DP IB Geography: SL

Your notes

Causes of Global Climate Change

Contents

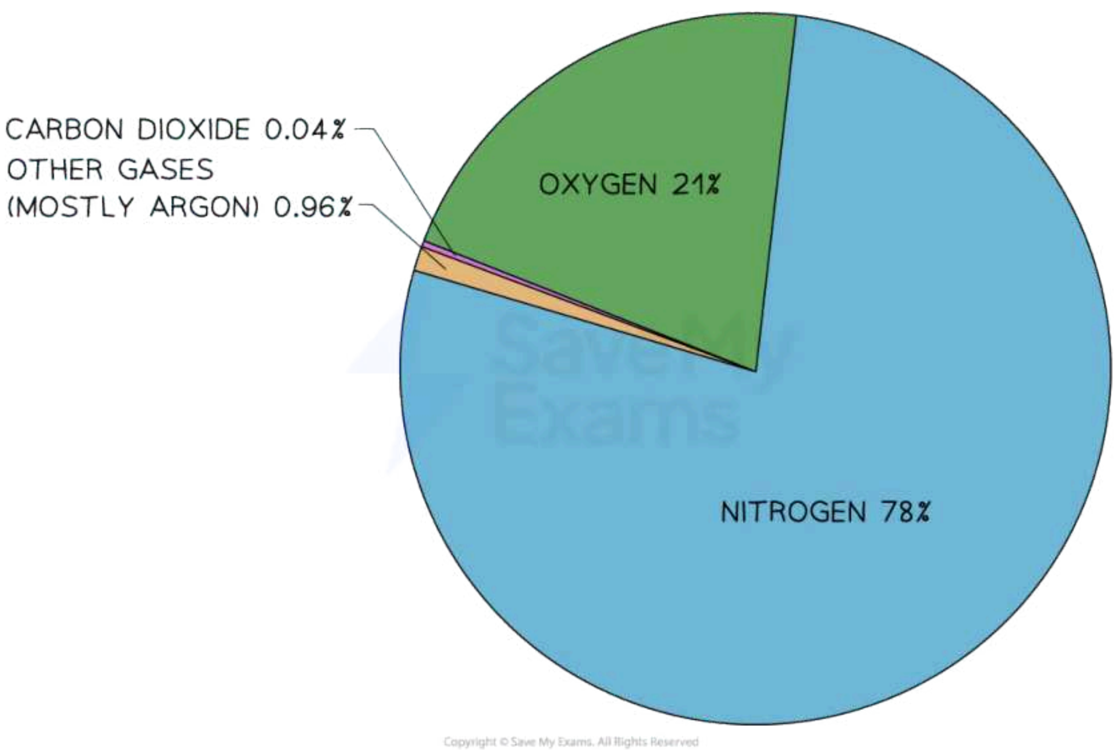
The Atmospheric System

Your notes

Structure of the Atmosphere

- The **atmosphere** is an **envelope** of **mixed, gases**
- Which is h**eld in place by gravitational attraction**
- It consists of **nitrogen (78%), oxygen (21%)** and **1% trace gases**

Gasses of the atmosphere



Other gases include water vapour, nitrous oxide, ozone, and methane

Atmospheric layers

- The atmosphere is 10,000 km in height
- But gravity compresses 99% of the atmosphere to within 40 km of the Earth's surface
  - 50% of the atmosphere is in the first 5.6 km

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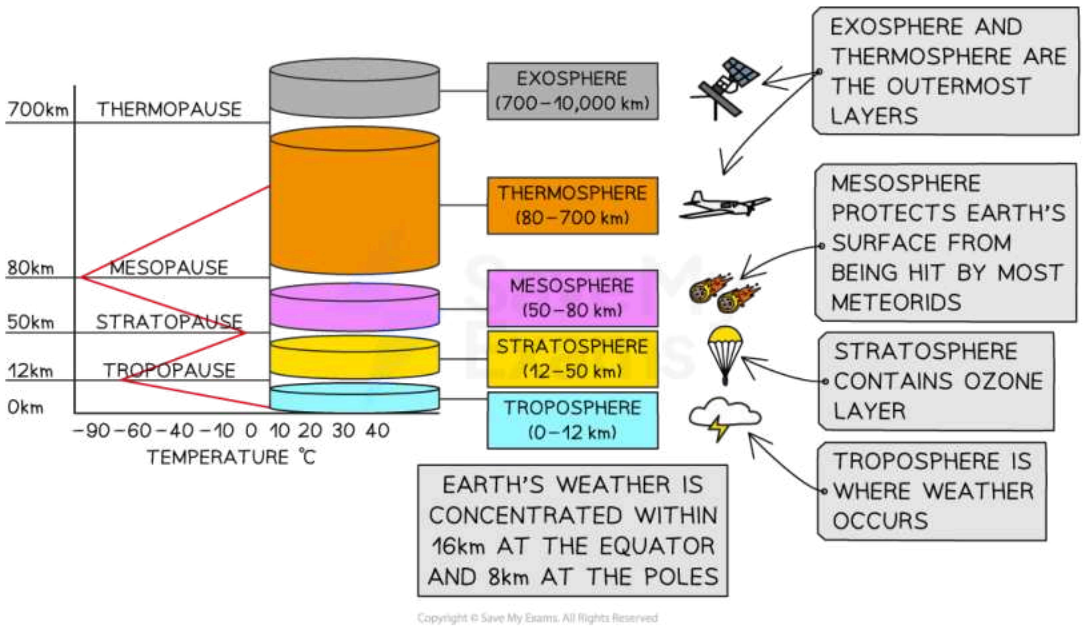
Atmospheric layers

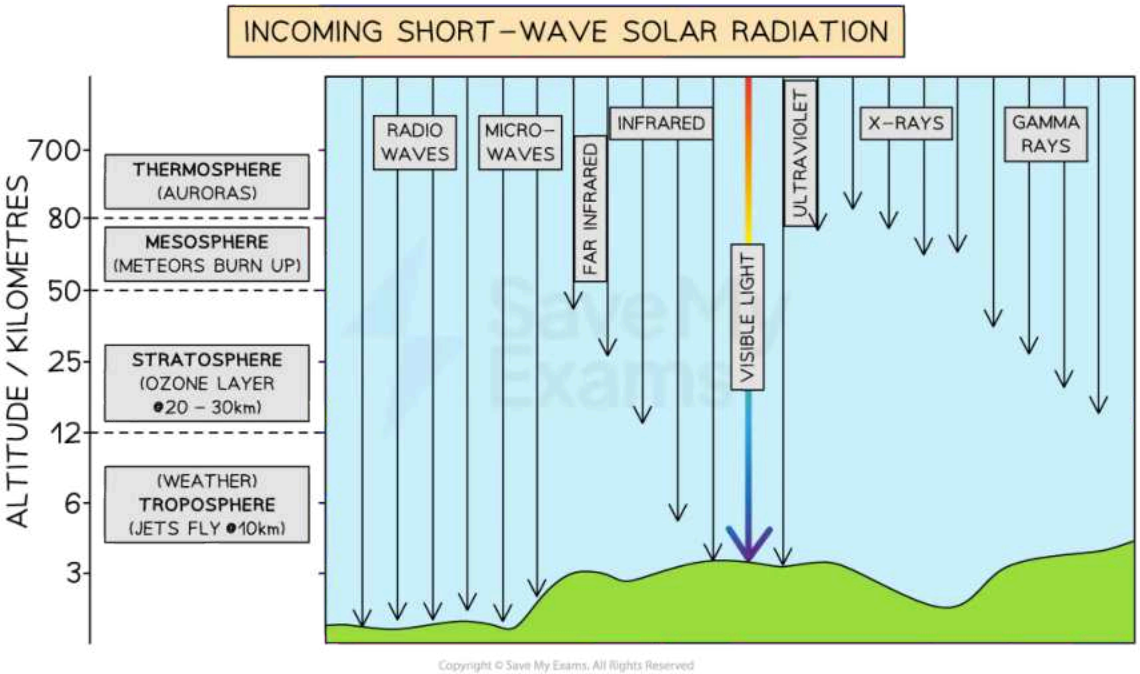


Energy Balance

Atmospheric heat budget

- The Sun is Earth's primary source of energy
- It provides more energy in an hour than humans use in a year
- Energy is received as **short-wave radiation** - **insolation**

