CLIMATE CHANGE: Past, Present and Future

University of Reading

- Session 2: The Greenhouse Effect
  - Recap: The Norse Greenland Colonies
  - Recap: Definitions
  - The Earth's Radiative Energy Balance
  - The Greenhouse Effect
  - Break (8pm)
  - Recap and Current climate news

Definitions…

- *"climate is what we expect, weather is what we get"*
- **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"*
- *"Weather influences what clothes to wear each day, climate determines the contents of your wardrobe."*

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.

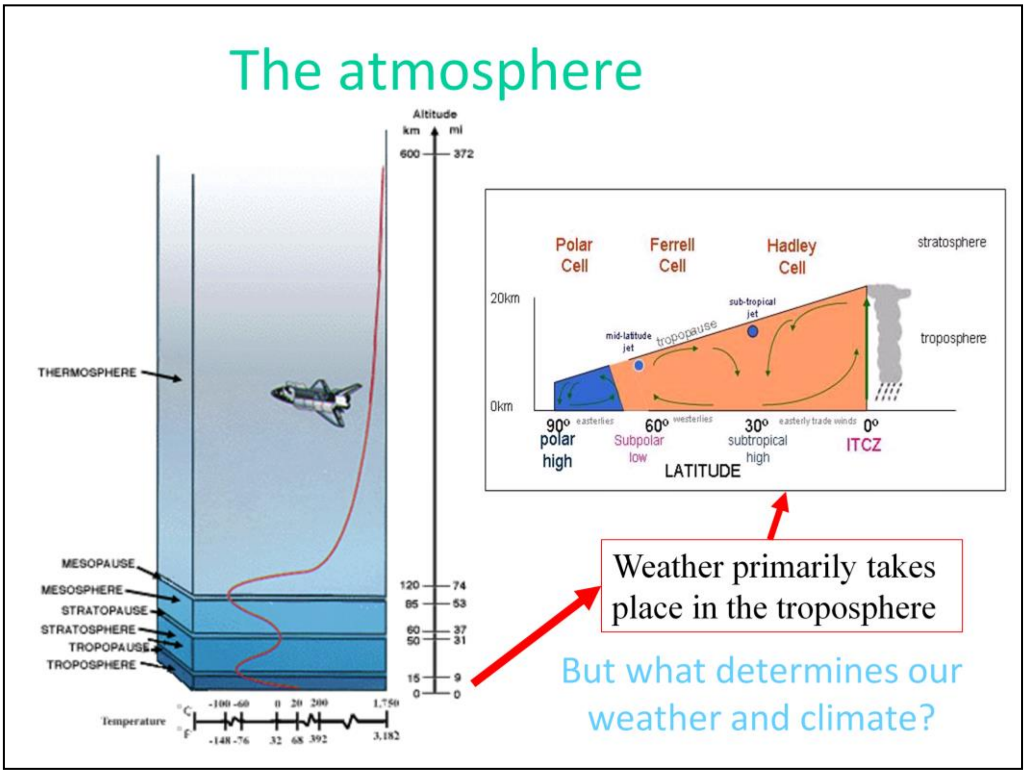
The atmosphere

- A thin film of gas

The Lowest 16km contains about 90% of atmosphere's mass

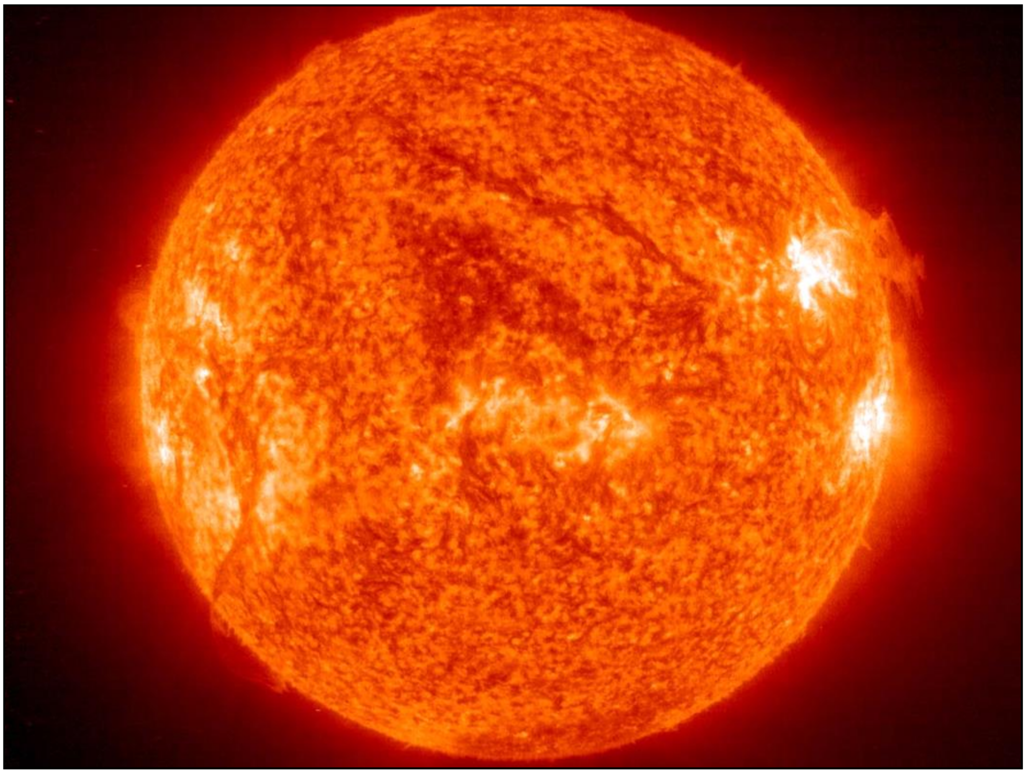
The Earth's radius is about 6000 km for comparison

