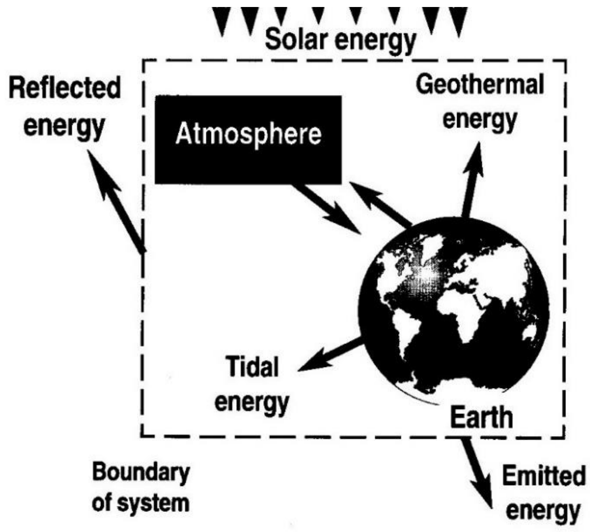
Revision Notes – THE ATMOSPHERE

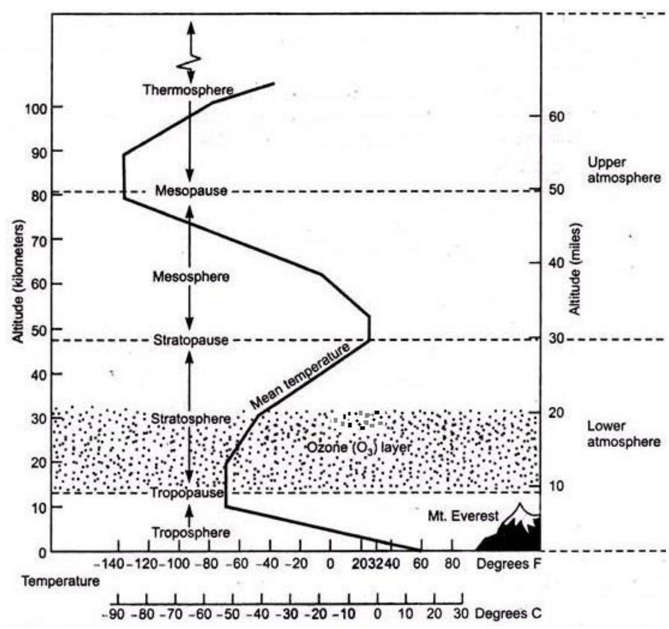
The Atmospheric System



The Earth-Atmosphere system

The earth and its atmosphere can be viewed as a closed system (**earth-atmosphere system**), dependent on continuing **inputs of energy from the sun**. There are also some very small energy contributions from the earth's interior (geothermal energy) and tidal energy.

The Structure of the Atmosphere

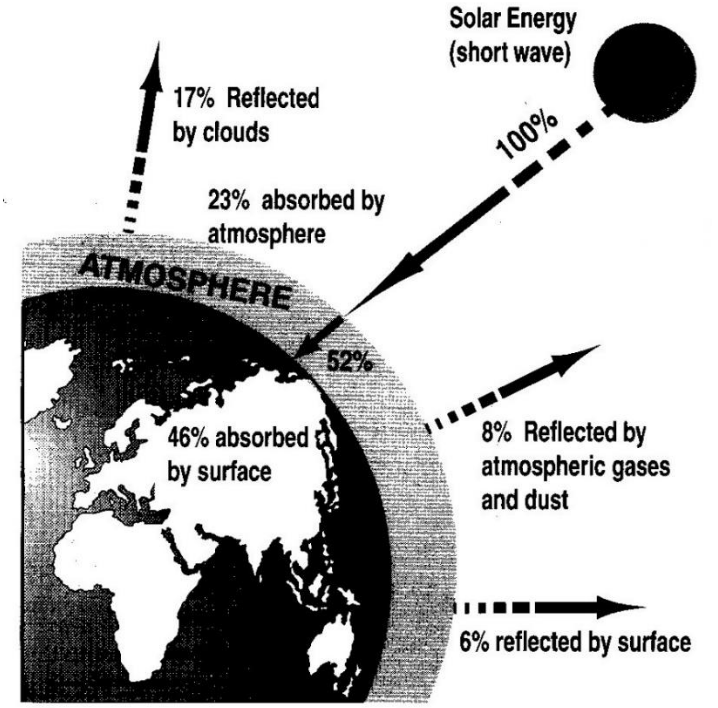


The atmosphere consists of 4 identifiable layers ; the **troposphere, stratosphere, mesosphere,** and **thermosphere**. The diagram shows the different layers of the atmosphere and how temperature changes with altitude, from the ground up to space.
99% of the atmosphere is made up of two gases Nitrogen and Oxygen.

The troposphere is the lowest layer of the atmosphere. **This is the layer where we live and where weather occurs**. **Temperature in troposphere generally decreases with altitude**. The boundary between the stratosphere and the troposphere is called the **tropopause**. The **jet stream** is located at this level and it marks the highest altitude which can influence the weather.

Energy Transfers in the Atmosphere

The solar energy which drives the earth-atmosphere system is received and transformed in a series of energy transfers, most of these within the atmosphere itself.



Some of the solar energy is reflected back into space (25%)
Some is **absorbed** (23%), **transformed** into heat and is then emitted as **long-wave radiation**.
52% of the original solar energy finally reaches the earth's surface where **46% is absorbed** (and later radiated back into the atmosphere), **and a small amount is reflected into space (6%).**
For every 100 units of energy provided by the sun, **31 are reflected back into space** while 69 are absorbed by the earth and its atmosphere. The 31% lost by reflection is termed the earth's **albedo**.

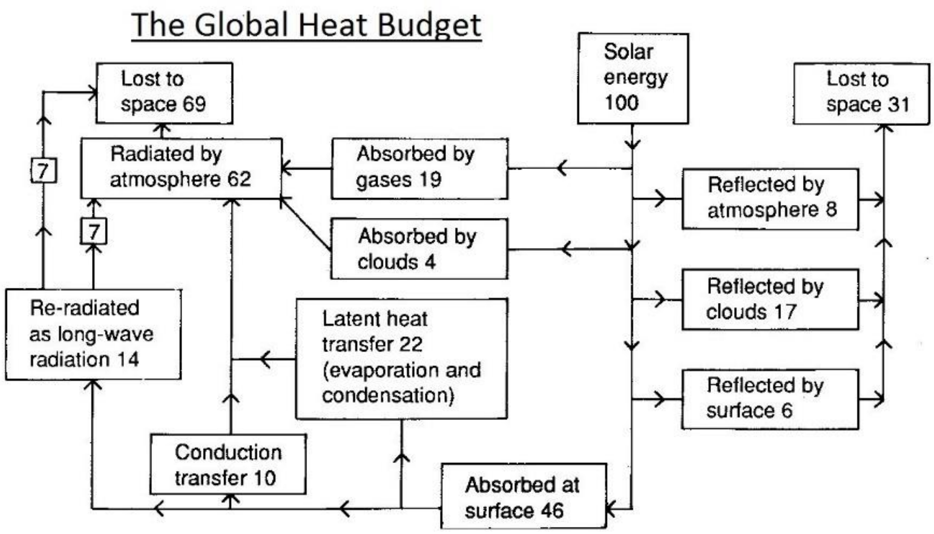
The maintenance of high temperatures by the atmosphere, allowing in short-wave radiation and trapping the bulk of the outgoing long-wave radiation, is sometimes called the "**greenhouse effect**". The enhancement of this greenhouse effect from increases in carbon dioxide and other greenhouse gasses, which trap the outgoing heat, is what causes so much concern as global temperature increases.

