LECTURE OBJECTIVES

1. Discuss the dynamism of natural environments in the tropics
    - Discuss the various factors affecting temperature in the tropics

INTRODUCTION

The Earth is constantly receiving incoming heat energy from the sun in the form of **insolation** (**in**coming **sola**r radia**tion**). This energy influences our planet's climate and weather and which, when converted by photosynthesis in green plants, supports all forms of life.

This heat energy received from the sun must be balanced by outgoing heat energy radiated back into space from the Earth as otherwise the Earth will experience a continuous increase in temperature. Since the Earth does not experience a continuous increase in temperature (human induced global warming excluded), this means that incoming energy is matched by outgoing energy from the earth.

HOW IS ENERGY TRANSFERRED?

Before we understand the radiation balance, we will need to first understand how heat energy is transferred. Heat energy can be transferred via 3 mechanisms (Fig. 1):

(i) Conduction

Conduction is the transfer of heat through matter by molecular activity. The energy is transferred through collisions from one molecule to another, with the heat flowing from the higher temperature to the lower temperature. Hence, direct contact of molecules is required. This implies that land (solids) can ***conduct*** heat better than water bodies (liquids) which in turn, conduct heat better than air (gases).

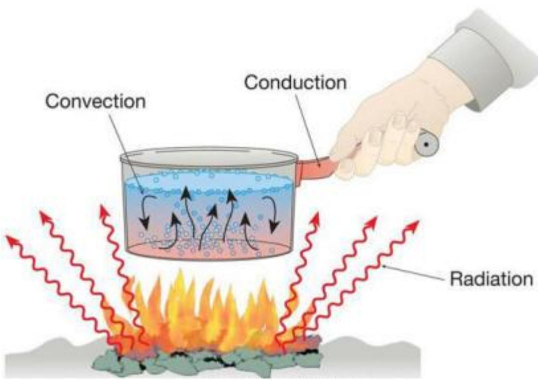
(ii) Convection

Convection is the transfer of heat by circulation within a **fluid** (i.e. liquids like ocean, gases like air) where atoms and molecules are free to move about. On a global scale, convection in the atmosphere creates a huge world-wide air circulation which is responsible for the redistribution of heat. Redistribution of heat also occurs in the form of ocean currents.

(iii) Radiation

Unlike conduction and convection, radiation is the only process of heat transfer that does not require a medium (solid or fluid) to travel through. Radiation is the only mechanism of energy transfer through the vacuum of space and thus, radiation is the heat-transfer mechanism by which solar radiation reaches the Earth from the sun.

Fig. 1 – Three mechanisms of heat transfer: conduction, convection, radiation



WHAT IS THE EARTH'S ENERGY BUDGET/ RADIATION BALANCE?

The ***radiation balance*** (also known as energy budget / heat budget) shows the equilibrium between incoming energy from the sun and outgoing energy from the Earth (Fig. 2). The radiation balance thus prevents, at least in the short term, significant rises or falls of the average temperature of the Earth.

