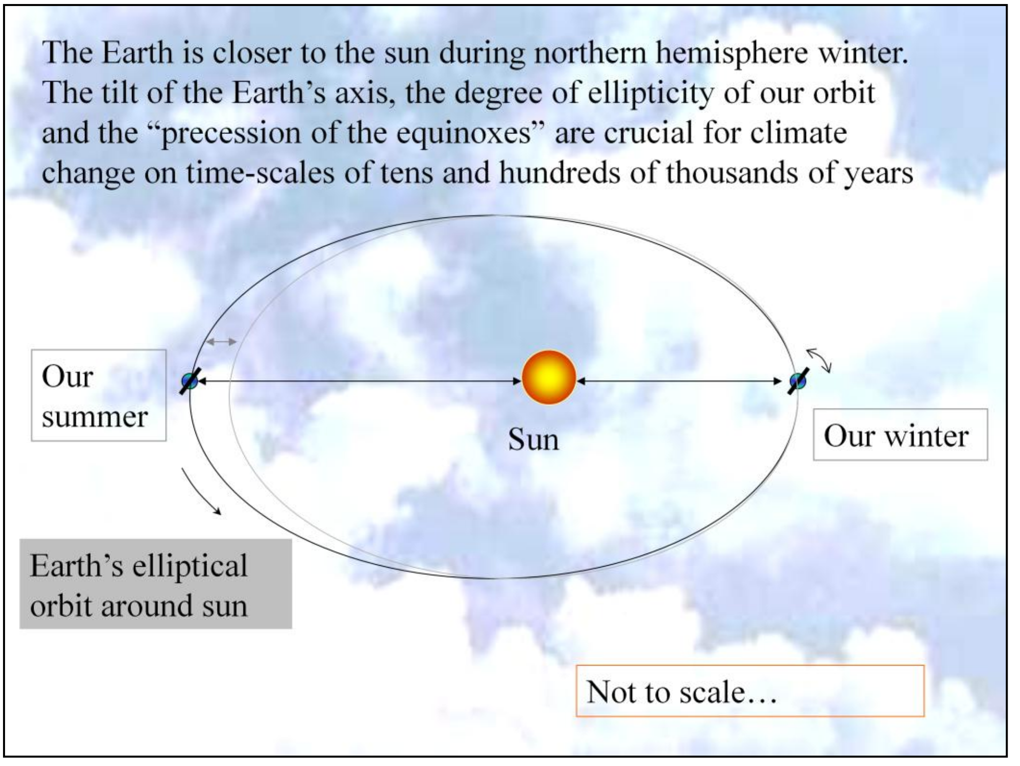
For two identical beams of sunlight (solar energy), the beam falling on **B** is spread over a larger area than at **A** so **A** will receive more energy for each square metre. An additional effect is that the solar beam at **B** passes through a longer path through the atmosphere since it is entering the atmosphere at an angle.



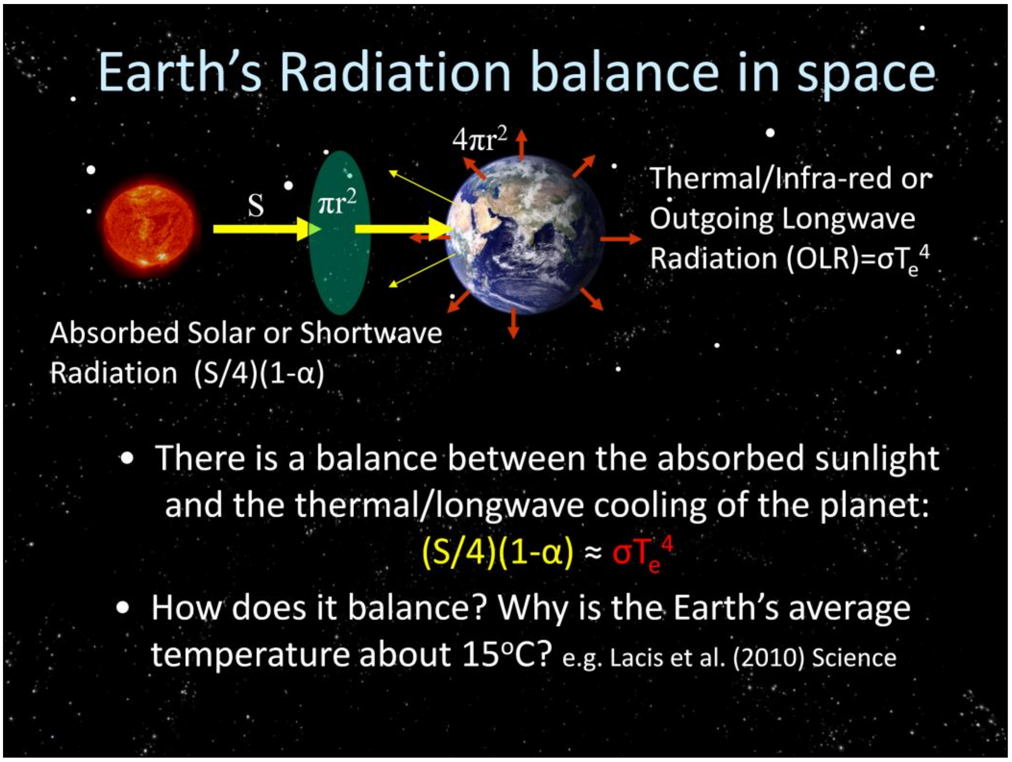
In the northern hemisphere summer, the tilt of the Earth's axis causes the solar beam at **B** to become more concentrated, thereby providing more energy than during northern hemisphere winter. Conversely in northern summer, the beam at **C** is spread more thinly, explaining why it is winter in the southern hemisphere during northern summer.



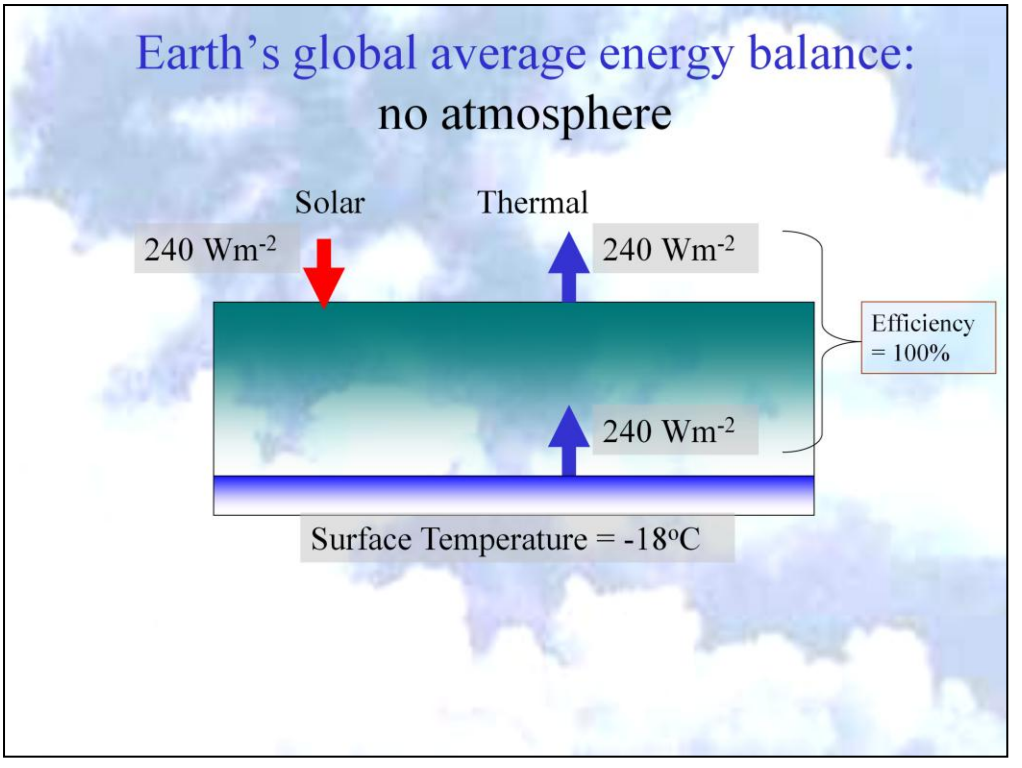
The reverse is true in northern hemisphere winter… The tilt of the Earth's axis explains our seasons but over longer periods of time it is also important for changes in climate (much more in Climate Change course).