The Global Heat Budget

If there was no human interference with the atmosphere, the earth as a planet would not be getting appreciably hotter or colder.

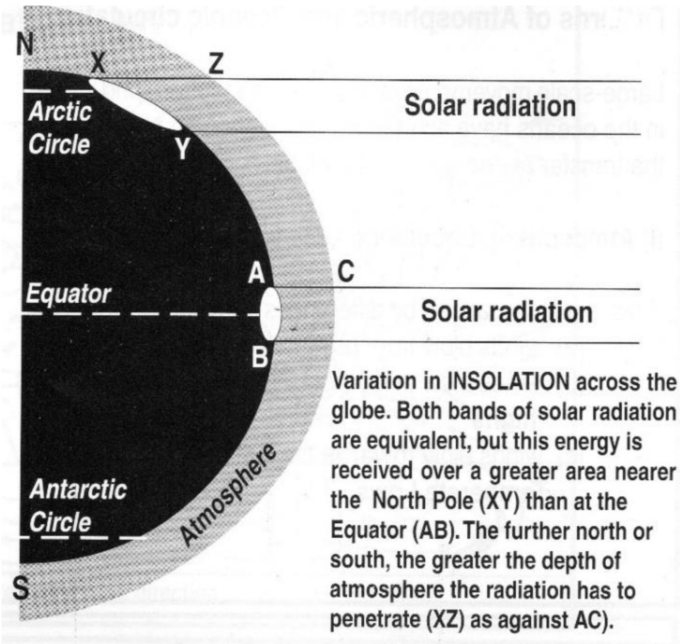
Of the 46% (let's call this 46 units for ease of reference) of the solar energy which reaches the earth's surface, 14 units are re-radiated as long-wave radiation (7 into space directly and 7 into the atmosphere), 10 units are returned to the atmosphere by **conduction** and 22 units are transferred by **latent heat**. Conduction is the transfer of heat between the earth's surface and the atmosphere it is in contact with. However only the lowest portion of the atmosphere is warmed in this way, as air is a poor conductor. Transfer by **latent heat** is where water is evaporated at the earth's surface, rises in the atmosphere and transfers heat energy as it condenses. Of the 46 units of energy received by the earth's surface 39 units are transferred to the atmosphere. The atmosphere receives most of its energy from the earth's surface. The most significant aspect of the earth's **heat budget** is that **the atmosphere is largely heated from below.**

Over 99% of all energy in the earth-atmosphere system comes from the sun, **46% of the energy warms the sea and land while 22% powers the global hydrological cycle.**



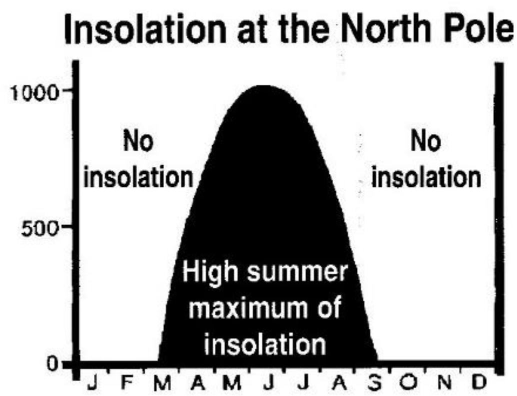
Global Insolation

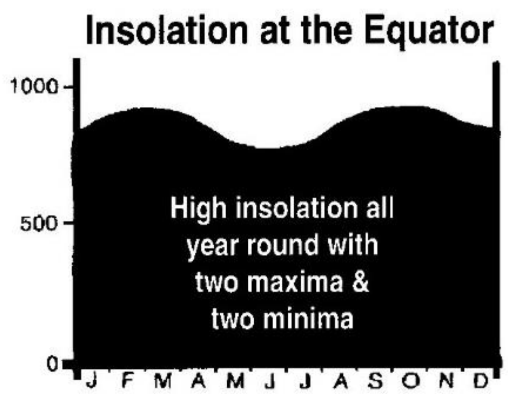
Energy from the sun heats the atmosphere and the oceans. Most energy is received by equatorial regions. The wind and ocean circulation redistribute some of this heat from equatorial to polar regions.



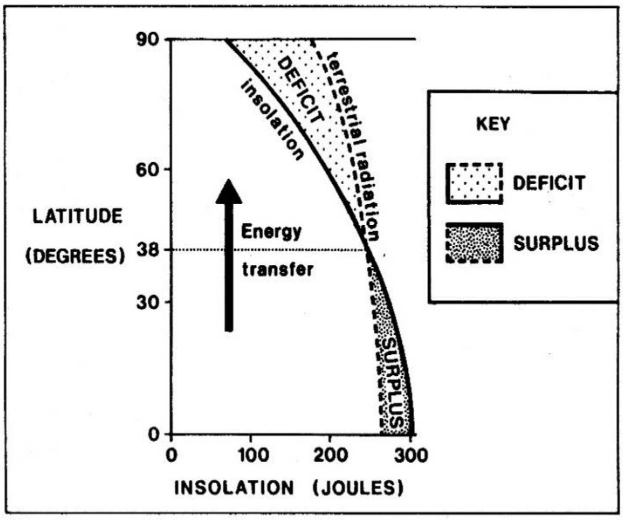
Variation in INSOLATION across the globe. Both bands of solar radiation are equivalent, but this energy is received over a greater area nearer the North Pole (XY) than at the Equator (AB). The further north or south, the greater the depth of atmosphere the radiation has to penetrate (XZ) as against AC).

Because the earth is spherical the sun's radiation (**insolation**) only strikes the earth's surface at the perpendicular between the Tropics of Cancer and Capricorn. **The further away from the Tropics, the larger the surface area hit by the solar energy** and therefore surface heating is much less. Also, **the sun's radiation must pass through more of the atmosphere before reaching the surface,** because the of the oblique angle, and hence reduces the heating still further. This difference in global insolation helps to explain the variation and distribution of temperatures over the earth.





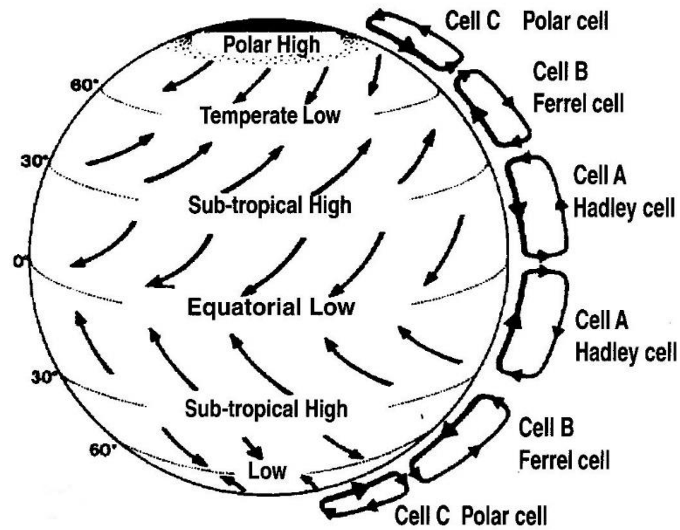
Atmospheric Circulation



Radiation budget -
more energy absorbed than re-radiated in lower latitudes, while in high latitudes more is re-radiated than recieved - hence transfer of energy from low to high latitudes.