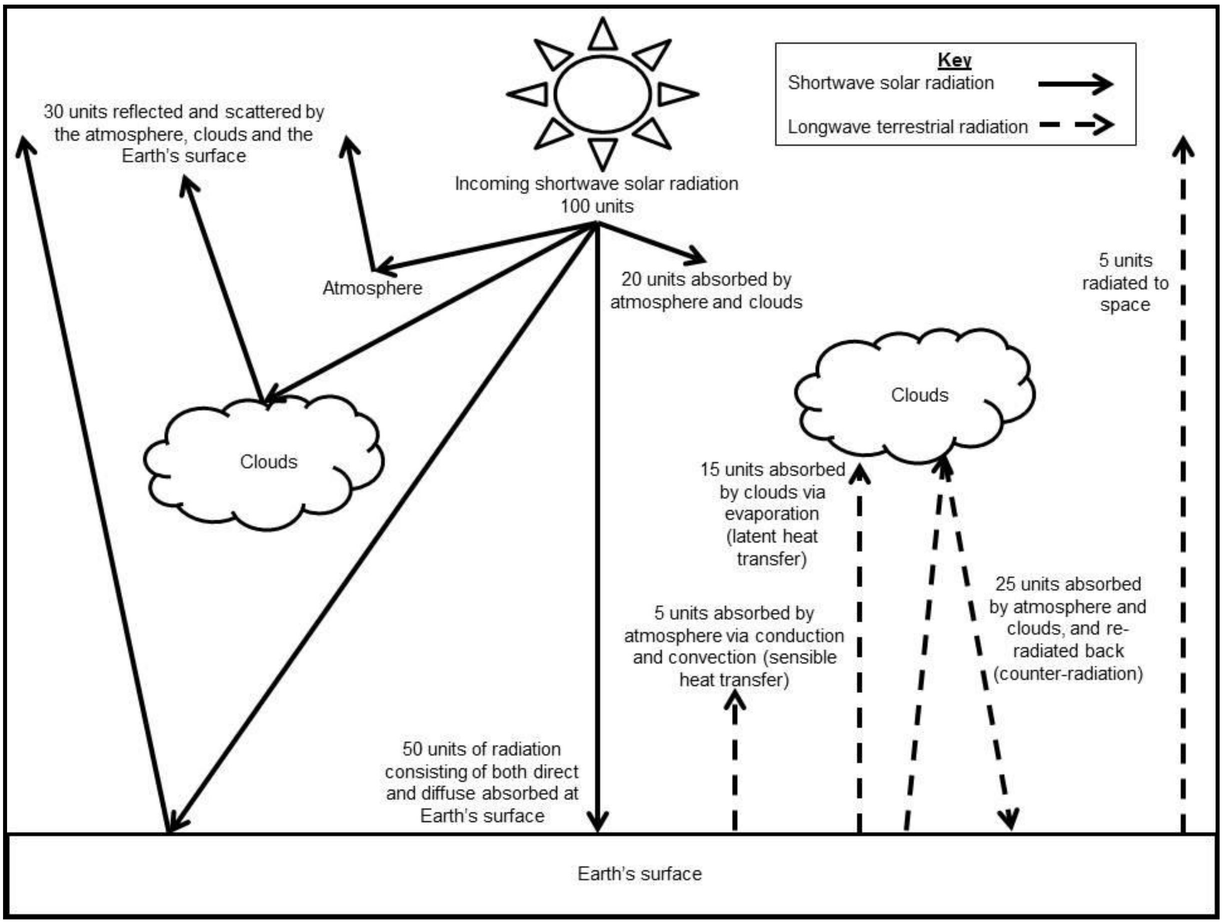


Fig. 2 - Incoming and outgoing radiation

30% of the earth's incoming insolation is reflected and scattered back to space. The remaining 70% of the solar radiation that is not reflected back is

a) absorbed by the atmosphere (20%) or
b) absorbed by the earth's surface. (50%).

What happens to incoming solar radiation?

Insolation from the sun consists of mostly ***shortwave radiation*** which is not easily absorbed by the atmosphere. As solar radiation travels through the atmosphere to the earth's surface, it may undergo several processes, namely:

(i) Reflection

Reflection refers to the process whereby solar radiation bounces directly back into space without being absorbed or performing any work.

Objects and surfaces will reflect differing amounts of sunlight. This can be measured using albedo. ***Albedo*** refers to the reflective quality of a surface. It is the percentage of radiation returning from a given surface compared to the amount of radiation initially striking that surface.

Light-coloured and smoother surfaces have higher albedo. Dark-coloured and rough surfaces have lower albedo. For example:

- Fresh snow has the highest albedo at 75% - 95% (meaning 75% - 95% of the sunlight will be reflected) hence contributing to low temperatures at the polar areas.
- Clear water surfaces, due to their transparency, have a ***low albedo*** compared to land.
- Clouds have an average albedo of 60%, hence places with high amount of cloud cover may receive lesser amount of insolation.

(ii) Scattering

Scattering is the process whereby a beam of solar radiation is broken down into many weak rays by atmospheric gases or clouds. When sunlight strikes very small objects, such as air molecules and dust particles, the light itself is deflected in all directions. The scattered radiation will still be shortwave in nature but it will reach the earth's surface in a diffused manner thus the name ***diffuse radiation***.

(iii) Absorption

Absorption is the conversion of incoming shortwave radiation into heat energy. Only 20% of insolation is directly absorbed by the atmospheric molecules, dust and clouds. The rest is absorbed by the earth's surface (both land and water). Once absorbed, the shortwave radiation is converted to sensible heat, which is subsequently re-radiated as long wavelength radiation.

Upon absorbing shortwave radiation, the earth's surface is heated up and is therefore able to radiate heat. This radiation is different from insolation in that it has a much longer wavelength and is known as ***terrestrial radiation*** *or* ***longwave radiation***.

As the atmosphere does not readily absorb direct solar radiation, it is mostly heated up indirectly by absorbing the ***longwave radiation*** that is emitted back into the atmosphere from the earth surface. This longwave radiation is more readily absorbed by the atmosphere than incoming insolation

(iv) Re-radiation

Re-radiation refers to emission of radiation after absorption of incoming radiation. Short wave radiation absorbed by Earth's surface is re-radiated as longwave radiation back to the atmosphere. A portion of this longwave radiation that is absorbed by the atmosphere is re-radiated back to the earth's surface. This is called ***counter-radiation***.

The amount of counter-radiation varies directly with the amount of cloud cover. The greater the cloud (and dust) cover, the greater the amount of counter-radiation. This would mean that more heat is trapped within the earth. Counter-radiation is an important process as it gives rise to the greenhouse effect.

HOW IS THE EARTH KEPT WARM? –THE GREENHOUSE EFFECT

The ***greenhouse effect*** (Fig. 3) refers to the warming of the Earth's atmosphere due to outgoing longwave radiation being absorbed and trapped. The greenhouse effect occurs naturally on Earth due to the presence of clouds that re-radiate outgoing longwave radiation and greenhouse gases.

Greenhouse gases are gases which absorb longwave radiation, leading to the greenhouse effect. Greenhouse gases include carbon dioxide, carbon monoxide, methane, nitrogen oxides and chloroflorocarbons (CFCs).

