Topic 6 Atmosphere

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Topic 6 Content

- 6.1 The Earth’s Atmosphere
- 6.2 Causes and Effects of Climate Change
- 6.3 Management Strategies of Climate Change
- 6.4 Stratospheric Ozone

6.1 The Earth's Atmosphere

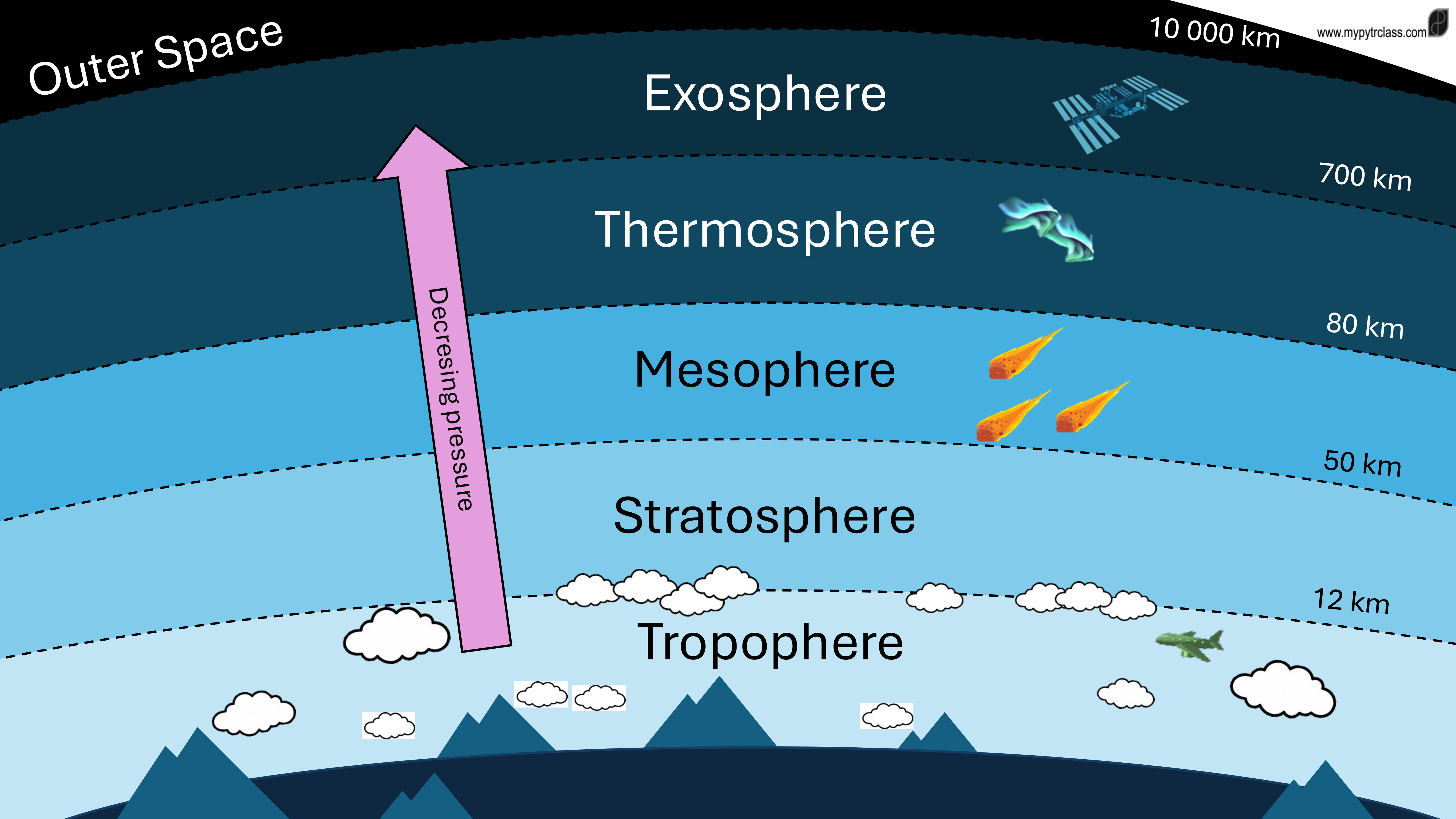
Knowledge Statements

- The atmosphere forms the boundary between Earth and space. It is the outer limit of the biosphere and its composition and processes support life on Earth.
- Differential heating of the atmosphere creates the tricellular model of atmospheric circulation that redistributes the heat from the equator to the poles.
- GHGs and aerosols in the atmosphere absorb and re-emit some of the infrared (long-wave) radiation emitted from the Earth's surface, preventing it from being radiated out into space. They include water vapour, carbon dioxide, methane and nitrous oxides (GHGs) and black carbon (aerosol).
- The greenhouse effect keeps the Earth warmer than it otherwise would be due to the broad spectrum of the Sun's radiation reaching the Earth's surface and infrared radiation emitted by the warmed surface then being trapped and re-radiated by GHGs.

Part 1: Earth's Atmospheric Layers

The Earth's Atmosphere

- **Transitional boundary**
  - The atmosphere forms the boundary between Earth and outer space and serves as the outermost limit of the biosphere.
- **Composition**:
  - Nitrogen (N_2): 78%
  - Oxygen (O_2): 21%
  - Trace gases (~1%): carbon dioxide (CO_2), argon (Ar), neon (Ne), hydrogen (H_2), ozone (O_3), and variable water vapour (H_2O).
- **Greenhouse gases**:
  - CO_2 accounts for only 0.04% of gases but plays a critical role in the greenhouse effect.
  - Human activities have increased concentrations of CO_2 and other GHGs, altering the climate.