As well as energy transfers between the earth's surface and the atmosphere there are also energy transfers at a horizontal level, between low latitudes and high latitudes. **Poleward of latitude 38° in both hemispheres there is less solar energy absorbed than terrestrial energy emitted**; whereas **between 38°N and 38°S there is more energy absorbed than emitted.** Energy is transferred from the low latitude **surplus areas** to the high latitude **energy deficient** areas. Without this transfer of energy, the low latitudes would get increasingly hotter and high latitudes even colder.

Atmospheric Circulation Model



The simple three-cell model of atmospheric circulation proposed by Ferrel included the tropical **Hadley cell** with **rising equatorial air and descending air at the subtropics (around 30° latitude).** This cell also includes air movement at ground level between the sub-tropics and the equator to replace the rising equatorial air, which has created a zone of low pressure. This area of **low pressure** is caused by the heated air at the equator which expands, becomes less dense (heavy) and rises. As the heated air rises through the atmosphere the "weight of air" on the surface is lessened and this results in a low pressure area.

Differences in air pressure create air movement (wind) and in this case the **wind moves from the high-pressure subtropics to the low-pressure equatorial zone.**

As water vapour condenses it releases energy - as the air moves poleward, it warms the atmosphere in the middle latitudes.

The **poleward moving air subsides** (sinks) in the subtropics because the space available in the upper atmosphere decreases poleward. This causes a **subtropical high-pressure zone** at about 30° latitude.

A **polar cell** in this model is due to cold, dense air subsiding in polar regions (**polar high-pressure zone**) and moving to lower latitudes where it expands as is moves into more space and is warmed by the earth's surface.

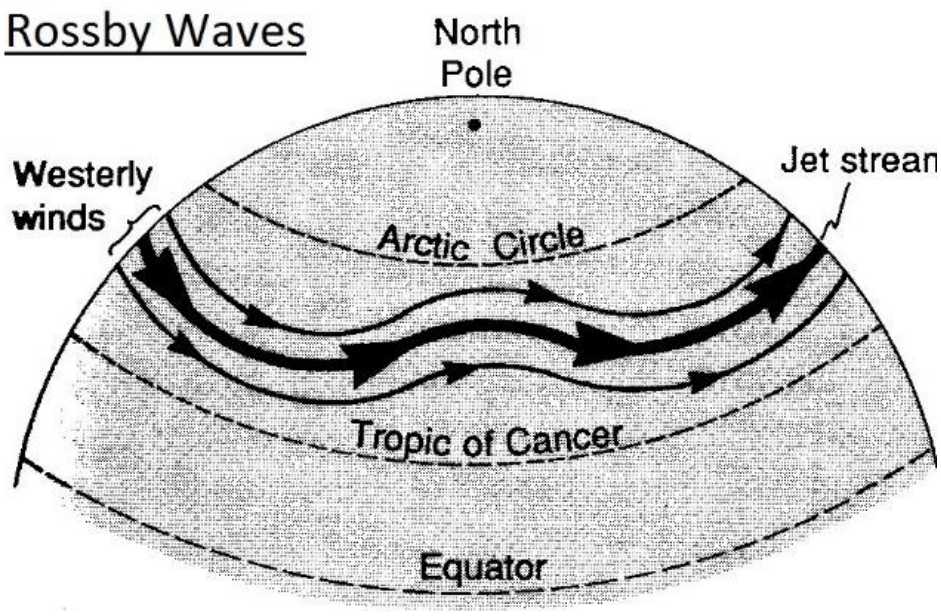
The **Ferrel cell** between the other two is a response to the two **thermally direct cells**. This cell feeds warm air to high latitudes and transfers cold air back to the subtropics for warming.

This simple three-cell model is a useful simplification of reality.

Improvements in atmospheric circulation models

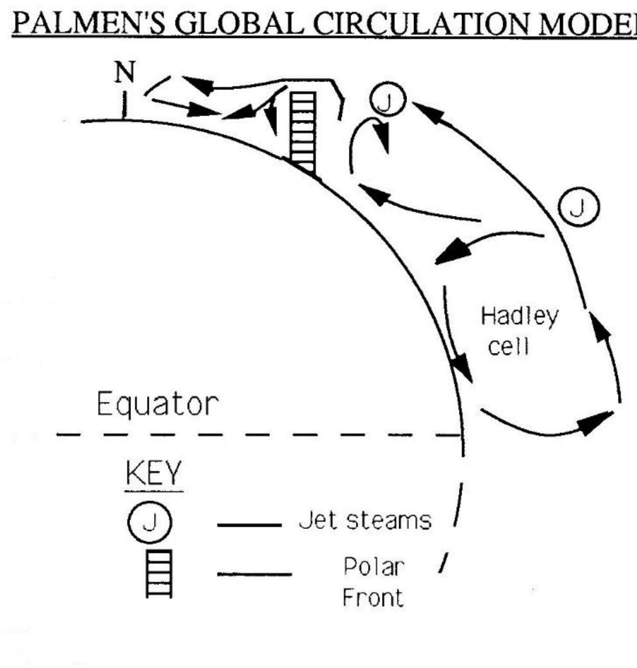
Research early in the 20th century revealed the existence of large-scale belts of fast-moving winds. These wind belts follow a wave-like pattern, first poleward then towards the equator and so on. These wave-like patterns are known as planetary waves or **Rossby waves** and occur at altitudes of 10,000 to 12,000 metres. Within these wind belts there is a core of very fast-moving air (**the jet stream**) where the wind can reach speeds of up to 350-450 km per hour. There are two jet streams in each hemisphere: the polar jet stream which lies between about 30°and 50° latitude and the subtropical jet stream at about 20° to 30° latitude.

The jet streams are generated by the temperature differences between polar and subtropical air and between subtropical and equatorial air. The polar jet stream is the most vigorous of the two because the temperature difference between polar and subtropical air is more marked than the difference between subtropical and equatorial air.



The addition of jet streams and a **polar front** (a boundary between the cold polar air and warm sub-tropical air) improves the simple three cell model.

Further improvements in our understanding have led to modifications of this Rossby model. The modifications proposed by Palmen in 1951 are still generally accepted today.



The model is still a simplification of reality as the patterns of wind circulation are influenced by the distribution of land and ocean as well as high mountain barriers but gives a good understanding of the mechanics of global circulation.

