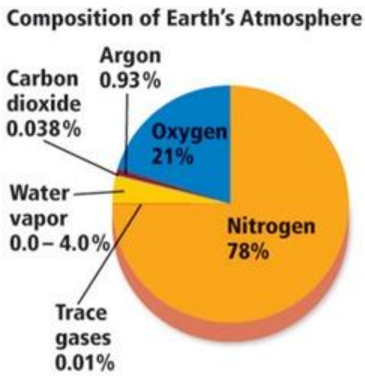
UNIT 4: HOW CAN THE IMPACTS OF HUMAN ENERGY USE BE REDUCED?

AREA OF STUDY 2 - IS CLIMATE PREDICTABLE?

Key knowledge

Major factors that alter Earth's atmosphere

• the structure of the atmosphere and the relative proportions of different gases, including greenhouse gases, that regulate the natural and enhanced greenhouse effects



The mixture of gases known as the atmosphere (aka air), protects life on Earth by absorbing ultraviolet radiation and reducing temperature extremes between day and night.

The atmosphere is not static. Interactions involving the amount of sunlight, the spin of the planet and tilt of the Earth's axis cause ever changing atmospheric conditions.

Ozone (O3) in the stratosphere absorbs most of the damaging ultra-violet radiation from the sun. Carbon dioxide (and other Greenhouse gases) retain some of radiant energy (aka infrared radiation) as heat.

Note 0.038% CO_2 is often expressed as 380 ppm.

• the astronomical cycles that affect natural variability in climate, including Milankovitch cycles (variations in Earth's eccentricity, axial tilt and precession) and solar cycles

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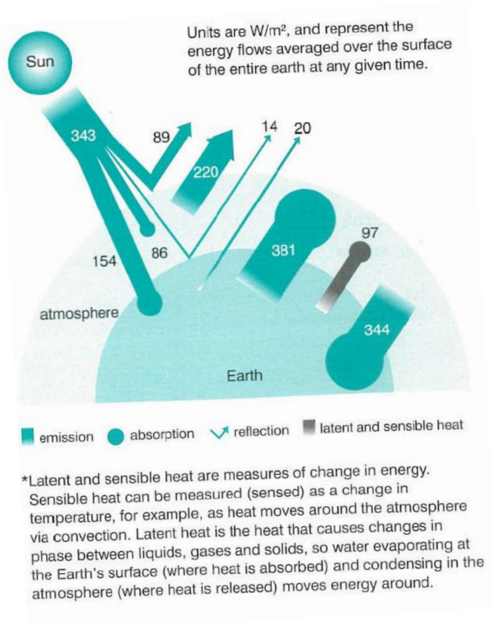
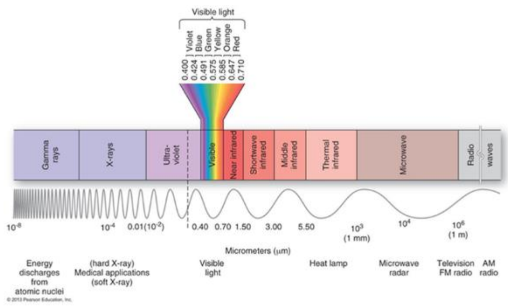
• the solar energy that is absorbed, re-emitted and reflected by atmospheric gases and Earth's surface, including the albedo effect, the interaction of energy with greenhouse gases, and the First Law of Thermodynamics

EM radiation of different frequencies is scattered, reflected and absorbed by different amounts in the atmosphere. Only the visible and radio bands, some low frequency ultraviolet radiation and some regions in the infrared are able to make it all the way to the ground.