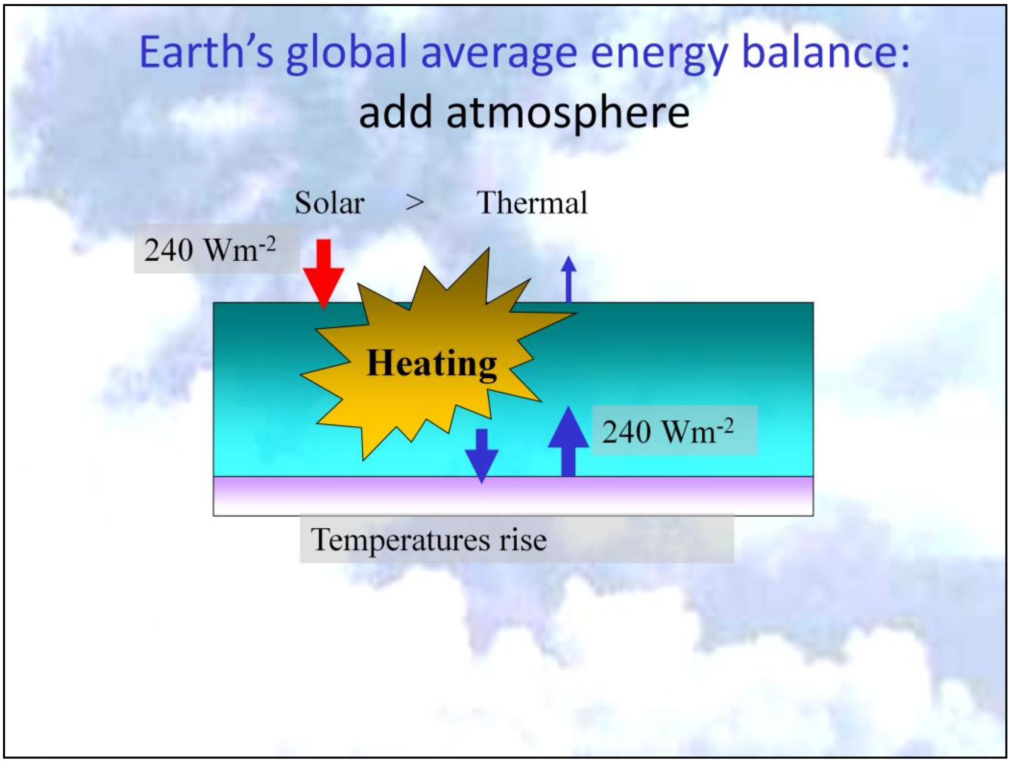
In Australia, December is their summer and the Earth is at its closest point to the sun so you have to be more careful about getting sunburnt compared with a similar location in the northern hemisphere. In fact the lower ozone levels and very dry climate makes using sunblock particularly important in the non-tropical regions of Australia.



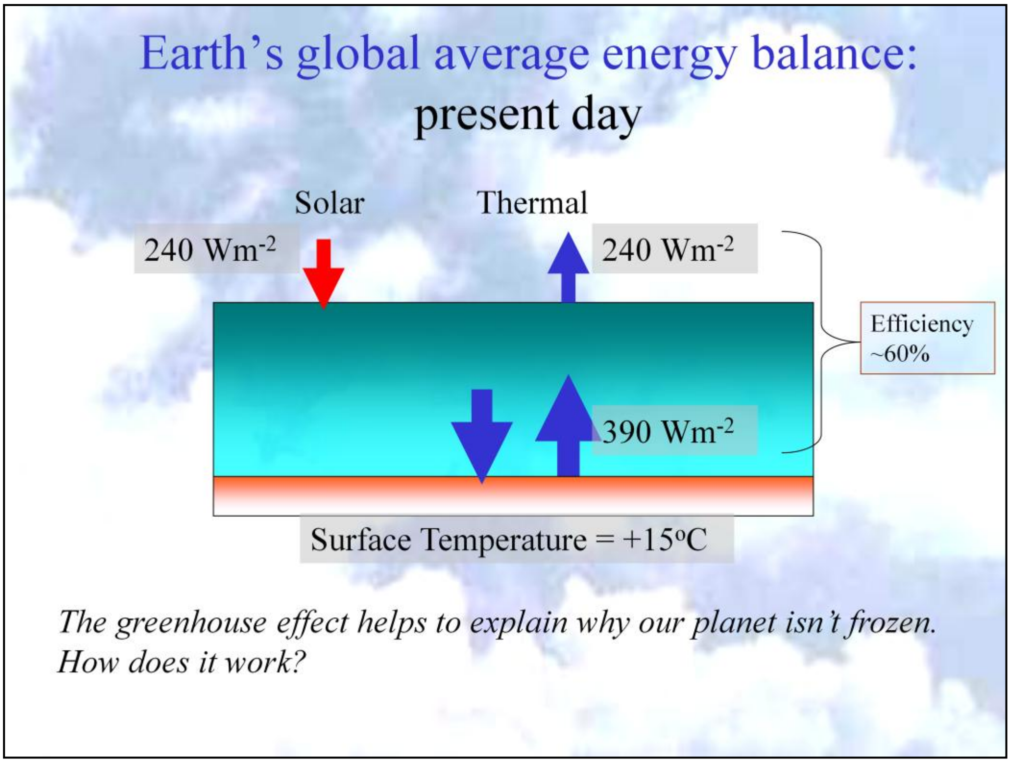
The constant supply of radiative energy from the sun would continue to heat the planet up were it not for a balancing flow of longer wavelength infre-red radiative energy away from the planet and back to space. The warmer a body, the more radiative energy is emitted. For the Earth, the planetary emitted longwave radiation approximately balances in the absorbed sunlight and this balance is achieved at a global annual surface temperature of around 15^{o}C. The sunlight received by the Earth is equal to the solar constant (1360 Wm^{-2}) divided by the ratio of the area of a circle to the surface area of a sphere (4) and only a fraction of this (about 70%) is absorbed by the Earth since some is reflected back to space by clouds, the surface and atmospheric aerosol (the reflected fraction is termed the albedo (alpha) and is around 30%. From space the Earth appears to be emitting at a