The greenhouse effect should not be confused with the term global warming. Global warming occurs when there is an *'enhanced'* greenhouse effect due to the build-up of greenhouse gases such as carbon dioxide and methane. **(We will return to these in subsequent lectures)**

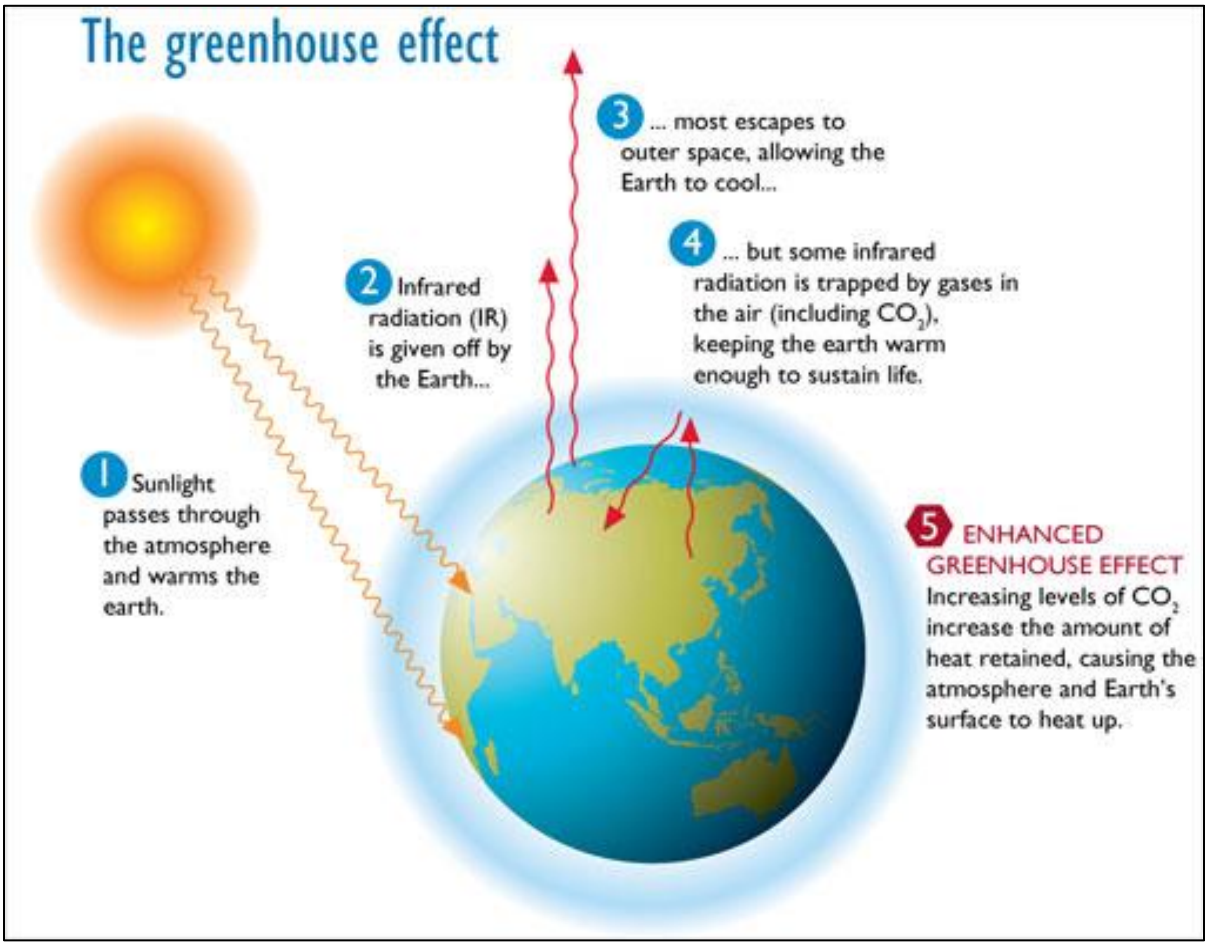


Fig. 3 - The Greenhouse and Enhanced Greenhouse effect

HOW IS ENERGY TRANSFERRED BETWEEN THE EARTH-ATMOSPHERE SYSTEM?

As mentioned earlier, energy is generally transferred via the processes of conduction, convection and radiation. Energy transfer between the Earth-Atmosphere system can occur via both horizontal and vertical heat transfer. The heat energy from the earth's surface can be transferred by the following mechanisms:

(i) Terrestrial Longwave Radiation

Terrestrial longwave radiation is radiation emitted upon heating of the Earth's surface (via absorption of shortwave radiation). It is easily absorbed by the atmosphere providing a means in which the surplus heat on the earth surface can be transferred to the atmosphere.

(ii) Sensible Heat Transfer

Sensible Heat Transfer refers to the transfer of heat by the process of **conduction** (via contact with warm surface) and **convection** (via mixing of rising hot air with colder air).

(iii) Latent Heat Transfer

Latent Heat Transfer refers to the transfer of heat between the earth's surface and the atmosphere through changes of state such as evaporation and condensation. (We will discuss this when we talk about cyclone formation).

VARIATIONS IN ENERGY BUDGET

At the global level, there will always be equilibrium between incoming radiation from the sun and outgoing radiation from the earth. This explains why the earth as a whole has not become progressively hotter or colder (ignore global warming for now). On the local level however, there can be a net gain, loss or zero difference. It can vary according to the time of day and according to latitudes. We will look into the latitudinal variation in this section.

WHY IS THERE DAILY VARIATION IN LOCAL ENERGY BUDGET (NET RADIATION)?