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 attitude…

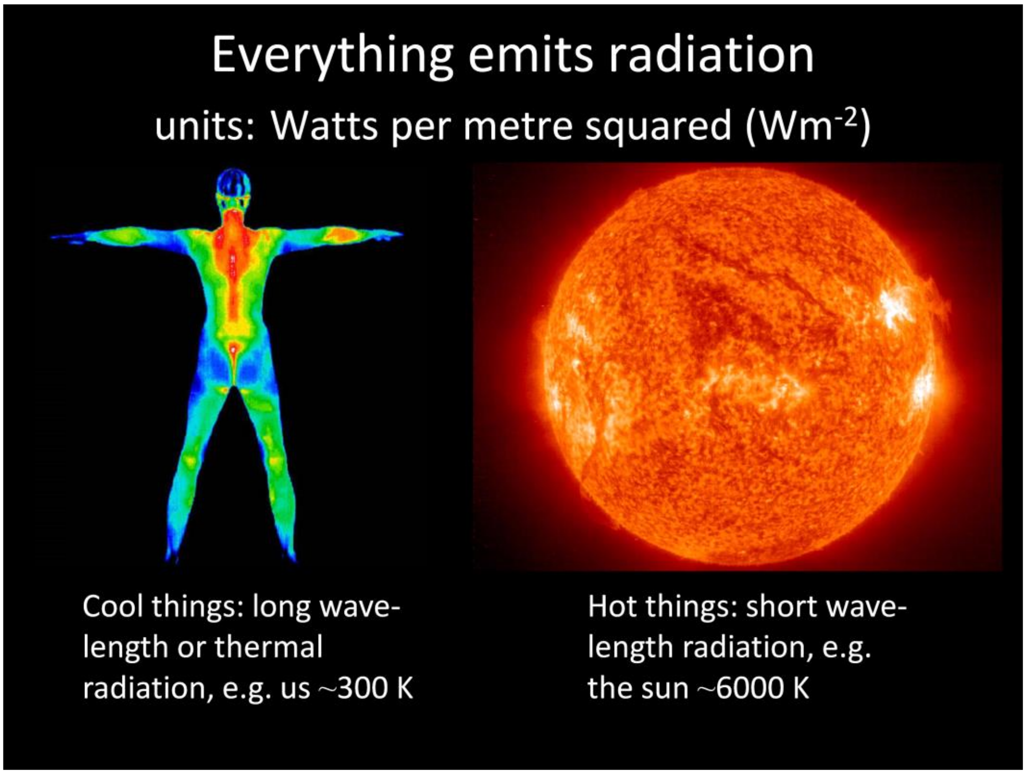


The clouds, winds and rain that comprise our weather take place in the troposphere which is about 8km deep at the poles, rising to up to 16km deep in the tropics, and holds about 80% of the atmosphere. The temperature drops off with altitude as is readily observable by a walking up a mountain. Temperature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

But how does the atmosphere affect our climate and what drives Earth’s climate and the atmospheric and oceanic circulations that determines weather patterns?

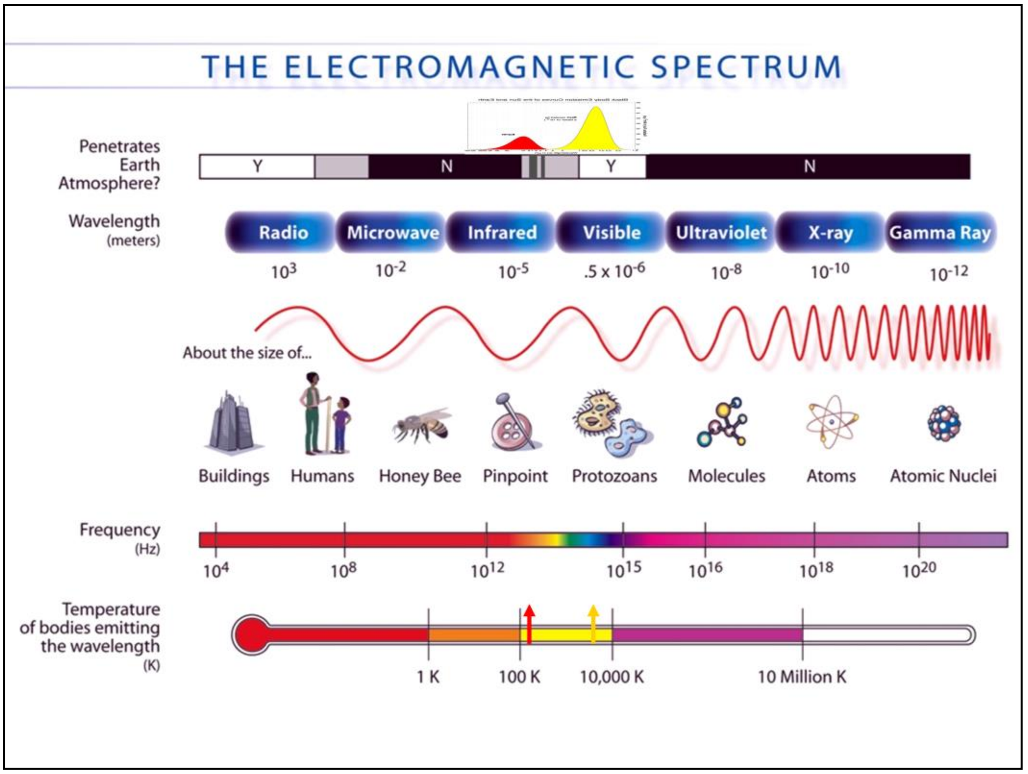


What determines the present day climate zones? The sun is the ultimate power source for the climate "machine". The uneven distribution of heating over time and across the globe lead to the flows of air and water that produce weather patterns. On longer time-scales, small changes in the energy balance and the resulting circulation of the atmosphere can produce significant fluctuations in climate.

