Cambridge AS & A Level · Geography 9696 · Notes

Atmosphere and weather AS

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What you need to know

By the end of this topic you should be able to:

1. **Explain the diurnal (24-hour) energy budget.** By day: incoming (shortwave) solar radiation, reflected solar radiation, energy absorbed into the surface and subsurface, sensible heat transfer, longwave radiation and latent heat transfer by evaporation. At night: longwave radiation, latent heat transfer as dew forms, sensible heat transfer and absorbed energy returned to the surface. Explain how **albedo** controls how much energy a surface takes in.
2. **Explain the global energy budget.** Why low latitudes have a radiation **excess** and high latitudes a **deficit**; how **wind belts** and **ocean currents** move energy from one to the other; and why temperature, pressure and wind belts change with the seasons, through latitude, the distribution of land and sea, and ocean currents.
3. **Explain weather processes.** The changes of state of water in the air (evaporation, condensation, freezing, melting, deposition, sublimation); the causes of precipitation (convection, frontal uplift, orographic uplift and radiation cooling); and how clouds, rain, hail, snow, dew and fog form.
4. **Explain the human impact on the atmosphere.** The enhanced greenhouse effect and global warming: the evidence for it, its possible causes (human and natural) and its atmospheric impacts.
5. **Use an urban climate case study.** One urban area, showing how human activity changes its temperature (the **urban heat island**), humidity, precipitation and winds.

It is examined in Paper 1: a compulsory 10-mark resource question (Question 2) and an optional 30-mark structured question (Question 5).

Understand it

Shortwave in, longwave out

All the energy that drives weather comes from the Sun. The Sun is very hot, so it gives out **shortwave** radiation (mostly visible light). The Earth's surface and atmosphere are much cooler, so they give out **longwave** (infrared) radiation, which we feel as heat. Keep the two apart: the atmosphere lets most shortwave radiation through, but water vapour, carbon dioxide and clouds absorb much of the longwave radiation the ground gives off.

Of the solar radiation arriving at the top of the atmosphere, about 30% is reflected straight back to space (mostly by clouds), about 20% is absorbed by gases, dust and clouds, and about half is absorbed by the surface. Radiation that is absorbed warms whatever absorbs it, which then gives the energy out again as longwave radiation.

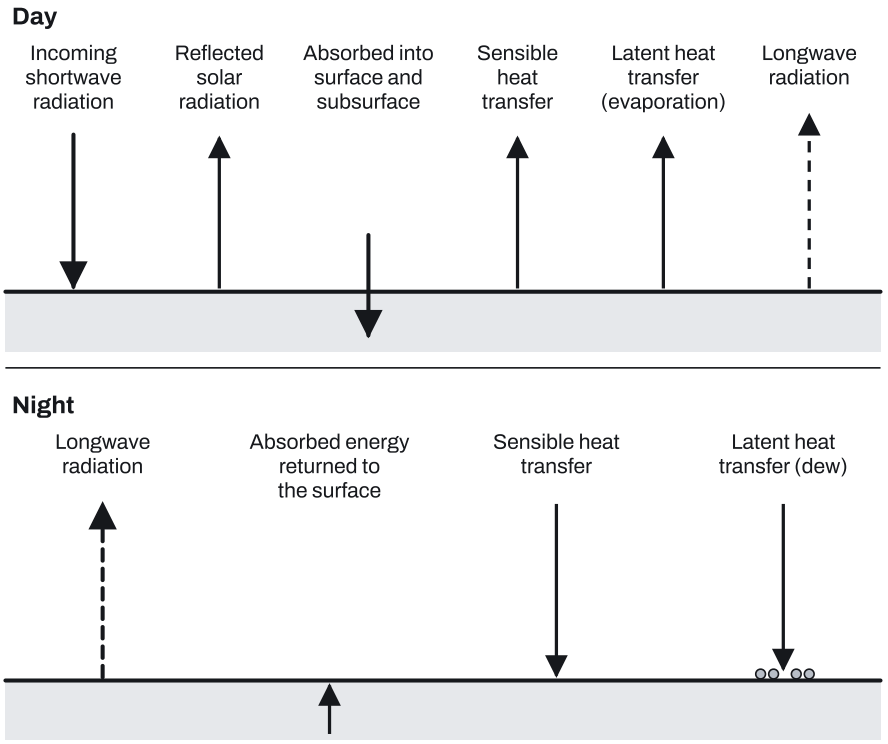
Albedo is the proportion (usually given as a percentage) of incoming solar radiation that a surface reflects. A high albedo means the surface reflects a lot and absorbs little, so it stays cooler.

Surface	Albedo (%)
Fresh snow	80–90
Thick cloud	60–90
Desert sand	30–40
Grass	20–25
Deciduous forest	15–20
Coniferous forest	5–15
Tarmac	5–10
Sea, with a high sun	5–10
Earth as a whole	about 30

Light, smooth, dry surfaces have high albedos; dark, rough or wet ones low albedos. Water's albedo rises when the sun is low, because light glances off it. If 800 W/m² of sunlight reaches grass with an albedo of 25%, the grass reflects 200 W/m² and absorbs 600 W/m²; fresh snow at 85% reflects 680 W/m² and absorbs only 120 W/m².

The diurnal energy budget

The **diurnal energy budget** tracks the energy arriving at and leaving a small area of the ground's surface through a day and a night. Its components are the arrows in the diagram.



By day (six components):

1. **Incoming (shortwave) solar radiation**: the energy input. It is greater with a high sun (low latitude, summer, midday) and clear skies; clouds, dust and pollution reflect and absorb part of it on the way down.
2. **Reflected solar radiation**: set by the surface's albedo. Reflected radiation is still **shortwave**; it is not absorbed, so it does not warm the surface.
3. **Surface absorption**: the energy absorbed into the surface and conducted down into the **subsurface** (soil, rock, buildings). Surfaces that conduct heat well (wet soil, rock, concrete) carry energy down and store it; poor conductors (dry sand, snow) keep it in a thin hot top layer.
4. **Sensible heat transfer**: heat moved from the warm surface into the air by conduction and then **convection**, as warm air rises in pockets and cooler air replaces it. It changes the air's temperature; you can feel it.
5. **Latent heat transfer (evaporation)**: where there is water, some of the incoming energy is used up turning that water into vapour, so less is left to warm the ground. The energy is stored in the water vapour and released when it condenses later. Moist surfaces (wet soil, forests, lakes) stay cooler than dry ones for this reason.
6. **Longwave radiation**: the warm surface gives off longwave radiation all the time. Part goes to space; much is absorbed by water vapour, carbon dioxide and clouds, which send some back down.

The energy left over after reflection, longwave loss, sensible and latent heat transfer is what heats the ground, so the surface warms through the morning and is hottest in the early afternoon.

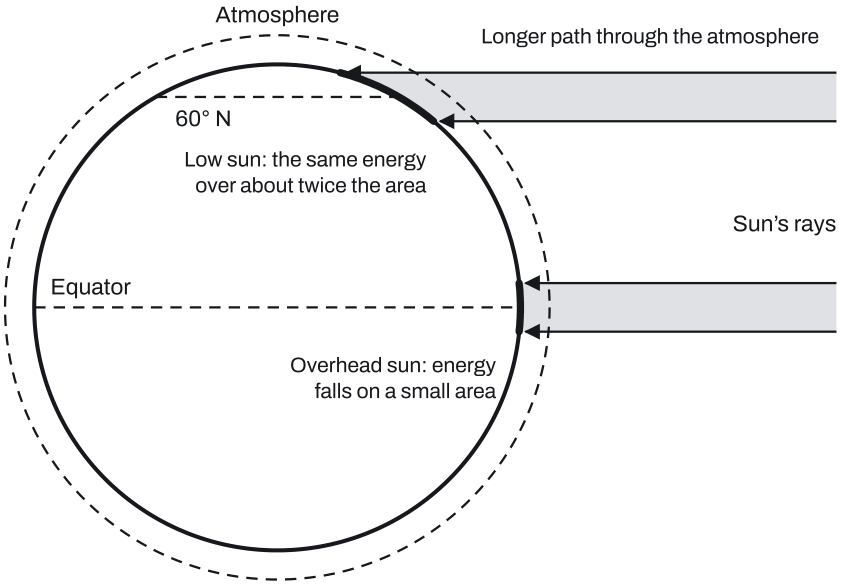
At night (four components): with no incoming solar radiation and no reflection, albedo plays no part.