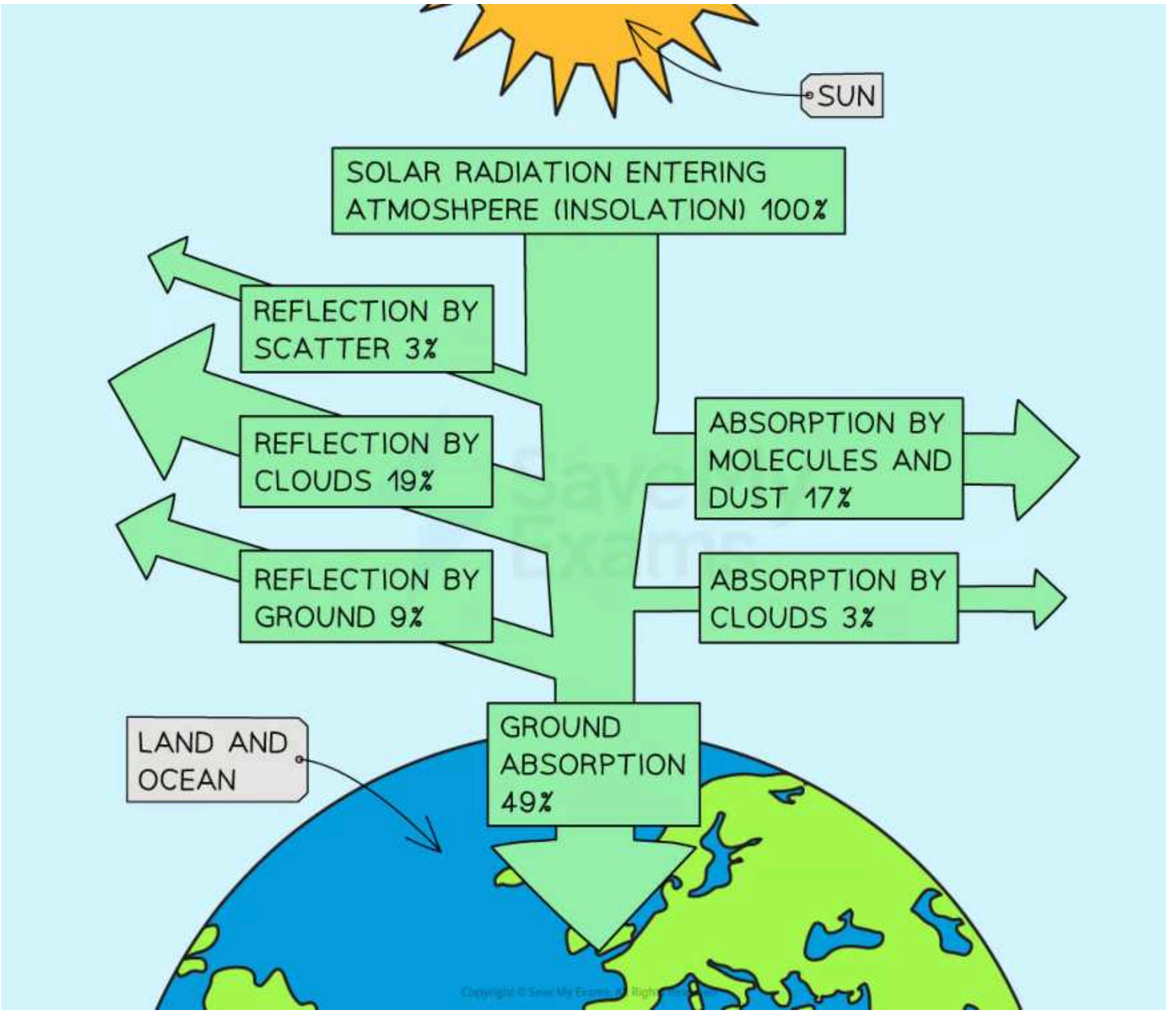
Insolation



The atmosphere can block harmful waves from reaching the Earth's surface

- Earth's **atmospheric heat budget depends** on the **balance between:**
  - **Insolation** and
  - **Outgoing long-wave radiation**
- Some energy is lost passing through the atmosphere, but there is an overall **net gain** of energy at the **surface**
- **Polar regions have a net deficit (they** receive about 24% of insolation) due to absorption, reflection and scattering – albedo effect
- The **atmosphere itself** has an **overall net deficit** of energy
- To compensate, heat is moved from the surface to the atmosphere by **radiation, conduction** and **release of latent heat** – **the natural greenhouse effect**

Earth's energy budget



The global energy budget model assumes that the surface is flat grassland, hence differences between polar and equatorial regions

Atmospheric energy budget as a system

- An **energy budget** refers to:
  - The **amount of energy entering** a system
  - The **amount leaving** the system
  - The **transfer of energy** within the system

Atmospheric Energy System

Input	Energy from the Sun and Earth
Output	Loss of energy to space
Transfer/flow	Convection, conduction and radiation
Stores	Land, oceans, clouds and atmosphere

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- If the atmosphere loses more energy than it gains, it will cool down
- However, if the atmosphere gains more energy than it loses, it will heat up
- This is **global warming**, where more energy is retained in the atmosphere
- There is also the difference between **day and night or the diurnal energy budget**

Daytime energy budget

- There are **6 components** to the **daytime** energy budget:
  - **Incoming (shortwave) solar radiation (insolation)**
    - Strongly influenced by cloud cover and latitude
    - At the equator, the Sun's rays are more concentrated than at the poles
  - **Reflected solar radiation**
    - The amount of reflection depends on the type of surface
    - Referred to as the **albedo effect,** the higher the percentage, the more insolation is reflected
  - **Surface absorption**
    - Depending on the surface, heat is transferred either quickly or slowly to the sub-soil layers
  - **Sensible heat transfer** (conduction and convection)
    - This involves losing or gaining energy without a phase change
      - Water vapour doesn't change, but moves heat from one area to another
  - **Long-wave radiation**
    - This is emitted by the surface and passes into the atmosphere, and eventually into space
  - **Latent heat transfer** (evaporation and condensation)

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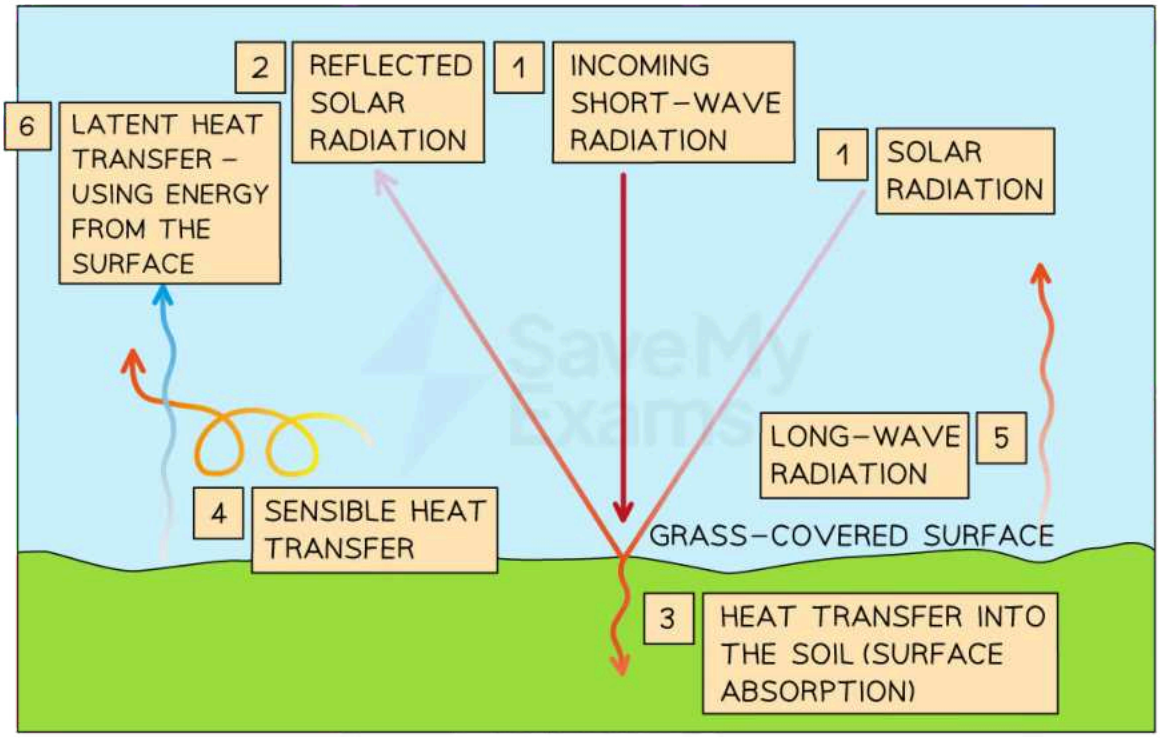
- This does involve a phase change - gas to liquid, etc. and uses a lot of energy
- **Sublimation** is when a solid turns to gas without becoming a liquid and vice versa

Daytime energy budget



Sensible and latent heat transfers

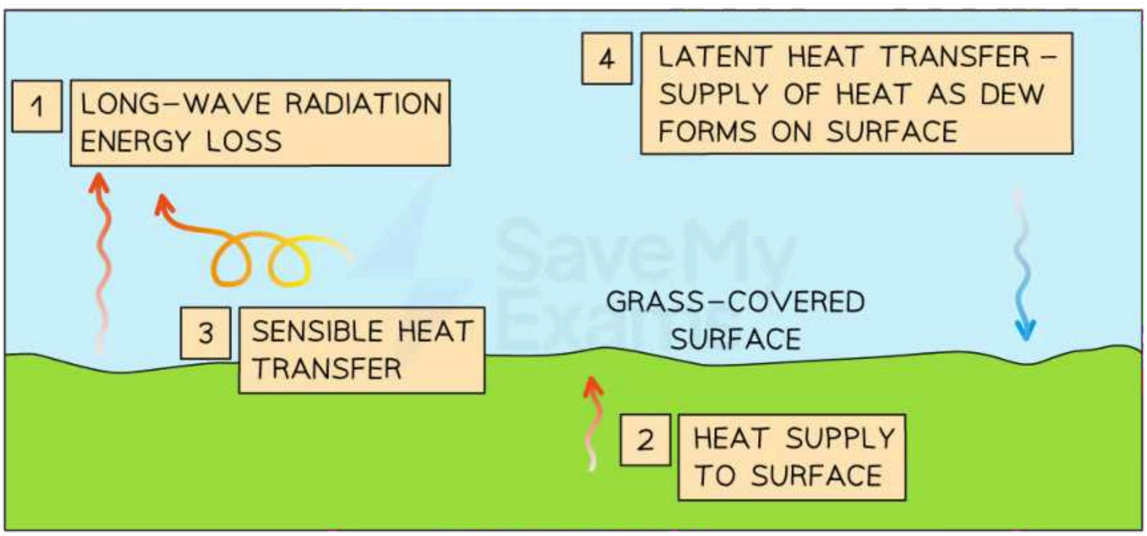
- **Sensible heat** is felt when touching a warm object
- Can be measured with a thermometer
- Moves heat from **warmer to colder** objects by:
  - **Conduction**: direct contact
  - **Convection:** fluid moves heat away from a surface (such as the ocean)
- **Latent heat (hidden heat)** is energy that is absorbed, stored and released at a molecular level
- It cannot be measured by a thermometer
  - For example, when liquid changes to vapour or solid to liquid, heat energy is absorbed from the surroundings

- When the vapour turns back to liquid or solid, latent heat is released, warming the surroundings
- This is why it is cooler by water in summer (water has taken the heat from its surroundings) and warmer in winter (water is releasing heat to its surroundings)

Night-time energy budget

- There are **4 components** to the **night-time** energy budget:
  - **Long-wave radiation**
  - **Sub-surface radiation**
  - **Sensible heat transfer** (conduction and convection)
  - **Latent heat transfer** (condensation)

Night-time energy budget



There is no insolation at night, therefore, energy is released

- **Long-wave radiation**
  - During the night, there is a net loss of energy from the surface
  - With clear skies, temperatures fall quickly
  - Under cloudy conditions, the loss is reduced as clouds return some longwave radiation to the surface
- **Sub-surface supply**