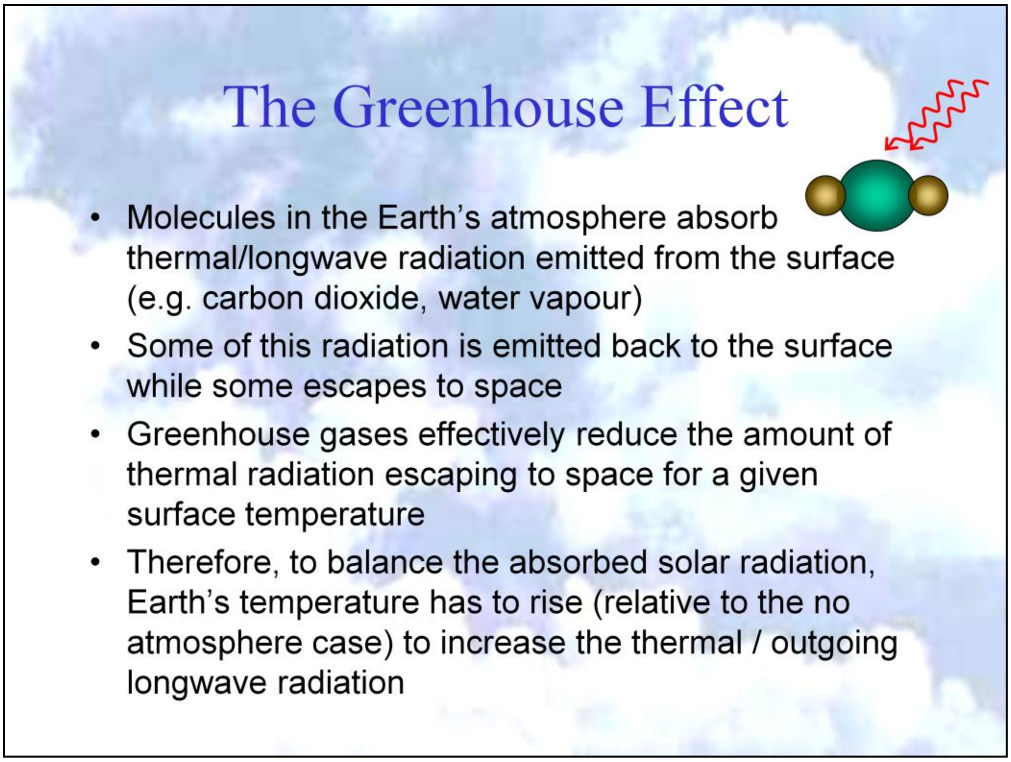
The Earth without a Greenhouse Effect would be frigid since the Earth would cool more efficiently by emitting thermal radiation from the surface straight out into space. To balance the absorbed solar radiation (around 240 Wm^{-2}) you would only need a temperature of $-18^{o}C$.



Adding an atmosphere reduces the outgoing thermal radiation to space, and so the absorbed solar energy is greater than the outgoing thermal energy and the planet warms up.



As the planet warms up, it emits more thermal energy since warmer bodies emit more thermal (longwave) radiative energy. The Earth warms up until the outgoing thermal energy equals the absorbed solar energy, resulting in a global temperature of about 15^{o}C, around 33^{o}C warmer than without a greenhouse effect. This is an unrealistic case since we are assuming that the Earth's albedo would remain unchanged but is a useful thought experiment.

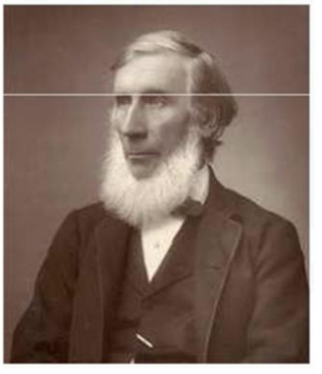


The shapes of the molecules determines which particular wavelengths of radiation they can absorb. Water is a particularly "bendy" molecule so can absorb across a much of the electromagnetic spectrum. Carbon dioxide is a linear molecule which can only absorb thermal radiation at particular frequencies. Nevertheless, this absorption is substantial.

The greenhouse effect was discovered by Joseph Fourier in 1824, first reliably experimented on by John Tyndall in 1858, and first reported quantitatively by Svante Arrhenius in 1896.