1. **Longwave radiation**: the surface loses heat by longwave radiation and cools. This is greatest on **clear, calm nights**, when nothing sends the radiation back; clouds act as a blanket and keep nights mild.

2. **Absorbed energy returned to the surface**: heat stored in the subsurface by day flows back up to the cooling surface, slowing its cooling. Concrete, rock and wet soil store a lot; dry sand stores little, which is why deserts get so cold at night.
3. **Sensible heat transfer**: if the air is warmer than the cold surface, heat moves from the air to the ground; wind brings in more warm air and stops the surface cooling as much.
4. **Latent heat transfer (dew)**: as the surface cools to the dew point, water vapour condenses on it as dew and releases latent heat, which slows further cooling.

The global energy budget: radiation excess and deficit

Over a year, the Earth as a whole gives out as much energy as it receives, so its average temperature stays steady (apart from global warming). But latitudes differ.

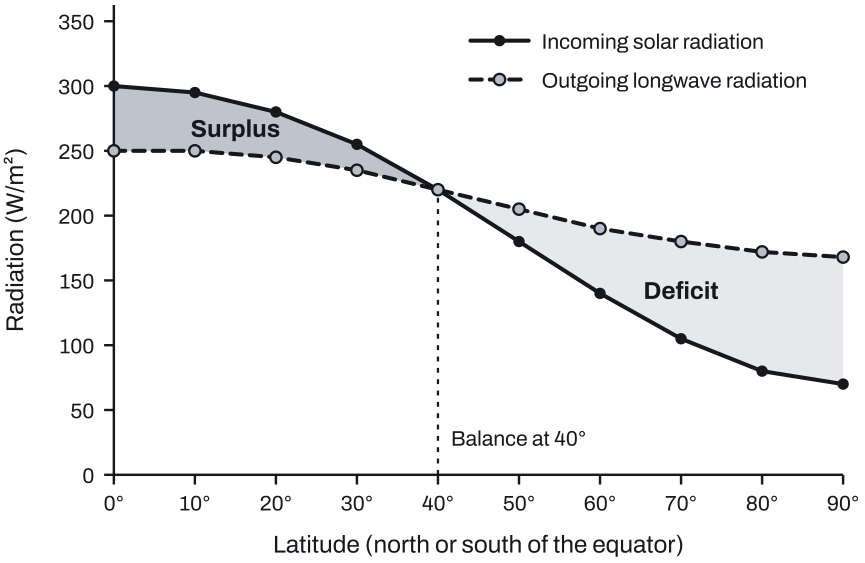


Low latitudes receive more incoming solar radiation because:

- **the angle of the sun's rays is high.** Near the equator the noon sun is overhead or nearly so, and the energy in a beam falls on a small area. At an equinox the noon sun is only 30° above the horizon at 60° N, so the same beam is spread over twice the area ($1 \div \sin 30^\circ = 2$) and each square metre gets half as much;
- **the rays pass through less atmosphere.** A low sun's rays take a longer, slanting path through the air, so more is scattered, absorbed and reflected by gases, dust and cloud before reaching the ground;
- **day length and the seasons.** Near the equator days are about 12 hours long all year. Because the Earth's axis is tilted (23.5°), high latitudes have long summer days but months of little or no sun in winter;
- **albedo.** Snow and ice at high latitudes reflect most of what does arrive.

It is not distance from the Sun. The Sun is about 150 million km away, so the poles are no further from it than the equator in any way that matters. The Earth is actually closest to the Sun in early January, during the northern winter.

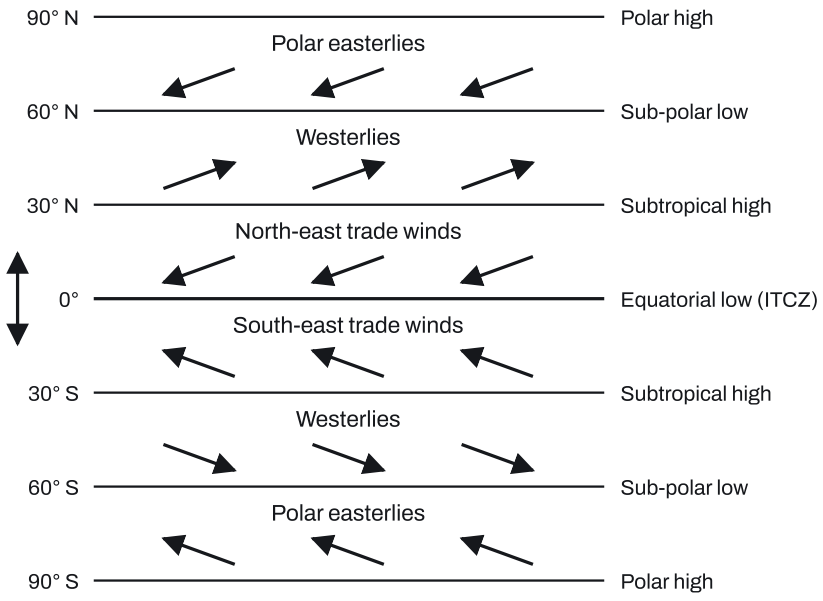
Outgoing longwave radiation also falls towards the poles, because colder surfaces give out less, but it changes much less than the incoming radiation.



So between the equator and about 40° N and S there is a **radiation surplus** (excess): more energy comes in than goes out. Poleward of about 40° there is a **radiation deficit**. At the equator the surplus is $300 - 250 = 50$ W/m²; at 80° the deficit is $172 - 80 = 92$ W/m². Yet the tropics do not get hotter every year and the poles colder, because **energy is moved poleward**, mostly by the atmosphere (winds) and the rest by ocean currents.

Atmospheric transfers: wind belts and ocean currents

Wind belts are bands of wind that blow from a fairly constant direction over a wide area for long periods. They exist because air moves from **high pressure** (where air sinks) to **low pressure** (where air rises), and the Earth's spin deflects it (the **Coriolis effect**: to the right in the northern hemisphere, to the left in the southern).



The belts shift north in June–July and south in December–January

The pattern comes from the **three-cell (tricellular) model**:

- **Hadley cell (0–30°)**: strong heating at the equator makes air rise, giving the **equatorial low**, where the trade winds meet: the **inter-tropical convergence zone (ITCZ)**. Rising air cools, giving heavy convectional rain. At height it flows poleward, cools and sinks at about 30°, giving the dry **subtropical highs** (the hot deserts). Surface air returns to the equator as the **trade winds**.
- **Ferrel cell (30–60°)**: surface air flows poleward from the subtropical highs as the **westerlies**.
- **Polar cell (60–90°)**: cold, dense air sinks at the poles (**polar high**) and flows out as the **polar easterlies**. Where they meet the warmer westerlies at about 60° (the **polar front**), air rises, giving the **sub-polar low** and its depressions.

How the winds move energy:

- They carry **sensible heat**: the westerlies carry warm subtropical air poleward, and the polar easterlies carry cold air towards the equator.
- They carry **latent heat**: the trade winds pick up water vapour evaporated from warm tropical seas, and the energy is released where it condenses into cloud and rain, often far away. Tropical cyclones are very powerful carriers of heat out of the tropics.
- High in the atmosphere, fast **jet streams** follow wave-shaped paths around the globe (**Rossby waves**). The waves carry warm air poleward and cold air equatorward and steer the depressions of the mid-latitudes.

Ocean currents are large, steady movements of surface water, driven mainly by the prevailing winds and turned by the Coriolis effect into great loops (gyres). **Warm currents** carry heat from the tropics towards the poles along the western sides of oceans, such as the Gulf Stream and its extension, the **North Atlantic Drift**. **Cold currents** return cold water towards the equator along the eastern sides, such as the **California**, **Benguela** (south-west Africa) and **Peru** currents. Air moving across a current is warmed or chilled, and

moistened, by the water beneath it, and onshore winds then bring that air over the coast. Deep down, the **ocean conveyor belt** (thermohaline circulation) moves water and heat slowly around all the oceans: cold, salty water sinks in the North Atlantic and returns to the surface elsewhere centuries later.

Winds carry most of the energy outside the tropics; close to the equator ocean currents carry a large share.