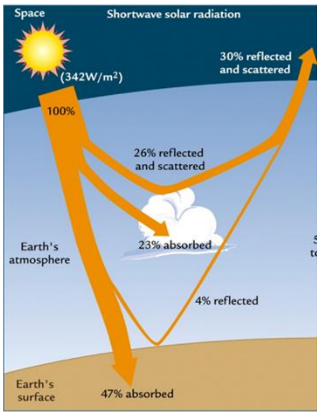


The solar radiation that does pass through the atmosphere is absorbed by the natural greenhouse gases which serve to keep the surface temperature at an average of 15^0 C. This process is known as the Natural Greenhouse effect. The most significant natural greenhouse gases are:

1) water vapour
2) carbon dioxide
3) methane
4) nitrous oxide
5) various chlorofluorocarbons
6) various halons



The greenhouse gas molecules absorb energy of a specific frequency of radiation which causes these molecules to vibrate causing temperature to rise. Water and Nitrogen molecules do not do this which is why they are not considered Greenhouse gases



The vast majority to the Sun's radiation that reaches the Earth is in the visible spectrum. Of this incoming radiation;

- ✓ 47% is absorbed by the Earth
- ✓ 23% is absorbed by the atmosphere
(mostly in the ozone layer, but also by water vapour and greenhouse gases)
- ✓ 26% is reflected back by clouds
- ✓ 4% is reflected by the Earth's surface

Evidence has shown increasing levels of specific gases are responsible for increased absorption of radiant energy. As the levels of these Greenhouse gases increase, more thermal energy is being retained than previously. This theory is known as the Enhanced Greenhouse Effect. The major atmospheric gases (nitrogen, oxygen and argon) are mostly unaffected by infrared radiation.

Compound	Formula	Contribution (%)
Water vapour/clouds	H_2O	36–72%
Carbon dioxide	CO_2	9–26%
Methane	CH_4	4–9%
Ozone	O_3	3–7%
Nitrous oxide	N_2O	1.5%
Chlorofluorocarbons	CFCs	0.1%

TABLE 2.2.1 Greenhouse gas contribution to the enhanced greenhouse effect

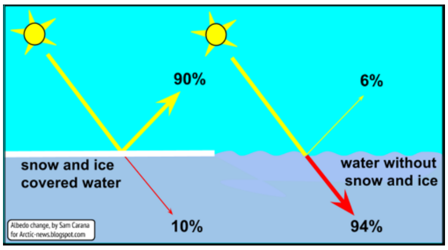
- Water vapour is the main contributor to the GHE
- CO_2 is the gas most influenced by human activity hence it's significant to the EGHE

Albedo effect

Albedo (meaning 'whiteness') is the measure of the reflection of solar radiation out of the total solar radiation received by Earth. It is dimensionless and measured on a scale from;

0 (no reflection) to 1 (100% reflection)

Ice and snow have a high albedo (0.6 – 0.9), whereas water is more absorbent and less reflective (0.1).



The most significant projected impact on albedo is through future global warming. With the exception of Antarctic sea-ice, recently increasing by 1% a year, nearly all the ice on the planet is melting. As the white surfaces (ice) decrease in area, less energy is reflected into space, and the Earth will warm up even more.

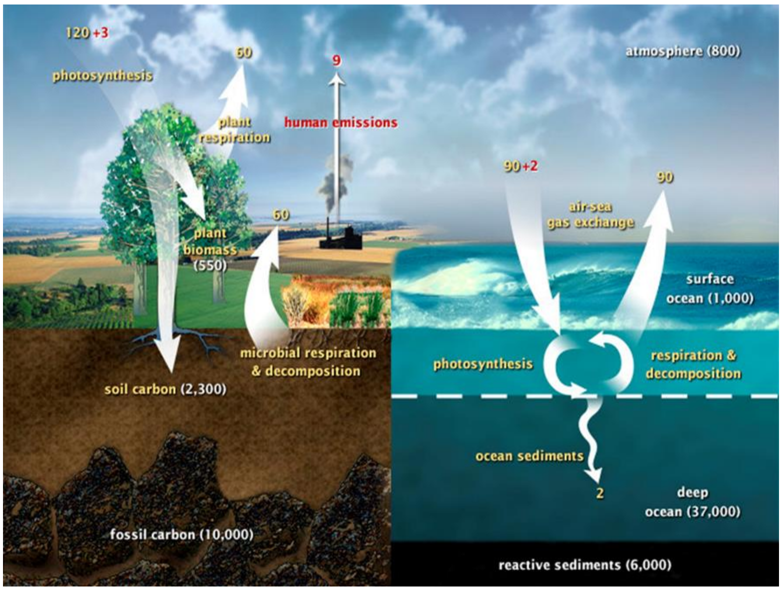
There is an Ice-albedo feedback loop, where the processes operating further enhance the process (positive feedback) ie less ice = more warming = less ice
Increased water vapour also has another effect, which is to increase the amount of cloud. As mentioned already, clouds can increase albedo (a negative feedback), but also warming (a positive feedback).