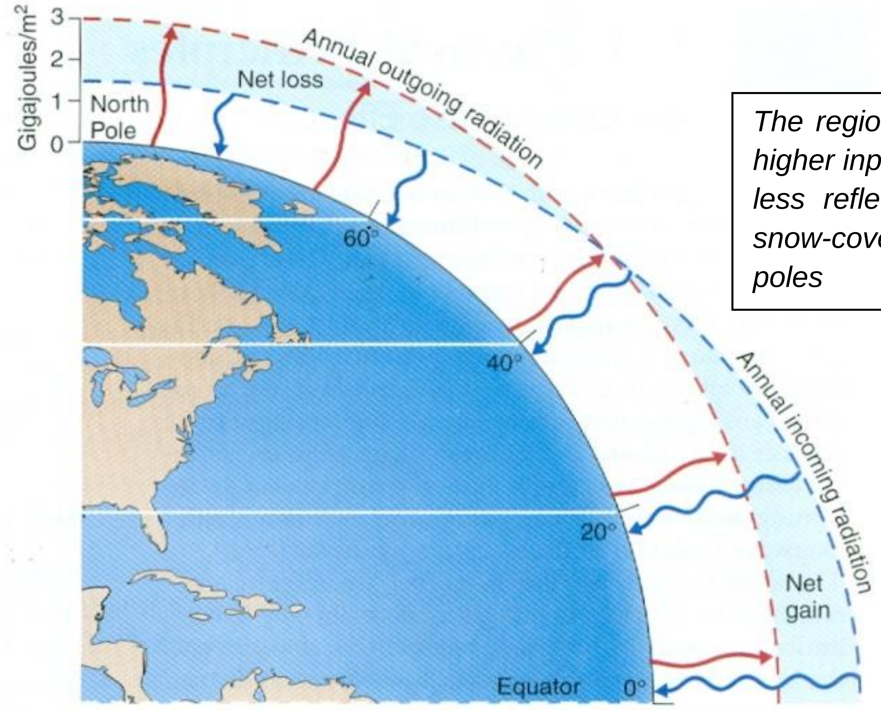
The local energy budget differs between day and night. Generally, the day experiences surplus in energy while the night experiences a deficit in energy.

During the day, the net radiation of a particular location on the Earth's surface is a **positive value** because incoming radiation absorbed by the Earth's surface exceeds the value of outgoing terrestrial (long wavelength) radiation.

On the other hand, the **net radiation is negative at night** when there is no incoming solar radiation and net radiation is dominated by outgoing terrestrial longwave radiation. Net radiation is zero when the incoming and outgoing components are in perfect balance, which occurs only infrequently.

(I) Latitudinal Variation in Net Radiation

Although there is an overall balance between incoming and outgoing radiation for the earth as a whole, the balance between incoming and outgoing radiation varies with latitude. On an annual basis, the Earth's surface-atmosphere system gains more radiation than it loses between about 38° North and South latitude, and it loses more than it gains poleward of these two parallels, ie ***there is a surplus of net radiation between 38^{0}N and 38^{0}S and a deficit everywhere else.*** (Fig. 4).



The regions at the Equator have higher input of solar radiation with less reflection compared to the snow-covered surfaces of the poles

Fig. 4 – Variation in net radiation across latitudes

If there were no other processes involved, the net gain of radiation between 38°N and 38°S would cause these regions to undergo continual heating and ever higher temperatures. Conversely, areas polewards of 38°N and 38°S would constantly cool. That does not occur, however, because the energy surplus at low latitudes is offset by the **horizontal heat transfer** polewards (Fig. 5). Thus it prevents the Equator from becoming increasingly hotter and the poles increasingly colder.

The poleward transfer of heat energy is done primarily by atmospheric circulation (80% of the heat transfer), and secondarily by oceanic circulation (20%). Atmospheric circulation (in the form of winds, jet streams and tropical cyclones) as well as oceanic circulation (warm and cild currents) are generated because ***spatial variations in heat cause differences in pressure to occur***. As the wind and water currents move, they transfer heat via convection across the globe.