Outer Space
10 000 km
www.mypytrclass.com
Exosphere
700 km
Thermosphere
80 km
Mesophere
50 km
Stratosphere
12 km
Tropophere
Decresing pressure

Activity 1

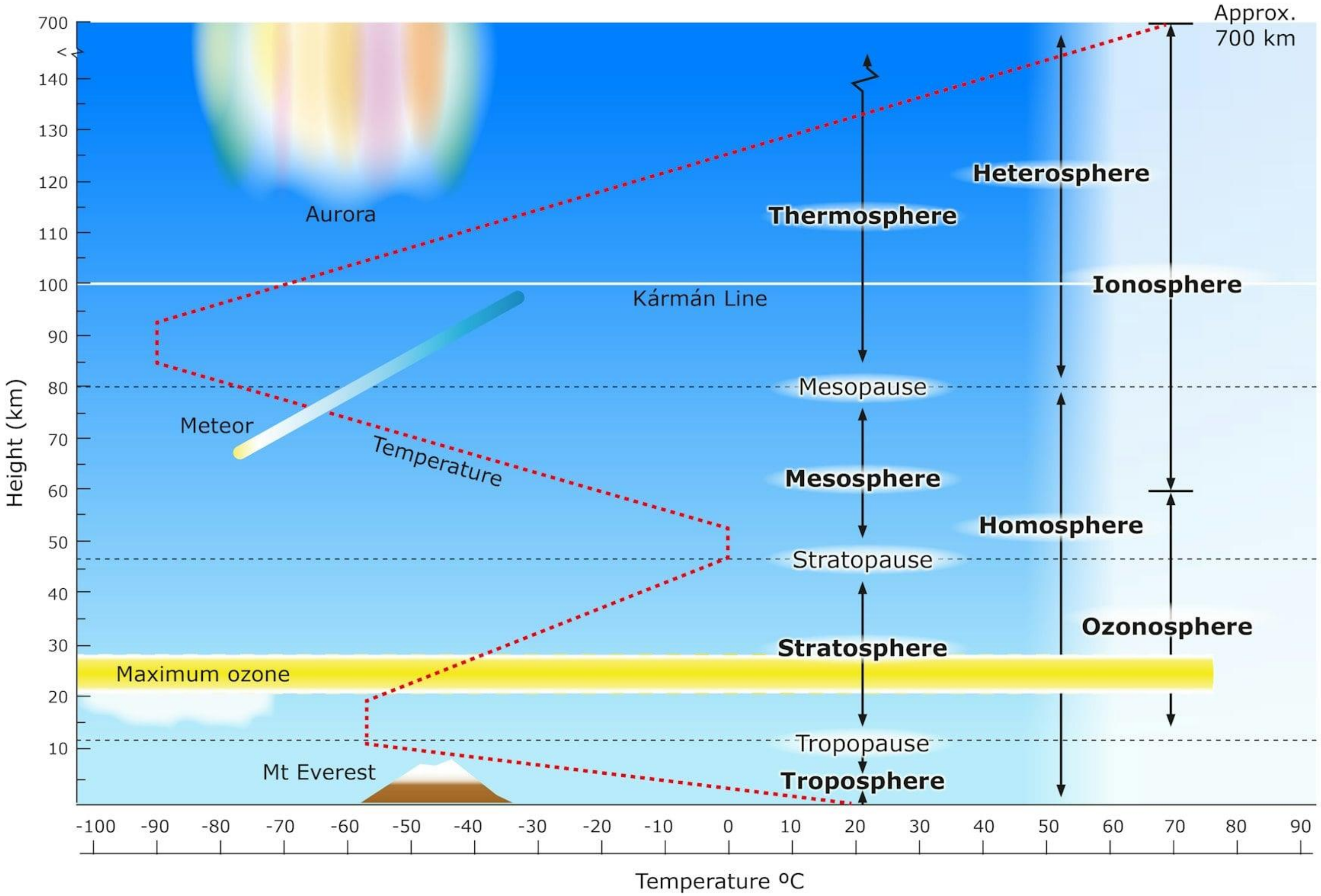
- The atmosphere includes a mixture of gases; these gases are redistributed through physical processes, such as wind. Summarise the air compositions from troposphere and to exosphere using the following table

Altitude (km)	Name of layer	Gasses present						
		N_2	O_2	CO_2	O_3	H_2O (g)	Other pollutants	Other traces

Activity 1 – The air compositions

Altitude (km)	Name of layer	Gasses present						
		N_2 (%)	O_2 (%)	CO_2 (%)	O_3 (%)	H_2O (g)	Other pollutants	Other traces
0–12	Troposphere	78	21	0.04	0.000004	0–4	Smoke, dust, pollutants from humans	Argon ~0.93%, Ne, He, CH_4, Kr, Xe
12–50	Stratosphere	78	21	0.04	0.001–0.01 (ozone layer)	Very low	Volcanic ash, pollutants from stratospheric injection	Argon, Ne, He
50–85	Mesosphere	78	21	0.04	Very low	Negligible	Meteor dust	Argon, He, Ne
85–600	Thermosphere	50–70 (lower)	20–30 (lower)	<0.04	Very low	Negligible	Very low	Atomic O, He, H
600+	Exosphere	Trace	Trace	Trace	Negligible	Negligible	Almost none	H, He dominate

Change in P and T



The Earth's Atmosphere

- **Altitude and life processes**:
  - Atmosphere extends ~1,100 km above Earth's surface.
  - Most life-relevant processes occur in the troposphere (0–10 km) and stratosphere (10–50 km), e.g., ozone formation and cloud development.
- **Geological changes**
  - Atmospheric composition has fluctuated significantly over geological timescales, affecting ecosystems and living organisms.

The Atmosphere as a Dynamic system

- Contains inputs, outputs, storages, and flows that regulate energy and matter.

- Activity 2
  - Draw a system diagram showing 2 flows and 2 transformations in the atmosphere

Redistribution of air and heat

Energy sources for Earth:

- Primary: solar radiation (insolation).
- Local sources:
    - Urban heat islands (localized warming).
    - Geothermal heat in tectonically active areas or thin lithosphere regions.

Driver of atmospheric circulation:

- Unequal solar heating across latitudes.
- Energy surplus between ~38°S and 38°N; energy deficit at higher latitudes.
- Energy transported from low to high latitudes to restore equilibrium.

Link between air circulation and pressure:

- Surface air converges into low-pressure regions → rises → diverges at tropopause.
- High-altitude convergence → air descends → surface high pressure → diverges outward.
- Global wind patterns shaped by spatial distribution of pressure systems and seasonal Sun movement.

Redistribution of air and heat

- Heat and pollutants are transported globally via atmospheric circulation.
- Water vapour content (relative humidity) varies spatially and temporally, influencing weather systems.
- Heat redistribution occurs through tricellular circulation and atmospheric-oceanic interactions.
- Global circulation is driven by uneven solar radiation:
  - Equator receives maximum solar energy.
  - Poles receive less energy, amplified by reflective ice and snow.
  - Circulation prevents extreme temperatures: without it, equatorial regions would be too hot and polar regions too cold.