Planetary wind circulation

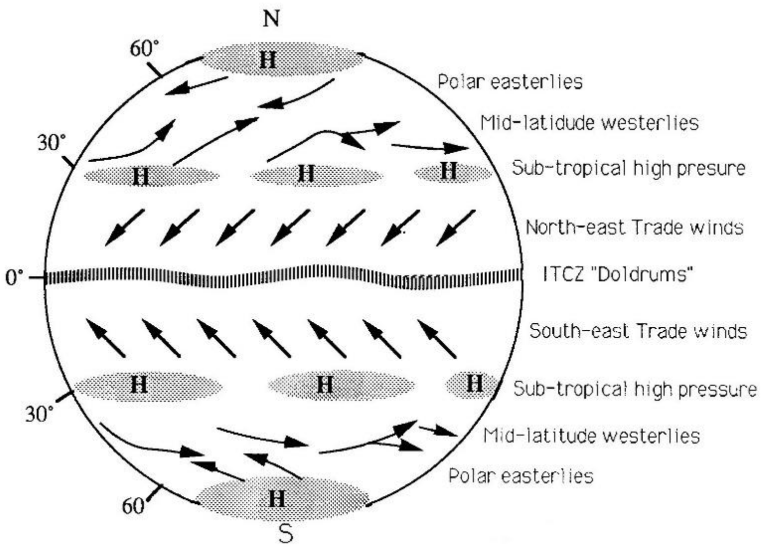
The major wind systems largely conform to broad latitudinal zones. There are two main wind belts in each hemisphere.

The **trade-wind belt** covers nearly half the earth's surface and is found between **latitudes 30° N and 30° S.** The trade winds are **fairly constant and predictable** because of the relative permanence of the subtropical high-pressure zones, from where they emanate.

The second major wind belt in each hemisphere is the **mid- latitude westerlies** which develop from the poleward sides of the subtropical high-pressure zone.

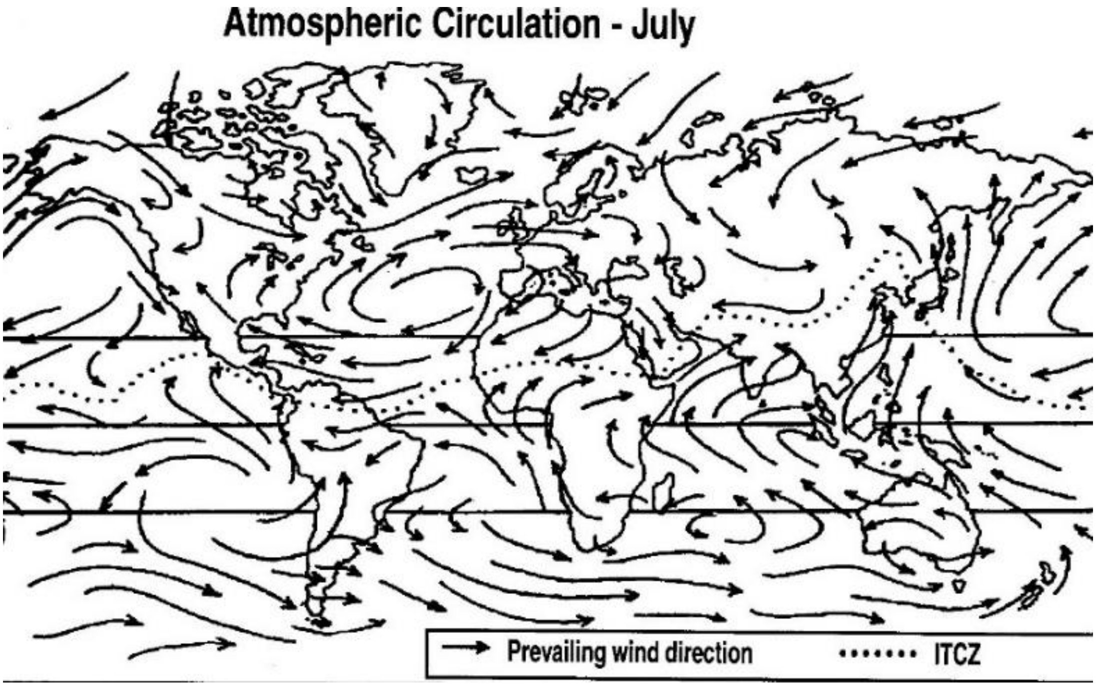
The trade winds from both hemispheres meet near the equator in what is called the **inter-tropical convergence zone** (**ITCZ**).

Global Wind Belts



The ITCZ moves between the tropics with the seasonal shift of the equatorial low pressure. Because this zone is an area of convection (uplift of air) the winds are weak and are called the '**Doldrums**'.

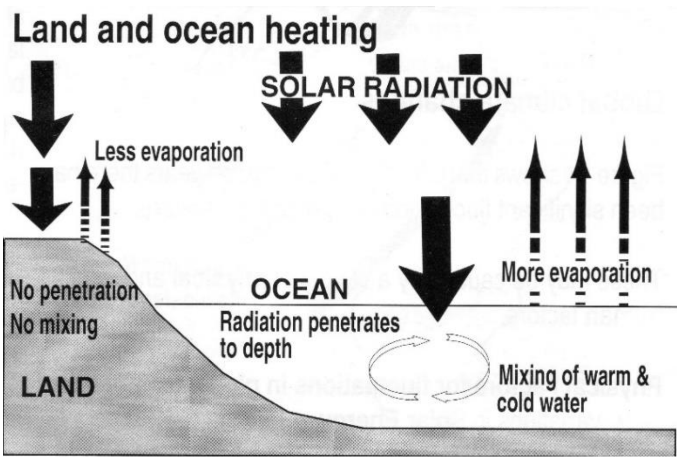
These idealised wind belts rarely exist in reality because of seasonal changes in insolation and the distribution of oceans, continents and major relief features. Average wind patterns for July are shown next for reference.



Prominent circulation features are relatively permanent. **The most noticeable features are the subtropical high-pressure cells at about 30°N and 30°S with the equatorial low-pressure zone,** with converging winds in the vicinity of the ITCZ.

Land and water differences

In general, land surfaces heat faster and to a higher level than water surfaces. However, land surfaces also cool faster and reach lower temperatures when solar energy is absent. Oceans cool at a slower rate because the heat is dispersed through some depth, so they act as a **store of energy**. Temperature ranges over large land masses are therefore greater than over large areas of water.

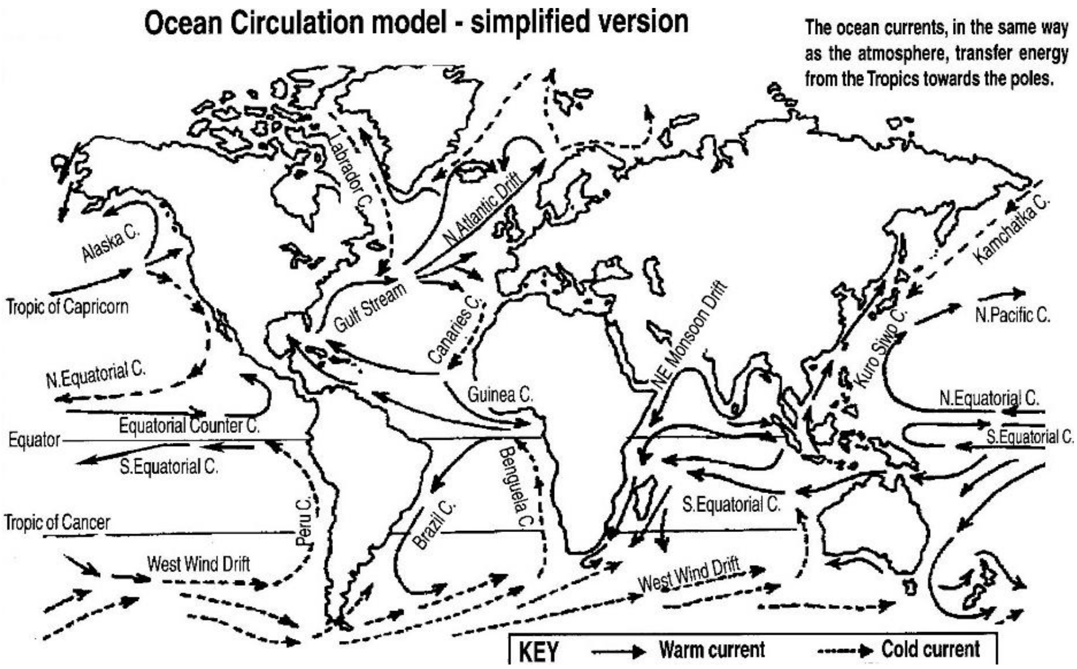


More heat is also lost by surface evaporation over water than over land. The land only absorbs heat at the surface and can therefore reach higher temperatures.