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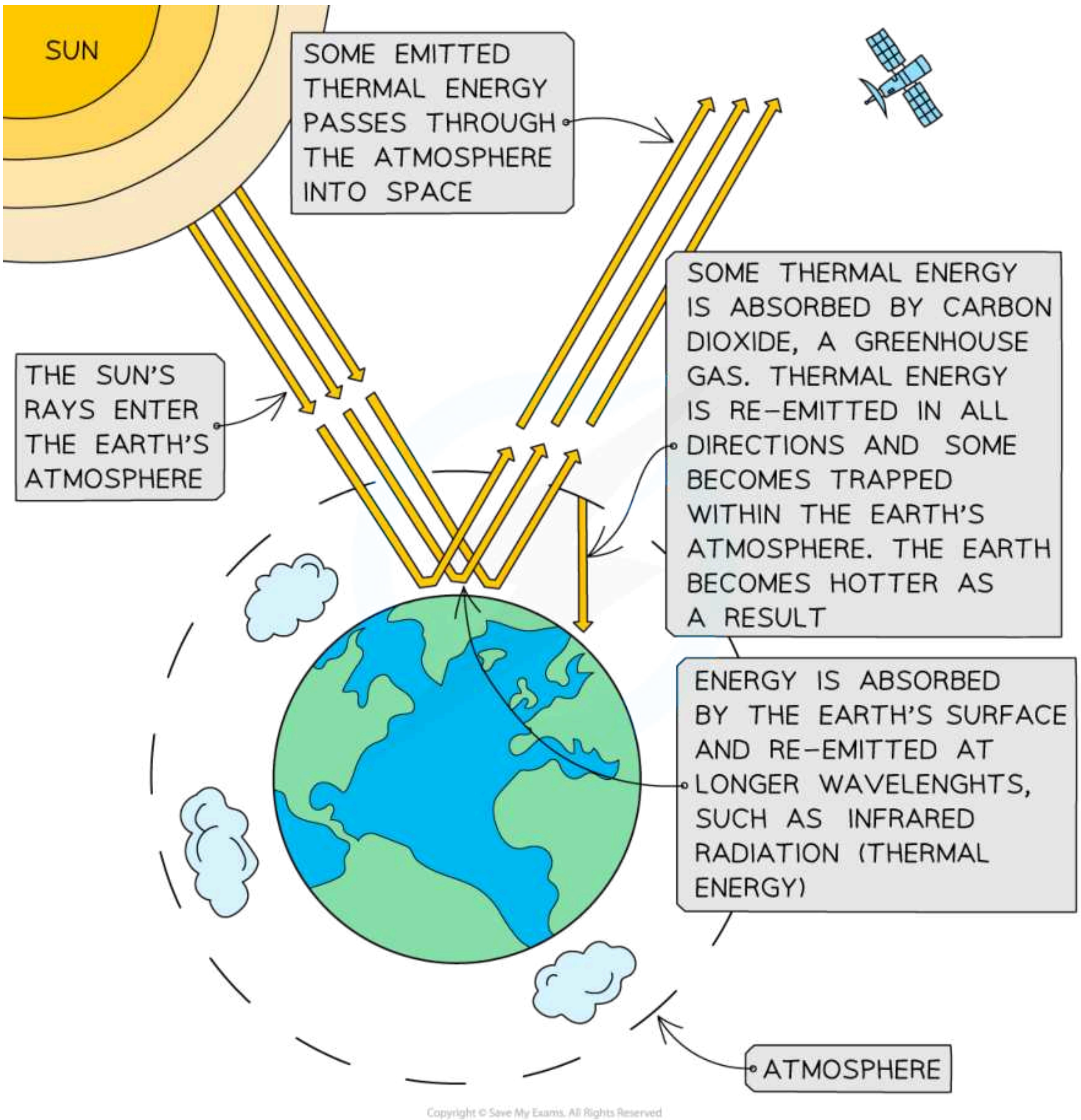
  - The heat stored during the day is transferred (conducted) to the cool surface during the night
  - This energy supply can reduce the size of night-time temperature drop on the surface
- **Sensible heat transfer** (conduction and convection)
  - Moving warm air adds energy and helps keep temperatures up
  - But, if cold air moves in, energy levels will fall, possibly reducing temperatures
- **Latent heat transfer** (evaporation and condensation)
  - At night, water vapour near the ground can condense to form dew
  - The process releases latent heat, and supplies energy to the surface, producing a small gain of energy
  - However, if there is enough evaporation, this can lead to cooling

Natural Greenhouse Effect

- Water vapour, CO_2, methane, ozone, NOx and CFCs all contribute to keeping Earth warm
- They are natural greenhouse gases (GHGs) and keep a global average temperature of 15°C
- Without them, the Earth's global temperature would be around -18°C and not suitable for life

Natural greenhouse effect



Greenhouse gases absorb and then re-emit energy into the atmosphere

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Examiner Tips and Tricks

Don't get confused - the greenhouse effect is a natural process and is necessary for life on Earth. The accelerated or enhanced greenhouse effect refers to the changes in the greenhouse effect (mostly due to human activity) that are commonly referred to as global warming.

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Levels of GHGs

- **Water vapour** is the **most abundant** greenhouse gas
  - It accounts for about 95% of GHGs by volume
  - Water vapour is responsible for 50% of the natural greenhouse effect
  - Human activities indirectly affect temperature and moisture through:
    - Deforestation, land-use changes, and burning fossil fuels
- **Carbon dioxide (CO_2)** accounts for 20% of the greenhouse effect
  - Levels have risen from 315 parts per million (ppm) in 1950 to over 421 ppm in 2022
  - 2050 levels are expected to be 550 ppm
  - Increase is due to human activities - burning fossil fuels and deforestation
    - Deforestation also decreases carbon storage, as trees remove CO2 from the atmosphere during photosynthesis
- **Methane** accounts for 17% of the natural greenhouse effect
  - Methane is 28 times more potent than CO_2 at warming the Earth
  - Produced naturally and through human activities such as:
    - The decay of organic matter in wetlands, forests, and oceans
    - Agriculture (particularly rice growing and livestock farming), fossil fuel extraction, and waste landfills
- **Chlorofluorocarbons (CFCs)** and **hydrofluorocarbons (HFCs)** account for 1.5% of GHGs in the atmosphere
  - These are **man-made chemicals** that are:
    - 10,000 times better than CO_2 at trapping heat
    - Increasing at a rate of 6% per year
    - Banned by many countries as they deplete the ozone layer - 1 CFC atom can destroy thousands of ozone molecules
- HFCs are weak ozone-depleting substances but are strong greenhouse gases

Examiner Tips and Tricks

Do not confuse the ozone layer with global warming.

Yes ozone is a greenhouse gas, but the ozone layer protects the Earth from ultraviolet light.

Ozone is different because it absorbs incoming UV light and outgoing infrared light from the Earth.

The hole in the ozone layer increases the rate of skin cancer by allowing more UV rays to enter the atmosphere. It has no effect on incoming solar energy.

Your notes

Global Energy Balance Change

Your notes

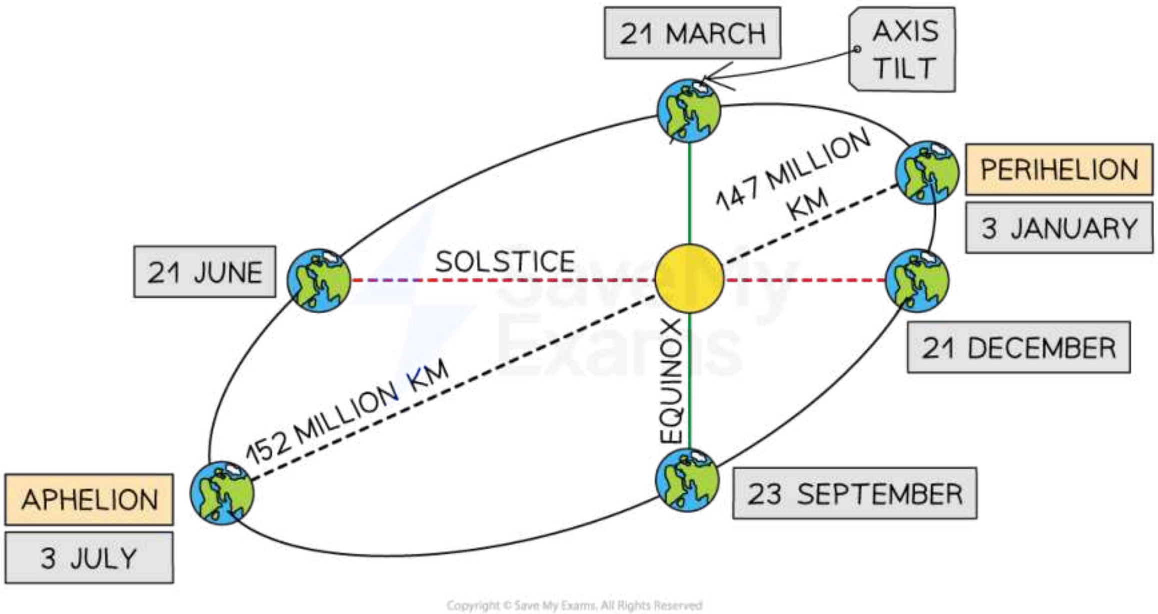
Variations in Solar Radiation

- The Earth's energy budget (EEB) establishes Earth's climate
- When the budget balances, temperatures on the Earth remain mostly constant
- However, the incoming and outgoing energy don't balance
- The imbalance is partly caused by **insolation**, as it varies seasonally and with natural changes in the Earth's atmosphere
- Changes in the make-up of the atmosphere alter the amount of energy absorbed and reflected
- Changing factors such as greenhouse gases, water vapour etc., result in small, but significant energy imbalance on Earth
- Other factors include:
  - Distance
  - Seasonal change
  - Latitude
  - Reflectiveness (albedo)

Factors affecting global insolation

- **Distance from the sun**
  - Earth's orbit around the Sun is **elliptical**
  - Perihelion is when the Earth is closest to the Sun and insolation travels less distance
  - Aphelion is when the Earth is furthest away from the Sun - insolation has to travel further

Elliptical orbit of Earth



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- **Latitudinal differences**
  - Insolation has to pass through more atmosphere in the polar latitudes
  - Insolation is spread over a larger area in the polar regions
  - The Sun is overhead at the Equator and tropical latitudes receive more insolation