Seasonal variations in temperature, pressure and wind belts

Latitude and the overhead sun. The overhead (noon) sun moves between the Tropic of Cancer (23.5° N, about 21 June) and the Tropic of Capricorn (23.5° S, about 21 December). The zone of strongest heating follows it, so the ITCZ and the pressure and wind belts move north in the northern summer and south in the northern winter, a month or so behind the sun. Places near the edges of the belts change seasons: the Sahel gets rain only in summer, when the ITCZ reaches it, and the Mediterranean has hot dry summers when the subtropical high moves over it and wet winters when the westerlies return. Seasonal temperature differences are small near the equator (the sun is always high) and large at high latitudes (long summer days against dark winters).

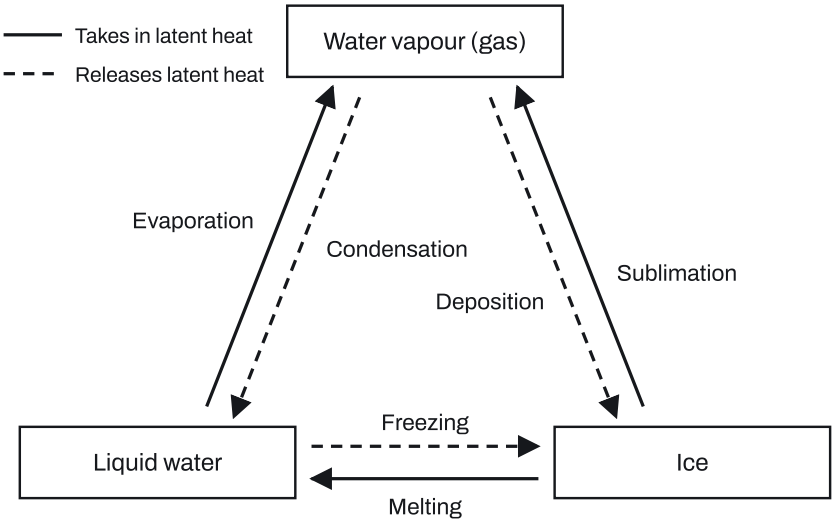
Land and sea distribution. Water has a much higher **specific heat capacity** than rock and soil (about four to five times), so it needs much more energy to warm by 1 °C. The sea also lets the sun's energy penetrate several metres, mixes it through a deep layer, and uses energy to evaporate. So **the sea heats and cools slowly; land heats and cools quickly**.

- In summer, land is hotter than the sea at the same latitude; in winter it is colder. Coasts have mild winters and cool summers (a **maritime** climate); continental interiors have hot summers and very cold winters (a **continental** climate). On maps, **isotherms** bend poleward over the continents in summer and equatorward in winter.
- Pressure follows temperature: in summer, hot continents develop **thermal low pressure** as warm air rises; in winter, cold continents develop **high pressure** as cold, dense air sinks, such as the Siberian high. Over the sea the pattern reverses.
- These changes shift the belts further over land than over sea. The ITCZ reaches about 20–25° N over South Asia in July but stays a few degrees from the equator over the oceans. This drives the **South Asian monsoon**: a summer low over northern India draws in moist south-west winds and heavy rain; in winter, high pressure over the cold interior sends dry north-east winds out.

Ocean currents. A coast beside a warm current has warmer winters than other places at its latitude; a coast beside a cold current has cooler summers. Thanks to the North Atlantic Drift, Bergen in Norway (60° N) has January averages a little above 0 °C, while Churchill on Canada's Hudson Bay (59° N) averages below –20 °C. Cold currents keep coasts cool and dry, such as the Namib Desert beside the Benguela Current. The effect is strongest on west coasts in the mid-latitudes, where the westerlies blow the ocean's influence inland.

Moisture in the atmosphere: changes of state

Water exists in the air as a gas (**water vapour**), a liquid (droplets) and a solid (ice crystals). Each change of state takes in or gives out **latent heat**, energy that changes the state without changing the temperature.

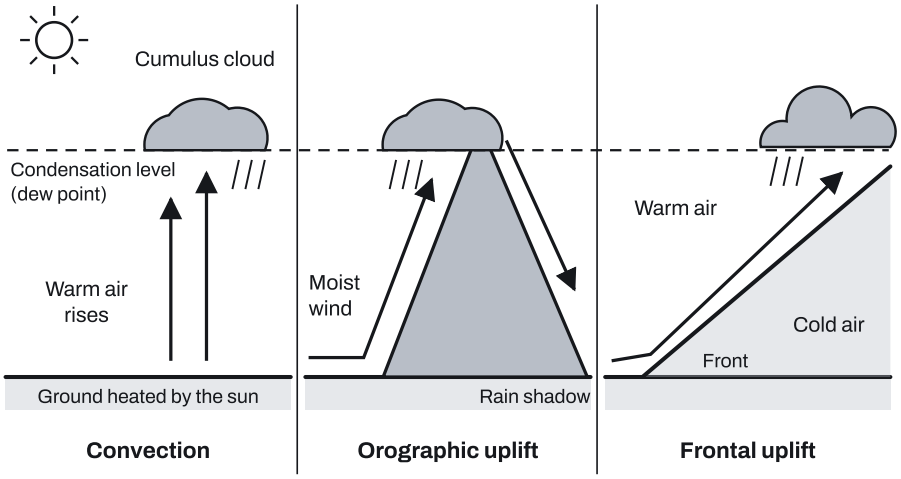


- **Evaporation**: liquid water changes to water vapour when heat is added. It is fastest with high temperatures, dry air, wind (which carries the moist air away) and plenty of water. It takes in latent heat, so it cools the surface.
- **Condensation**: water vapour changes to liquid droplets when air is **cooled to its dew point**, the temperature at which it becomes **saturated**. In the air, droplets form on tiny **condensation nuclei** (dust, salt, smoke); on the ground, as dew. It releases latent heat.
- **Freezing**: liquid water changes to ice when cooled below 0 °C. Cloud droplets often stay liquid far below 0 °C (**supercooled** droplets) until they touch an ice crystal or a nucleus. It releases latent heat.
- **Melting**: ice changes to liquid when warmed above 0 °C. It takes in latent heat.
- **Sublimation**: ice changes straight to water vapour without becoming liquid first (mark schemes also accept the reverse). It takes in latent heat.
- **Deposition**: water vapour changes straight to ice on a surface or a nucleus, such as hoar frost on a cold night. It releases latent heat.

Air can hold more water vapour the warmer it is. **Relative humidity** is how much it holds compared with the most it could hold at that temperature; at 100% the air is saturated.

Why air rises: the causes of precipitation

Air cools when it rises, because pressure falls with height, so the air expands, and expanding air cools (**adiabatic cooling**), by roughly 10 °C for every 1000 m while it is unsaturated. If it cools to its dew point, condensation forms cloud; the latent heat released keeps the air warmer than its surroundings, so it keeps rising. Inside the cloud, droplets collide and **coalesce** (or ice crystals grow) until they are heavy enough to fall as precipitation. Every cause of precipitation is a way of making moist air rise and cool, except radiation cooling.



- **Convection.** The sun heats the ground strongly; the air above it warms, expands, becomes less dense and rises in **thermals**. It cools to dew point, building **cumulus** clouds and, with strong heating and moist air, towering **cumulonimbus** clouds with heavy afternoon showers and thunderstorms. Typical of equatorial regions all year (Singapore has frequent afternoon thunderstorms), continental interiors in summer, and cities, whose heat island adds to the heating.
- **Orographic (relief) uplift.** A moist wind meets a mountain barrier and is forced to rise up the **windward** slope; it cools, condenses and gives cloud and heavy rain. Having lost much of its moisture, the air sinks down the **leeward** slope and warms adiabatically, so it is dry: a **rain shadow**. In New Zealand, the westerlies give Milford Sound, on the windward side of the Southern Alps, about 6700 mm of rain a year, while Christchurch, in the rain shadow, gets about 600 mm.
- **Frontal uplift.** Where a warm air mass meets a cold one, the warm, less dense air is forced to rise over the cold air along a **front**. At a **warm front**, warm air rises gently over cold air, giving a wide belt of layer cloud (nimbostratus) and long periods of steady rain. At a **cold front**, cold air undercuts the warm air and pushes it up steeply, giving cumulonimbus, short heavy showers and sometimes hail. Fronts form in the **depressions** of the mid-latitudes, such as those crossing the UK and New Zealand on the westerlies.
- **Radiation cooling.** On clear, calm nights the ground loses heat by longwave radiation and cools the air touching it (by conduction) to its dew point, without the air rising. This gives dew, frost and radiation fog, but not heavy precipitation.