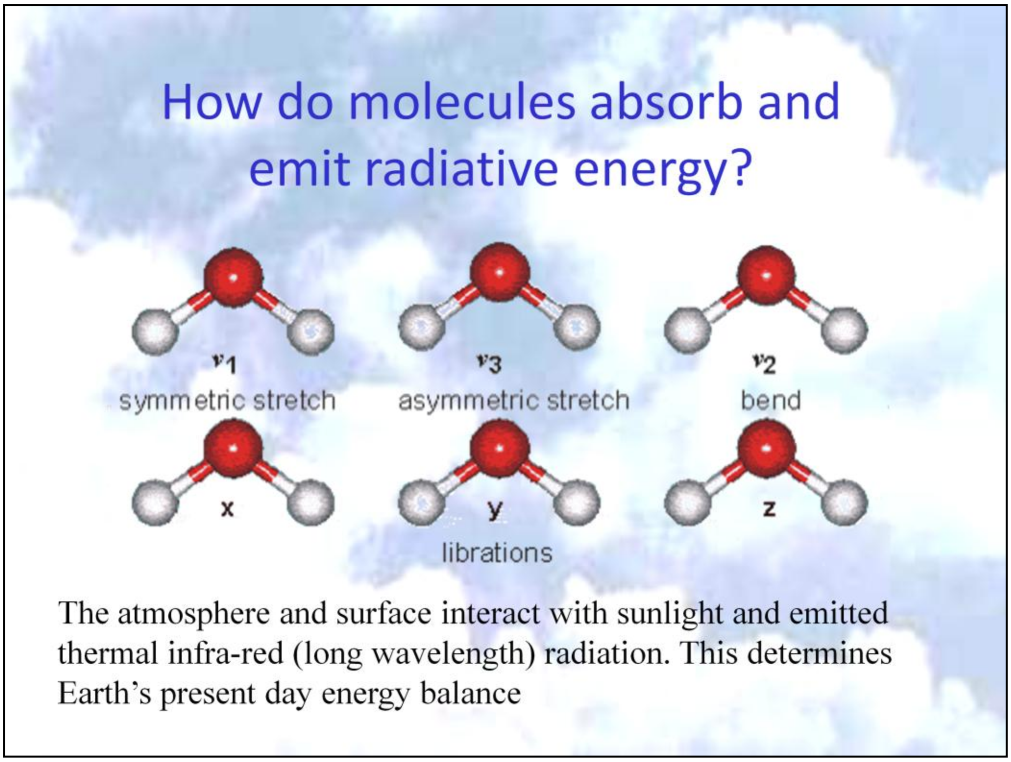
Joseph Fourier

John Tyndall

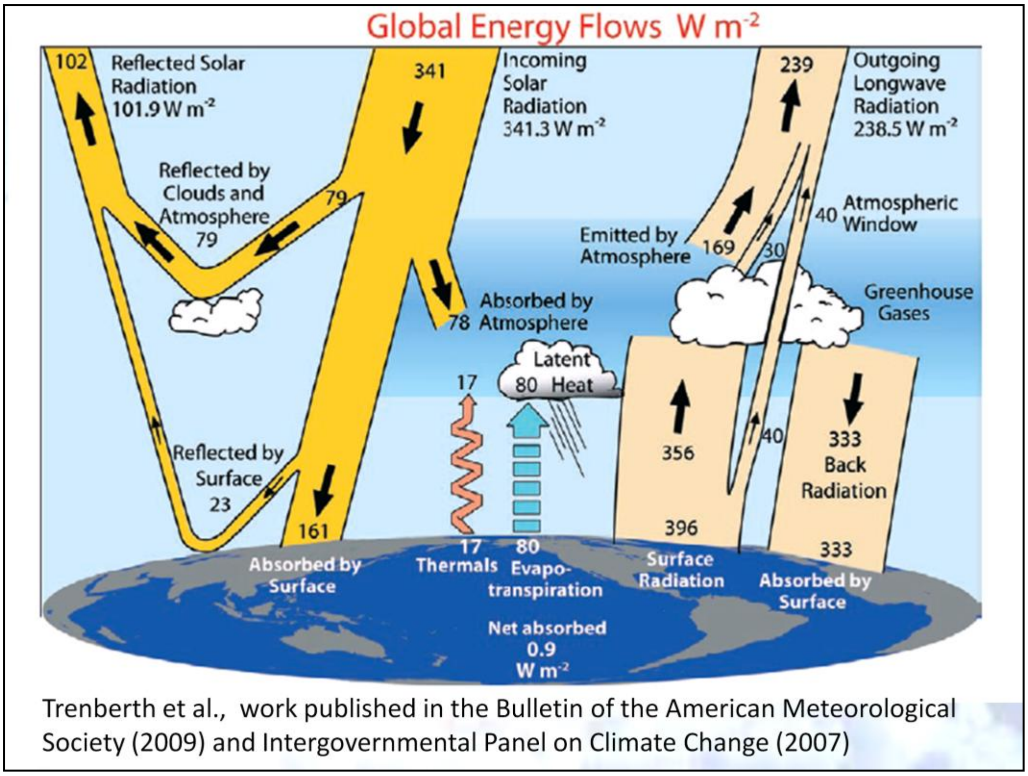


Courtesy of Prof. Richard Somerville http://richardsomerville.com

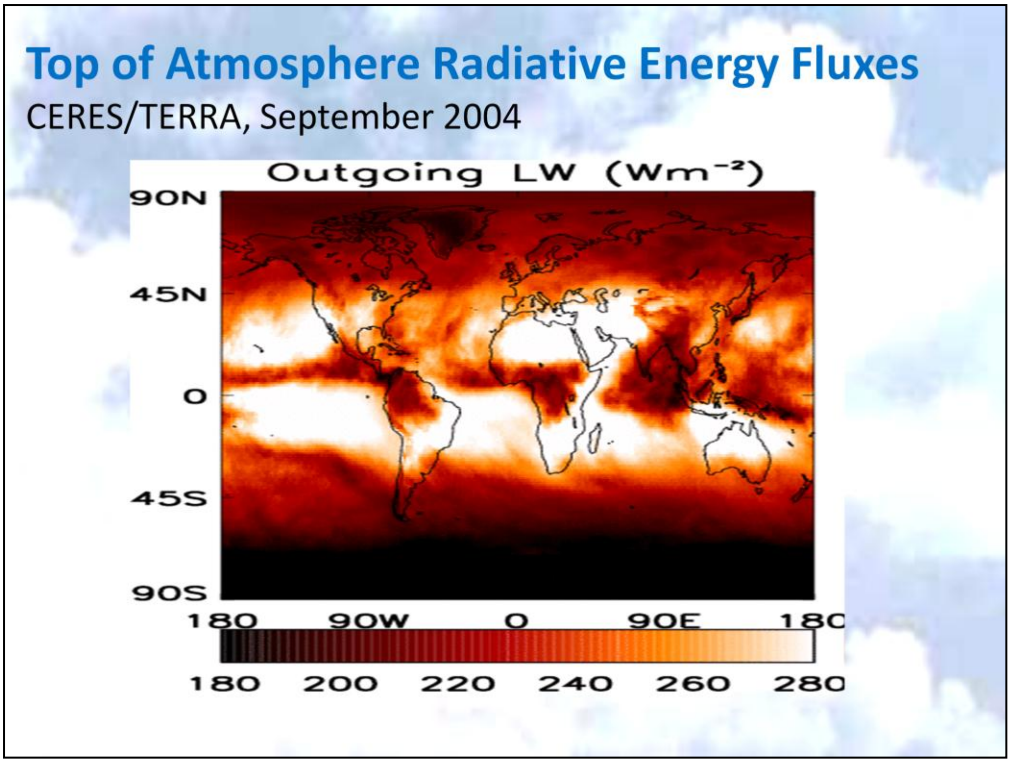
There is some controversy over whether Fourier actually “discovered” the greenhouse effect in our current definition (see Wikipedia).



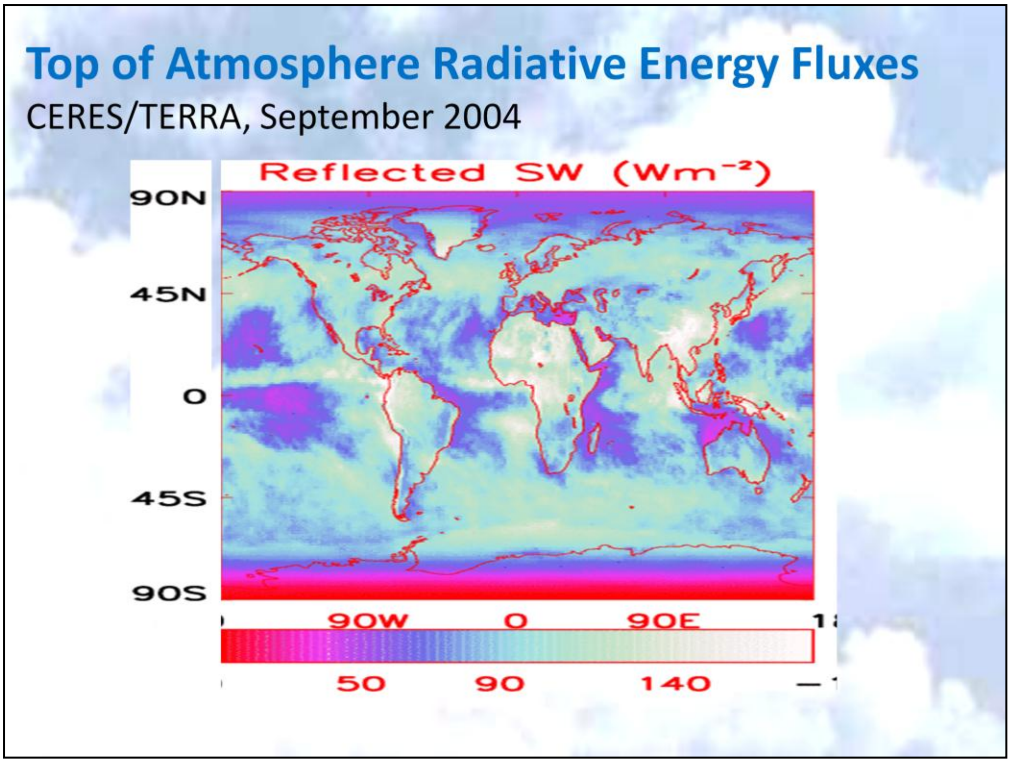
Transitions between the energy levels of greenhouse gases. These energy levels are quantised and obey the laws of quantum mechanics. For typical atmospheric temperatures, the energy levels are associated with vibrational and rotational modes. Water vapour is particularly versatile at absorbing over the longwave (and shortwave) electromagnetic spectrum. It is a polar molecule with an ability to bend, stretch and vibrate in a number of ways, therefore absorbing in many different frequencies. Even in the non absorbing regions, collisions between different atmospheric molecules can spread out or blur the precise absorption region.