Uneven distribution of insolation

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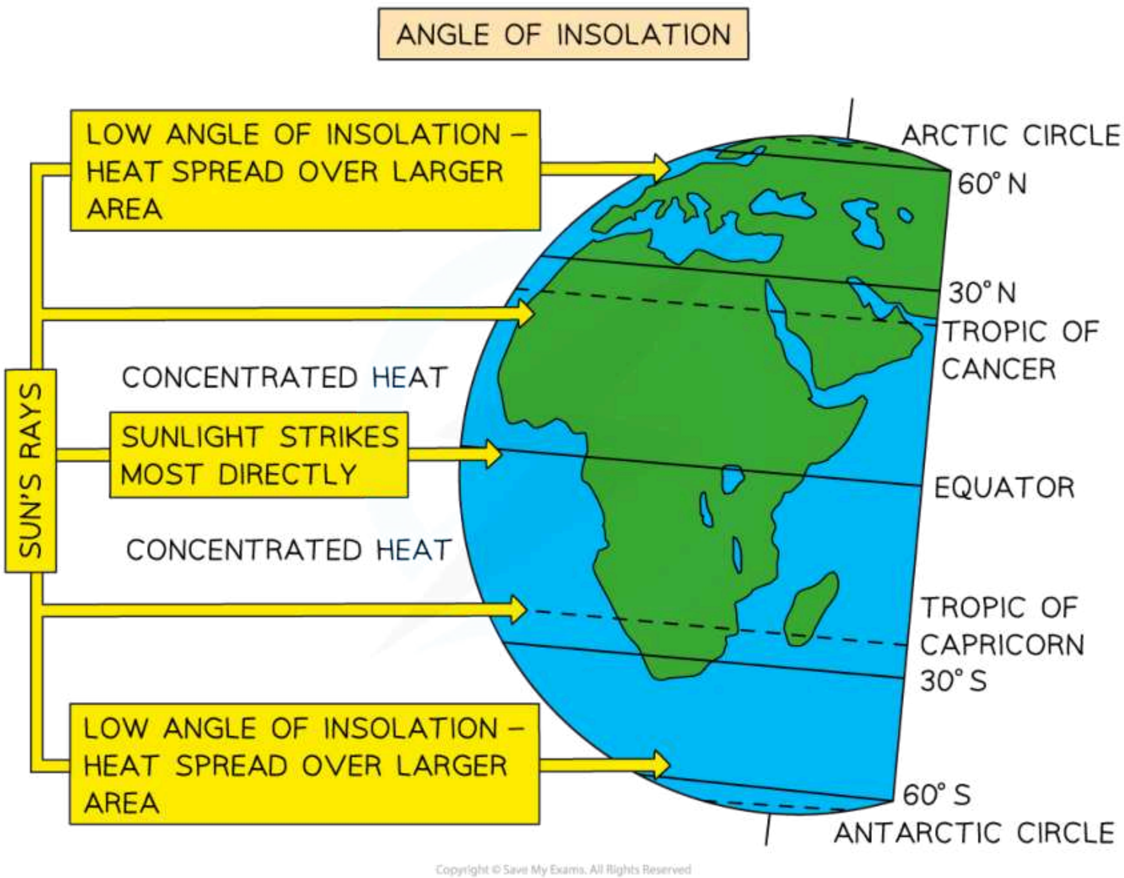
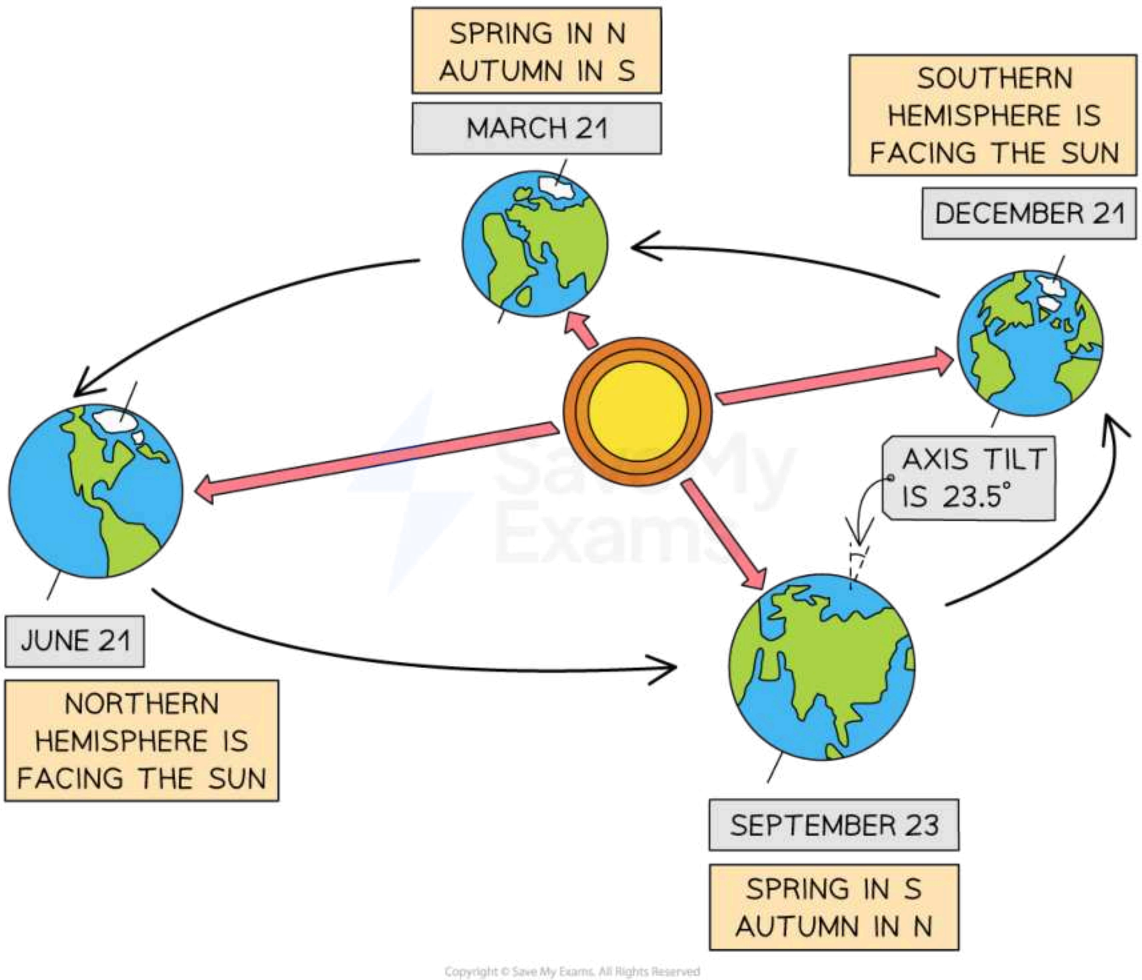


- **Seasonality and diurnal differences**
  - The Earth is permanently tilted in the same direction on its axis
  - This tilt changes which hemisphere is facing the Sun as the Earth orbits throughout the year
  - This creates the seasons and daylight availability
  - Therefore, differences in the amounts of insolation gained or lost across the globe throughout the year

Seasonality affects global energy



Milankovitch cycles

- Milankovitch cycles describe the effects of changes in the Earth's movements on its climate over thousands of years
- In the 1920s, Milankovitch suggested that variations in eccentricity, tilt, and wobble of the Earth's orbit resulted in cyclic changes in the amount of solar radiation reaching the Earth
- Therefore, orbital changes influenced climatic patterns on Earth

Cycle	Time in Years (approx.)	Effect

Eccentricity (shape)	100,000	The Earth's orbit is currently elliptical making it closer to the Sun in January than in July. This results in the seasons being more extreme in the Southern Hemisphere than in the Northern Hemisphere. This shape will move to become more circular and this leads to cooler, even seasons, as the distance from the Sun will be more equal
Obliquity (tilt)	40,000	If the Earth's axis were vertical, there would be no seasons – the same part of the Earth's surface would be facing the Sun throughout the year. The more angled the axis, the more extreme the seasons are (hotter summers and colder winters)
Precession (wobble)	26,000	The axis also traces a circle in space and every 26,000 years the Earth wobbles on its axis and this changes which star we see as the North Star – currently it is Polaris, but 13,000 years ago, it would have been Vega

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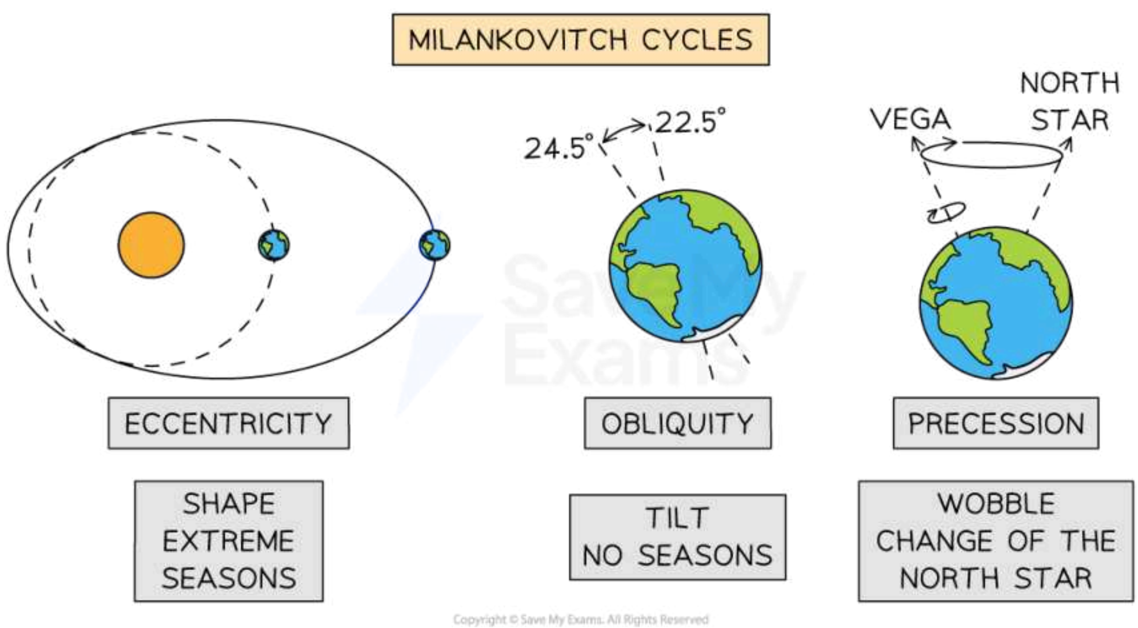
Milankovitch cycles