Often several causes work together: monsoon rain on the Western Ghats of India is both convectional and orographic, and a front crossing mountains gives far more rain than either alone.

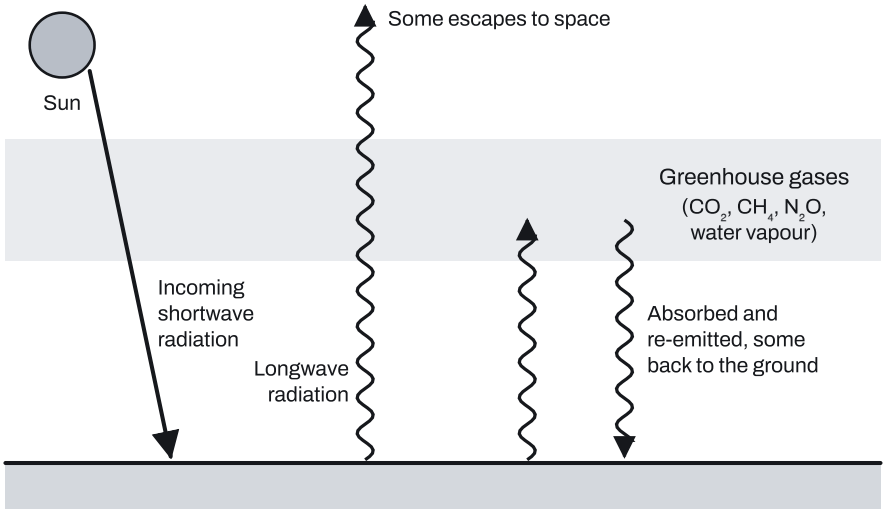
Clouds, rain, hail, snow, dew and fog

- **Clouds** are visible masses of tiny water droplets or ice crystals suspended in the air, formed when air cools to its dew point and the vapour condenses on nuclei. **Cumulus** (heaped) form in rising thermals; **stratus** (layered) form where a wide sheet of air rises gently or is cooled from below; **cirrus** (wispy) are high ice clouds; **cumulonimbus** are thunderstorm clouds that can reach 10 km or more.
- **Rain**: cloud droplets are far too small to fall. In warm clouds they grow by colliding and coalescing until heavy enough to fall. In clouds that reach below freezing, ice crystals grow (below), fall, and melt into raindrops on the way down.

- **Hail**: forms in **cumulonimbus** clouds with strong **updraughts**. An ice pellet starts where an updraught lifts a droplet into air colder than 0 °C. As it moves through the cloud it meets **supercooled** droplets (liquid water below 0 °C), which turn to ice the moment they touch it (**accretion**). The pellet is swept up and down many times, so it grows in shells, like the layers of an onion. Once it is heavier than the updraught can support, it drops out of the cloud as hail, too large to melt on the way down.
- **Snow**: needs moisture and cold. In the part of a cloud colder than 0 °C, vapour turns directly into tiny ice crystals, which form among supercooled droplets. The crystals grow by drawing vapour from the droplets, and many join to form a flake. A flake heavy enough to fall arrives as snow if the air beneath the cloud is about 0 °C or colder. If that air is a little warmer, flakes start to thaw, become sticky and clump into big, wet flakes; if it is much warmer, they thaw completely and land as rain.
- **Dew**: water droplets that condense directly onto cold surfaces such as grass, when clear, calm nights let the surface cool to the dew point by radiation. If the dew point is below 0 °C, vapour turns straight to ice by deposition, giving hoar frost.
- **Fog**: cloud at ground level, which cuts visibility below 1 km. Air near the ground is cooled to its dew point, or more moisture is added to it, and droplets condense on nuclei.
  - **Radiation fog**: on clear, calm nights (often under anticyclones in autumn and winter) the ground cools by longwave radiation, and the air touching it cools to dew point by conduction. A light breeze mixes the cool layer a little deeper; strong wind stops it forming. It collects in valleys, where cold, dense air drains downhill, and clears as the morning sun warms the ground. Example: the Po Valley in northern Italy.
  - **Advection fog**: warm, moist air moves horizontally over a colder surface (cold sea, a cold current or cold land) and is cooled from below to dew point. It can form at any time of day and in wind. Examples: San Francisco's summer fog, where Pacific air crosses the cold California Current, and the Namib coast beside the Benguela Current.
  - **Valley (inversion) fog**: cold air sinks into valley floors beneath warmer air above (a temperature inversion) and condenses there.
  - **Hill (upslope) fog**: moist air forced up a slope cools to dew point, so the cloud base sits on the hills.
  - **Steam fog**: very cold air moves over much warmer water; water evaporates into it and immediately condenses.
  - **Frontal fog**: rain falling from the warm air above a front evaporates into the cold air beneath, adding moisture until it is saturated.

Every type forms by cooling air to its dew point or adding moisture, but radiation cooling is only one of the ways of cooling.

The greenhouse effect and the enhanced greenhouse effect



The ground absorbs shortwave radiation, warms and gives out longwave radiation

The natural greenhouse effect. Greenhouse gases (water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and others) let incoming **shortwave** radiation pass through, but **absorb outgoing longwave** radiation from the surface and re-emit it, part of it back down. Without them the Earth's average surface temperature would be about −18 °C instead of about 15 °C. The greenhouse effect is natural and necessary.

The enhanced greenhouse effect is the extra warming caused by **human activity raising the amounts of these gases**, so more longwave radiation is trapped and the atmosphere warms: **global warming**.

Gas	Main human sources
Carbon dioxide	Burning fossil fuels (power stations, vehicles, industry), cement making, deforestation (trees store carbon, and burning releases it)
Methane	Cattle and other livestock, rice paddies, landfill, leaks from gas, oil and coal production, drained or flooded wetlands
Nitrous oxide	Nitrogen fertilisers, vehicle engines, industry
Halocarbons (CFCs and their replacements)	Refrigerants and aerosols; very powerful per molecule; CFCs are now banned under the Montreal Protocol

Methane traps about 28 times as much heat as the same mass of CO_2 over 100 years, and nitrous oxide about 270 times, but CO_2 causes most of the warming because there is so much more of it. **Water vapour** is the most abundant greenhouse gas, but human activity changes it only indirectly: a warmer atmosphere holds more.

The hole in the ozone layer is a different problem. Ozone depletion lets in more ultraviolet radiation; it is not the cause of global warming.

Evidence for global warming:

- **Measured temperatures**: the global average surface temperature in 2011–2020 was about 1.1 °C higher than in 1850–1900, and the warmest years on record are all recent ones (2024 was about 1.5 °C above). The oceans are warming too. The warming is uneven: the Arctic has warmed about three to four times as fast as the world as a whole since 1979.
- **Rising greenhouse gases**: measurements at Mauna Loa, Hawaii, since 1958 show CO_2 rising every year, to over 420 parts per million (ppm) in the 2020s, against about 280 ppm before 1800.
- **Past climates**: air bubbles trapped in **ice cores** from Antarctica and Greenland record CO_2 and temperature (from oxygen isotopes) for 800 000 years; CO_2 never went above about 300 ppm in that time. **Tree rings**, pollen in lake and peat sediments, ocean-floor sediments and corals extend the record. They show that temperature and CO_2 have risen and fallen together, and that today's rise is unusually fast.
- **Ice and sea level**: most mountain glaciers are retreating; Arctic sea-ice extent in September has fallen by about 13% per decade since satellite records began in 1979; the Greenland and Antarctic ice sheets are losing mass; sea level has risen about 20 cm since 1900, from melting land ice and the expansion of warmer water.
- **Living things and extremes**: earlier springs, species moving poleward and uphill, **coral bleaching** in warmer seas, more frequent heatwaves and heavy rainfall. The oceans are also becoming more acidic as they absorb CO_2.

Possible causes. Human activity, through the gases above, is the main cause of recent warming. Natural factors also change climate:

- **variations in the Earth's orbit and tilt** (Milankovitch cycles), over tens of thousands of years; too slow to explain warming over decades;
- **solar output**, which varies slightly over the 11-year **sunspot** cycle; it has not risen since about 1980, while temperatures have;
- **volcanic eruptions**, whose sulphate aerosols reflect sunlight and **cool** the Earth for a year or two (Mount Pinatubo, 1991, by about 0.5 °C). Volcanoes give out far less CO_2 than human activity.