Two-thirds of the earth's surface is water and this receives two thirds of the insolation. Therefore, the redistribution of energy from the equator to the poles by the oceans is significant. **Ocean currents** are the mechanism for this exchange of energy.

Ocean currents

Ocean currents are largely produced by temperature differences and energy transfer from wind to water.
Winds over the ocean surface also drag surface water. However, the Coriolis force causes ocean currents to flow at about 45° to the right of the prevailing winds (in the northern hemisphere).
Density differences can also produce flow in ocean waters.
In the Tropics, equatorial rainfall reduces salinity of the ocean water while in the drier sub-tropics evaporation is greater than rainfall and hence increased salinity. High salinity water tends to subside while on the surface a current tends to flow from areas of low salinity to areas of high salinity. tend to move parallel to the salinity gradient.



Below a latitude of about 30°, **the west coasts of continents have contact with cold currents** (e.g. Canaries Current and California Current) whereas the **east coasts are in contact with warm currents** (e.g. Gulf Stream, Brazil Current). Above about latitude 45° the positions are reversed with west coasts in contact with warm currents (e.g. North Atlantic Drift) and east coasts in contact with cold currents (e.g. Kamchatka and Labrador Currents).

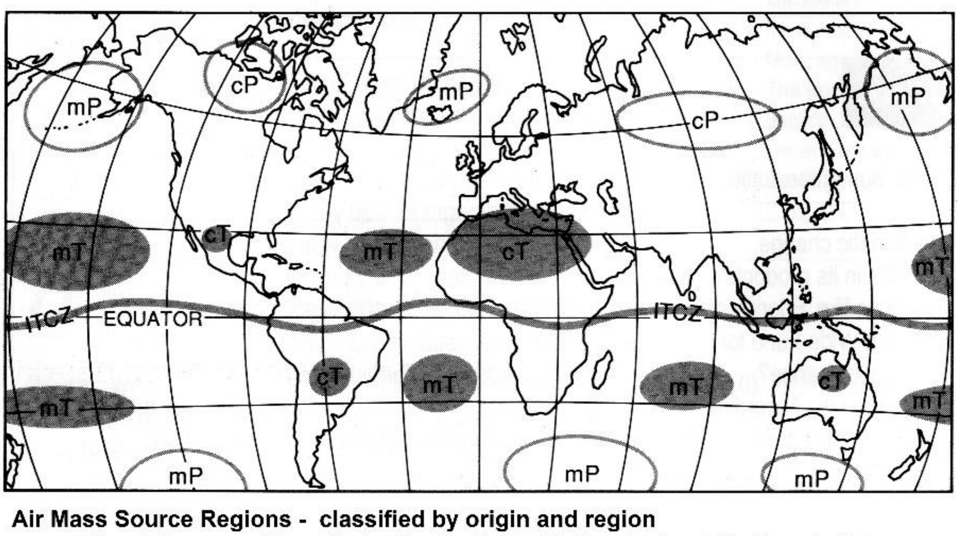
Ocean currents can have a significant effect on climate. For example, the United Kingdom owes its relatively mild winters and ice-free waters to the North Atlantic Drift which is an extension of the Gulf Stream. This warm current keeps the average January temperature in Valentia (Western Ireland) at about 7°C while on a similar latitude in Tomsk, central Russia, it is -21°C.

Air Masses

Origin and movement

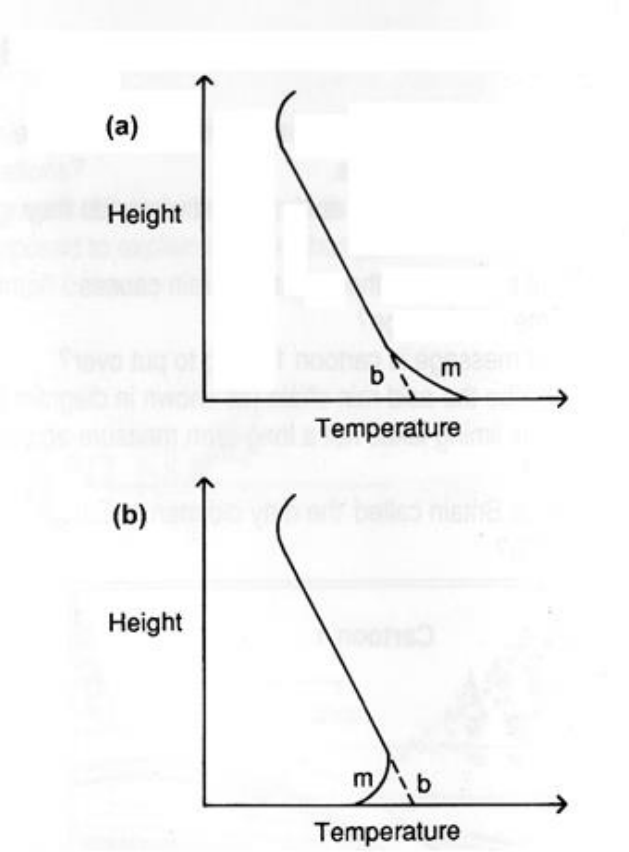
The source regions for these **air masses** are usually places where surface geography is fairly uniform, such as over deserts, oceans, large plains and ice-covered areas. Air which is slow moving or gently subsiding over these areas can **acquire uniform temperature and humidity characteristics**. These large volumes of air with relatively uniform characteristics are called **air masses**.

The main source regions for air masses are shown in the following map, which marks their average position at the equinoxes.



Air Mass Source Regions - classified by origin and region
c - continental, m- maritime, A- Arctic, P - Polar, T- Tropical and E - Equatorial

The air tends to retain its characteristics of heat and humidity for some time but is gradually modified by the earth's surface and by solar insolation. Because the earth's surface plays such an important part in the modification of the air, the lower layers are affected first. An air mass moving equatorward from the poles is heated in its lowest layers. This makes the air unstable because the temperature gradient is steepened and convective cloud is likely to develop. Conversely air moving polewards is cooled in the lowest layers lessening the temperature gradient and making the lower air more stable.