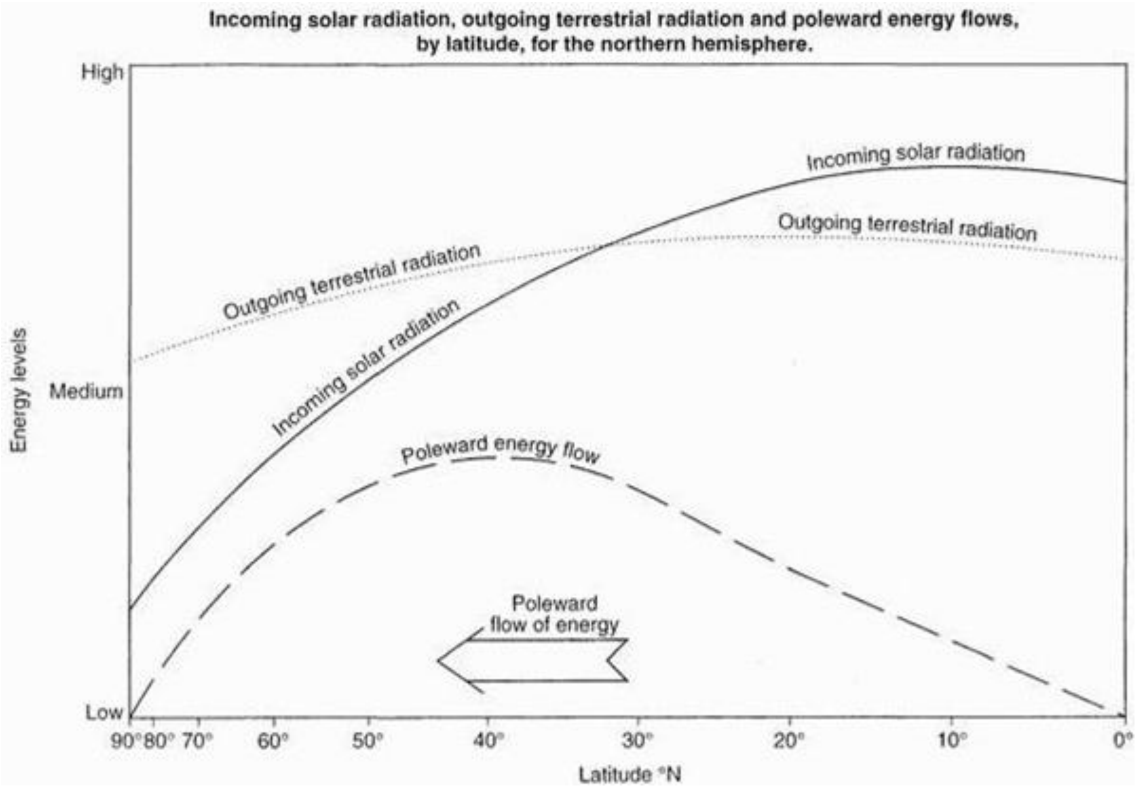


Fig. 5 – Poleward transfer of heat energy

Ocean currents are a major component in the process of horizontal transfer of heat energy. Warm currents carry water polewards and raise the air of the maritime environments where they flow. Cold currents carry water towards the Equator and so lower the temperatures of coastal areas. Examples of cold currents include the Humboldt and Equatorial current, while warm currents include the North Pacific Drift and the Gulf Stream (Fig. 6).

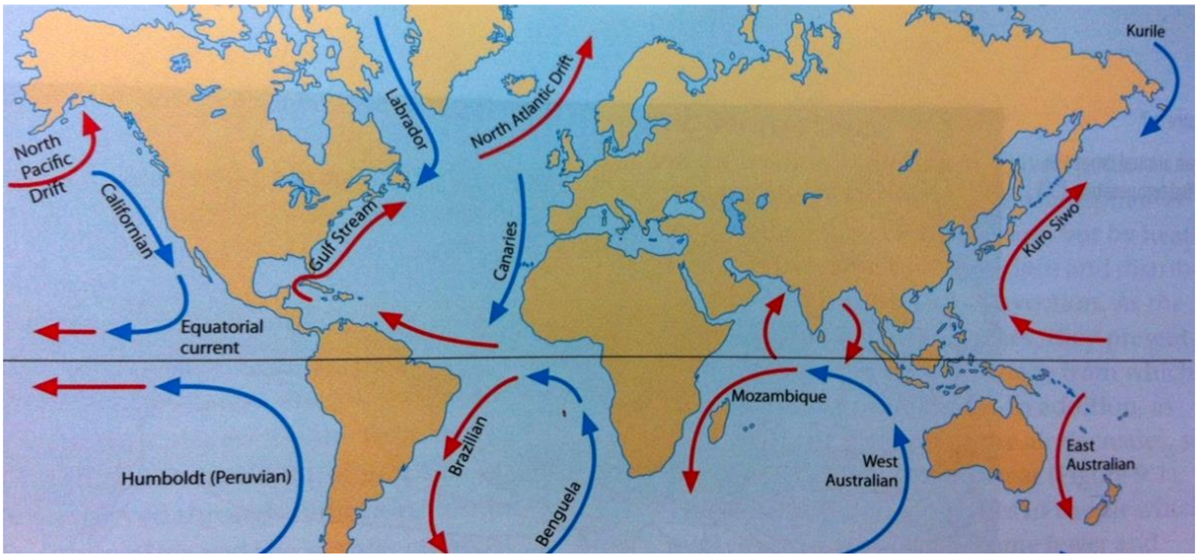


Fig. 6 – Major Ocean Currents

Therefore, latitudinal variations in net radiation will result in two main processes occurring, which are horizontal heat transfers as well as vertical heat transfers.

WHAT ARE THE FACTORS INFLUENCING THE TEMPERATURE PATTERNS OF CLIMATE ZONES IN THE TROPICS?

The various factors influencing temperature patterns of climate zones in the tropics include:

Factor	How it affects temperature
Latitude	Average annual temperature
Axial Tilt of Earth/Length of daylight hours	Seasonality/ Annual variation of temperature
Altitude	Average annual temperature
Cloud Cover	Diurnal temperature range
Ocean currents	Average annual temperature

1. Latitude (which affects insolation received and reflected)

a. Latitude is the angular distance north or south from the equator of a point on the earth's surface. (ie a way to measure distance from the equator) The equator has 0° latitude and the poles (which are furthest from the equator) have a maximum of 90°

b. Latitude influences the average annual temperature of a location, by influencing

i. the angle of incidence (Beam spreading) and

ii. the distance through the atmosphere that insolation has to penetrate before reaching the earth's surface (Beam depletion)

c. The **angle of incidence** refers to the angle at which insolation hits the earth's surface.

i. Due to the spherical nature of the earth, the angle of incidence is zero at the sub-solar point and increases away from it.

ii. The sub-solar point refers to the point receiving perpendicular insolation at a given moment and therefore the highest intensity of insolation[1]. The intensity of insolation decreases away from the sub-solar point. This is due to beam spreading.

iii. ***Beam spreading*** is the increase in the surface area over which insolation is distributed in response to an increase of solar angle. The greater the spreading, the less intense the insolation is. At higher latitudes, insolation reaches the earth at a lower angle of incidence. Beam spreading occurs, and the same amount of radiant energy is spread over a larger area, reducing the amount of insolation received per unit area. (Fig. 7).

iv. Tropical climates thus have a high average annual temperature of at least 18°C due to their **low latitudes which result in high angles of incidence and minimal beam spreading which allows it temperature to be higher than 18°C.**

[1] The sub-solar point varies with latitude throughout the year from 23.5°N in June to 23.5°S in December.