The shape, tilt and wobble of Earth's movement over thousands of years, affects long-term climate

Sunspots and solar flares

- **Increased sunspot activity and solar flares** are linked to **higher** average **temperatures**

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- **Sunspots** are areas of intense and **complicated** magnetic fields that emit **solar plasma flares** thousands of kilometres above the sun
- The flare quickly rises to temperatures of **20 million °C**
- These bursts of high-energy radiation have the same energy as a few million volcanic eruptions on the Earth
- Sunspots range from Earth-size 'pimples', to swollen scars halfway across the surface of the Sun
- The Sun goes through **11-year cycles of solar activity**

Ejection of solar plasma from the Sun

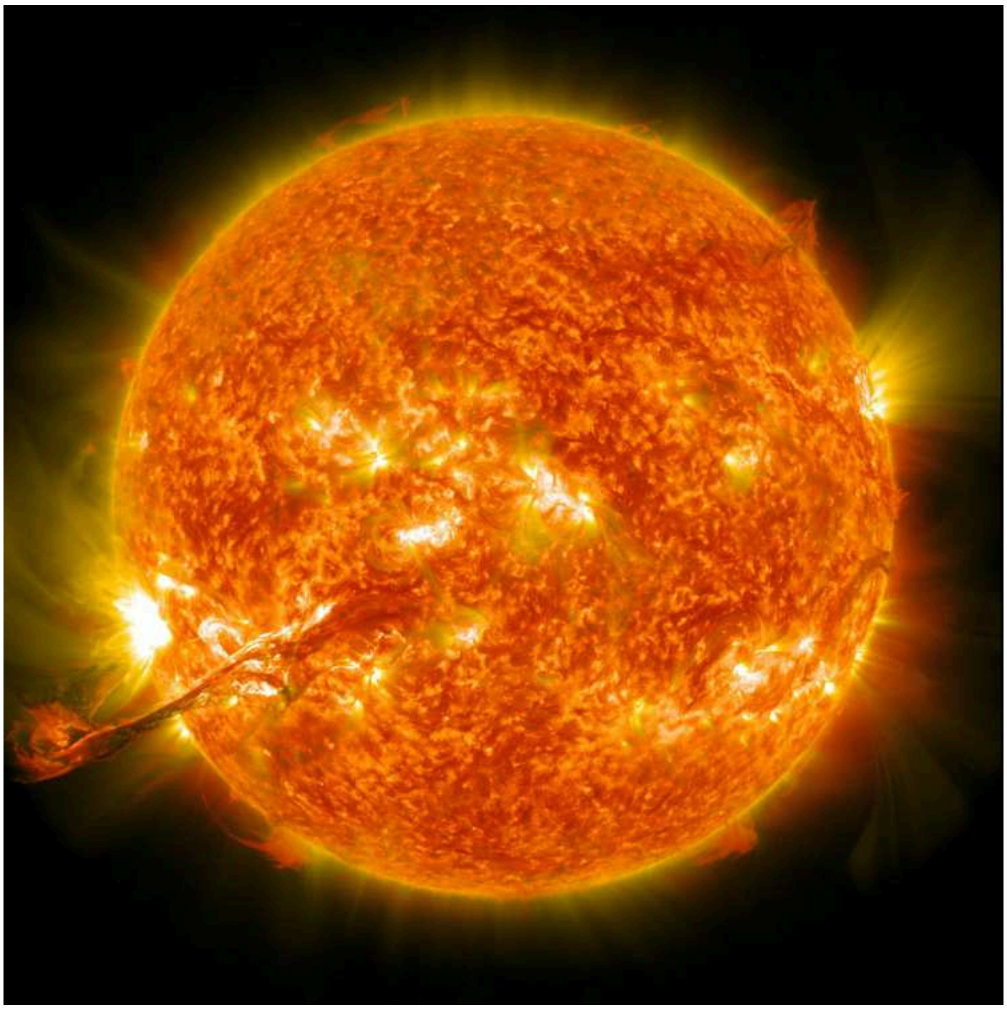

Photo by NASA on Unsplash

The more 'spots' on the Sun's surface, the higher the Sun's output

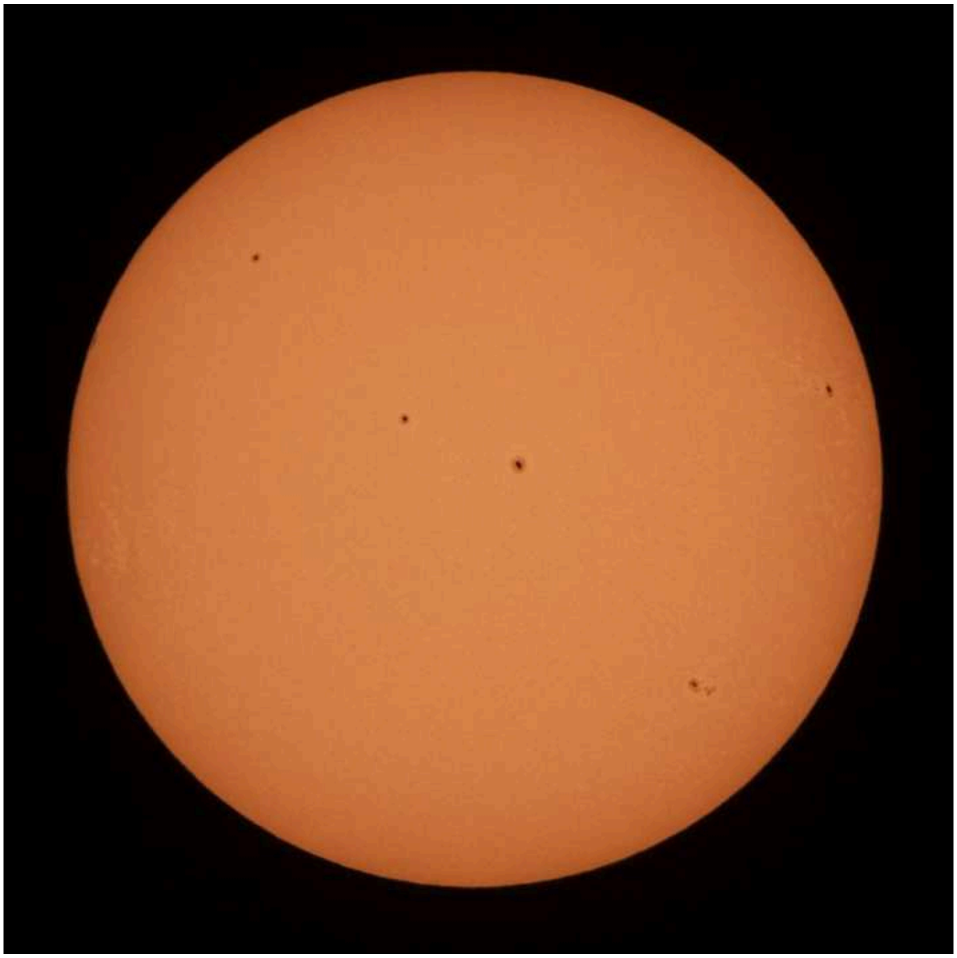

Photo by The Adaptive on Unsplash

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Cloud cover

- Clouds have higher albedos than the surface below, so more short-wave radiation is reflected back to space
- Cloud cover at the equator reflects insolation – more is reflected having a **net cooling effect**
- At the **same time**, clouds help contain the heat that would otherwise be emitted to space, through 'longwave warming,' which has a **net warming effect**
  - **High, thin clouds**, such as cirrus, **allow** insolation to pass through but absorb some long-wave radiation, **warming** the Earth's surface
  - **Deep convective clouds**, especially cumulonimbus, **neither** heat nor cool overall

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- An **overcast sky** with complete cloud cover of low thick clouds – stratus and stratocumulus, can reflect 80% of insolation and **cool** the Earth's surface

Global Dimming

- **Global dimming** is caused by the increase of pollution in the atmosphere
- Overall decline of 1–2% in insolation per decade since the 1950s
- Between 1960 and 1990, the northern hemisphere saw a reduction of between 4% and 8% in insolation
- Pollution controls in Europe and parts of North America have seen some recovery or **global brightening**
- China and India have seen further, regional declines
- Southern hemisphere is largely unaffected although increased development is having an impact
- There are two timescales:
  - **Short-term natural**
  - **Long-term anthropogenic**

Short-term Natural Global Dimming

Cause	Impact
Volcanic eruptions	Large-scale eruptions block insolation and reduce temperatures The 1991 eruption of Mount Pinatubo, Philippines, reduced global temperatures by 1°C in 1992
Atmospheric dust and asteroids	Asteroids and meteors increase the amount of dust in the atmosphere, which decrease temperatures
Wildfires	Wildfires have increased in size and intensity over the last decade. In 2020, wildfires burned more than a million acres in Oregon and more than 4 million acres in California. Although smoke eventually clears, it adds to global dimming because of fine matter and particles

Long-term Anthropogenic Global Dimming

Cause	Impact
Aerosols	These are fine, solid particles or liquid droplets in the air and other gases. Most aerosols scatter light and some insolation back out to space, which exerts a cooling

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	effect on the climate
Particulate Matter	These include sulphur dioxide, ash, and soot, which are by-products of burning fossil fuels. Once in the atmosphere, they absorb and reflect insolation before it reaches the Earth's surface, causing dimming and cooling
Water Droplets	Water droplets pick up particulates such as soot, ash, sulphur dioxide, etc. to form heavy, polluted 'brown clouds'. These clouds reflect light and energy back out to space, resulting in global dimming
Vapour Trails (Contrails)	Contrail vapour from airplanes, flying high in the sky, reflect heat from the sun back out to space, causing global dimming

Planetary Albedo

- **Planetary albedo** is the **amount of sunlight reflected from Earth's surface**
- **Fresh snow and ice** have the highest albedos, **reflecting** up to **95%** of sunlight
- **Ocean surfaces** absorb most sunlight, and so have **low albedos**
- **Hot bodies (sun)** produce **shortwave radiation**, whereas, **cold bodies (Earth)** produce **longwave radiation** which is **easily absorbed by GHGs and clouds**

Positive & Negative Feedback

- A feedback loop is a cycle within a system that either increases (positive) or decreases (negative) the effects on that system to achieve **equilibrium**
- **Positive feedback amplifies (enhances) a change** and are **destabilising**
- **Negative feedback 'checks' or dampens change** and are **stabilising**
- **Dynamic equilibrium**
  - A system in a total state of balance is difficult to find, as nature is dynamic (ever changing)
  - Constant short-term adjustments are usually made through negative feedback to maintain balance
  - This process is referred to as 'dynamic equilibrium'.