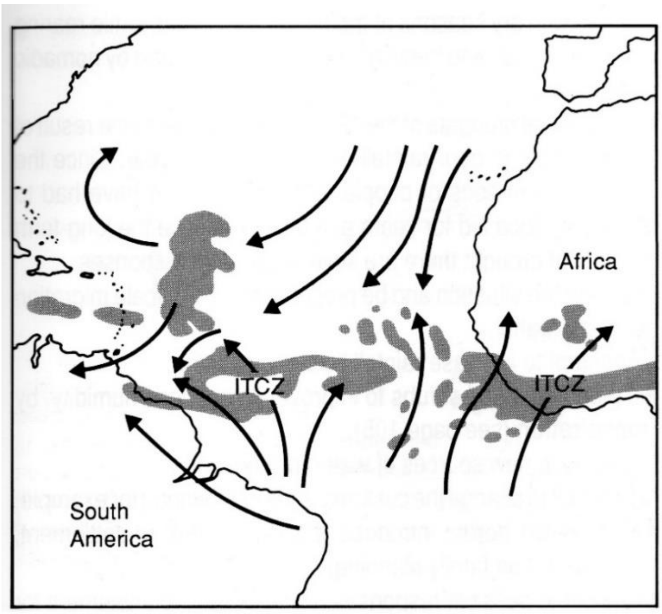


Air Mass modification

a) Polar air, warmed at base, unstable air providing convective cloud
b) Tropical air cooled at base, stable air, providing low-level cloud and fog (on graph
b - temperature gradient before modification
m - after modification

Air masses and the inter-tropical convergence zone

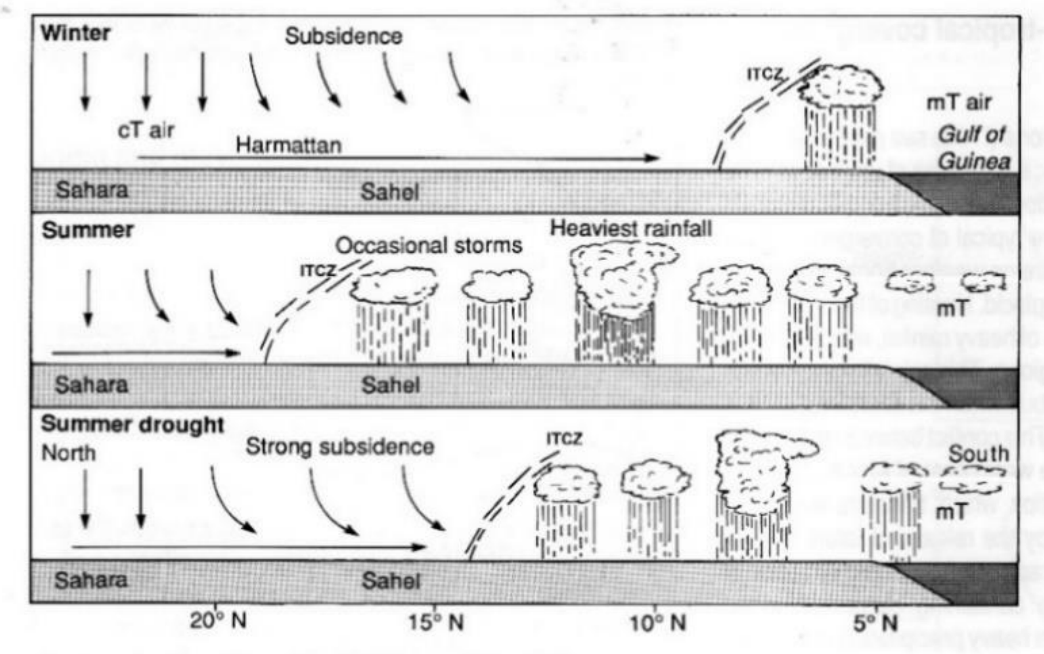
The inter-tropical convergence zone (ITCZ) is where the trade winds converge; it is an area of **uplift of air**.
The air that converges on the I**TCZ does not have the differences in temperature and density** that are typical of convergence at the polar front, and therefore there are **no weather fronts**.
Heating of the tropical air can cause instability and periods of heavy rainfall, which is of vital importance to some tropical regions.
This rainfall occurs when mT (maritime Tropical) air is drawn in over the land but, when the source region is a continent, dry weather persists. This conflict between mT and cT (continental Tropical) is played out each year over the west coast of Africa.



The position of the inter-tropical convergence zone at one point in time is shown by the areas of cloud cover as seen from space. As shown here it is not a straight line and the areas of cloud and rain are separated by areas of clear sky.

Clouds in the ITCZ form clusters which are separated by cloud-free areas. These cloud clusters form where the weak trade-wind inversion is broken through and convection occurs to great heights, forming towering cumulonimbus clouds.

From January to July the ITCZ moves northwards across West Africa bringing cloudy humid conditions.
This moist air gives rise to little rainfall at its northern edge where it meets dry subsiding cT air from the Sahara Desert.



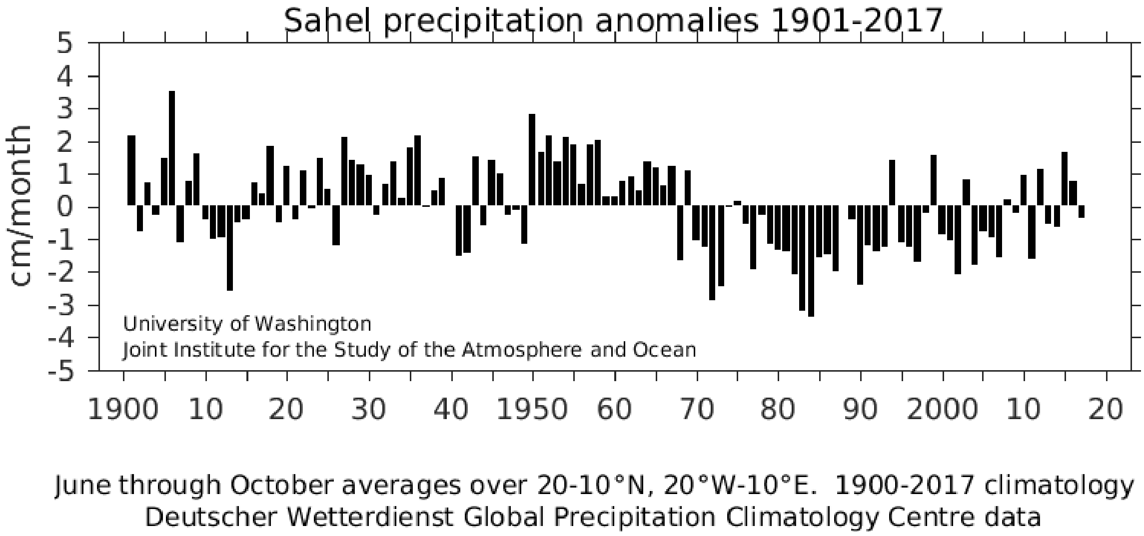
Seasonal migration of the ITCZ over West Africa.
Dry winds from the north dominate much of West Africa in the winter.
In "normal" summers, heavy rains migrate northwards but decrease in frequency and duration, towards the northwards edge of the mT air.
When there is strong subsidencve over the Sahara, in the summer, this can prevent the mT air migrating as far north and causes summer droughts over the Sahel region.

The ITCZ doesn't migrate much over the ocean but over land the position reflects the latitude of maximum insolation.