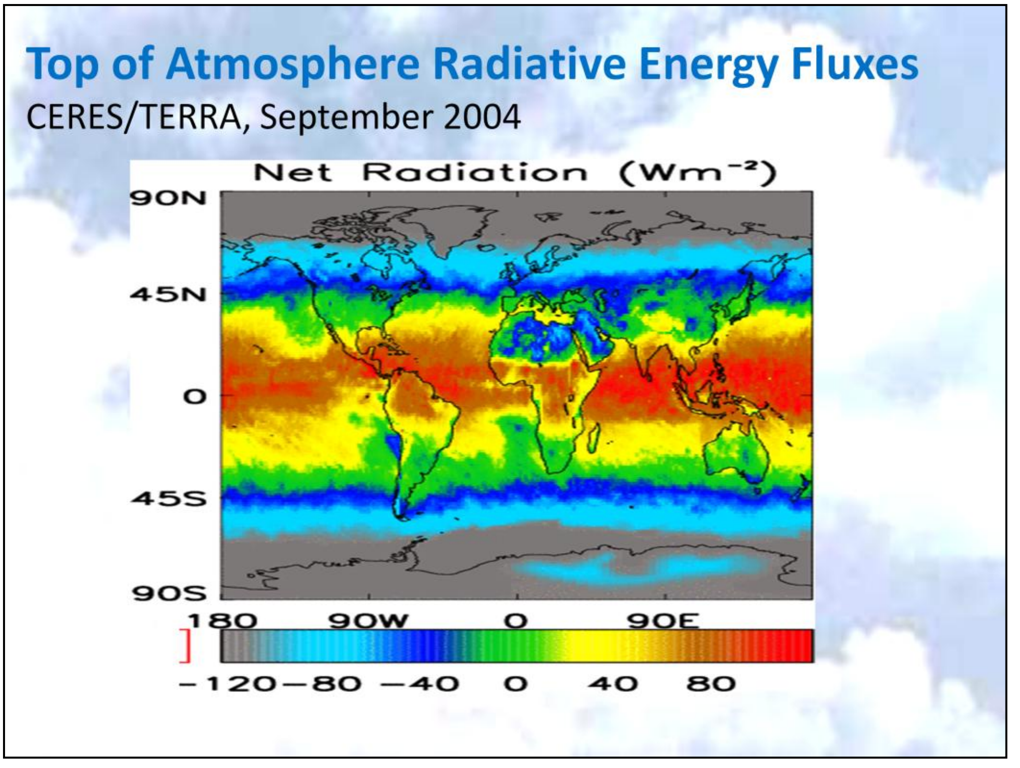
Based upon satellite data, ground-based data and detailed physical models, this diagram shows our current understanding of energy flows in the climate system. In addition to shortwave (solar) radiation and longwave (infra-red) radiation, there is also a flow of "sensible" and "latent" energy from the surface (e.g. evaporative cooling) to the atmosphere (latent heating through precipitation). The temperature lapse rate (fall in temperature with height) is driven by continual radiative cooling but balanced to some extent by latent heating, resulting in observed lapse rates of around 6-10 ^{o}C per km (test this out by climbing a mountain!).



Outgoing longwave radiation is highest in the warm sub-tropics and lowest in the cold polar regions. But why is it also low in the inter-tropical belt?

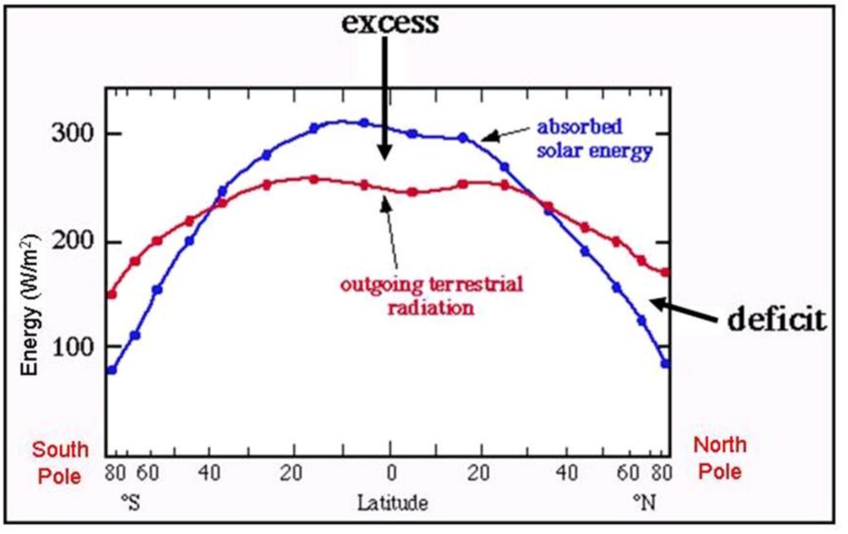


Reflected sunlight is lowest at the winter pole where the sun is permanently set. However, it is also low in the cloud-free sub-tropical oceans where the dark ocean absorbs a large fraction of the incident solar rays.