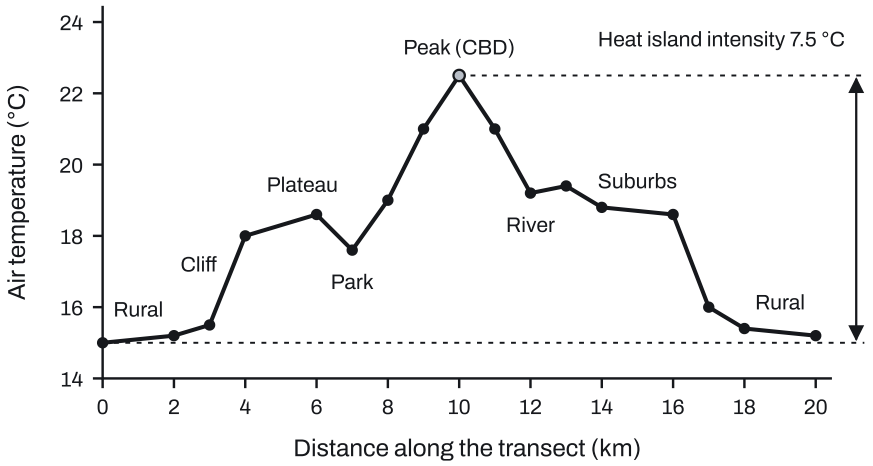
Feedbacks amplify warming once it starts: melting snow and sea ice lower the albedo, so more radiation is absorbed (the **ice–albedo feedback**); thawing **permafrost** releases methane and CO_2; warmer air holds more water vapour (about 7% more for every 1 °C), itself a greenhouse gas.

Atmospheric impacts:

- higher temperatures, with more and stronger **heatwaves** and fewer frosts;
- more evaporation and water vapour, so **heavier rainfall** and flooding in some places, but more **drought** in others (such as the Mediterranean), where higher temperatures dry soils out;
- stronger **tropical cyclones**, fuelled by warmer oceans, with more rainfall;
- changes in wind and pressure patterns: wind belts and storm tracks may shift poleward, and a weaker temperature difference between the Arctic and the tropics may make the jet stream wavier, holding weather patterns in place;
- the impacts vary from place to place: the greatest risks are in low latitudes and continental interiors, where heat stress and drought are already high, and in poorer countries with less money to adapt.

Urban climates

Cities change every part of their local climate. The biggest change is temperature.



Temperature: the urban heat island. Cities are warmer than the countryside around them, most of all at night and in calm, clear weather (anticyclones). The difference between the warmest urban temperature and the rural temperature is the **heat island intensity**: $22.5 - 15.0 = 7.5$ °C in the transect above. A typical profile has a **cliff** (a steep rise at the edge of the built-up area), a **plateau** over the suburbs, a **peak** over the dense centre (the CBD), and cool dips over parks and water. The reasons:

- **Urban materials**: tarmac, concrete, brick and dark roofs have **low albedos** and **high heat capacities**. They absorb and store a lot of energy by day and release it as longwave radiation at night, keeping the air warm.
- **Building shape**: tall buildings and narrow streets (**urban canyons**) trap radiation by reflecting it between walls, and block the view of the open sky, so longwave radiation escapes more slowly at night.
- **Anthropogenic heat**: heat released by people's activities: vehicles, industry, heating, air conditioning, lighting and people themselves.
- **Less evaporation**: rain runs off quickly into drains and there is little vegetation or open water, so less energy goes into evapotranspiration (latent heat) and more into heating the air.
- **Pollution**: a dome of dust and gases absorbs and re-emits longwave radiation, like a local greenhouse effect, though it also reduces incoming sunshine by day.
- **Lower wind speeds** in sheltered streets mean the warm air is not carried away.

Within a city, temperatures vary with these factors: the CBD is hottest (densest buildings, most traffic and activity); parks, rivers and lakes are cooler (evapotranspiration, different albedos, more open sky); industrial areas can form secondary peaks. Weather matters too: strong winds and cloud weaken the heat island, and the city's climate still sits within its regional climate, set by latitude, continentality and the passing weather systems.

Humidity. Relative humidity is usually **lower** in cities by day, because there is less vegetation and open water to supply vapour and the air is warmer. At night humidity can be a little higher than in the countryside, where dew forms and removes vapour from the air.

Precipitation. Cities can get **more** rain, especially from summer thunderstorms: the heat island strengthens convection, buildings force air upwards, and pollution supplies extra condensation nuclei. The 1970s METROMEX study of St Louis, USA, found more summer rain and thunderstorms downwind of the city. Cities get **less snow lying**, because it melts faster on warm surfaces. **Fog** was once much more frequent (smoke supplies nuclei), but clean-air laws have reduced it; cities now often have less fog than the countryside, because they are warmer.

Winds. Buildings make the surface rough, so average wind speeds are **lower** than in open country and calms are more frequent. But tall buildings **funnel** wind along streets (**canyoning**) and create gusts and **eddies** at their base. On calm nights the heat island can draw a gentle **country breeze** inwards towards the centre.

Case study: London, UK

- **Temperature**: London's heat island is strongest on calm, clear nights: during the August 2003 heatwave, central London was up to about 9 °C warmer than the surrounding countryside on some nights. Causes: dense brick, stone and tarmac in the centre, heat from traffic, offices and the Underground, and air conditioning. Large parks such as Hyde Park and the River Thames are cooler.
- **Humidity**: lower relative humidity in the centre by day than in the surrounding green belt, with fewer trees and less exposed soil.
- **Precipitation**: snow settles less in central London than in the suburbs and countryside. In December 1952, the Great Smog (radiation fog trapped under an anticyclone, mixed with coal smoke) killed about 4000 people in the following days; after the Clean Air Act of 1956, smoke fogs became rare.
- **Winds**: average wind speed is lower than in open country, but tall towers in the City of London and Canary Wharf funnel wind and cause strong gusts at street level.
- **Evaluation**: human activity clearly changes London's climate, most strongly its night-time temperatures in calm weather; on windy, cloudy days the effect is small, and London's mild, wet maritime climate, set by its latitude and the westerlies, is unchanged. Green roofs, more trees, lighter-coloured surfaces and keeping the parks and river corridors open are ways to reduce the heat island.

Key facts and formulas

There is no formula list in Paper 1, so learn all of these.

Formula	Status
Albedo (%) = reflected solar radiation ÷ incoming solar radiation × 100	Learn it
Solar radiation absorbed by a surface = incoming solar radiation × (1 – albedo as a decimal)	Learn it
Net radiation = incoming radiation – outgoing radiation (positive: surplus; negative: deficit)	Learn it
Urban heat island intensity = highest urban temperature – rural temperature	Learn it

Formula	Status
Temperature range = highest temperature – lowest temperature (give °C)	Learn it

Term and meaning	Status
Incoming solar radiation: shortwave radiation from the Sun reaching the Earth's surface or atmosphere	Learn it
Reflected solar radiation: incoming shortwave radiation that is not absorbed but sent back by clouds or the surface	Learn it
Longwave radiation: infrared radiation given out by the Earth's surface and atmosphere after they absorb shortwave radiation	Learn it
Albedo: the proportion (%) of incoming solar radiation reflected by a surface	Learn it
Sensible heat transfer: heat moved into or out of an area by conduction, convection or advection, changing the temperature (heat you can feel)	Learn it
Latent heat transfer: heat taken in or released by a change of state (evaporation, condensation) without a change of temperature	Learn it
Evaporation: the change of liquid water into water vapour when heat is added	Learn it
Condensation: the change of water vapour into liquid droplets when moist air is cooled to its dew point	Learn it
Sublimation: the change of ice directly into water vapour (or the reverse) without becoming liquid	Learn it
Deposition: the change of water vapour directly into ice on a surface, such as frost	Learn it
Dew point: the temperature at which air becomes saturated and condensation begins	Learn it
Convection: air warmed at the surface expands, becomes less dense and rises in pockets, carrying heat upwards	Learn it
Radiation cooling: the cooling of the ground and the air next to it by outgoing longwave radiation, mainly on clear nights	Learn it
Wind belts: bands of wind blowing from a consistent direction over a wide area for long periods, from high to low pressure	Learn it
Clouds: visible masses of tiny water droplets or ice crystals suspended in the air	Learn it
Hail: solid precipitation of ice pellets built up in layers in cumulonimbus clouds	Learn it