Simple feedback system

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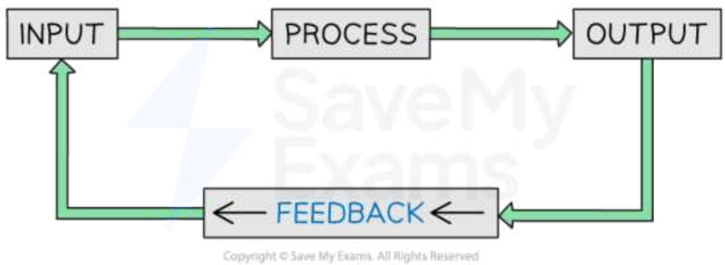
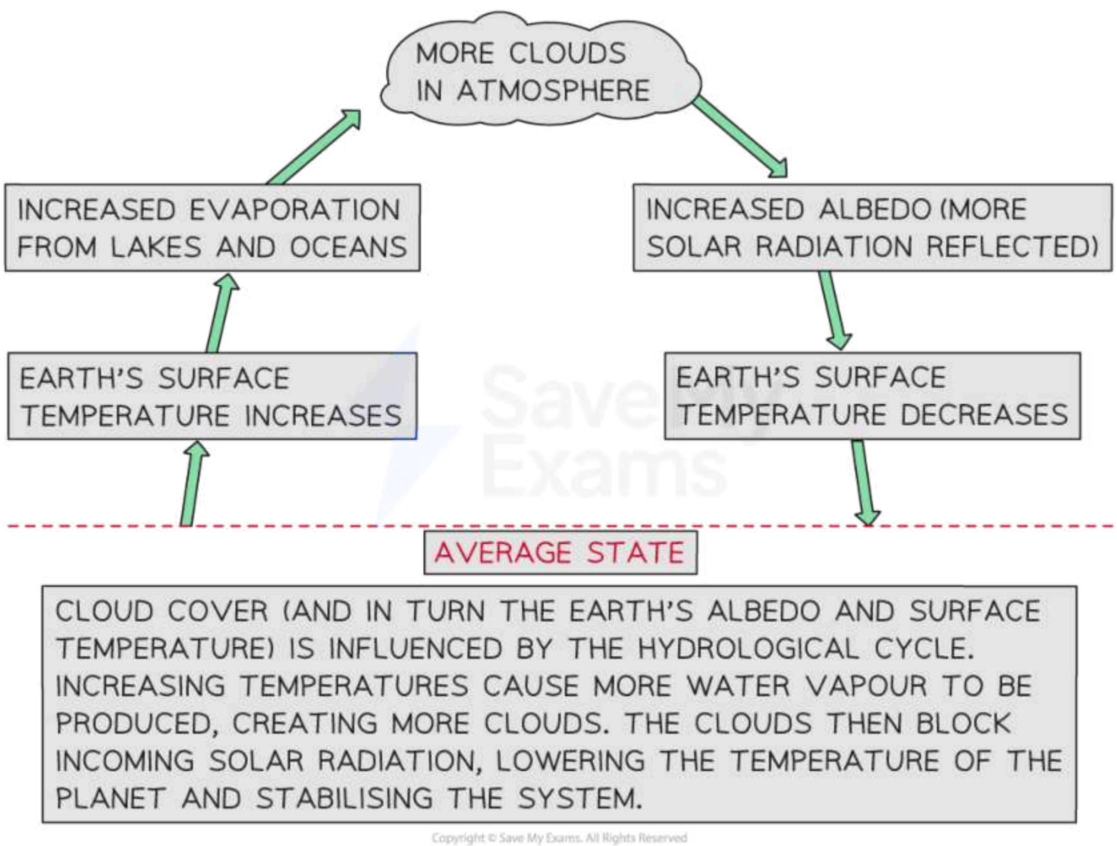


Changes to the processes in a system (disturbances) lead to changes in the system's outputs, which in turn affect the inputs

Example of a negative feedback loop



Effect of negative feedback through clouds

- Many positive feedback loops contribute to global warming

Examples of positive feedback loops

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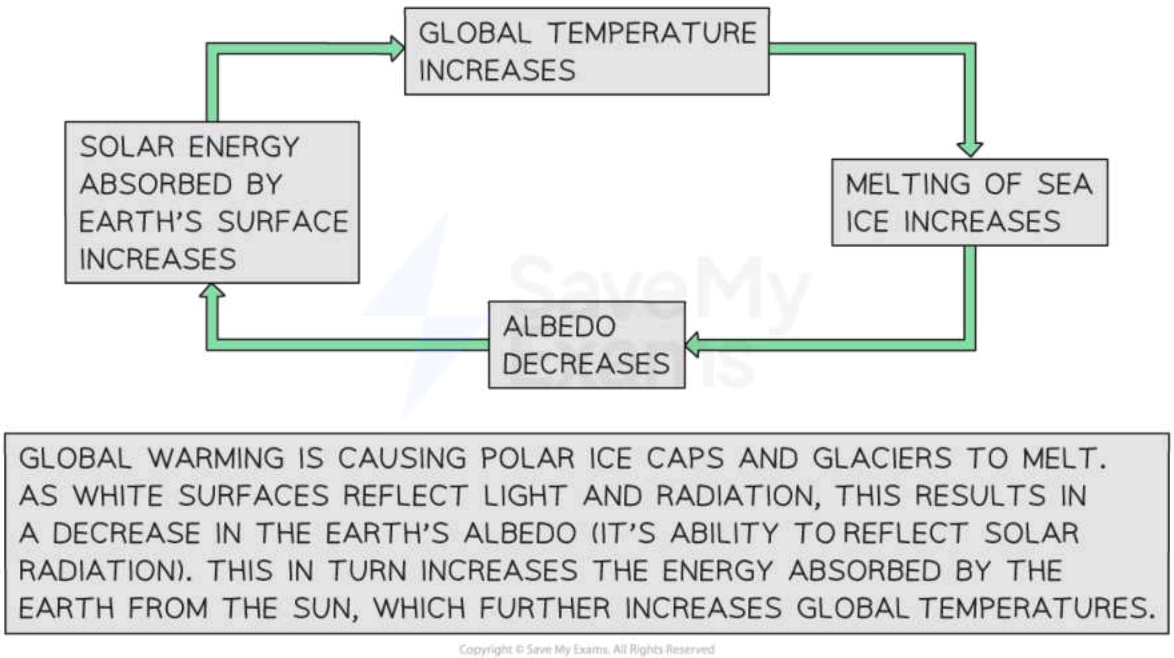

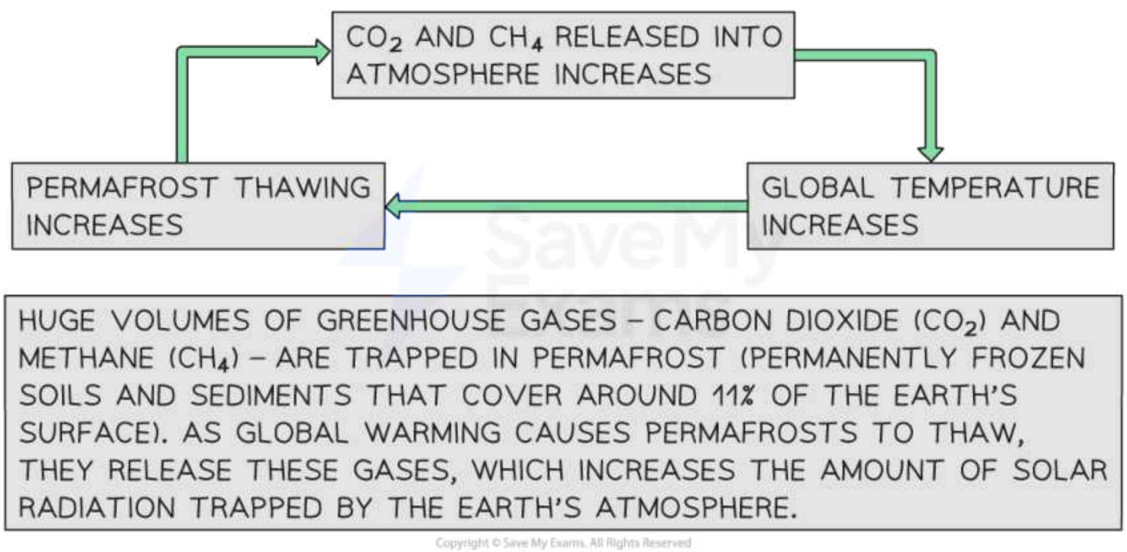

Effects of positive feedback on ice-cap melt and permafrost thawing

Examiner Tips and Tricks

Remember that a positive or negative feedback loop doesn't indicate whether the loop is good or bad.

In a system, a feedback loop is something that enhances or checks a process to bring the system back into balance.