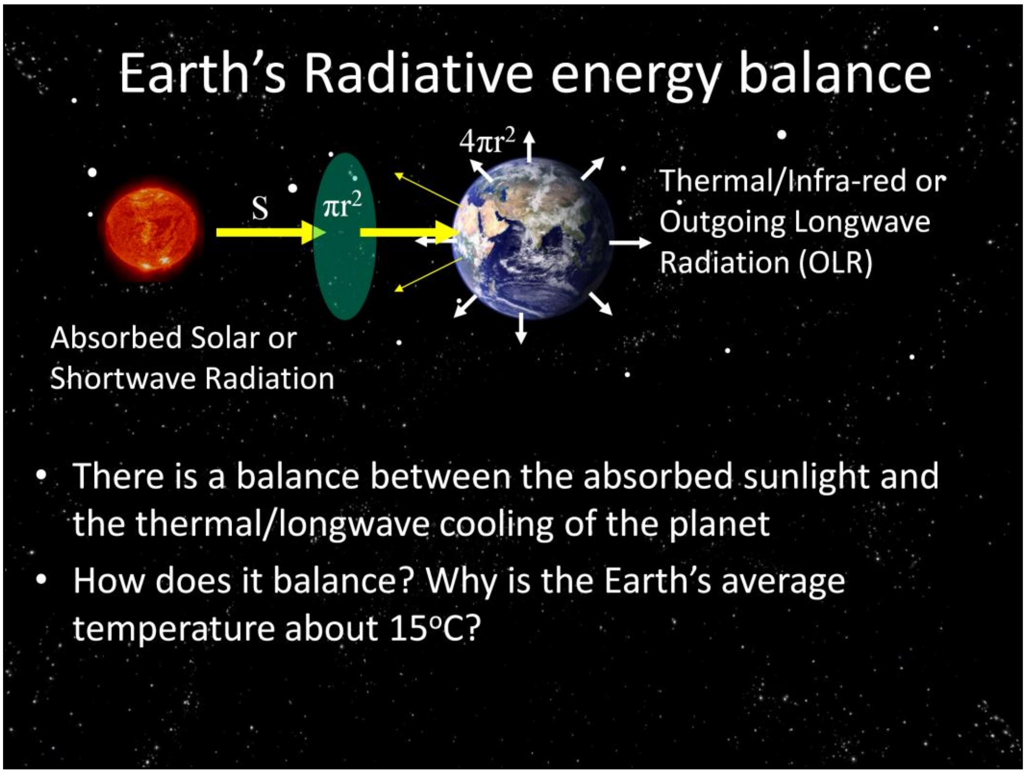


The amount of radiation emitted is approximated by: $F=\sigma T^4$, where σ is the Stefan Boltzman Constant ($5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$) and T is the temperature in Kelvin. So a body at around the Earth's surface temperature (288 K) will emit 390 Wm^{-2} of radiation energy. The Earth actually emits more like 240 Wm^{-2} of thermal radiation out to space, showing that something is reducing the cooling efficiency. *Can you calculate what the Earth's effective emitting temperature is?*

(or F=56.7xTxTxTxT/1 billion) or about a 5 Wm^{-2} increase for each oC increase at Earth's temperatures.



In the above graph, the first bar is a key to the electromagnetic radiation that either, do or don't penetrate the earth's atmosphere. Y is for yes and N is for no. Although some radiation are marked as *N* for no in the diagram, some waves do in fact penetrate the atmosphere, although extremely minimally compared to the other radiations. Next the wavelengths are expressed in terms of meters, using scientific notation. Notice the spectrum goes from the longer Radio waves, at 103 meters, all the way to the shorter Gamma Rays, at 10-12 meters. Next the various wavelengths are compared to sizes found in everyday life. The peak of the main infrared absorption band of carbon dioxide is at Wavelength: 15 µm (microns: 10-6 metres).



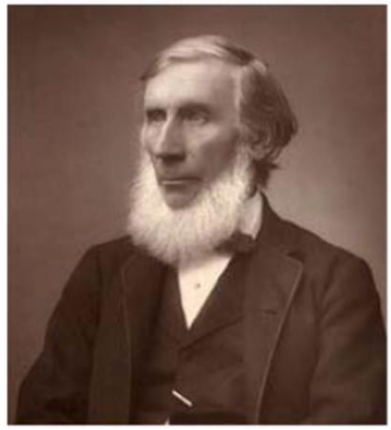
If the absorbed solar radiation increases, there is more energy arriving than departing. This would result in the planet warming.

The warming continues until the outgoing thermal radiation increases enough to once again balance the absorbed solar radiation. The sunlight is received on one side of the globe, while thermal radiation is continually lost out to space from all regions of the planet.

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

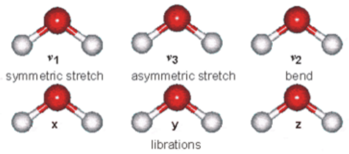


Slide courtesy of Richard Sommerville

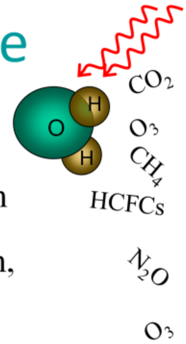
Tyndall explained the "greenhouse effect" in a public lecture in January 1863 entitled "On Radiation Through The Earth's Atmosphere". He emphasized that our environment would be much colder at nighttime in the absence of the greenhouse effect. [Wikipedia]

…Svante Arrhenius later misunderstood Fourier's explanation and then misattributed his own misunderstanding of how greenhouses work to Fourier (Arrhenius, 1896). Uncritical acceptance of such claims (without checking the source texts) is how the misconception that Fourier discovered the "greenhouse effect" made its way into modern literature. For historical details see James Rodger Fleming, Historical Perspectives on Climate Change (Oxford, 1998). [Wikipedea]

See also presentation by Dufresne (2010): http://meghatropiques.ipsl.polytechnique.fr/erb2010/dmdocuments/DAY3/27-Duf_ERB_Paris.pdf



The Greenhouse Effect

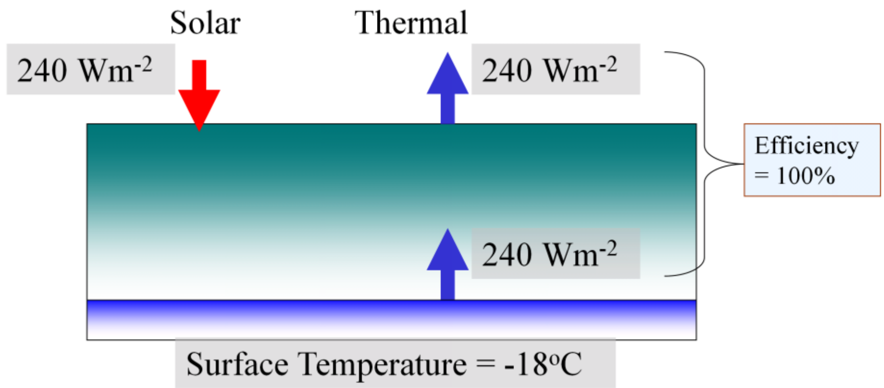


- The physical structure of molecules determines which wavelengths of electromagnetic radiation may be absorbed/emitted e.g. through vibration, rotation, spin, electron transitions, etc
- The water molecule is particularly versatile in its absorption/emission properties
- Radiation absorbed by molecules is re-emitted at the local temperature, in all directions
- Greenhouse gases effectively reduce the efficiency of Earth's ability to cool through thermal radiative emission to space
- To balance the absorbed solar radiation, Earth's temperature has to be sufficient to combat this radiating inefficiency to generate the necessary outgoing longwave radiation

What would the Earth be like without a greenhouse effect?