Term and meaning	Status
Dew: water droplets condensed onto cold surfaces, usually on clear, calm nights	Learn it
Snow: ice crystals formed directly from water vapour in clouds, joined into flakes that fall to the ground	Learn it
Rain: liquid water drops, grown from cloud droplets, heavy enough to fall from a cloud	Learn it
Freezing: the change of liquid water into ice below 0 °C, releasing latent heat	Learn it
Melting: the change of ice into liquid water above 0 °C, taking in latent heat	Learn it
Fog: cloud at ground level, with visibility below 1 km	Learn it
Enhanced greenhouse effect: extra warming from the rise in greenhouse gases caused by human activity	Learn it

How to do it

We have tagged 60 questions for this topic (2021–2025, all from Paper 1), 54 different (Papers 12 and 13 were the same in June 2022, 2023 and 2024). Every one is a multi-part Question 2 or Question 5, so all 60 mix types and the counts add up to more than 60.

Question type	Questions
Evaluate a statement about weather or climate (15-mark essay)	30
Describe or compare the pattern in a figure	28
Read, identify or calculate a value from a figure	25
Define or describe atmospheric terms and processes	21
Explain how uplift causes precipitation, or suggest reasons for a rainfall or cloud pattern	21
Explain how human activity changes urban climate	17
Explain the enhanced greenhouse effect and rising global temperatures	15
Explain how hail, snow, fog, dew or a state of water forms	13
Explain the latitudinal pattern of radiation excess and deficit	13
Explain seasonal variations in pressure and wind belts	11
Explain the diurnal energy budget	10
Explain how albedo, clouds and the atmosphere reflect or absorb radiation	9

Question type	Questions
Explain seasonal variations in temperature	8
Describe and explain the evidence for and impacts of global warming	6
Explain how wind belts and ocean currents transfer energy	6

Short parts (3–5 marks) give 1 mark for a simple point and 2 (sometimes 3) for a developed one. The 8-mark (b) parts are marked in levels (Level 3, 6–8 marks), and the 15-mark (c) essays in four levels (Level 4, 12–15 marks).

1. Evaluate a statement about weather or climate (15-mark essay) (30 questions)

The statement names one factor as "the main" cause or effect. Plan:

1. **Introduction**: define the key terms and name the alternatives you will weigh.
2. **Explain the named factor fully**, with processes and examples.
3. **Weigh every other factor**, saying where and when each matters more.
4. **Use located examples** throughout: with none, the maximum is 6.
5. **Conclude with a judgement** on "how far", usually by place, season or conditions.

Statement about	Weigh it against
Convection (or any one uplift) as the main cause of precipitation	Orographic and frontal uplift and radiation cooling; by region (equatorial convection, mid-latitude fronts, mountain relief, monsoons) and season
Radiation cooling as the main cause of fog	Advection, valley, hill, steam and frontal fog; by location (inland valleys against cold coasts) and weather
Albedo as the main factor in the diurnal energy budget	Incoming radiation (latitude, cloud), surface absorption, sensible and latent heat, longwave radiation; albedo acts only by day
Incoming solar radiation as the most important factor in the global energy budget	Outgoing longwave radiation, albedo, transfers by wind belts and ocean currents
Wind belts against ocean currents as the main transfer of energy	Both, plus latent heat, tropical cyclones, jet streams; ocean currents strongest near the equator, winds beyond
Land/sea distribution against latitude (or ocean currents) for seasonal temperature or pressure	All three, with examples such as Vancouver and Winnipeg, or Bergen and Hudson Bay
Human activity as the cause of global warming	Orbital cycles, solar output, volcanoes; feedbacks

Statement about	Weigh it against
Large organisations (companies, governments) as the main cause of global warming	Individuals' energy use, transport and diet; farming and deforestation; who decides and who emits
Whether the atmospheric impacts of global warming vary with location	Latitude, continentality, coasts and islands, monsoon and cyclone regions, polar amplification (the Arctic warming fastest); ability to cope
The evidence for global warming coming from past climates	Ice cores, tree rings, sediments against modern measurement (thermometers, Mauna Loa, satellites, glacier retreat)
Temperature as the main urban effect, or how far human activity changes urban climate	Humidity, precipitation and winds in a named city; regional climate and weather conditions

Pick out every key word: "main", "most", "seasonal", "diurnal", "with the aid of a case study".

2. Describe or compare the pattern in a figure (28 questions)

1. **State the overall pattern first**: where it is highest and lowest, which way it changes (with latitude, distance from the coast or the CBD, height, time).
2. **Add the detail**: exceptions and anomalies, and any link to location (coast, mountains, latitude, CBD).
3. **Quote data with units**: one mark is usually kept for data, or the total is capped at 3 without it.
4. **Only describe**: no reasons unless the question asks "why".

A **pattern** is a distribution over space (where); a **trend** is a change over time. On a map or a graph by latitude, describe the pattern, not year-to-year changes. If the figure shows **changes** (for example "temperature change since 1980"), describe the changes, not the actual temperatures. For **compare**, link each point ("whereas", "both", "higher than"); separate descriptions are capped at about 2 marks.

For the urban profile above: "Temperatures are lowest in the rural areas (15.0 °C at 0 km) and rise steeply at the edge of the city, then stay around 18–19 °C over the suburbs. The highest temperature is 22.5 °C in the CBD at 10 km. There are cooler dips over the park (17.6 °C) and the river."

3. Read, identify or calculate a value from a figure (25 questions)

1. **Read the key or axis carefully**, including which line or map the question names. A range in a key is accepted as a range ("6–13 mm").
2. **Show working** for a difference, range or total: "at 60°: 140 − 190 = −50 W/m²".
3. **Give units every time** (°C, mm, W/m², %): without them the mark is lost.

"Name the effect" on an urban temperature map is the **urban heat island**. A cloud-cover estimate from a satellite image is given as a percentage (or oktas, eighths of the sky).

4. Define or describe atmospheric terms and processes (21 questions)

Two marks each: **what it is (1)**, then **the qualifier that makes it exact (1)**. Learn the definitions in "Key facts and formulas". Condensation needs **cooled to dew point** and **gas to liquid**; latent heat needs **change of state without a temperature change**; sensible heat needs **conduction or convection** and **changes temperature**; albedo needs **proportion of incoming solar radiation** and **reflected**; longwave radiation needs **emitted by surfaces** after **absorbing shortwave**. "Describe the process of convection" [3]: the sun heats the ground (1), the air above warms, expands and rises (1), cooling to form cloud (1). Atmospheric deposition is **not** fluvial deposition.

5. Explain how uplift causes precipitation, or suggest reasons for a rainfall or cloud pattern (21 questions)

The chain the mark schemes reward every time:

1. **The trigger** that forces moist air to rise (convection, a mountain barrier, a front).
2. **Rising air cools** (adiabatically) **to its dew point**.
3. **Condensation** on nuclei forms cloud, releasing latent heat that drives more uplift.
4. **Droplets coalesce** (or ice crystals grow) until heavy enough to **fall**.

For one named mechanism, describe its trigger in detail (frontal: warm air forced up over cold air, gently at a warm front and steeply at a cold front). For "the causes of precipitation" [8], cover convection, orographic and frontal uplift (and radiation cooling) with examples. A diagram is credited.

For **"suggest reasons for the pattern"** of rain or cloud on a map or satellite image, use the clues it gives:

- **Relief**: more rain or cloud on windward slopes and coastal mountains, a rain shadow beyond.
- **Prevailing winds**: which coast faces the moist wind (westerlies, trade winds, monsoon).
- **Distance from the sea**: rainfall falls inland as air loses moisture (continentality).
- **Temperature**: convection over hot land; little rain where **cold currents** or **sinking air** (subtropical or polar high pressure) keep air stable and dry.

Give each reason with its process: "the coastal mountains force the westerlies to rise (1), so the air cools to dew point and rain falls on the windward side (1)". Keep the rain shadow for places beyond the mountains; it does not explain the wet side.