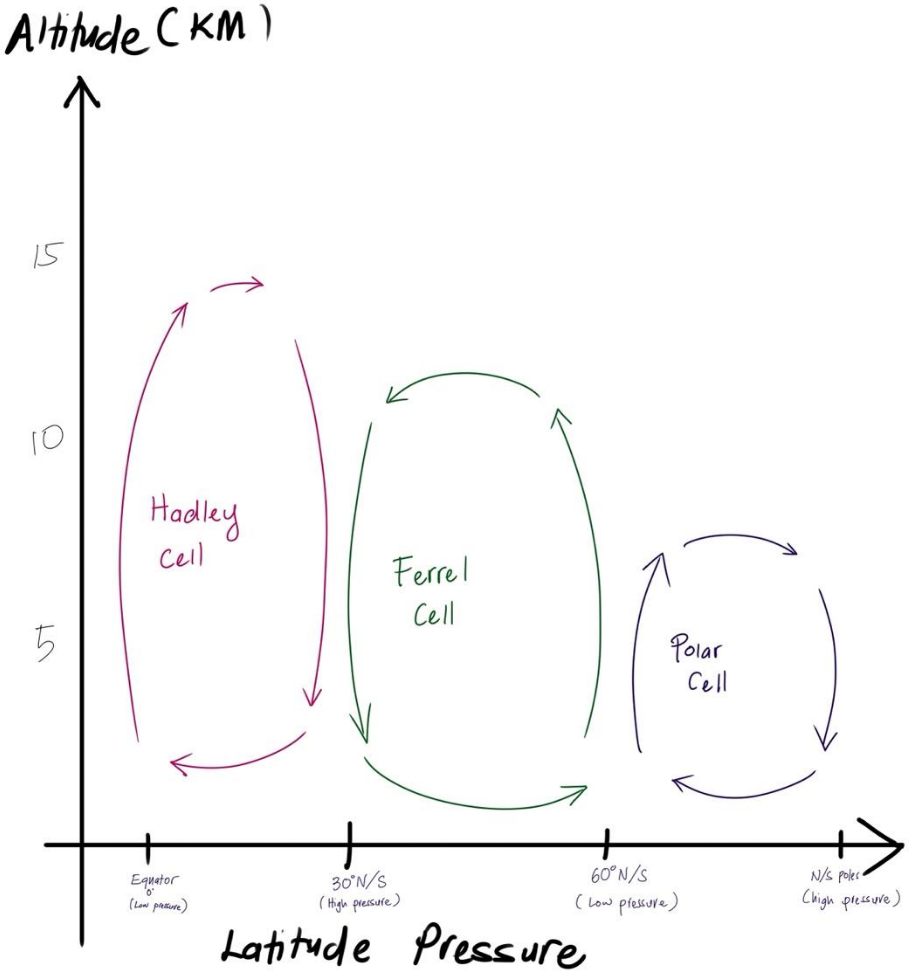
Activty 3

By using an illustration, explain how air and heat are redistributed throughout the Earth's atmosphere using the tricellular air circulation model

Redistribution of air and heat

Tricellular circulation model:

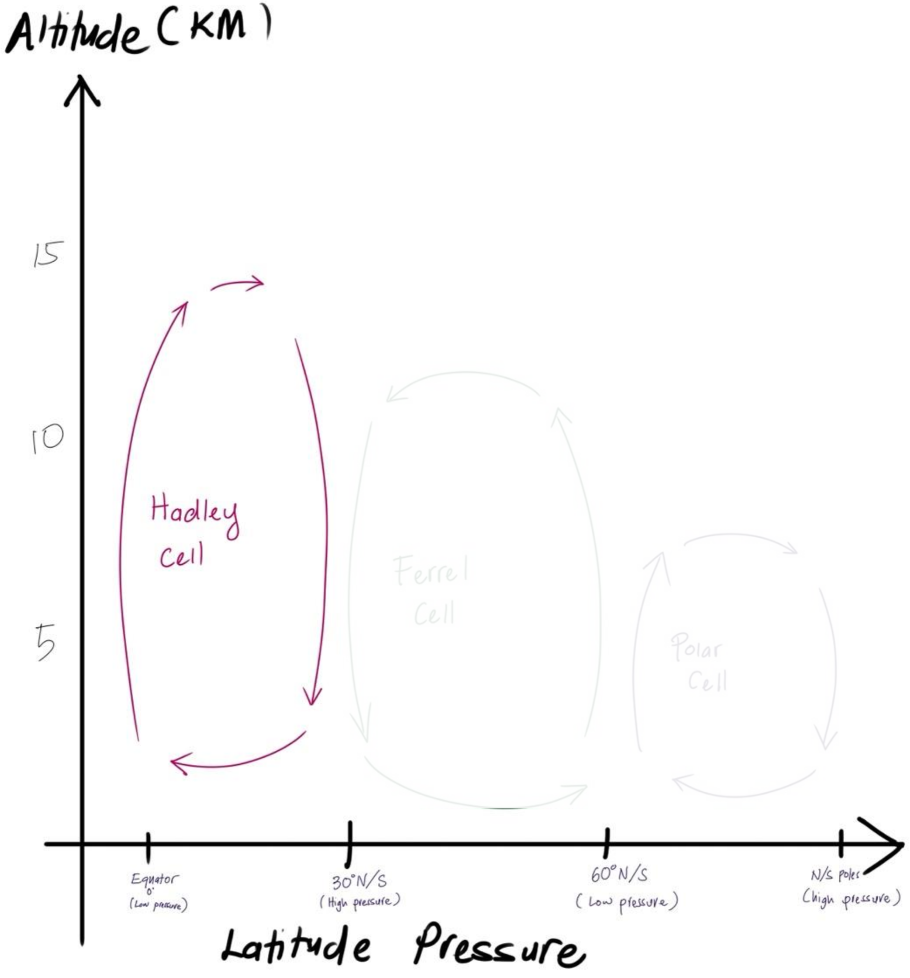
- Comprises Hadley, Ferrel, and Polar cells.
- Conceptual framework for large-scale movement of energy and air across the globe.



Redistribution of air and heat

Equatorial dynamics

- Intense solar heating at equator → air rises → low-pressure zone.
- Air moves poleward, cools, becomes denser → subsides in subtropics (~20–30° N and S) → high-pressure zones.
- Some air returns equatorward → completes **Hadley cell** (convectional circulation).