• carbon sequestration in land, water and air that results in short-term (<100 years) and long-term (>1000 years) carbon storage

The main driver of global climate change is carbon dioxide (CO2) emissions. Carbon sequestration is the process by which carbon is taken back out the atmosphere and safely stored somewhere else in the biosphere.

Nature already has processes for carbon capture and storage. Some forms of natural carbon sequestration and storage include;

- ✓ plants and trees (photosynthesis)
- ✓ living organisms
- ✓ soils
- ✓ oceans



This diagram of the fast carbon cycle shows the movement of carbon between land, atmosphere, and oceans in billions of metric tons of carbon per year. Yellow numbers are natural fluxes, red are human contributions in billions of metric tons of carbon per year. White numbers indicate stored carbon.

Scientists have proposed a number of methods we could use to capture carbon and store it. Some of these methods rely on catching the carbon before it gets into the atmosphere. Other methods would remove the carbon already in the atmosphere;

- ✓ Biosequestration
- ✓ Agriculture
- ✓ Bioengineering
  - o Seaweed Cultivation
  - o Iron Fertilization
- ✓ Geoengineering
  - o Bioenergy with Carbon Capture and Storage (BECCS)
  - o Burial

Everyone agrees, though, that the best way to reduce the impact of CO2 emissions would be to drastically reduce CO2 emissions. But some of these methods could also help to restore the balance.

• the lifespans of greenhouse gases and their ability to absorb infra-red radiation and hence their warming potentials

The contribution a gas makes to the greenhouse effect depends upon several factors;

- ✓ The capacity of the gas to absorb heat energy (aka Global Warming potential GWP)
- ✓ The length of time the gas persists in the atmosphere
- ✓ The concentration of the gas in the atmosphere

TABLE 21.1 Attributes and concentrations of major greenhouse gases

Greenhouse gas	Formula	Pre-industrial concentration	2014 concentration[1]	Atmospheric lifetime (years)	Global warming potential	Increase since pre-industrial concentration
Carbon dioxide	CO_2	280 ppm	400 ppm	50 to 20	1	43%
Methane	CH_4	700 ppb	1,833 ppb	43,070	21	160%
Nitrous oxide	N_2O	275 ppb	327 ppb	120 to 150	310	19%
			2005 concentration[2]			
Chlorofluorocarbons (CFCs) and halons	e.g. CF_2Cl_2 (known as CFC-12)	0	868 ppt	102	125 to 152	
Hydrochlorofluorocarbons (HCFCs)	e.g. $CHClF_2$ (known as HCFC-22)	0	202 ppt	12	125	
Perfluorocarbons (PFCs)	e.g. CF_4	0	77 ppt	50,000	6,500	
Sulfur hexafluoride	SH_6	0	5.6 ppt	11000	23,900	

ppm = parts per million (by volume) ppb = parts per billion (by volume) ppt = parts per trillion
[1] (WMO, 2015) [2] (Rekacewicz & UNEP/GRID-Arendal, 2005)

Nitrogen and oxygen molecules consist of two atoms 'tightly bound' atoms. Therefore, light 'photons' (visible and IR) go right through N_2 and O_2