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.

Earth's global average energy balance: no atmosphere

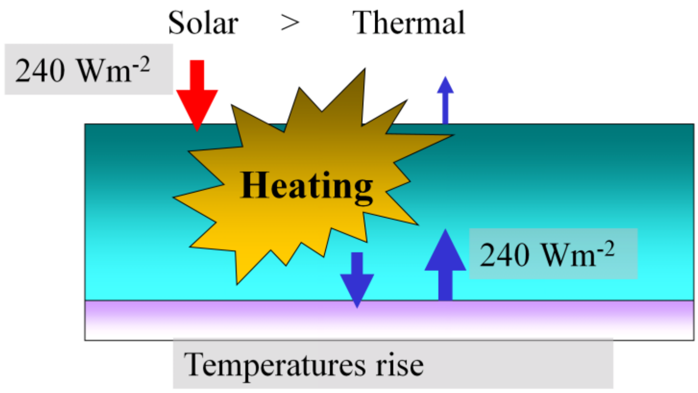


The Earth without a Greenhouse Effect would be frigid since the Earth would cool more efficiently by emitting thermal radiation from the surface straight out into space. Without an atmosphere the surface of the Earth will emit the same amount of energy out to space that is received from the sun. This would produce a global temperature of around minus 18^{o}C. An atmosphere makes the loss of energy from the Earth less efficient so that the surface has to warm to a higher level to produce the 235 Wm^{-2} required to balance the absorbed solar energy.

$F=\sigma(273-18)^4=(5.67x10^{-8})x(255)^4=\ldots$

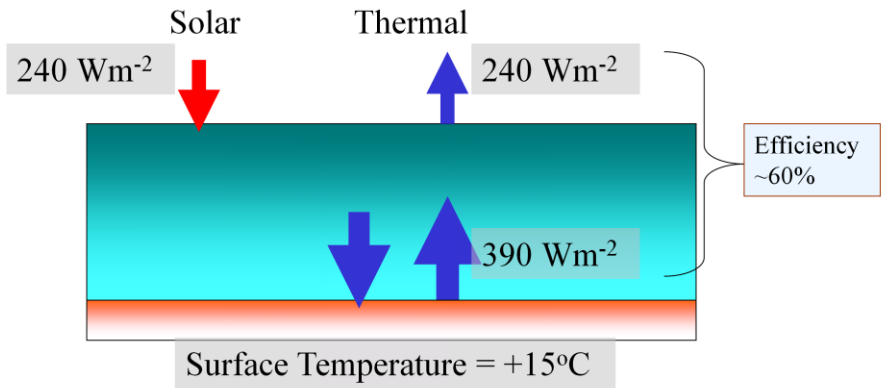
[32 F = 0^o C=273.15 K]

Earth's global average energy balance: add atmosphere

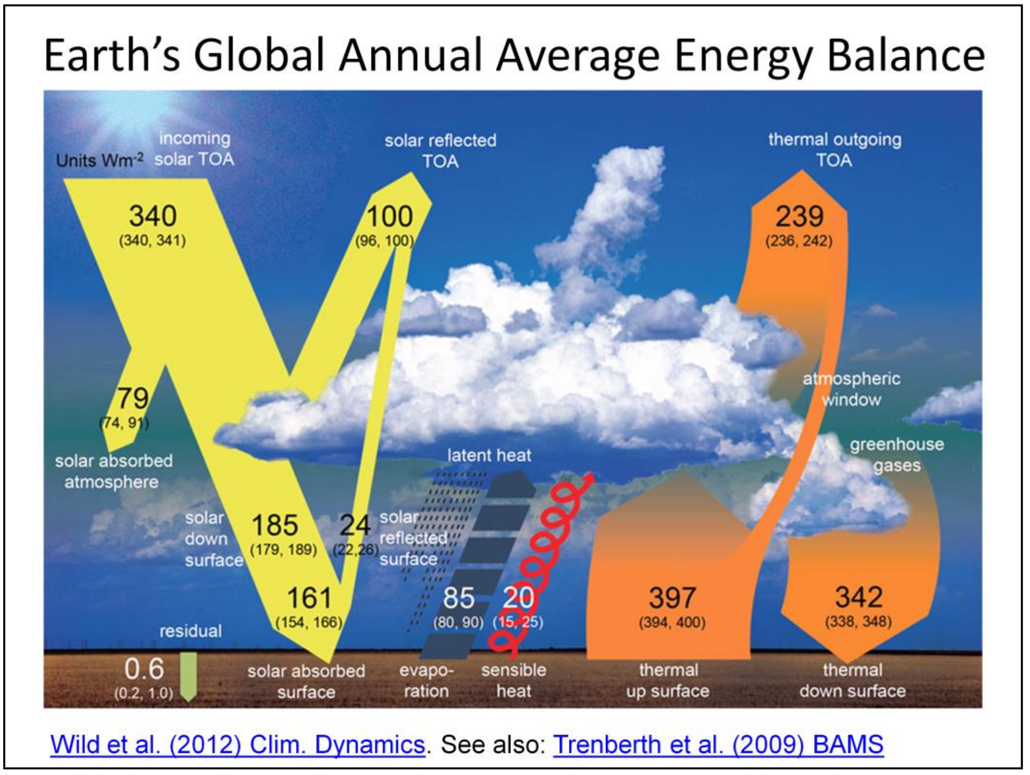


Adding an atmosphere reduces the outgoing thermal radiation to space, and so the absorbed solar energy is greater than the outgoing thermal energy and the planet warms up.