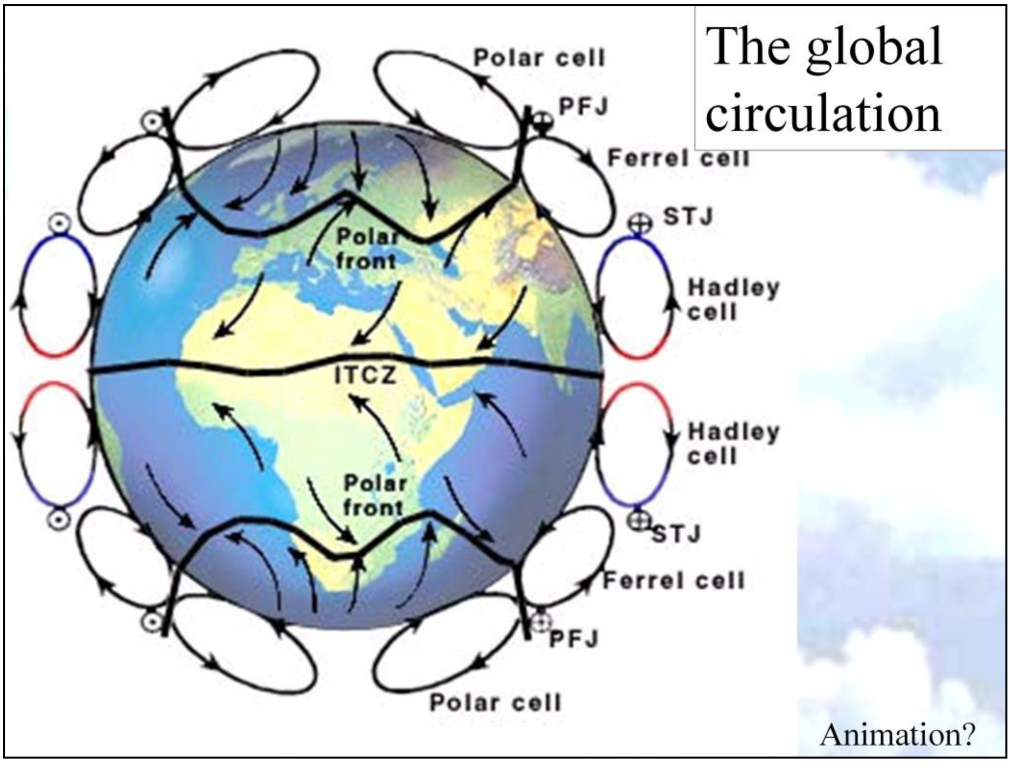
The net radiative energy is a balance between the absorbed solar radiation and the outgoing longwave radiation and is generally positive at low latitudes and negative at high latitudes. A surprising result is that the Sahara loses more radiative energy than it gains. Why is this?

Earth’s Energy Budget



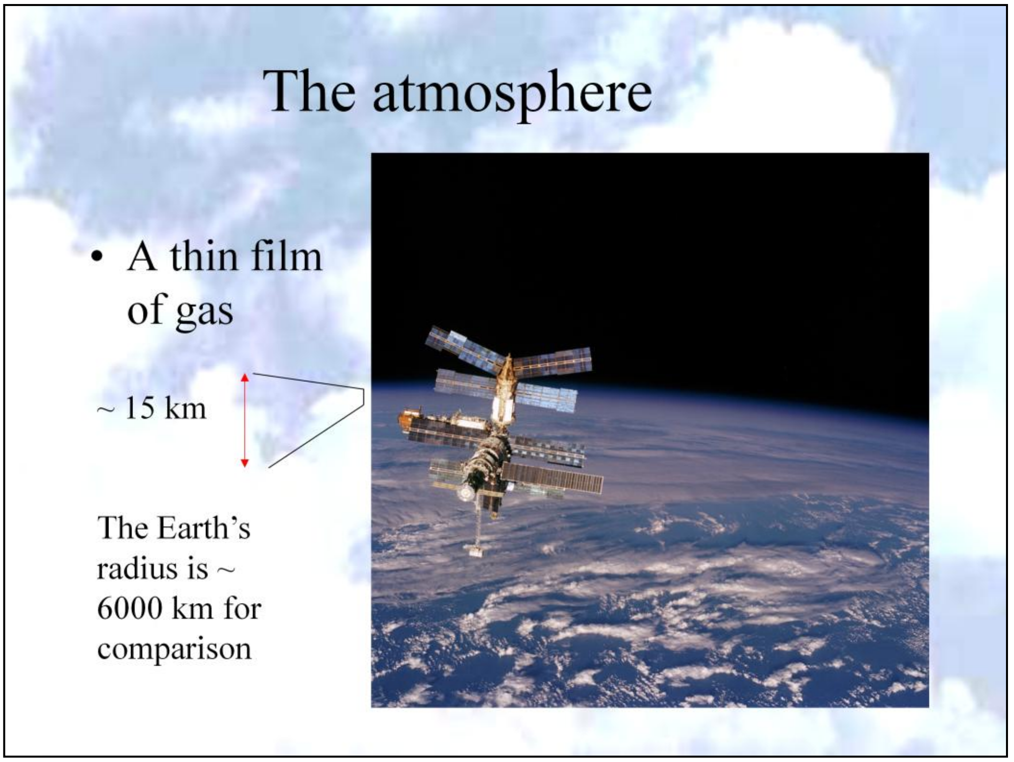
Why don’t the tropics get hotter and hotter and the poles colder?

Due to the angles of incident solar radiation, there is more energy received nearer to the equator than at the poles. This leads to an excess of solar energy over thermal outgoing energy in the tropics. Why doesn’t the tropics get hotter and hotter and the poles colder and colder?

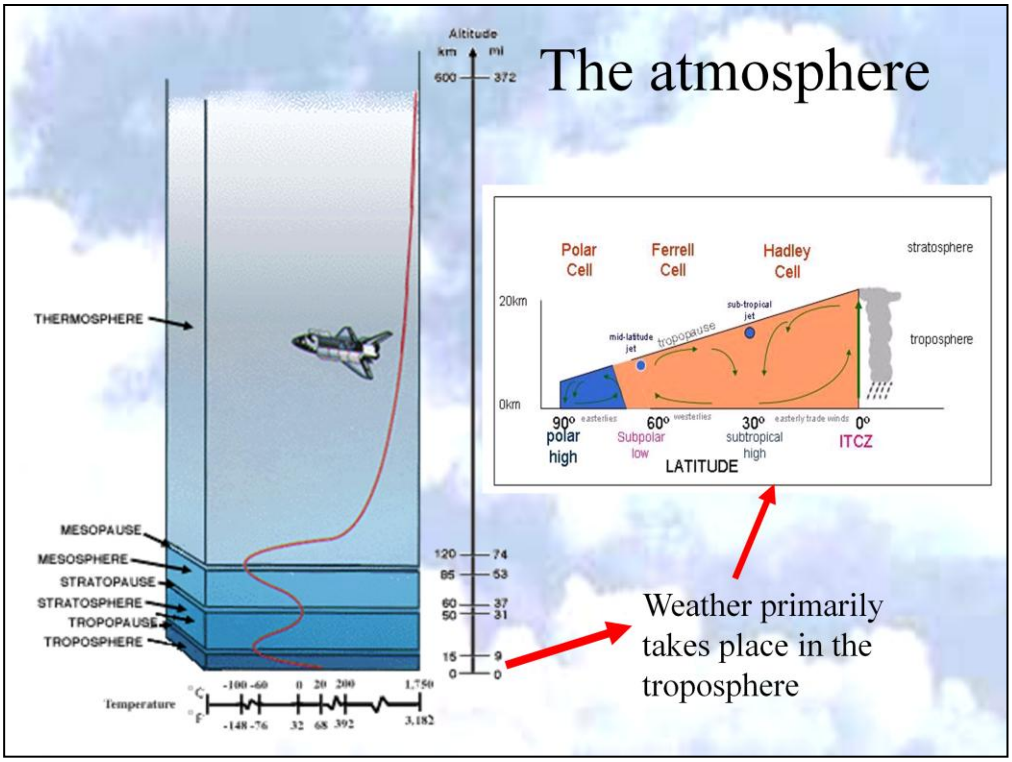


The extra energy in the tropics is transported pole-ward by the atmospheric and oceanic circulations.