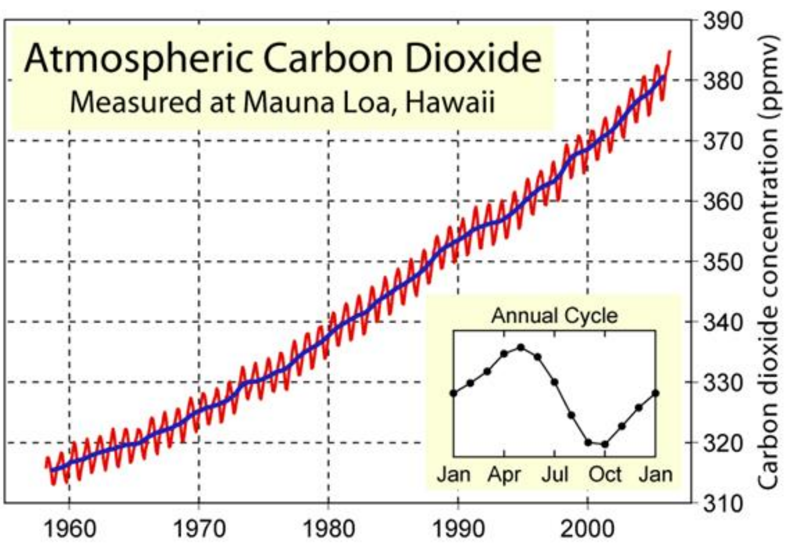
Water and carbon dioxide molecules consist of three atoms 'loosely bound' atoms. Therefore, Infrared photons get absorbed by H_2O and CO_2 molecules (and give them energy in the form of heat). The H_2O and CO_2 don't keep the energy... they 're-radiate' it.

• the altered proportions of different gases in the atmosphere over time resulting from human activities including use of fossil fuels.

Many scientist credit Charles Keeling's graph with first bringing attention to the effect of human activity on the atmosphere and climate. The graph is based on long term measurements taken at a remote observatory in Hawaii. The data on atmospheric Carbon Dioxide from Mauna Loa Observatory provided our longest record (5 decades) of data and are considered significant in first bringing the world's attention to Human induced CO_2 levels.

The oscillations (in red) are due to the fact that in the Northern hemisphere spring vegetation growth absorbs CO_2

Long range estimates indicate CO_2 levels have not been over ~300ppm for probably several million years.



Measurements that give useful information about changes in the climate

There are numerous short term, medium term and long term natural cycles that influence the Earth's climate. Similarly, there is also no debate that there is a direct link between atmospheric Greenhouse gas concentrations and climate. The current rate and magnitude of these changes and the effect the Earth's climate is the big question facing us today.

To better understand what is happening in the present, we need to investigate what happened in the past.

• methods used for measuring and understanding past and present changes in the atmosphere: ice core samples, paleo-botany, atmospheric and ocean temperature monitoring, climate models

Scientist use a range of methods to measure past and present changes in our atmosphere. These methods include;

- ✓ Ice core samples
- ✓ Paleoclimatology
- ✓ Atmospheric and ocean temperatures

Ice cores are long cylinders of glacial ice recovered by drilling through glaciers. Scientists retrieve these cores to look for records of climate change over the last 100,000 years or more.

The physical properties of the ice and of material trapped in it can be used to reconstruct the climate over the age range of the core.

- the proportions of different oxygen and hydrogen isotopes provide information about ancient temperatures
- the air trapped in tiny bubbles can be analysed to determine the level of atmospheric gases such as carbon dioxide.
- the borehole temperature is another indicator of temperature in the past (since heat flow in a large ice sheet is very slow).

This data can be combined to find the climate model that best fits all the available data.

Paleoclimatology is the study of climates for which direct measurements were not taken. Paleoclimatology uses a variety of proxy methods from the Earth and life sciences to obtain data previously preserved within;

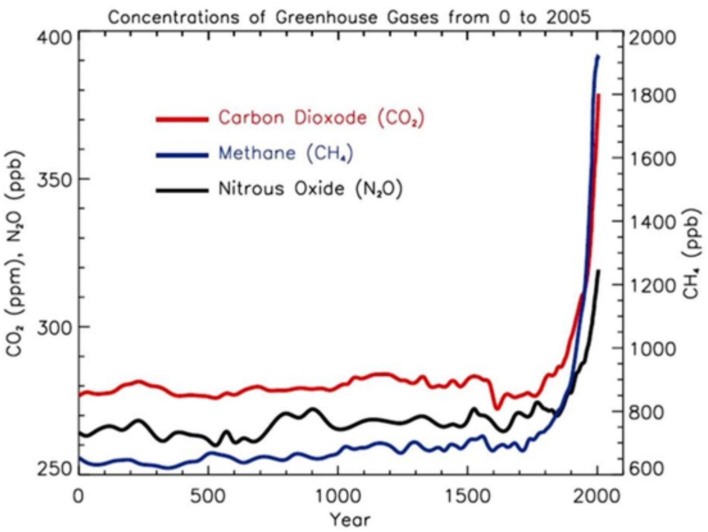
- Rocks
- Sediments
- Boreholes
- ice sheets
- tree rings
- Corals
- Shells
- microfossils