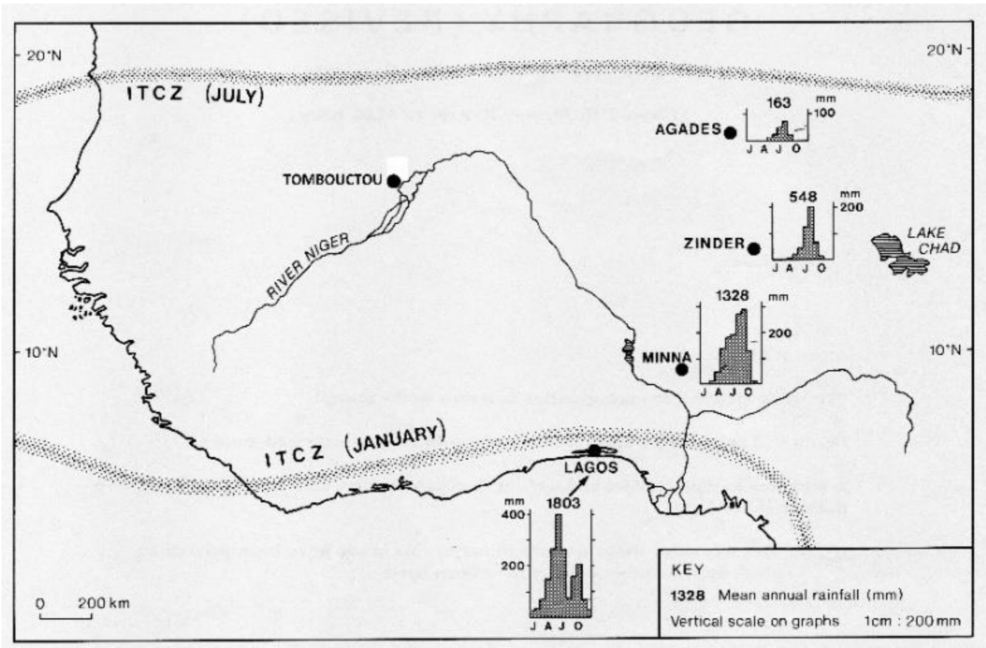
ITCZ migration and its effect in West Africa

The marginal lands bordering the Sahara Desert have suffered since the 1970s from a combination of overpopulation (of humans and livestock) and drought which has **desiccated** large tracts of land. During the 1950s greater than average rainfall encouraged the extension northwards of agriculture and the increase in livestock numbers. But about average rainfall in the 1960s and drought from the 1970s right through until 2007 has brought about southward migration as **desertification** has claimed marginal lands.

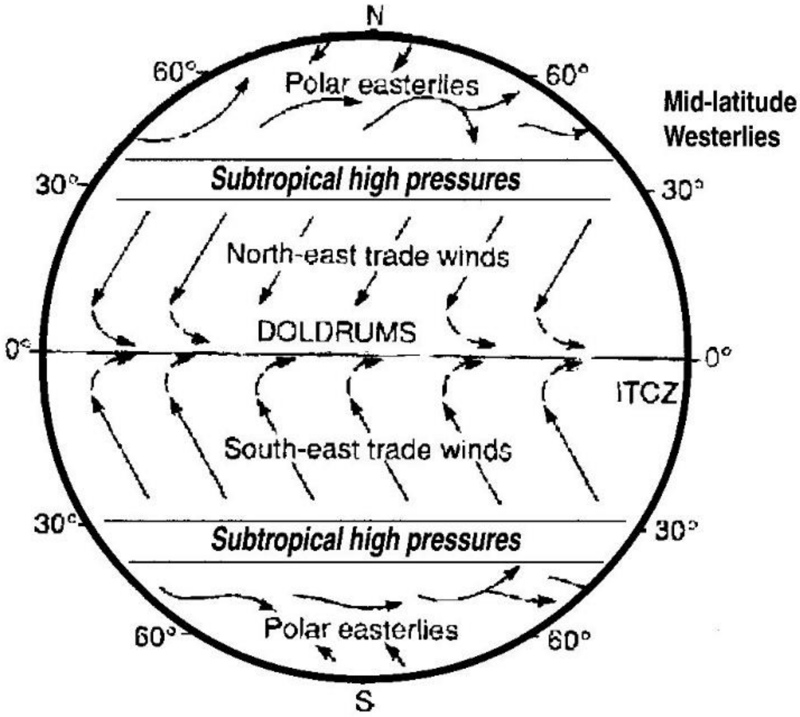
The climate of the Sahel has been variable over the last 100 years and runs of dry or wet years are a part of the natural variability of the Sahel's climate. However, the length of regional droughts is now statistically significant and points to the region going through a **climatic change** which will lead to the southward extension of the Sahara Desert.



During the drought years there has been an equatorward shift in the ITCZ of some 200-300 km. The shift does vary from place to place but this shift has caused the failure of the rains in many Sahel countries. The subtropical high-pressure zone has also drifted south causing strong subsidence over the Sahara and stronger, dry north-east trade winds into the Sahel.



Exam Style Questions



1 a) Describe and explain the distribution of the principal pressure belts of the globe, giving the latitude for each. (5)

b) Explain fully why pressure belts shift in latitude throughout the year. (5)

Either

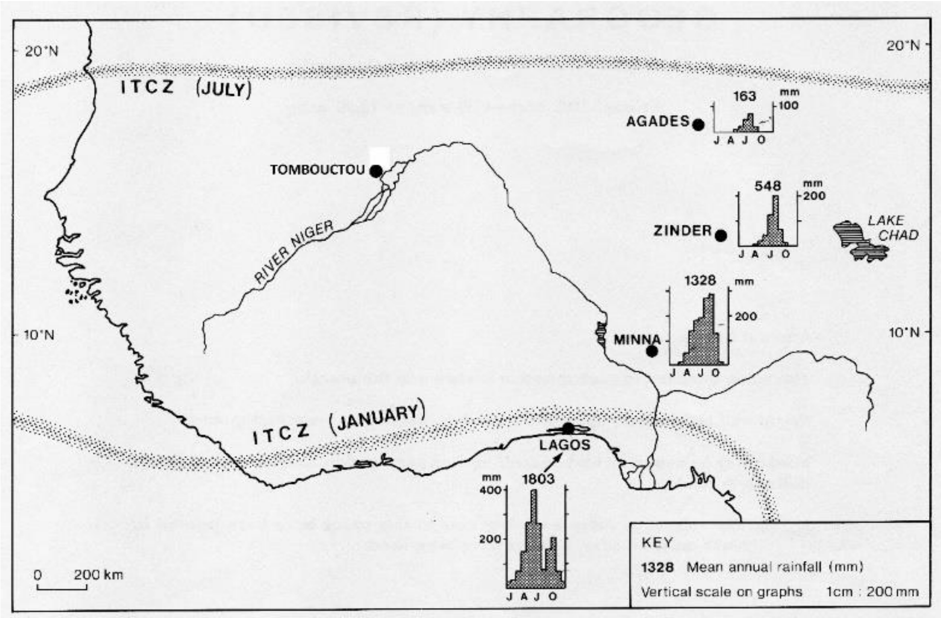
ci) Why do the landmasses of North America and Asia disrupt the belted pressure pattern of the globe? (5)

or

cii) Why do the idealised winds shown on the diagram rarely exist in reality? (5)

and

d) Why don't the winds flow directly between the main pressure belts? Explain the forces which influence the wind. (5)