6. Explain how human activity changes urban climate (17 questions)

1. **Name the cause**: urban materials (low albedo, high heat capacity), building shape (canyons), anthropogenic heat, less vegetation and water, pollution, lower wind speeds.
2. **Develop it**: what it does to energy (absorbs by day, releases longwave at night; less latent heat; trapped radiation) and so to temperature.
3. **Use the resource**: match causes to places (CBD hottest, parks and water cool).

For variation **within** one city, explain why the CBD, suburbs, parks and water differ. "Global warming" or "CO_2 emissions" alone earn nothing here: the heat island is a local effect, a different scale from global warming. For a case-study essay, cover **temperature, humidity, precipitation and winds** with facts about one named city, and weigh human activity against the regional climate and the weather (the heat island is strongest in calm, clear anticyclones).

7. Explain the enhanced greenhouse effect and rising global temperatures (15 questions)

1. **The natural effect**: named gases let shortwave in but **absorb outgoing longwave** radiation and re-emit it, warming the atmosphere.
2. **The enhancement**: the **increase** in these gases, linked to **named human activities** (fossil fuels, deforestation, livestock, rice, fertilisers). Without the enhanced part, answers are capped at about 3 of 5.
3. **Development**: feedbacks (sea-ice albedo, permafrost methane, water vapour) and the natural factors (volcanoes, sunspots, orbital cycles), with a judgement on which matters most.

When a graph shows warming (say since 1980), tie the explanation to it: steady rises match rising emissions; short dips can follow large eruptions. Leave out the ozone hole.

8. Explain how hail, snow, fog, dew or a state of water forms (13 questions)

Give the full sequence of processes, as in "Understand it": hail needs **updraughts, supercooled droplets, repeated rising and falling, layers, too heavy to hold**; snow needs **water vapour, ice crystals, growth, falling through cold air**; dew needs **clear calm night, radiation cooling, surface reaches dew point**; fog needs **at least two types** (radiation and advection) for full marks.

For a **photo** of snow, ice or water on different surfaces, suggest reasons with processes: altitude (colder, more snowfall), aspect (sun-facing slopes melt first), shelter from trees or buildings, heat leaking from roofs, dark low-albedo surfaces (tarmac) absorbing more and melting snow or ice, gritted or busy roads.

9. Explain the latitudinal pattern of radiation excess and deficit (13 questions)

1. **Define and locate**: a surplus where incoming exceeds outgoing (between the equator and about 40° N and S); a deficit poleward of that. Refer to **both** incoming and outgoing.
2. **Explain the surplus**: high sun angle concentrates energy on a small area; a short path through the atmosphere means less scattering and absorption; long days all year.
3. **Explain the deficit**: low sun angle spreads the same energy over a larger area; a long path through the atmosphere; high albedo of snow and ice; long dark winters from the tilt of the axis.
4. **Add a labelled diagram** of the sun's rays if it helps; finish with the poleward transfer of energy that balances it.

Never give distance from the Sun as a reason.

10. Explain seasonal variations in pressure and wind belts (11 questions)

1. **Link pressure to temperature**: warm, rising air gives low pressure; cool, sinking air gives high pressure.
2. **Latitude**: the overhead sun moves between the tropics, so the ITCZ and the pressure and wind belts shift north in June–July and south in December–January.
3. **Land and sea**: continents heat and cool faster, so they develop thermal lows in summer and highs in winter, and the belts shift further over land (the monsoon).
4. **Ocean currents** strengthen or weaken these contrasts along coasts.

Answer the **seasonal** part: a description of the three-cell model alone, without its shift through the year, is not enough. For "state three characteristics of wind belts": consistent direction, wide area, long period, from high to low pressure, deflected by the Coriolis effect.

11. Explain the diurnal energy budget (10 questions)

1. **Name the components** for day (six) and night (four) as in "Understand it".
2. **Say what controls each**: cloud and latitude (incoming), albedo (reflected), surface type and conductivity (absorption), moisture (latent heat), wind (sensible heat), clear skies (longwave loss at night).
3. **Link day and night**: what is absorbed by day is returned and radiated at night.

For "the factors affecting the diurnal energy budget" [8], cover both day and night. Albedo affects only the daytime budget.

12. Explain how albedo, clouds and the atmosphere reflect or absorb radiation (9 questions)

- **Albedo of surfaces**: light surfaces such as snow and ice (80–90%) reflect most radiation and absorb little; dark surfaces such as tarmac (5–10%), coniferous forest and ploughed soil absorb most. Quoting values develops the point.
- **Before it reaches the surface**: **reflected** by clouds (thick cloud up to 90%), **scattered** by dust, aerosols and air molecules, **absorbed** by clouds, water vapour, ozone and dust.
- **Stopping longwave radiation leaving**: absorbed and re-emitted by greenhouse gases and clouds, partly back to the surface; scattered by dust.

13. Explain seasonal variations in temperature (8 questions)

1. **Latitude**: the overhead sun's movement and day length; small seasonal changes near the equator, large ones at high latitudes.
2. **Land and sea**: the sea's higher specific heat capacity makes it heat and cool slowly, so coasts have small annual ranges and continental interiors large ones.
3. **Ocean currents**: warm currents raise winter temperatures (North Atlantic Drift: Bergen against Hudson Bay); cold currents lower summer temperatures (California, Benguela).

Explain how the sea's temperature reaches the land: **onshore winds** carry it, so the effect fades inland. Land and sea breezes are daily, not seasonal: leave them out.

14. Describe and explain the evidence for and impacts of global warming (6 questions)

- **Evidence**: measured air and ocean temperatures, CO_2 records, ice cores and other past-climate records, glacier and sea-ice retreat, sea-level rise, ocean acidity, coral bleaching, changes in living things, more extreme events. Explain what each shows.
- **Impacts on the atmosphere**: more heat and water vapour, heavier rain, stronger storms, droughts, shifting belts and a wavier jet stream, feedbacks. Explain the chain for each.
- **Why impacts vary by place** (on a map): latitude (low latitudes already hot), continentality, coasts and islands moderated by the sea, river basins prone to flooding, and the ability of poorer countries to cope.

15. Explain how wind belts and ocean currents transfer energy (6 questions)

1. **Why transfer happens**: the surplus at low latitudes and the deficit at high latitudes.
2. **Wind belts**: air moves from high to low pressure; the westerlies carry warm air poleward, the polar easterlies cold air equatorward; latent heat in water vapour is released where it condenses; belts shift with the ITCZ; jet streams and Rossby waves.
3. **Ocean currents**: warm currents carry heat poleward (Gulf Stream, North Atlantic Drift), cold currents return equatorward (California, Benguela); onshore winds bring air warmed or chilled by a current over the land; the ocean conveyor belt.

Name real currents and belts; describing their positions alone is not enough without explaining how energy is carried.

Worked examples

Example 1

Use the global energy budget graph in "Understand it".

(a) (i) State the latitude at which incoming and outgoing radiation are equal. **[1]** (ii) Calculate the difference between incoming and outgoing radiation at 80°. **[1]**

(b) Compare the patterns of incoming and outgoing radiation shown. **[4]**

(c) Explain why latitudes poleward of this point have a radiation deficit. **[4]**

(a)(i) 40° (N or S) **(1)**.

(ii) $80 - 172 = -92$ W/m², a deficit of 92 W/m² **(1)**.

(b)

- Both fall from the equator towards the pole **(1)**.
- Incoming radiation falls much more steeply, from 300 W/m² at the equator to 70 W/m² at 90°, whereas outgoing radiation falls only from 250 W/m² to 168 W/m² **(1)**, with use of data.
- Incoming is greater than outgoing between 0° and 40°, whereas outgoing is greater poleward of 40° **(1)**.
- The lines cross at 40°, where both are 220 W/m² **(1)**.

(c)

- At high latitudes the sun is low in the sky, so the same beam of radiation is spread over a larger area of surface **(1)**, and it passes through a longer path of atmosphere, where more is scattered, absorbed and reflected **(1)**.
- Snow and ice have a high albedo (80–90%), so much of the radiation that arrives is reflected rather than absorbed **(1)**.
- The tilt of the Earth's axis gives months of little or no sunshine in winter, while the surface keeps losing longwave radiation, so outgoing exceeds incoming over the year **(1)**.