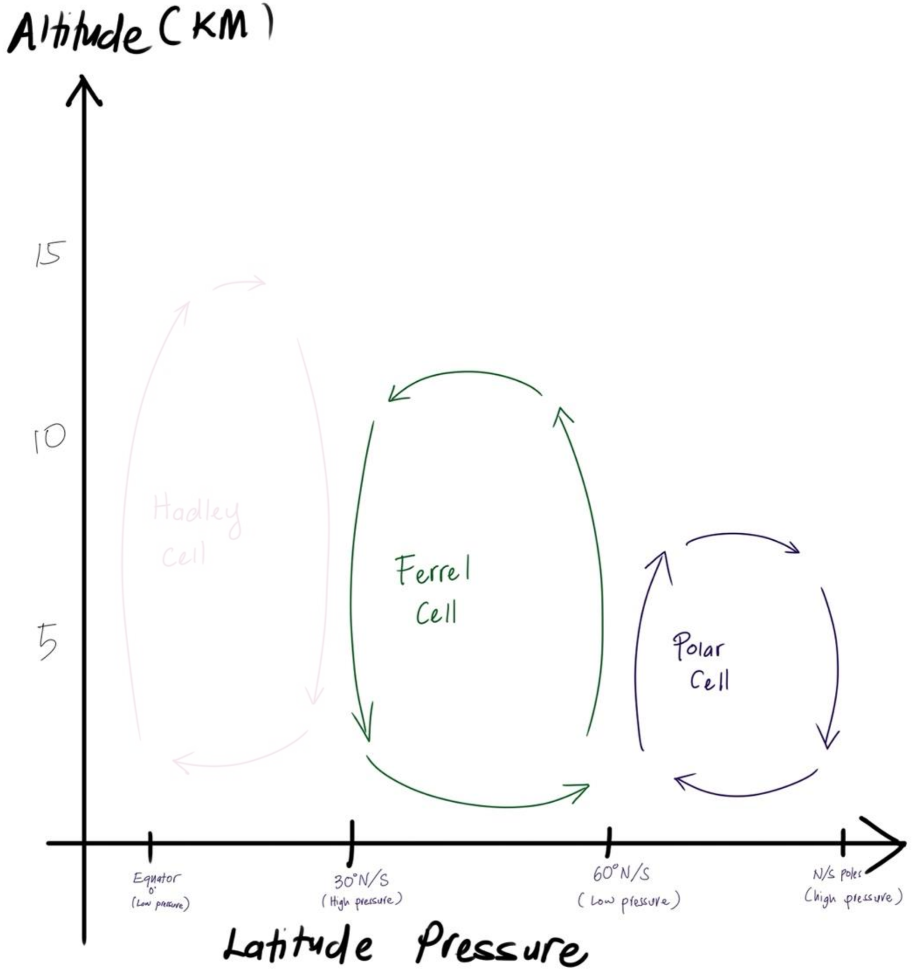
Redistribution of air and heat

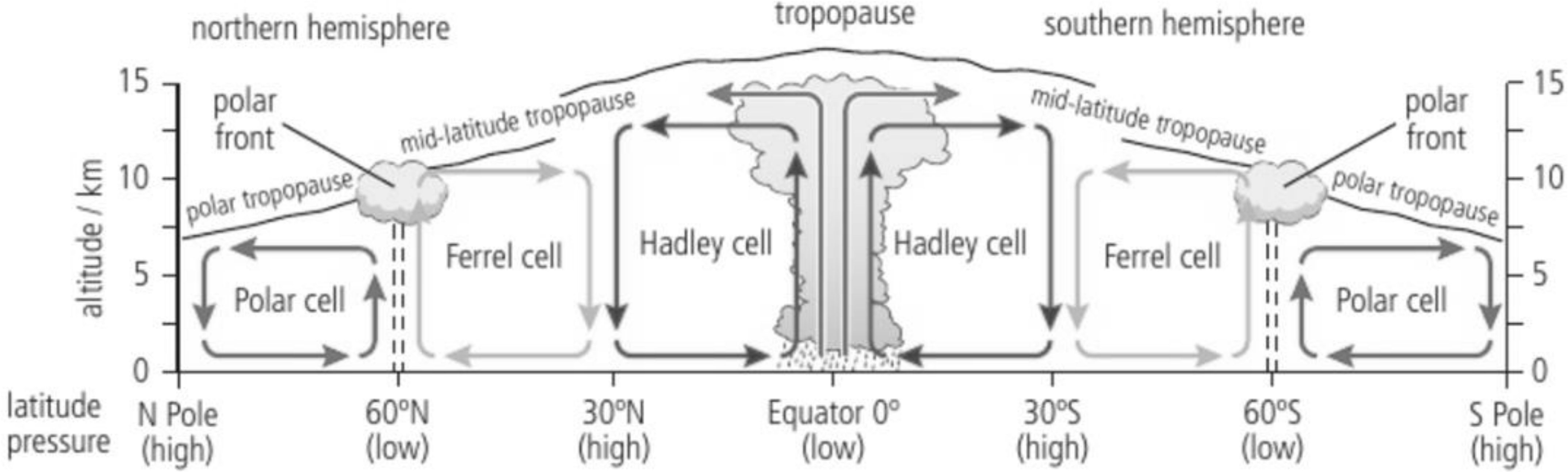
Polar cell

- cold, dense air sinks over poles → polar high pressure → flows equatorward.