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Enhanced Greenhouse Effect

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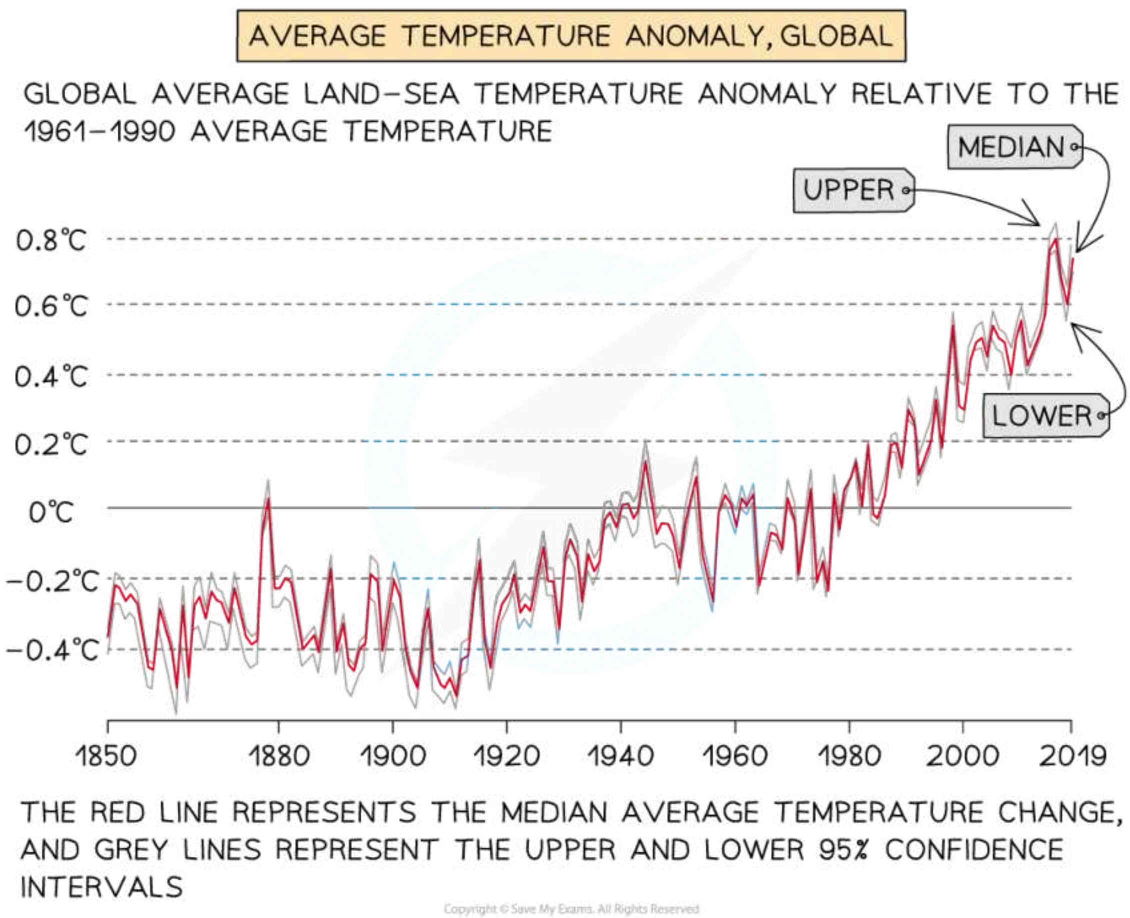
The Enhanced Greenhouse Effect

- The enhanced greenhouse effect is **different** from the natural greenhouse effect because it is primarily driven by **human activities** that release excessive amounts of greenhouse gases (GHGs) into the atmosphere, leading to an intensified trapping of heat and subsequent global warming
- While the natural greenhouse effect is a necessary process that helps regulate the Earth's temperature by trapping some heat to maintain a **habitable climate**, the enhanced greenhouse effect disrupts this balance as a result of greenhouse gas concentrations being artificially increased beyond natural levels
- Human activity has increased CO_2 levels in the atmosphere by more than 100 parts per million (ppm) to 420ppm in 2020
- Increased amounts of greenhouse gases have led to less long-wave radiation escaping the atmosphere
- Increasing global average temperatures by over 1°C since pre-industrial times

Average global temperatures



The natural and enhanced greenhouse effect

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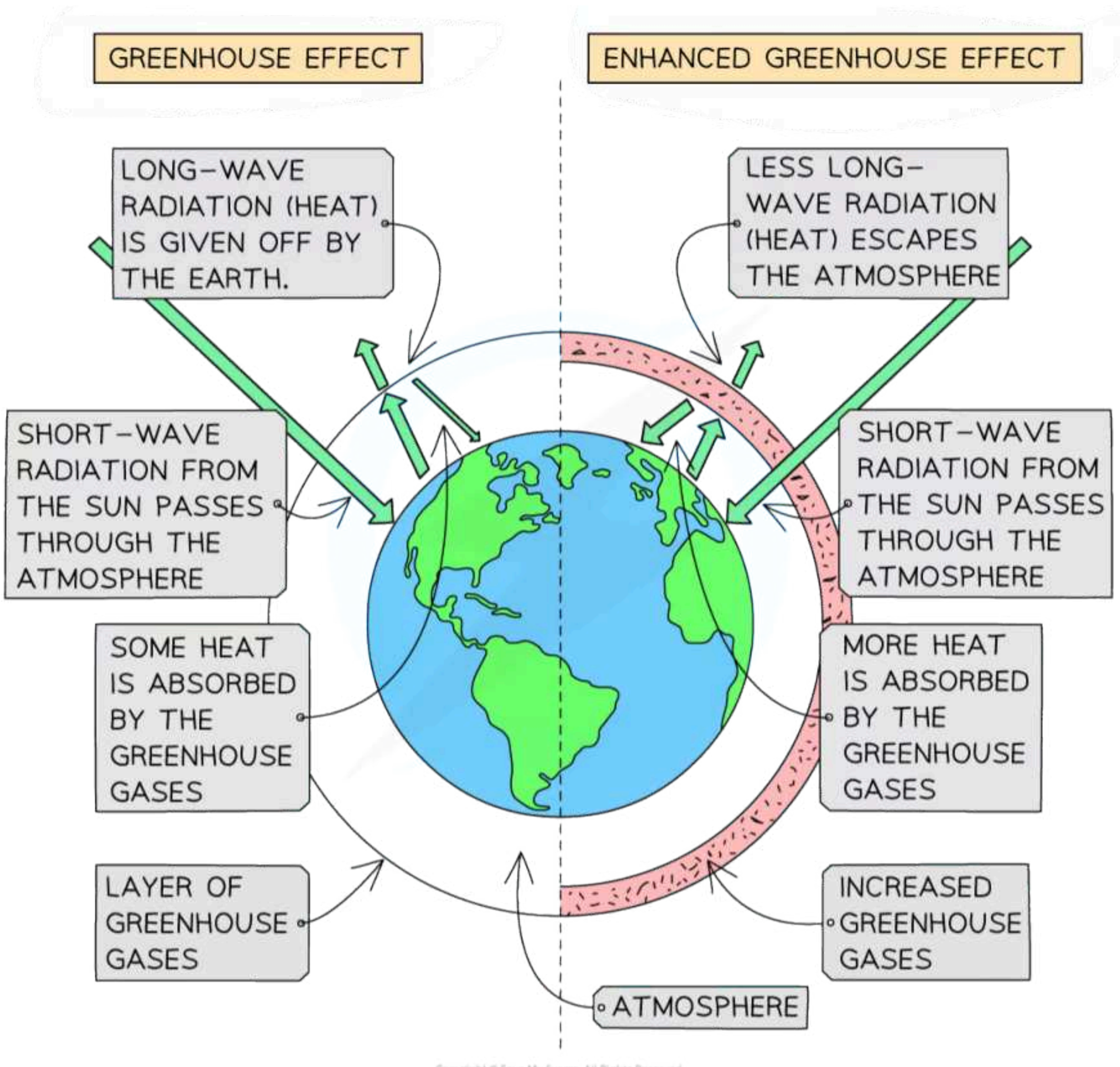

Human activities lead to the emission of greenhouse gases that enhance the natural greenhouse effect, contributing to global warming

Greenhouse Gases

Sources of Greenhouse Gases

Greenhouse Gas Annual % emitted	Time in Atmosphere	Sources

Carbon Dioxide (CO_2) **74.4%**	Unknown as the gas is not destroyed over time, but moves through the carbon cycle with different residence times on land, sea and atmosphere. Can be weeks, months, years or millennia	Burning of fossil fuels - power stations, vehicles Burning of wood Deforestation - trees utilise CO_2 in photosynthesis. The fewer trees there are the less CO_2 is removed from the atmosphere
Methane (CH_4) **17.3%**	11.8 years and is approx. 28 times more potent than CO_2 at warming the climate	Decay of organic matter - manure, waste in landfill, crops
Nitrous Oxide (N_2O) **6.2%**	109 years and is 273 times more potent at warming the climate than CO_2	Artificial fertilisers Burning fossil fuels
Fluorinated Gases **(CFCs, HFCs, sulphur hexafluoride, perfluorocarbons)** **2.1%**	A few weeks to thousands of years and climate warming potential varies from 12 times to 25,000 times more potent than CO_2	Aerosols Refrigeration units Air conditioning
Water Vapour	Although the most abundant of all the greenhouse gases, water vapour only has a residence time in the atmosphere of days and therefore, acts as feedback rather than a forcing of global warming	Most abundant greenhouse gas and levels are determined by temperature and humidity levels Human activities indirectly influence levels through changes in temperature and moisture, such as deforestation, land-use changes, and the burning of fossil fuels which release other greenhouse gases Global warming increases the rate of evaporation and increases air temperature which can hold more moisture

Global Variations in Greenhouse Gases

- Global average concentrations of carbon dioxide (CO_2), in 2022 were 50% above pre-industrial levels for the first time

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- Concentrations of methane (CH_4) also increased
- However, levels of nitrous oxide saw the highest year-on-year increase on record from 2021 to 2022
- Global greenhouse gas emissions are converted to **CO_2 equivalents (CO2e)** by multiplying each GHG by its 100 year **global warming potential (GWP)** value

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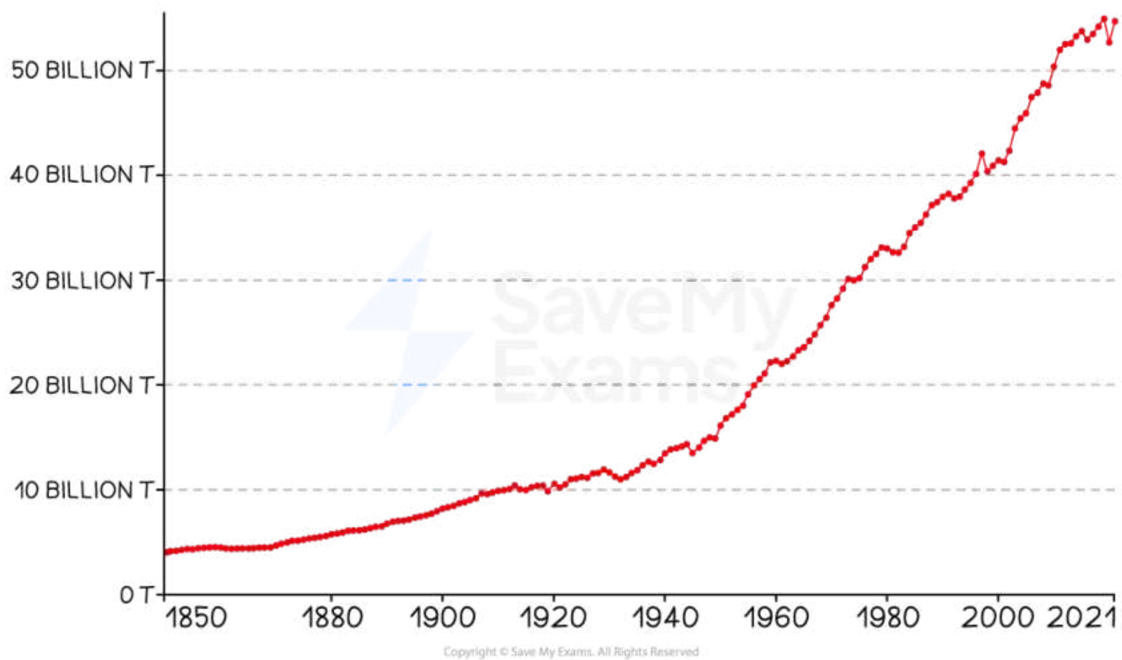
Global greenhouse gas emissions from 1850–2022