Example 2

(a) (i) Define the atmospheric terms 'freezing' and 'sensible heat transfer'. **[4]** (ii) Explain why some clouds produce snow rather than rain. **[3]**

(i) Freezing is the change of liquid water into ice **(1)** when it is cooled below 0 °C, releasing latent heat **(1)**. Sensible heat transfer is the movement of heat into or out of an area by conduction or convection **(1)**, which changes the temperature of the air, so it can be felt **(1)**.

(ii) Snow forms where the cloud is below freezing, so water vapour turns directly into ice crystals, which grow by taking vapour from the supercooled droplets around them **(1)**. The crystals stick together as flakes and fall when heavy enough **(1)**. They reach the ground as snow only if the air beneath the cloud is cold enough (about 0 °C or below); in warmer air they melt and fall as rain **(1)**.

Example 3

Explain why the annual range of temperature is greater in the centre of continents than on their west coasts in the mid-latitudes. **[8]**

The annual range is the difference between the warmest and coldest months. Vancouver, on Canada's west coast, averages about 4 °C in January and 18 °C in July, a range of 14 °C. Winnipeg, at almost the same latitude in the centre of the continent, averages about −16 °C in January and 20 °C in July, a range of 36 °C.

The main reason is the different specific heat capacities of land and sea. Water needs about four to five times as much energy as rock to warm by 1 °C; the sun's energy penetrates several metres into it and is mixed through a deep layer; and some is used in evaporation. So the sea warms slowly in summer and keeps its heat into winter, while land heats quickly in summer and loses heat quickly in winter under clear skies.

In the mid-latitudes the prevailing winds are the westerlies. On west coasts they blow onshore, bringing air that has crossed the ocean, cool in summer and mild in winter, so coasts have a small range. As the air moves inland, the sea's influence weakens, especially beyond mountain ranges such as the Rockies, which block maritime air; the centre of the continent gets its temperatures from the land beneath it, so summers are hot and winters very cold.

Ocean currents add to the contrast: the warm North Pacific Current keeps the coast near Vancouver mild in winter, just as the North Atlantic Drift does for north-west Europe. Inland, clear skies under winter high pressure allow strong radiation cooling, making winters colder still.

Level 3 (6–8 marks): land/sea heating explained in sequence, the role of the westerlies and distance from the coast, ocean currents, and real examples with data.

Example 4

'The urban heat island is caused mainly by the materials that cities are built from.' With the aid of examples, how far do you agree with this statement? **[15]**

Introduction. The urban heat island is the higher temperature of a city compared with the countryside around it, strongest at night in calm, clear weather. "Materials" means the surfaces: tarmac, concrete, brick, glass and roofs. They must be weighed against anthropogenic heat, building shape, reduced evaporation, pollution and the weather.

For. Urban materials have low albedos and high heat capacities: they absorb and store far more energy by day than fields or woodland and release it as longwave radiation through the night, which is why the heat island is greatest after dark. Impermeable surfaces also drain rain away, so less energy goes into evaporation. In London, the densest stone and tarmac of the centre coincides with the strongest heat island, and parks such as Hyde Park are cooler.

Against. Anthropogenic heat from traffic, heating, air conditioning and industry adds energy directly, and in cold-climate cities in winter it can be the largest single source. Building shape matters as well as material: tall, narrow canyons trap radiation and block the sky, slowing night-time cooling. Pollution domes absorb and re-emit longwave radiation. Above all, weather controls whether a heat island appears at all: in London's August 2003 heatwave, under calm anticyclonic conditions, the centre was up to about 9 °C warmer than the countryside on some nights, but on windy, cloudy nights the difference almost disappears.

Conclusion. Materials are the single most important cause, because their storage and release of heat explains why heat islands peak at night. But they act together with building shape, lost vegetation and human heat, and weather decides how strongly they show, so the statement is largely, not wholly, true.

Level 4 (12–15 marks): the named factor explained, weighed against several others with located examples, and a judgement that answers "how far".

Common mistakes

- **Explaining the energy deficit by distance from the Sun.** Examiners see this every year. The reasons are the angle of the sun's rays, the path through the atmosphere, albedo and the seasons.
- **Calling reflected radiation longwave.** Reflected solar radiation is still shortwave; only absorbed radiation is given out again as longwave.
- **Confusing the greenhouse effect with the ozone hole.** They are separate problems.
- **Blaming the urban heat island on global warming**, or answering a global warming question about urban pollution. One is local, the other global.
- **Thinking cities are more humid.** By day, relative humidity in cities is usually lower.
- **Ignoring "seasonal".** Questions on seasonal pressure, wind belts or temperature need the shift through the year (the overhead sun, the ITCZ, summer and winter over land), not just the three-cell model.
- **Writing about land and sea breezes** for seasonal or ocean-current questions. Breezes are daily.
- **Leaving out the uplift trigger**, or putting the rain shadow on the wet side of a mountain.
- **Describing hail as just frozen rain.** Give the repeated up and down movement and the layers.
- **Covering only one type of fog** when asked how fog forms.
- **Confusing atmospheric deposition with river deposition.**
- **Describing a trend when asked for a pattern**, or reading change values as actual values.
- **Forgetting units**, or quoting data without them.

How to get the marks

- **Units and working.** Every reading needs units; every calculation shows its working.
- **Develop each point.** In 3–5 mark parts, a simple point earns 1 and a developed point (cause → process → result) earns 2.
- **Describe** = what it shows, with data. **Explain** = reasons and processes. **Suggest** = apply what you know to an unfamiliar resource; any sensible reasons are credited. **Compare** = similarities and differences linked together. **Define** = precise meaning with its qualifier. **Briefly** = a few well-chosen points.
- **Use the resource.** In Question 2, quote figures from it, and use its clues (relief, coast, latitude, CBD) in the explanation part.
- **Both incoming and outgoing.** Energy budget answers need both sides for full marks.
- **8-mark (b) parts** are levelled: Level 3 (6–8) needs clear explanation of every part of the question, with examples or a labelled diagram.
- **15-mark essays** are levelled: Level 4 (12–15) needs a thorough, balanced assessment with located examples built in and a clear judgement. With no examples the maximum is 6.
- **Diagrams earn credit** when labelled and annotated with processes: the sun's rays at two latitudes, the three-cell model, uplift over a mountain, the energy budget.

Quick check

1. Define the atmospheric terms 'condensation' and 'sublimation'.
2. On a clear afternoon, 750 W/m² of solar radiation reaches fresh snow (albedo 85%) and a tarmac road (albedo 8%). Calculate how much each surface absorbs.
3. Using the urban temperature transect, calculate the heat island intensity, and suggest two reasons for the dip at 7 km.
4. Using the global energy budget graph, calculate the net radiation at 20° and at 70°, and say which is a surplus.
5. Explain why radiation fog forms on clear, calm nights but not on cloudy, windy ones.

Answers

1. Condensation is the change of water vapour into liquid droplets (gas to liquid) when moist air is cooled to its dew point. Sublimation is the change of ice directly into water vapour (or the reverse) without passing through the liquid state.
2. Snow: $750 \times 0.15 = 112.5$ W/m². Tarmac: $750 \times 0.92 = 690$ W/m², about six times as much.
3. $22.5 - 15.0 = 7.5$ °C. The park has vegetation, so more energy goes into evapotranspiration rather than heating the air; grass has a higher albedo than tarmac and stores less heat; there are no buildings releasing heat and more open sky, so longwave radiation escapes at night.
4. 20°: $280 - 245 = +35$ W/m², a surplus. 70°: $105 - 180 = -75$ W/m², a deficit.
5. On clear nights nothing absorbs and returns the longwave radiation the ground gives out, so the ground cools quickly and cools the air touching it to dew point. Cloud sends longwave radiation back and keeps the ground warmer. Calm air lets the cooled layer stay at the ground; wind mixes it with warmer air above, so it does not reach dew point.

Past questions to try

- **9696/11/M/J/25 Q5**: reflected solar radiation and latent heat, land and sea, latitude and the global energy budget, and an essay on human causes of warming.
- **9696/13/M/J/24 Q2**: a satellite image of cloud over Hawaii: describe the pattern and suggest reasons.
- **9696/12/O/N/24 Q5**: sensible heat and evaporation, frontal uplift, the latitudinal pattern of radiation, and an essay on land and sea.
- **9696/11/O/N/24 Q5**: convection, fog, wind belts transferring energy, and an essay on urban climates.