2. Due to the spherical nature of the earth, at higher latitudes, incoming insolation has to travel a longer distance through the earth's atmosphere before reaching the surface. As such, the insolation is subjected to more scattering and reflection, hence causing beam depletion. During the equinoxes (see below), other factors notwithstanding, the higher the latitude, the greater the amount of beam depletion.

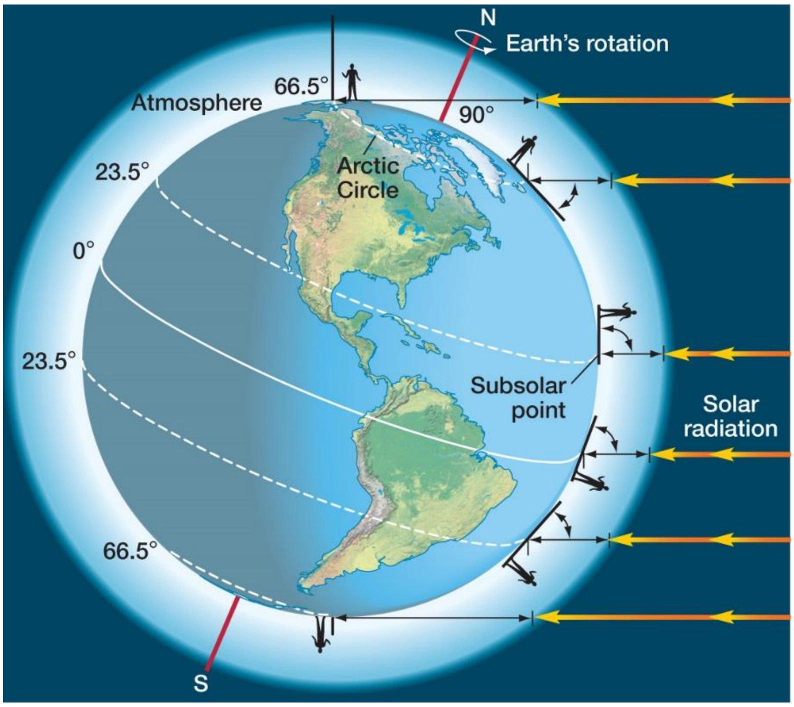


Fig. 7 – Beam spreading and Beam depletion

Please view: https://www.youtube.com/watch?v=39-IFrKGAg0

3. **Axial Tilt of the Earth: Seasonality in Annual Temperature**
   https://www.youtube.com/watch?v=taHTA7S_JGk

   a. The axial tilt of the earth (Fig. 8) refers to the angle between its equatorial plane and orbital plane. The earth has an axial tilt of 23.5°.

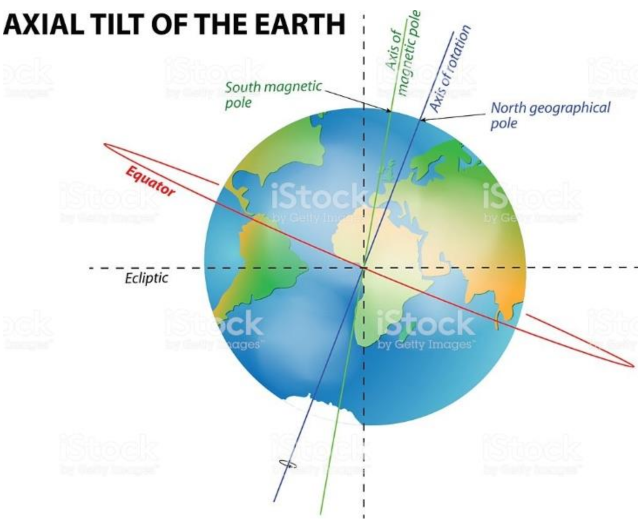


Fig. 8 - Axial tilt of the earth

b. The axial tilt of the earth influences the seasonality of temperature of a location by influencing (i) the latitude of the sub-solar point across the year, and (ii) the length of daylight experienced at a location across the year.

c. The **position of the overhead sun** changes throughout the year due to the axial tilt of the earth.

   i. Due to the axial tilt of the earth, the latitude of the sub-solar point (position where overhead sun is most direct) not always at the equator throughout the year.

   ii. The axial tilt of the earth and the orbit of the earth around the sun collectively cause the sub-solar point to migrate between the Tropic of Cancer (23.5°N) during the summer solstice in June and the Tropic of Capricorn (23.5°S) during the winter solstice in December (Fig. 9).

   iii. During the summer solstice in June, the northern hemisphere is tilted towards the sun and causes the sub-solar point to be overhead at the Tropic of Cancer. This means insolation received in the Northern hemisphere is higher than that of the Southern hemisphere, which is tilted away from the sun and receives less insolation. The reverse occurs in December when the sub-solar point is directly overhead at the Tropic of Capricorn.