Global greenhouse gas emissions by country 2021

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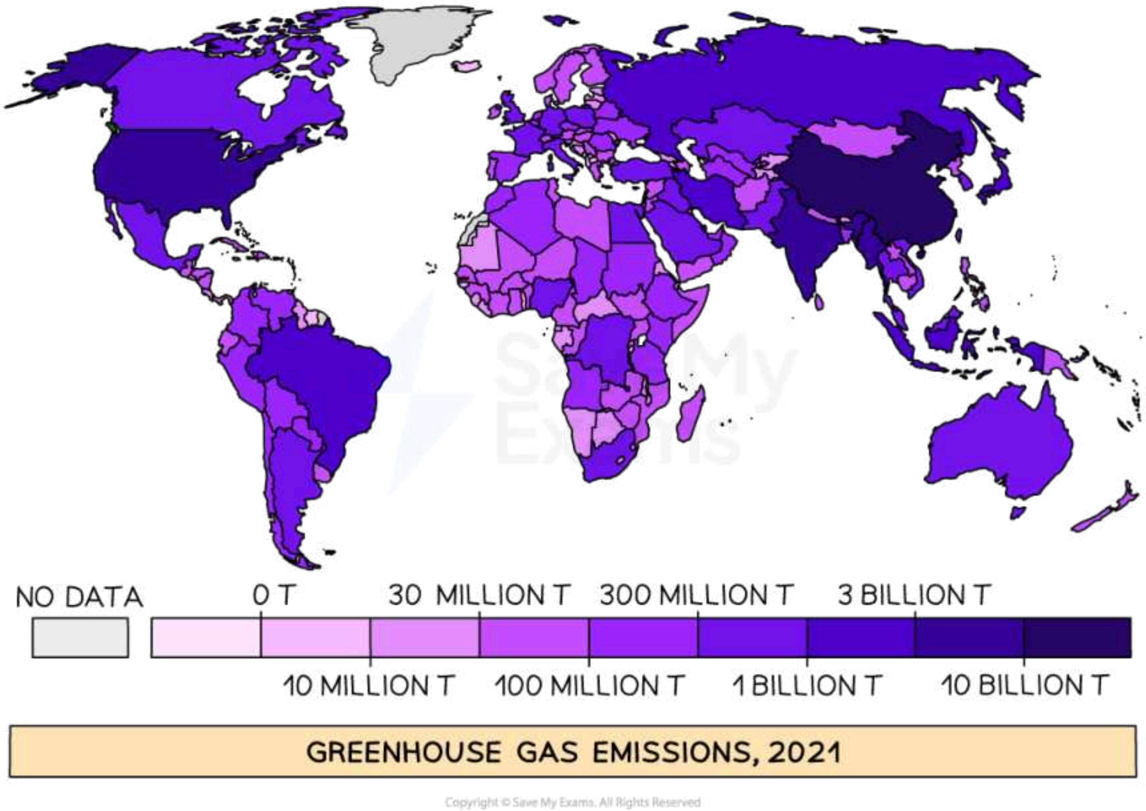

Global per capita greenhouse gas emissions 2021

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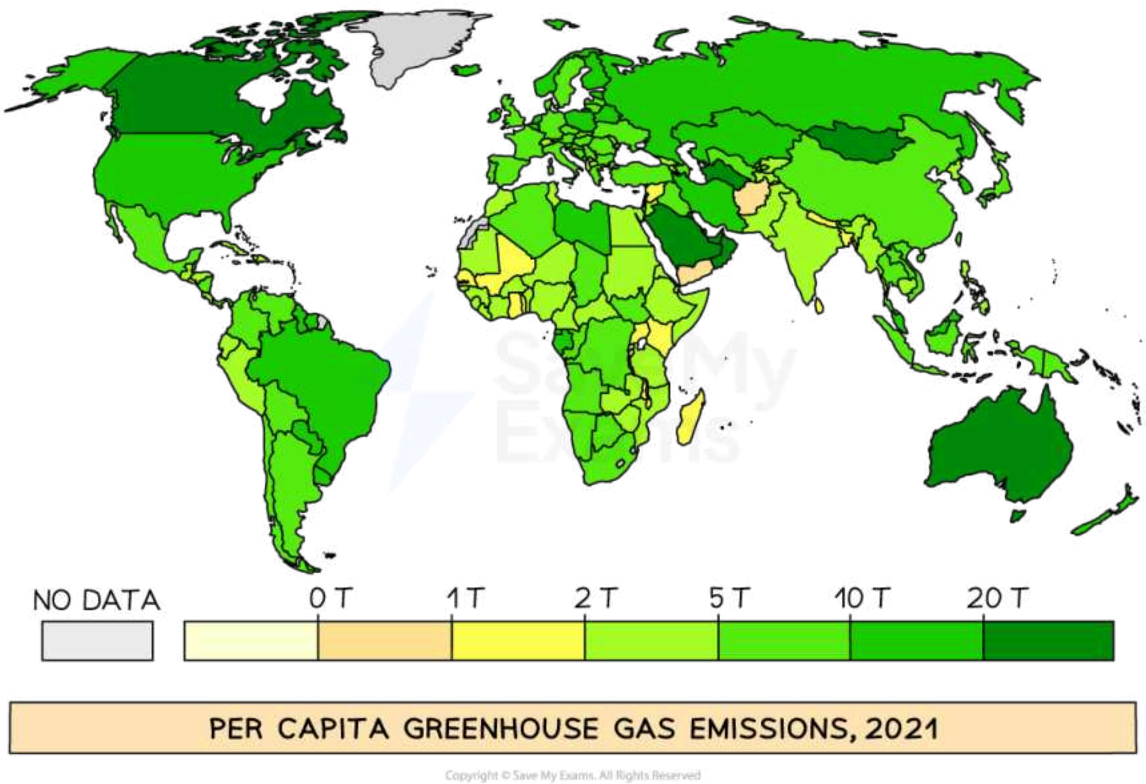

- Countries in the northern hemisphere emit more **carbon dioxide equivalents (CO2e)** annually in comparison to countries in the southern hemisphere
- For example, China emitted up to 13.71 billion tonnes of CO2e in 2021
- On the other hand, Australia emitted 602.5 million tonnes of CO2e in 2021
- However, Iceland is an anomaly, it is located in the northern hemisphere and emitted just 4.43 million tonnes of CO2e in 2021

Specific regions:

- In 2021, Oceania had the lowest rates of emissions at 738 million t and Asia had the highest at 29.7 billion t CO2e
- Africa emitted 4.7 billion t which was higher than South America at just 3.6 billion t CO2e
- South Africa and Democratic Republic of Congo emitted the most CO2e in 2021 at 553 million t and 545 million t respectively, with Nigeria a close third place at 445 million t of CO2e
- Europe emitted 6.82 billion t with North America emitting 7,86 billion t of CO2e

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Per capita emissions

- Total annual emissions shows which country emits the most as a whole, but this does not account for development and personal usage
- China and India are the two most populous countries but are portrayed as the top emitters
- Account for the population and China is 9.6t CO2e and India is 2.8t CO2e
- In this instance, Australia (23t) and Canada (20t) are both top emitters of CO_2 and Iceland is 12t CO2e due to the size of their population

Global variations in GHG sources

- HICs utilise a large amount of energy hungry technology through industrial processes and domestic usage
  - Domestic use includes lighting, heating and household appliances such as computers, mobile phone chargers, TVs, washers and dryers etc.
  - With the implementation of strict environmental laws to reduce their GHG emissions, and switching to low-energy new technologies along with the production of renewable energy with little to no emissions, HICs are now emitting fewer GHGs than industrialising MICs such as China and India
- MICs have a number of manufacturing industries, which increases their energy use and emissions
- However, domestic energy consumption is lower in comparison to HICs
- LICs generally have the lowest GHG emissions due to lack of industrial development
- Moreover, per capita income is lower, meaning less money is available to spend on high-energy products
- Despite HIC emissions being high, the increase in GHGs has been relatively stable
- However, as more LICs develop into MICs and more MICs develop into HICs, the demand for energy will increase
- Therefore, the growth in GHG emissions by these countries will increase
- Currently, it is the industrial regions of the world that are now producing the most emissions, such as China and India

Effect of globalisation and trade on GHG emissions

- As globalisation increased the manufacturing and export of goods, this led to the increase in GHG emissions from industries to meet market demand

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- As trade increased, so too did the transport of goods via ship, train, road and air, thereby, increasing emissions
- MICs and LICs, often have relaxed emission regulations, which encourages TNCs to re-located their manufacturing plants to avoid spending money on expensive modifications or buying new technology to capture emissions
- Trade in emerging economies may help improve the standard of living however, if people become reliant on these forms of trade for income, then there is no incentive for developing economies to take measures to reduce emissions
- Furthermore, as people earn money, their disposable income increases allowing them to afford products that are energy hungry such as televisions and air conditioners
- This results in a per capita GHG emissions increase

Examiner Tips and Tricks

If asked in the exam about global and regional trend of emissions, you need to be able to discuss this in general terms with a couple of specific facts to support your answer. You do not need a lot of data knowledge, but remember which regions have the highest, middle and lowest emissions.