The rotation of the Earth and the positions of continents and mountains complicate the circulation, leading to weather patterns.

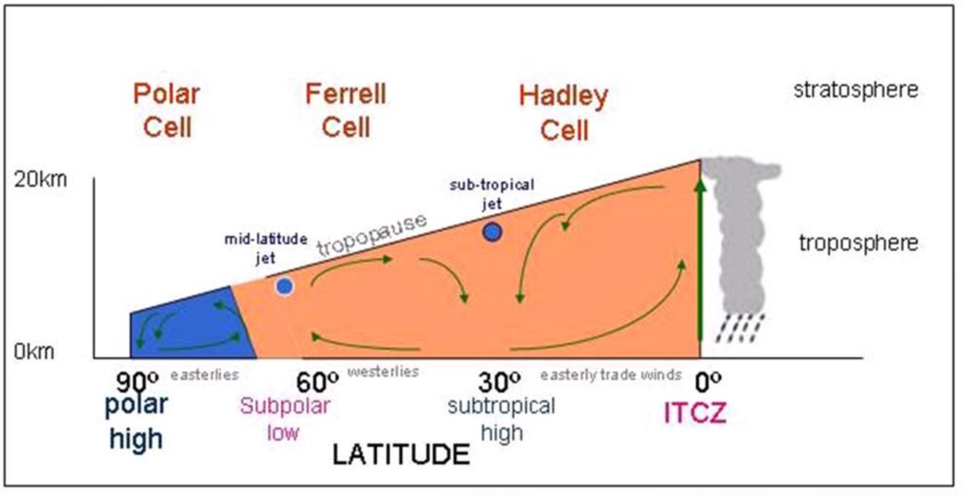


The atmosphere is a thin film of gas comprising (by volume) 78% Nitrogen, 21% Oxygen, 1% Argon, 0.04% carbon dioxide, trace amounts of Helium, Methane and Krypton and variable amounts of ozone and water vapour (gaseous water). Our weather primarily takes place in the lowest 10-15km of the atmosphere, in a well-mixed layer called the troposphere. In this layer is almost all the atmosphere's water and most of this is in the layers closest to the surface which supplies the moisture. Of this atmospheric water, most of this is invisible, in the gaseous "vapour" state while only a small fraction is liquid and ice and visible to us as cloud. Cloud is merely water vapour with atitude…

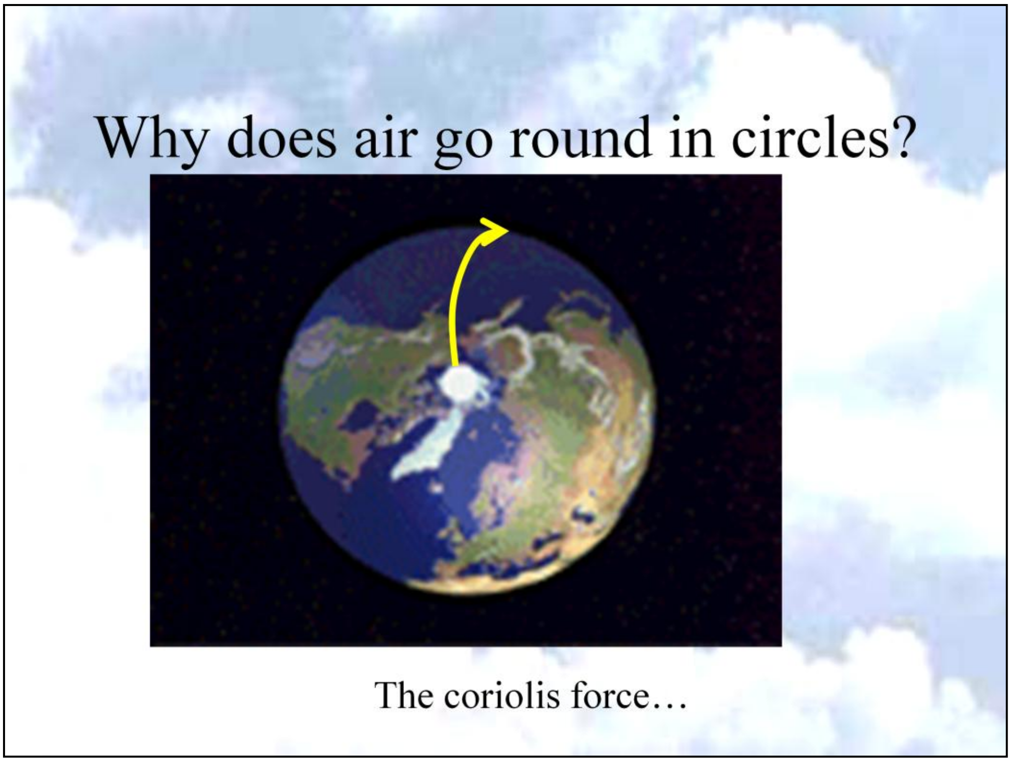


The clouds, winds and rain that comprise our weather take place in the troposphere which is about 8km deep at the poles, rising to up to 16km deep in the tropics, and holds about 80% of the atmosphere. The temperature drops off with altitude as is readily observable by a walking up a mountain. Temperature falls with height at an approximate rate of 6°C for every 1000m.

The global circulation



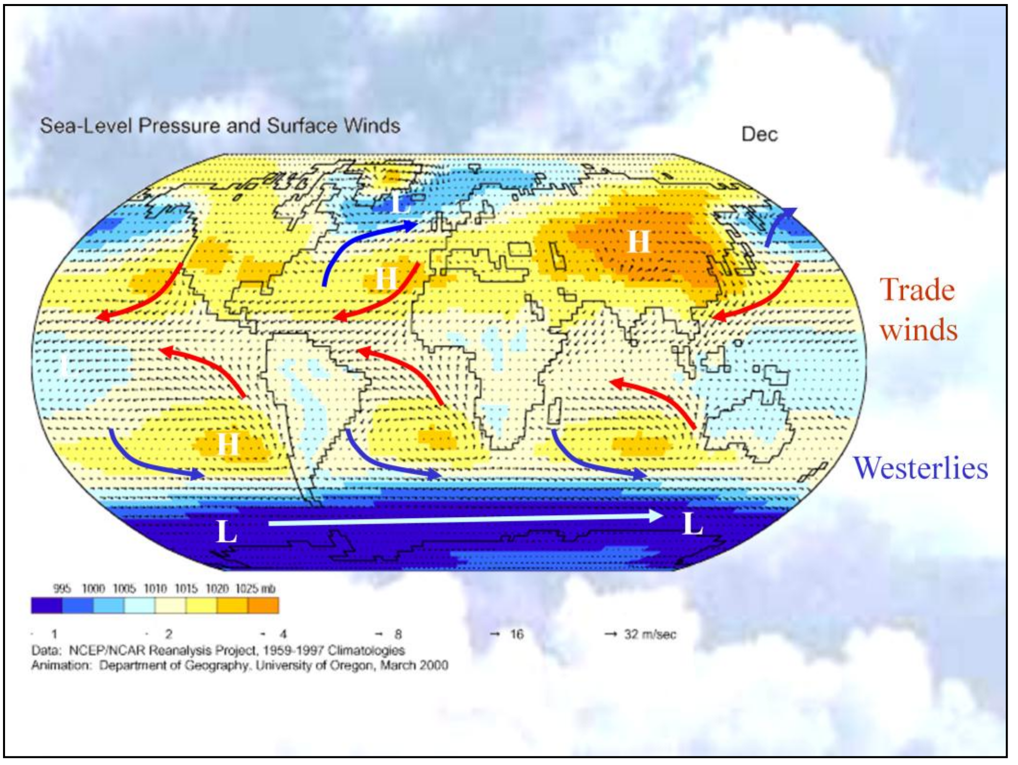
The warm buoyant air in the inter-tropical convergence zone produces uplift and large amounts of convective cloud. A pressure gradient at high altitudes leads to a strong poleward flow of air and a resulting return flow. The circulation is complicated by the spin of the Earth.