   iv. Hence, <u>this explains why tropical climates in the northern hemisphere tend to experience their highest monthly temperatures during the June-July period and lowest monthly temperatures during the December-January period. The reverse occurs for tropical climates in the southern hemisphere. (Fig. 10)</u>

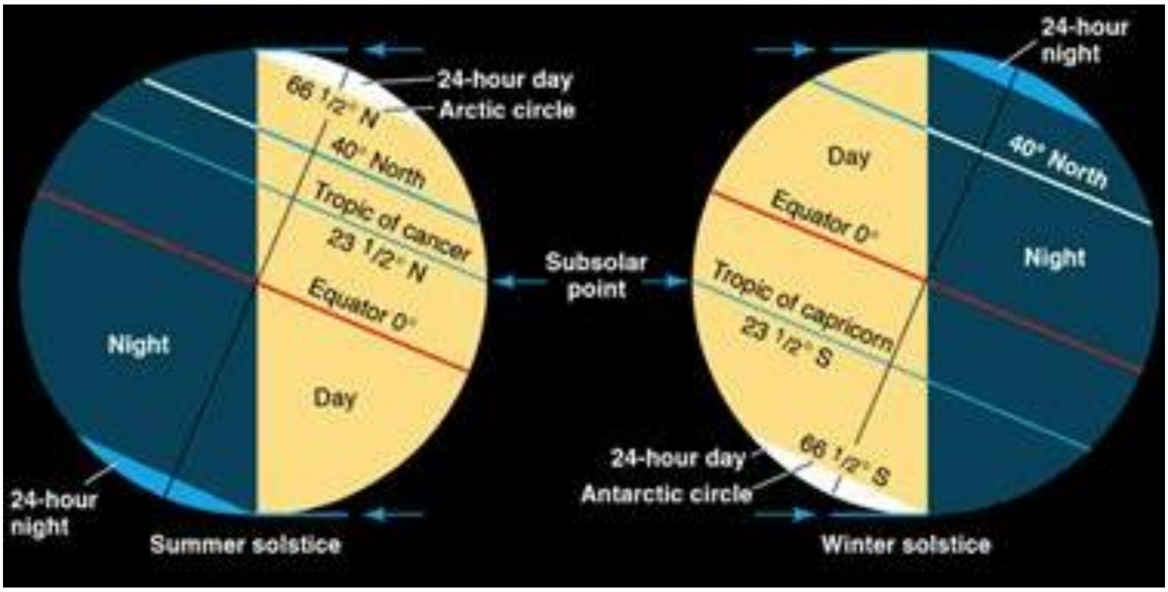


Fig. 9 - Sub-solar point in June and December
(Note: Sub-solar point will be at the equator in March and September)

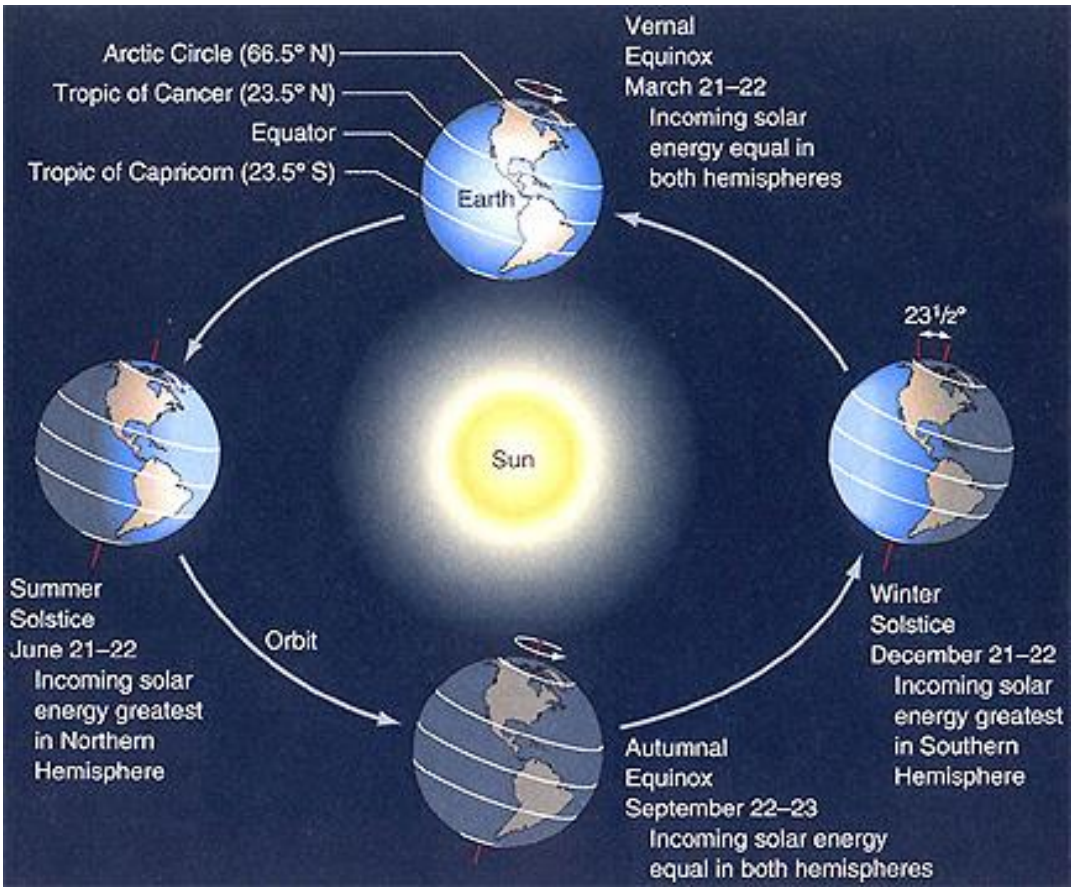


Fig.10 - Effect of the earth's axial tilt on amount of insolation received in a year for various latitudes

d. The **length of daylight** experienced at a location is also influenced by the axial tilt of the earth (Fig. 11).