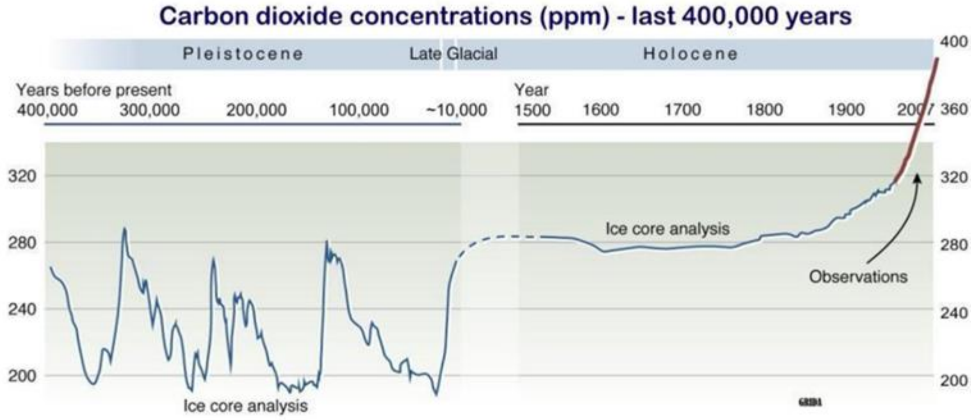
• magnitude and rate of change in individual atmospheric gas concentrations over different time periods (seasonally, annually and over millenia) due to natural events and human actions, including exponential increase in CO_2 post-industrial revolution

Many natural factors contribute and influence the concentration of greenhouse gases in our atmosphere including;

- forest fires
- animal respiration/decomposition
- volcanic activity

Since the Industrial Revolution human activity has caused a marked increase in greenhouse gas production effecting the natural energy budget of the earth. This process is known as the Enhanced Greenhouse effect.





Long range estimates indicate CO_2 levels have not been over ~300ppm for probably several million years.

• measures used to assess the rate of climate change: global average annual temperatures, regional and global sea level rise, and global snow and ice coverage.

Created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the objective of the Intergovernmental Panel on Climate Change (IPCC) is to provide governments at all levels with scientific information that they can use to develop climate policies. IPCC reports are also a key input into international climate change negotiations.

Consequences of changing the composition of gases in the atmosphere

• the impacts for organisms, including humans, and ecosystems of the natural greenhouse effect and the enhanced greenhouse effect

Climate change is the greatest challenge facing the world. Humans have created the challenge, and we have the solutions, skills and capacity to turn it around, and care for our Earth and ourselves. The impacts of future climate change and related sea-level rise will be experienced in many areas, from the natural environment to food security and from human health to infrastructure.

Among Australia's terrestrial ecosystems, some of the most vulnerable to climate change are;

- alpine systems as habitats shift to higher elevations and shrink in area
- tropical and subtropical rainforests due to warming temperatures (moderated or intensified by rainfall changes)
- coastal wetlands affected by sea-level rise and saline intrusion
- inland ecosystems dependent on freshwater and groundwater that are affected by changed rainfall patterns
- tropical savannahs affected by changes in the frequency and severity of bushfires.

• analysis and reporting of climate data including the interpretation of confidence measures of climate projections (calculation of standard deviation and probabilities are not required)

• projected consequences and uncertainties of the enhanced greenhouse effect on the four major Earth systems (atmosphere, biosphere, hydrosphere, lithosphere), and on the health of living things and on the environment, at a selected location.

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