Ferrel cell

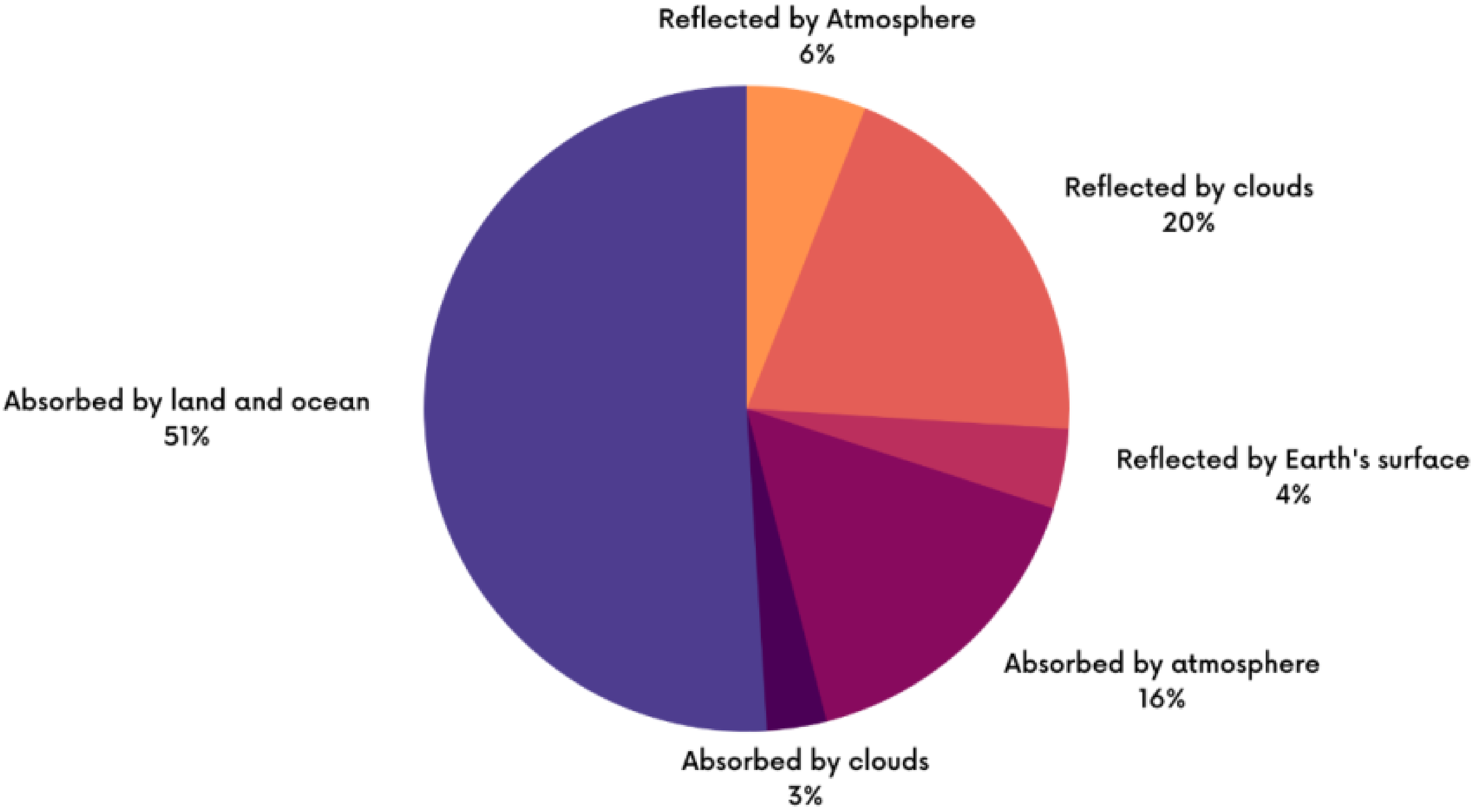
- lies between Hadley and Polar cells, driven indirectly by interactions of adjacent cells.





northern hemisphere
tropopause
southern hemisphere
15
10
5
0
altitude / km
polar front
mid-latitude tropopause
polar tropopause
Polar cell
Ferrel cell
Hadley cell
Hadley cell
Ferrel cell
Polar cell
latitude
pressure
N Pole
(high)
60ºN
(low)
30ºN
(high)
Equator 0°
(low)
30ºS
(high)
60ºS
(low)
S Pole
(high)

Part 2: Energy Budget



Earth's energy budget by percentage. Source: NASA

Energy balance

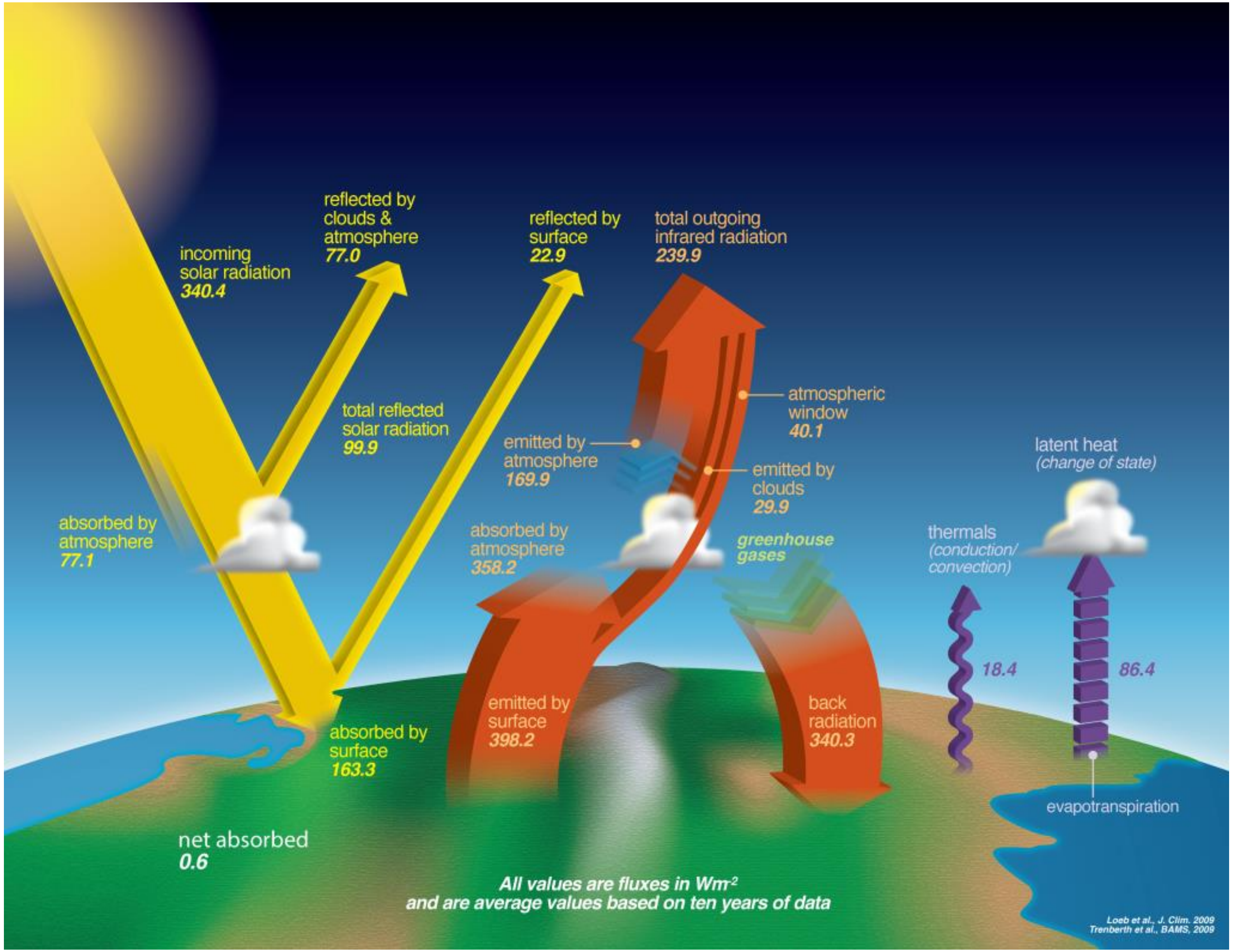
- Earth maintains equilibrium between incoming and outgoing energy at the top of the atmosphere → called the Earth's energy budget or radiation budget.
- Stable global temperatures require incoming energy = outgoing energy.
- Imbalance:
  - Incoming > outgoing → planetary warming.
  - Incoming < outgoing → planetary cooling.