Earth's global average energy balance: present day

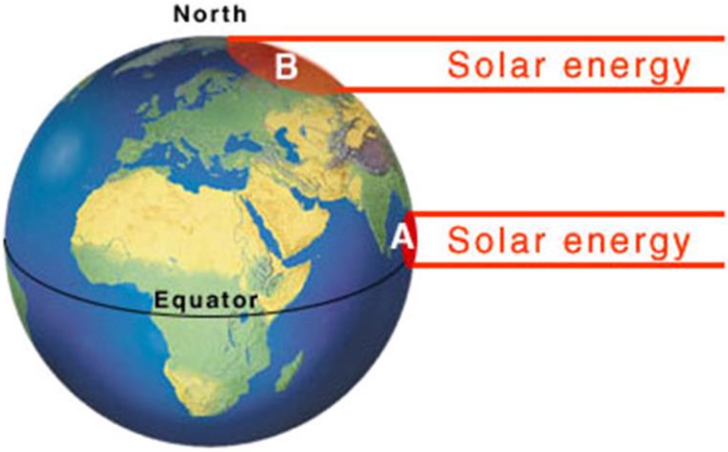


As the planet warms up, it emits more thermal energy since warmer bodies emit more thermal (longwave) radiative energy. The Earth warms up until the outgoing thermal energy equals the absorbed solar energy, resulting in a global temperature of 15ºC, about 33ºC warmer than without a greenhouse effect.



The incoming radiative energy from the sun is reflected back to space by clouds, the atmosphere and the surface. About half is absorbed by the Earth's surface and a fifth by the atmosphere. The absorbed solar energy is balanced by thermal (or infrared/longwave) radiation that is emitted out to space. Most of the thermal energy emitted by the surface is absorbed by the atmosphere and clouds and emitted back to the surface (the greenhouse effect). Most of the Earth's energy directly lost to space comes from the atmosphere. However, a large amount of energy is transferred from the surface to the atmosphere by thermals and evaporation as well as longwave thermal radiation.

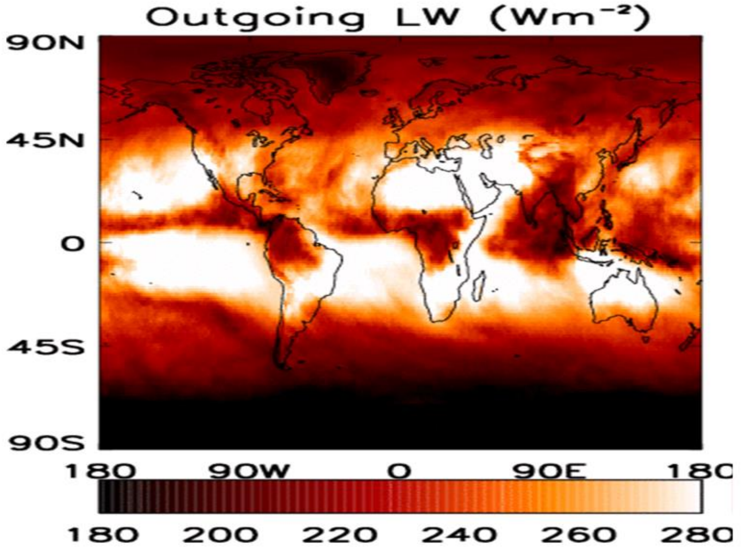
Energy Balance and Climate Zones



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-length through the atmosphere since it is entering the atmosphere at an angle.

Top of Atmosphere Radiative Energy Fluxes

CERES/TERRA, September 2004

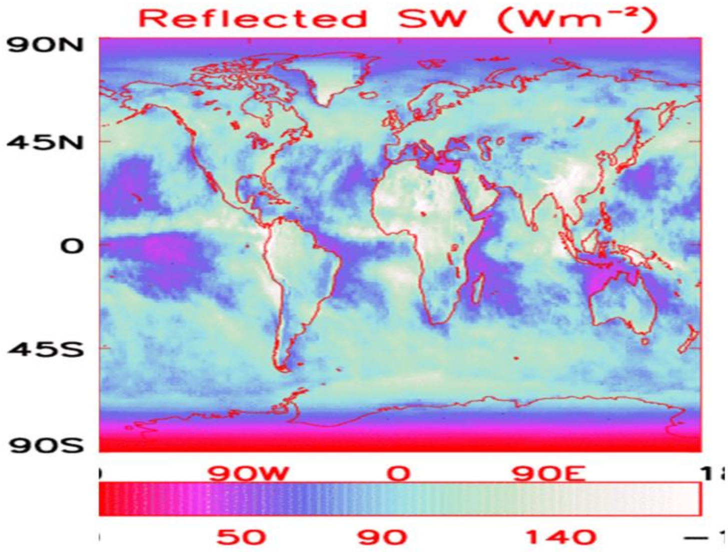


Satellites routinely measure the amount of radiative energy emitted by the planet (longwave/ thermal/ infra-red) and the reflected sunlight (shortwave /solar/visible radiation).

Above: Outgoing “thermal” or long wavelength radiative energy to space, measured by the CERES satellite during September 2004. Bright colours show large emission (primarily hot and cloud-free regions) while darker colours show weaker emission (colder and cloudy regions).

Top of Atmosphere Radiative Energy Fluxes

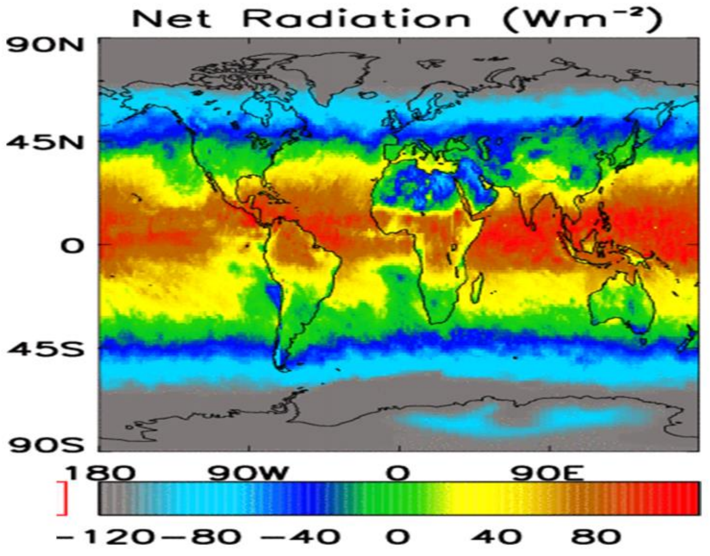
CERES/TERRA, September 2004



Reflected sunlight or short wavelength radiative energy to space, measured by the CERES satellite during September 2004. Bright colours show large reflection (shiny surfaces or clouds) while darker colours show less reflection (for example cloud-free oceans regions).