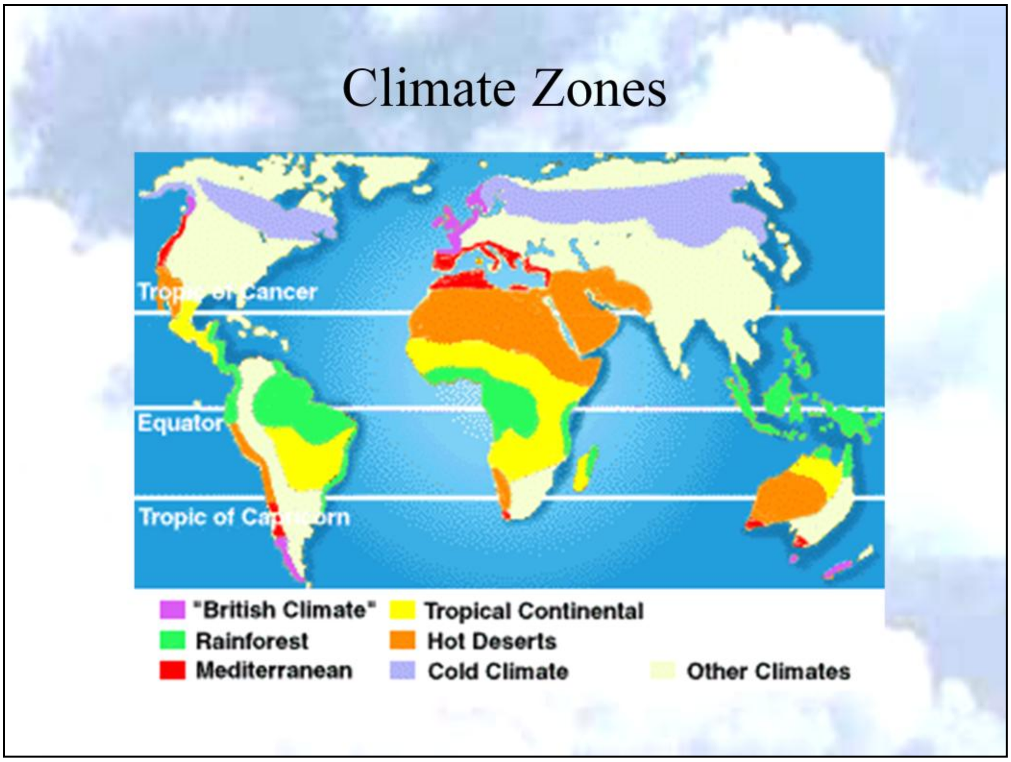
Air flows from high pressure to low pressure.

Away from the equator, the air flow is deflected by the rotation of the Earth, to the right in the northern hemisphere and to the left in the southern hemisphere.

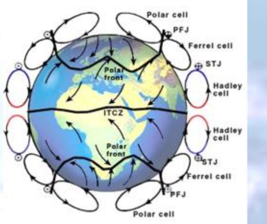
The curvature of the isobars and friction near the surface complicate this. Wind will be weaker and flow across the isobars near to the surface. For a given pressure gradient, air flows faster round high pressure; in reality wind is stronger around low pressure as isobars usually tighter. Wind flows clockwise round high pressure and anticlockwise around low pressure in the northern hemisphere. The reverse is true for southern hemisphere.



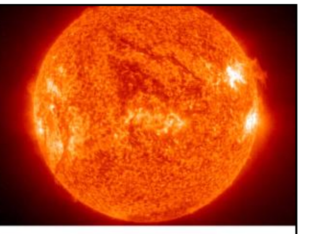
The location of branches of the general circulation help to determine the local climate type. For example, the UK is subjected to winds and ocean currents from the warm, moist south west. Warm buoyant air in the tropics rises and cools producing massive thunderstorms and lots of rainfall. This airflow spreads pole-wards at high altitudes and cools radiatively to space thereby becoming dense. Where this air sinks, upward motion crucial for forming cloud and rain, is suppressed and the climate is dry, such as the desert regions (Sahara, Kalahari, Australia, etc). The rotation of the Earth causes winds to "bend", knowledge of these wind patterns was crucial for trade as is clear by the naming of the sub-tropical "Trade winds".



The tropical climate zones are characterized by high rainfall, thereby supporting vast amounts of animal and plant life. The sun is overhead at midday over the equator twice every year (April and September) but once a year at the tropic of cancer (June) and tropic of Capricorn (December). The main tropical rain-bands follows behind the position of the maximum solar energy leading to distinct dry and wet seasons in some parts of the tropics. The largest example of this is the Asian monsoon (there is also an African monsoon). Where air sinks , supressing rainfall, for much of the year deserts form. This tends to be around the latitude of the tropics of Cancer and Capricorn (e.g. Sahara). The existance of cold ocean currents along the western coasts of continents amplifies this effect (e.g. Kalahari, Atacama, …). Mid latitude regions experience westerly wind and storms (disturbances in the air flow) leading to significant rainfall. Over the poles, air tends to sink leading to cold desert conditions. Subtle changes in the Earth's circulation patterns can have large local effects on climate (for example if a desert region moves into a once more moist regime).



Summary



- The present day climate is determined by the balance between absorbed sunlight (heating) and emitted thermal radiation (cooling)
- The resulting energy balance produces a circulation of the oceans and atmosphere
- The combination of the energy balance, the global circulation (winds and currents) and the distribution of oceans and mountains generates our present day distribution of climate zones

The balance between incoming solar energy and outgoing thermal energy sets up global circulation patterns producing our weather, the average of which over the course of the seasons and years determines our local climate. Changes in the radiative energy balance over time can result in changes in the average global temperature as well as introducing large changes in the local climatic norm. Changes in this balance can explain many of the past climate fluctuations experienced on Earth.