Energy balance

- Incoming solar energy:
  - Primarily shortwave radiation.
  - Mostly visible light, with smaller amounts of ultraviolet (UV) and infrared (IR).
  - Reflection (albedo): ~30% reflected by clouds, aerosols, and Earth's surface.
  - Absorption: ~70% absorbed by the surface and atmosphere.
- Role of absorbed energy:
  - Drives photosynthesis.
  - Heats land and oceans.
  - Powers evaporation.
  - Outgoing radiation:
  - Warmed surface emits longwave (infrared) radiation back toward space.

Energy balance

- Greenhouse effect:
  - Greenhouse gases (GHGs) absorb and re-emit some outgoing longwave radiation back to the surface → called back radiation.
  - Enhances surface warming.
  - Critical in regulating Earth's climate system.



The Earht's energy budget. Source: NASA

Activity 4

Identify the roles or functions of the following atmospheric gasses:

a) Nitrogen

b) Oxygen

c) Carbon dioxide

d) Water vapour

e) Methane

f) Ozone

Part 3: Greenhouse Gasses and Aerosols

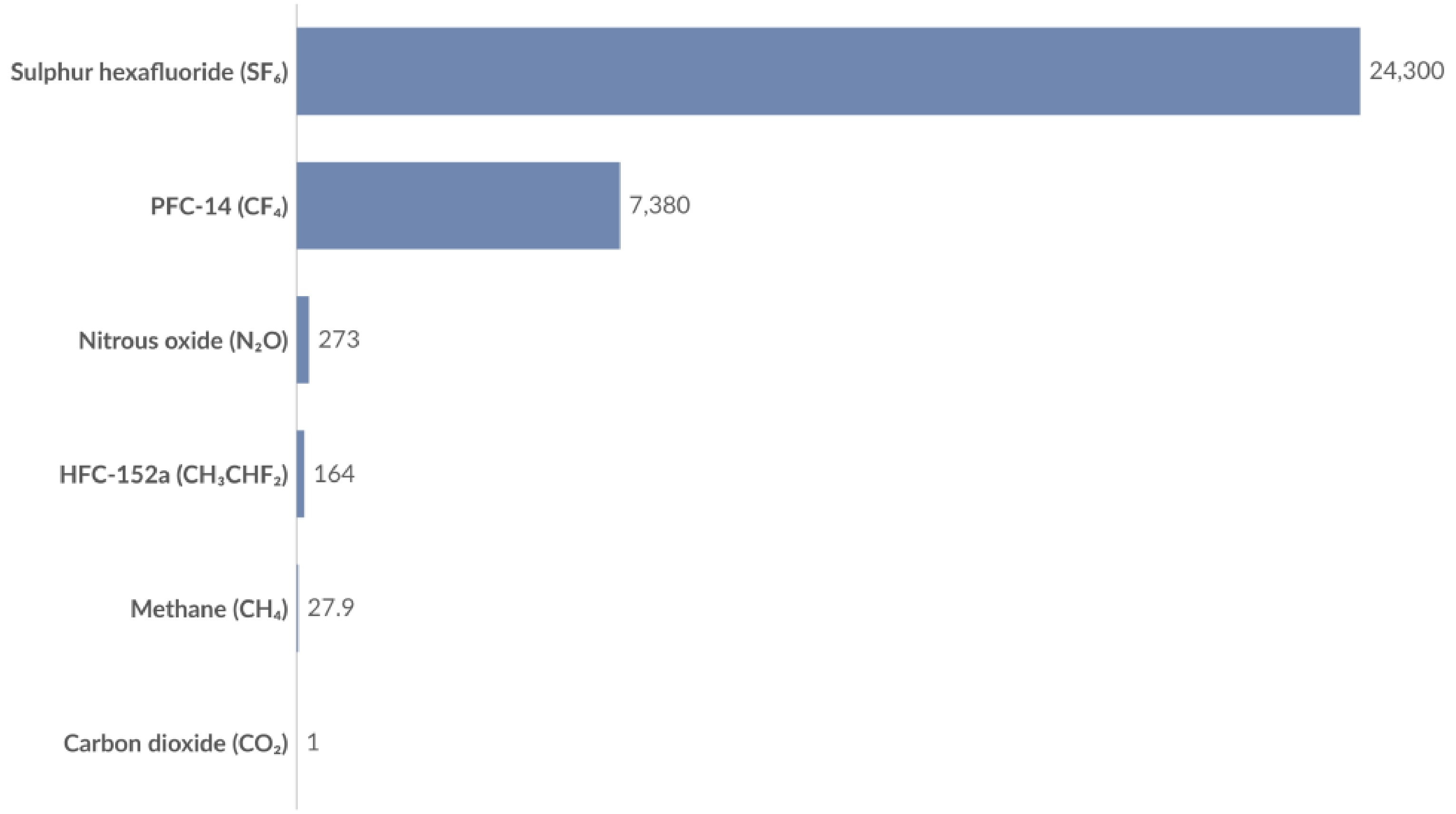
Roles of GHGs and aerosols

- Warming effects:
  - Allow incoming shortwave solar radiation to pass.
  - Absorb outgoing longwave radiation, contributing to warming.
- Cooling effects:
  - Primarily from aerosols (e.g., sulphur emissions from human activities).
  - Reduce the proportion of solar radiation reaching Earth → local/regional cooling.
  - Can increase cloud cover → reflect more sunlight → phenomenon called global/regional dimming.