Top of Atmosphere Radiative Energy Fluxes

CERES/TERRA, September 2004



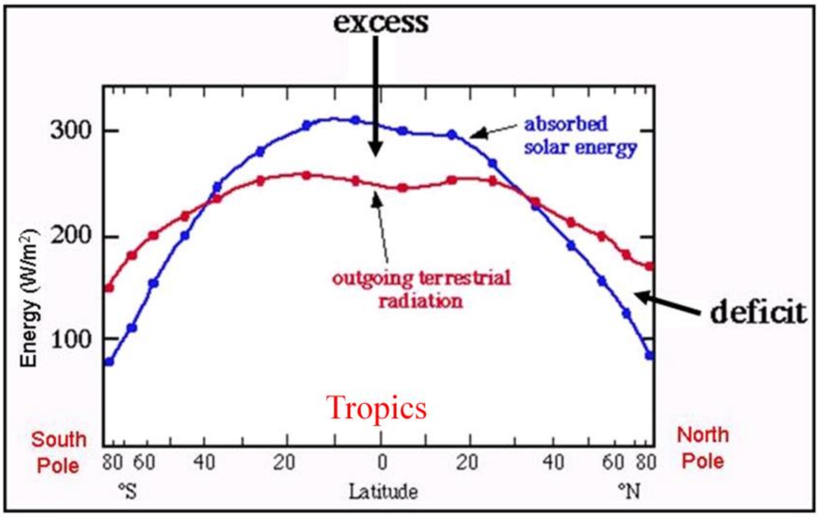
The net energy entering our planet is:

The incoming sunlight MINUS the portion of that sunlight reflected back to space MINUS the thermal/longwave emission of radiative energy back to space.

More energy is received than lost near to the equator (yellow and red colours) while more radiative energy is lost to space than is gained in sunlight (blue and grey colours)

The Net Radiation Balance

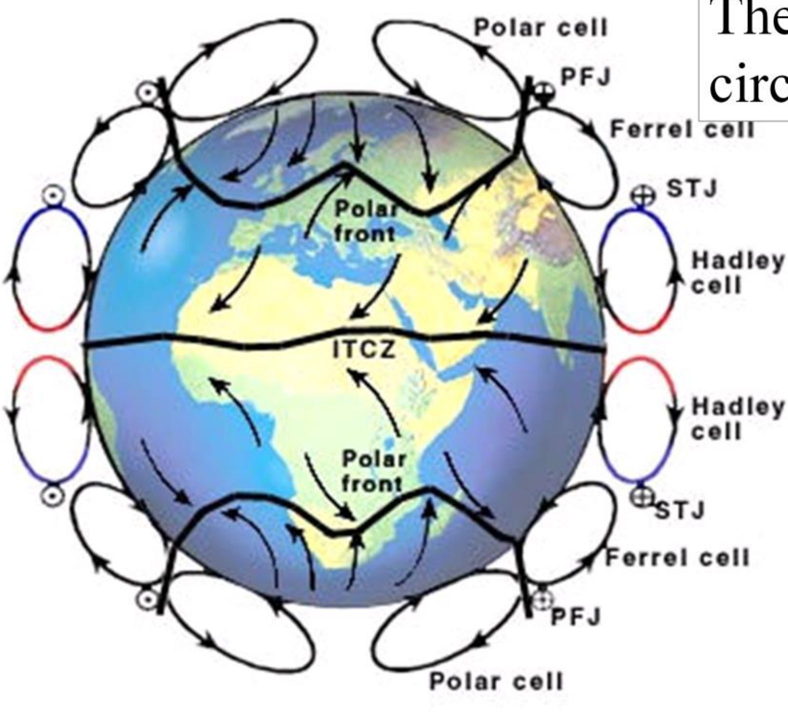
Why don't the tropics get warmer and warmer and the poles colder and colder?



[CLAUS movie]

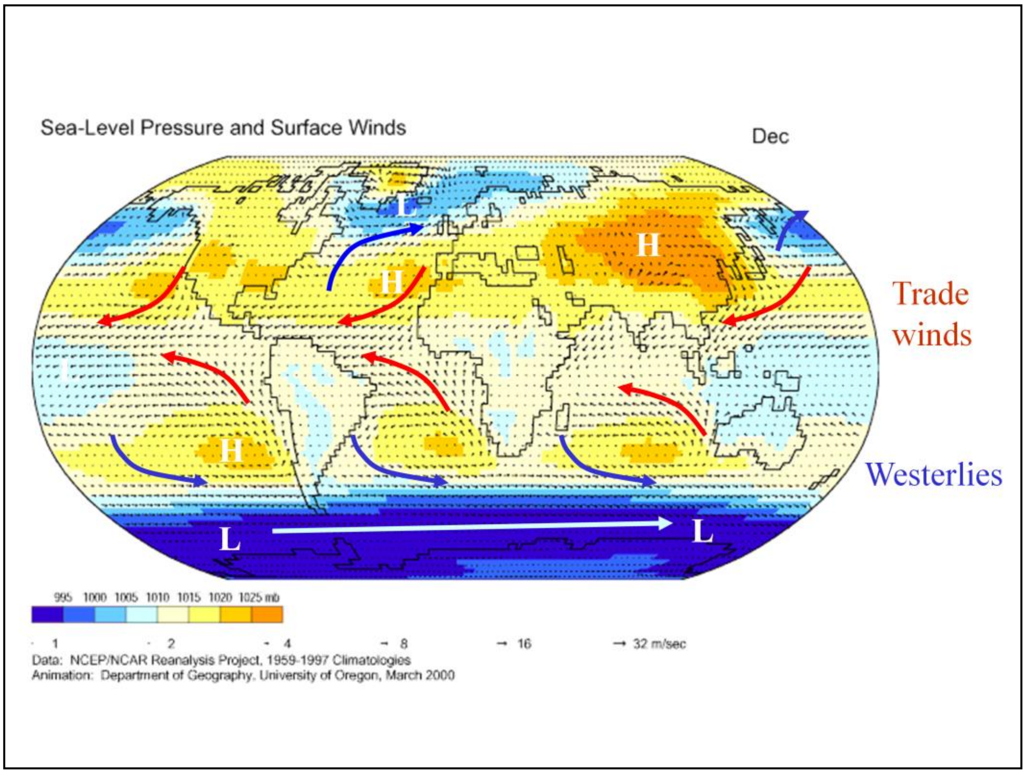
Due to the angles of incident solar radiation, there is more energy received nearer to the equator than at the poles. This leads to an excess of solar energy over thermal outgoing energy in the tropics. Why doesn't the tropics get hotter and hotter and the poles colder and colder?