2a) Explain the changing position of the inter-tropical convergence zone (ITCZ) between January and July. (5)

b) Explain why the seasonal pattern of rainfall is related to the migration of the ITCZ. (5)

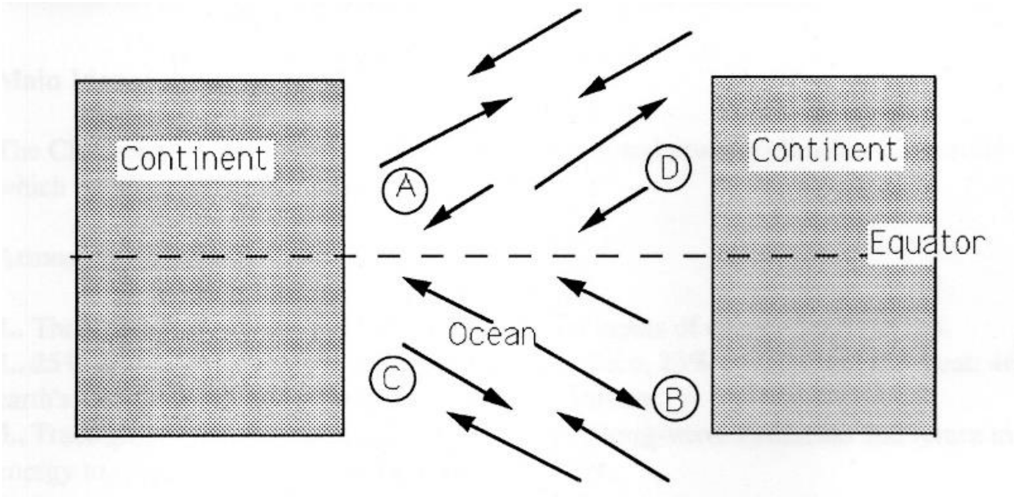
c) Account for the variation in annual rainfall for the Sahel region of Africa. (5)

Either

di) Identify and explain the main problems caused by the seasonal pattern of rainfall in West Africa. (5)

or

dii) What human problems have the droughts since the 1970s in the Sahel caused? (5)



The diagram above is a model of wind belts between two large continental areas.

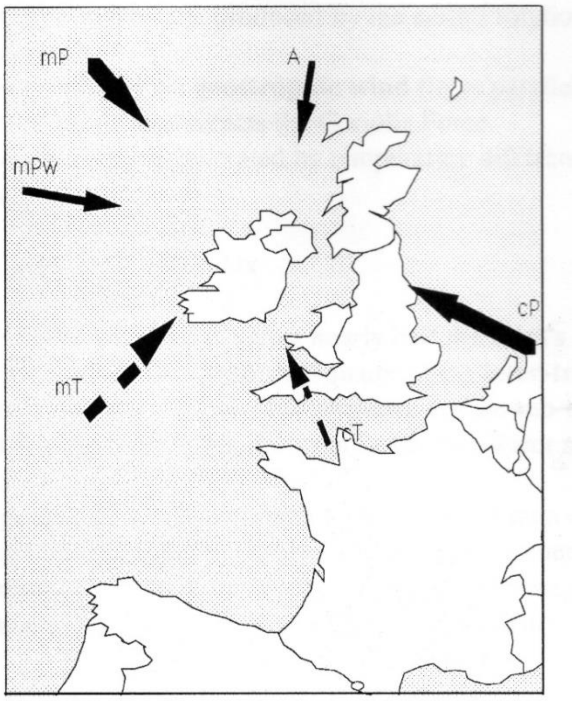
3a) Sketch the ocean current pattern likely to develop from these model conditions, indicating which are warm and which are cold currents.

(5)

b) Compare the model to the Atlantic and name the currents found at locations A to D. (4)

c) Explain the effect of ocean currents on climate in the North Atlantic.

(4)



4a) Account for the varying weather conditions experienced in the British Isles referring to the relevant air masses. (5)

b) Explain how air masses are modified as they move from their source regions. You may use diagrams to illustrate your answer. (4)

c) Explain how blocking anticyclones influence the weather in an area you have studied. (4)

Exam Style Questions and Marked Answers

Explain why there is a surplus of solar energy in the tropical latitudes and a deficit of solar energy towards the poles.

You may wish to use an annotated diagram or diagrams. (4)

Tilt of the axis results in the Sun being higher in the sky between the tropics throughout the year, focusing energy.✓ The sun's rays pass through more of the earth's atmosphere at the poles, meaning that more of the sun's energy is absorbed and reflected. ✓ The albedo effect at the poles means that the white colours of the snow and ice reflect the sun's rays, while at the equator the dark colours of the rainforest absorb heat. ✓ No solar insolation at the winter solstices at the poles producing 24-hour darkness, whereas the tropics receive insolation throughout the year. ✓

With the aid of diagrams, discuss the view that wind belts are the most important influence on the atmospheric transfer of energy.

(15)

Energy is transferred from the low latitude surplus areas to the high latitude energy deficient areas. ✓Without this transfer of energy, the low latitudes would get increasingly hotter and high latitudes even colder. ✓As early as 1735, George Hadley, a British scientist, suggested a tropical heat source powers global circulation and effects a transfer of energy from the Tropics to the Poles. ✓The simple three-cell model of atmospheric circulation proposed by Ferrel included the tropical Hadley cell with rising equatorial air and descending air at the subtropics (around 30° latitude). ✓

This cell also includes air movement at ground level between the sub-tropics and the equator to replace the rising equatorial air, which has created a zone of low pressure. ✓ This area of low pressure is caused by the heated air at the equator which expands, becomes less dense (heavy) and rises. As the heated air rises *through the atmosphere the "weight of air" on the surface is lessened and this results in a low-pressure area.* ✓ *Differences in air pressure create air movement (wind) and in this case the wind moves from the high-pressure subtropics to the low-pressure equatorial zone.* ✓ *The rising equatorial air carries with it considerable amounts of latent heat in the evaporated water from the oceans and land surface. Some of this energy is released as the water vapour condenses in the form of cumulonimbus clouds.* ✓ *The expansion of the rising air in the upper atmosphere creates an airflow in both northward and southward directions.* ✓ *More of the water vapour condenses and releases energy as the air moves poleward, warming the atmosphere in the middle latitudes.* ✓ *A polar cell in this model is due to cold, dense air subsiding in polar regions (polar high-pressure zone) and moving to lower latitudes where it expands as it moves into more space and is warmed by the earth's surface.* ✓ *The Ferrel cell between the other two is a response to the two thermally direct cells (circulation cells which owe their origin to temperature differences) and obtains energy from them. This cell feeds warm air to high latitudes and transfers cold air back to the subtropics for warming.*✓ *This simple three-cell model is a useful simplification of reality. It does not take into account the seasonal shifts in pressure belts or other forces governing global circulation.* ✓*Rossby waves are a mechanism for mixing air of different temperatures and are located at key locations in the atmosphere for the transfer of energy. The jet streams are generated by the temperature differences between polar and subtropical air and between subtropical and equatorial air.* ✓✓

Two-thirds of the earth's surface is water and this receives two-thirds of the insolation. Therefore, the redistribution of energy from the equator to the poles by the oceans is significant. Ocean currents are the mechanism for this exchange of energy. ✓

16 marks worth of valid points made – so providing a diagram is provided – full 15 marks awarded.

Three cell model diagram required to get full marks