Global warming potential of greenhouse gases relative to CO2

Our World in Data

Global warming potential[1] measures the relative warming impact of one unit mass of a greenhouse gas relative to carbon dioxide over a 100-year timescale.



Data source: IPCC (2021)

1. Global warming potential Global warming potential (GWP) measures the amount of heat absorbed by a greenhouse gas relative to the same mass of carbon dioxide (CO_2). It measures the amount of warming a gas creates compared to CO_2.
Carbon dioxide is given a GWP value of one. If a gas had a GWP of 10 then one kilogram of that gas would generate ten times the warming effect as one kilogram of CO_2.
Since greenhouse gases spend different amounts of time in the atmosphere, their global warming potential depends on the length of time that it's measured over. For example, GWP can be measured as the warming effect over 20 years, 50 years, or 100 years.
Potent but short-lived greenhouse gases – like methane, for example – will have a higher GWP when measured over 20 years than over 100 years.
The GWP value for methane over 100 years (GWP100) is 28. This means one kilogram of methane would cause 28 times the warming of one kilogram of CO_2.

Major GHGs (although low potential):

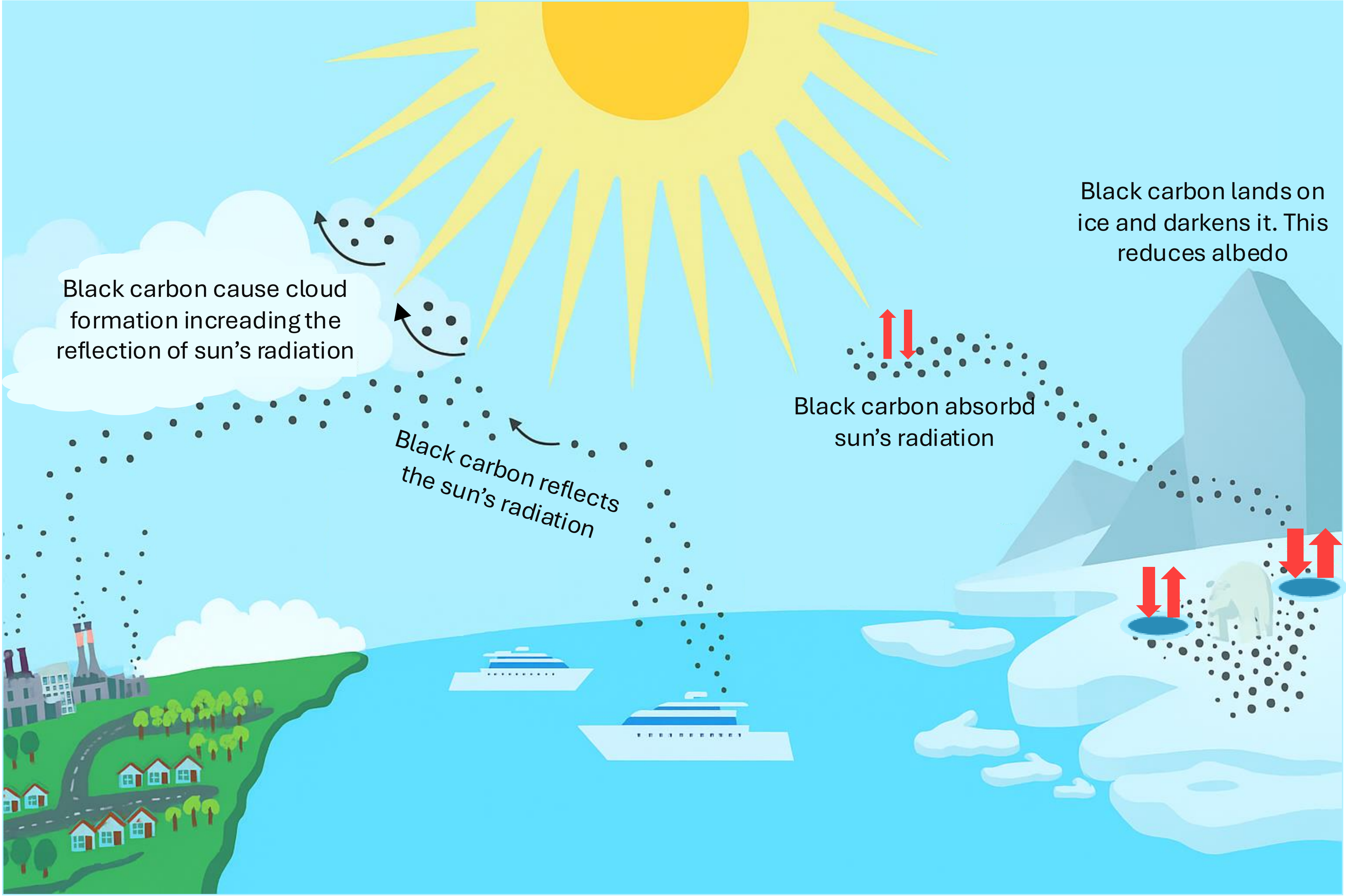
- Water vapour (H_2O)
- Carbon dioxide (CO_2)
- Tropospheric ozone (O_3)
- Methane (CH_4)
- Nitrous oxide (N_2O)

Black Carbon (Aerosol)

- **Sources:**
  - Biofuels: ~20% of global emissions
  - Fossil fuels: ~40%
  - Open biomass burning (savannahs, rainforests): ~40%
- **Properties:**
  - Fine particulate matter < 2.5 μm in diameter.
  - Short atmospheric lifetime: days to weeks, removed by precipitation.