The global circulation

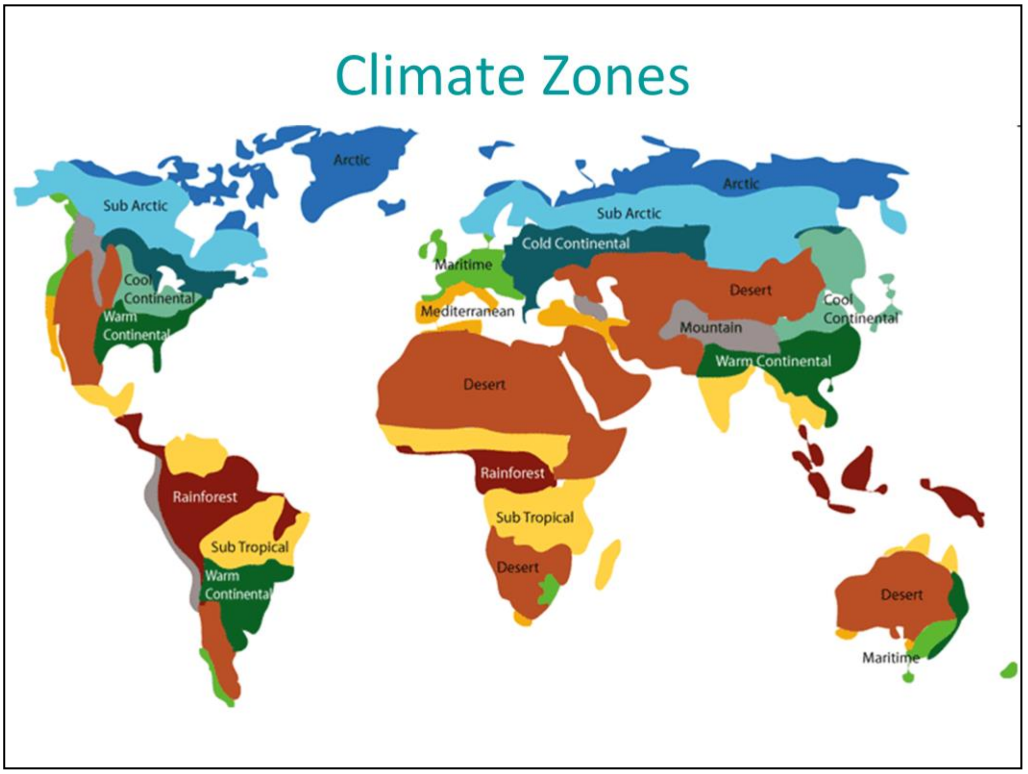


The extra energy in the tropics is transported pole-ward by the atmospheric and oceanic circulations.

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



The 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”.

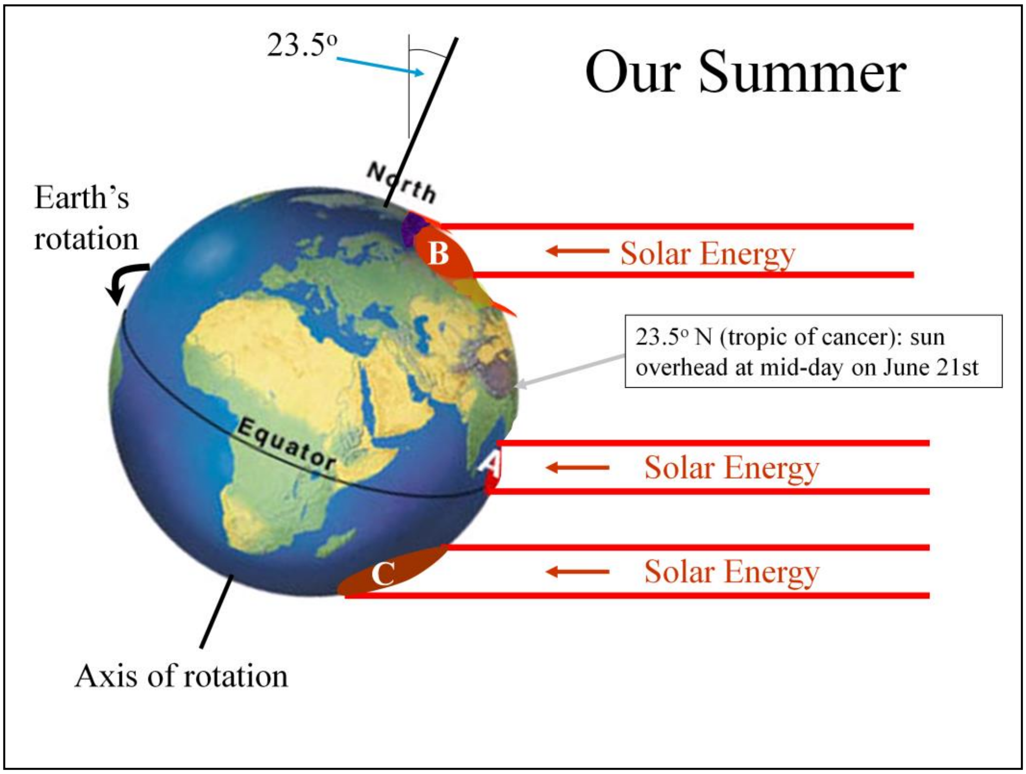


The tropical climate zones are characterized by high rainfall, thereby supporting vast amounts of animal and plant life. The sun is overhead at midday over the equator twice every year (April and September) but once a year at the tropic of cancer (June) and tropic of Capricorn (December). The main tropical rain-bands follow 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, suppressing 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 existence of cold ocean currents along the western coasts of continents amplifies this effect (e.g. Kalahari, Atacama, …).