Climate Effects of Black Carbon

- Direct effects:
  - Absorbs sunlight in the atmosphere → reduces albedo.
- Semi-direct effects:
  - Alters atmospheric stability and cloud cover by absorbing solar radiation.
- Snow and ice albedo effects:
  - Deposition on snow and ice lowers albedo → positive feedback loop:
    - Surface warming → accelerated ice melt → further albedo reduction.
- Indirect effects:
  - Changes cloud properties → influence absorption and reflection of solar radiation.
- Significance:
  - Combined direct and indirect snow–albedo effects → third largest contributor to positive radiative forcing since pre-industrial times (IPCC).
  - Key driver of Arctic ice melt.
  - Soot deposition on snow may account for up to 25% of observed global warming.



Black carbon cause cloud formation increading the reflection of sun's radiation
Black carbon reflects the sun's radiation
Black carbon absorbd sun's radiation
Black carbon lands on ice and darkens it. This reduces albedo

Activity 5

Outline positive and negative feedback loops involving aerosols

Positive feedback loop	Negative feedback loop

Part 4: The Greenhouse Effect

How Essential Greenhouse Effect is?

- Definition:
  - Natural process where greenhouse gases and aerosols absorb and re-emit longwave infrared (IR) radiation from Earth's surface.
  - Traps heat in the atmosphere → warms the planet.
- Importance for life:
  - Without it, Earth's average surface temperature would be ~–18 °C instead of ~15 °C.
  - Essential for maintaining habitable conditions.

The Greenhouse Effect

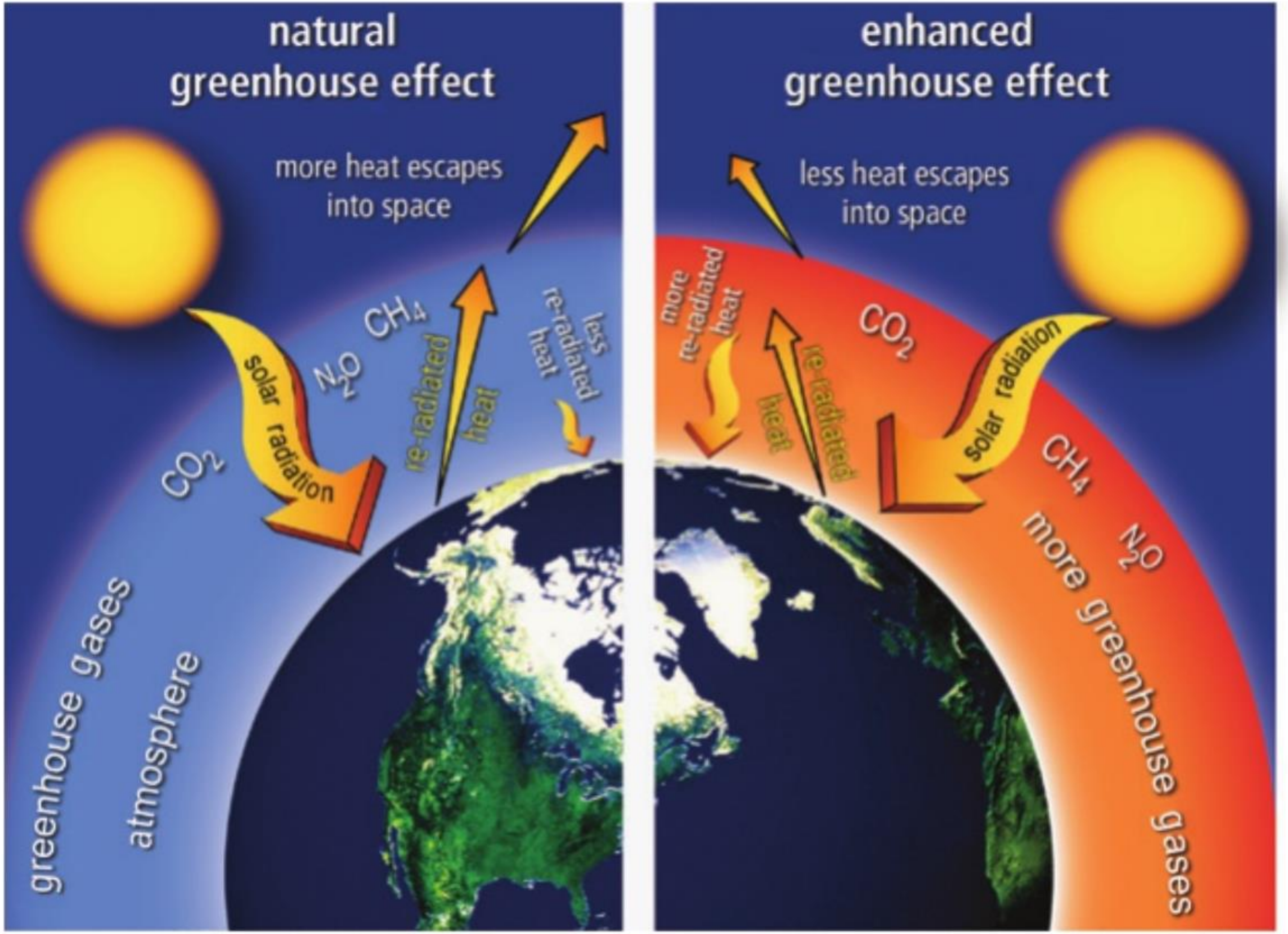
- O_2 and N_2: Majority of the atmosphere; do not absorb or emit longwave radiation.
- Greenhouse gases:
  - Water vapour (H_2O)
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous oxide (N_2O)
  - Ozone (O_3)
- These GHGs act as a thermal blanket by absorbing and re-radiating terrestrial radiation → natural greenhouse effect.
- Persistent feature of Earth's climate history.

Enhanced greenhouse effect (anthropogenic):

- Caused by human activities
  - fossil fuel combustion, industrial processes, land-use changes.
- Increases GHG concentrations → raises global temperatures above natural baseline.
- Leads to global warming, climate change, or climate crisis.
- Contribution of gases:
  - CO_2: Most significant due to high concentration and long atmospheric lifetime.
  - Other gases (CH_4, N_2O, tropospheric O_3): Important; combined effect ≈ 60% of CO_2's radiative forcing.

Activity 6

Explain greenhouse effect using a diagram


natural
greenhouse effect
more heat escapes
into space
solar radiation
re-radiated heat
less re-radiated heat
CO_2
N_2O
CH_4
greenhouse gases
atmosphere
enhanced
greenhouse effect
less heat escapes
into space
more re-radiated heat
re-radiated heat
solar radiation
CO_2
CH_4
N_2O
more greenhouse gases