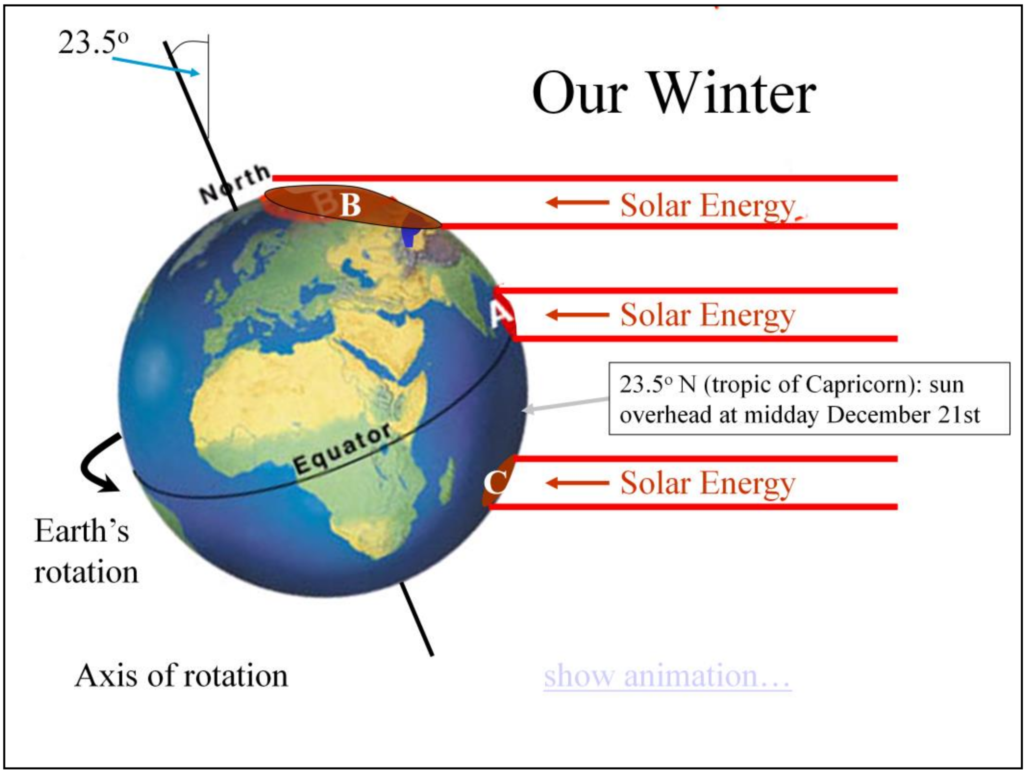
Current Climatic Zones

- The Earth’s radiation balance varies over many timescales
  - Daily Cycle (hours)
  - Weather patterns (days)
  - Seasonal Cycle (months)
  - Years and more… (see next week)
- The interaction between the Earth’s radiation balance, physical geography and the resulting global circulation defines the current climate experienced locally

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).

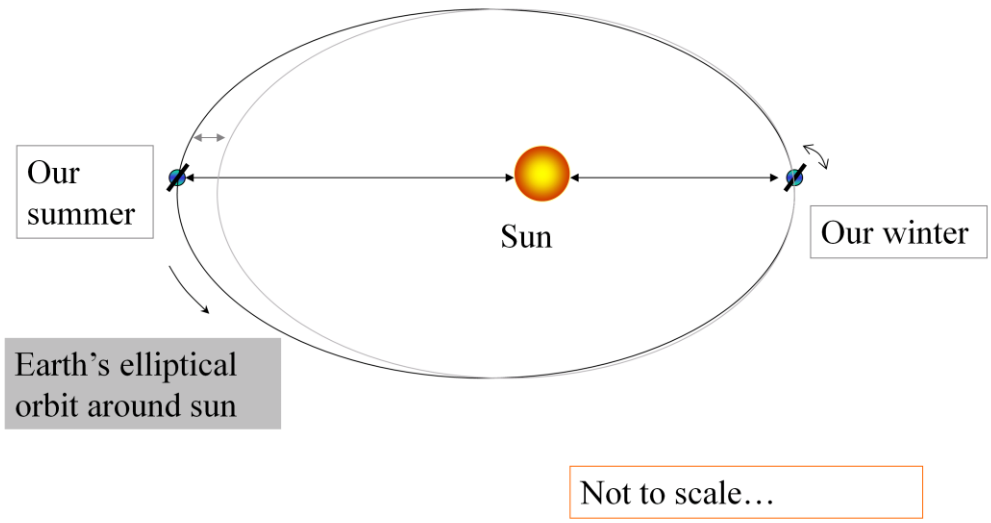


In the northern hemisphere summer, the tilt of the Earth's axis causes the solar beam at **B** to become more concentrated, thereby providing more energy than during northern hemisphere winter. Conversely in northern summer, the beam at **C** is spread more thinly, explaining why it is winter in the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

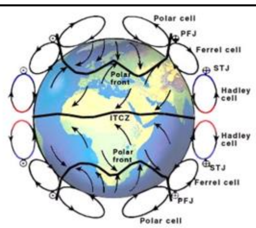


The reverse is true in northern hemisphere winter… The tilt of the Earth's axis explains our seasons but over longer periods of time it is also important for changes in climate (session 3).

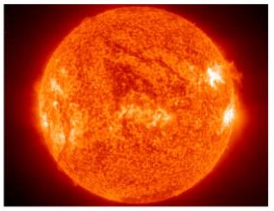
The Earth is closer to the sun during northern hemisphere winter. The tilt of the Earth's axis, the degree of ellipticity of our orbit and the "precession of the equinoxes" are crucial for climate change on time-scales of tens and hundreds of thousands of years



More about this in session 3… 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 sun-block particularly important in the non-tropical regions of Australia.



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.