   i. Due to the axial tilt of the earth, the period of daylight experienced across the latitudes is unequal across the period of a year as the tilt influences the length of time in which different latitudes are exposed to the sun within a 24 hour period.

   ii. For example, during the June summer solstice, latitudes in the northern hemisphere will experience longer hours of daylight compared to those in the southern hemisphere. Latitudes above 66.5°N (Arctic Circle) will experience a 24-hour period of continuous daylight, while any latitude above 66.5°S (Antarctic Circle) will experience a 24-hour period of continuous darkness. The reverse occurs during the December winter solstice.

   iii. During the March and September **equinoxes**, the length of daylight is equal for all latitudes as the tilt of the earth does not result in any hemisphere being orientated toward the sun.

   iv. Hence, this also <u>explains why tropical climates in the northern hemisphere tend to experience their highest monthly temperatures during the June-July period and lowest monthly temperatures during the December-January period. The reverse occurs for tropical climates in the southern hemisphere.</u>

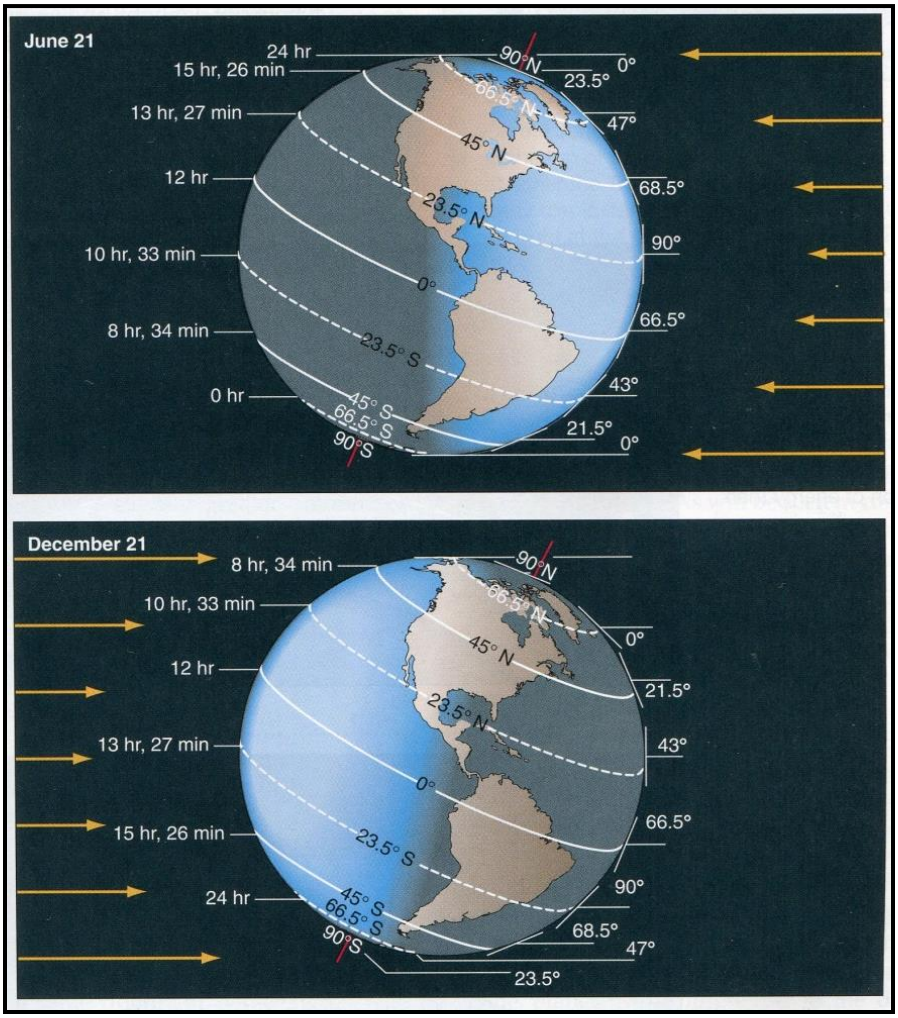


Fig. 11 - Length of daylight In June and December across all latitudes

4. Altitude

a. Altitude refers to the height of a point above sea level.

b. Altitude influences the average annual temperature of a location as temperatures decrease with increasing altitude. The rate at which temperature decreases with height is known as the environmental lapse rate. The average environmental lapse rate is 6.5°C/km.

c. Temperature decreases with altitude as the most important direct source of energy for the atmosphere is not insolation but longwave terrestrial radiation from the Earth's surface after insolation has been absorbed into the ground. Therefore, temperature decreases as altitude increases due to increasing distance away from the ground.

d. The air is also thinner at higher altitudes due to reduced pressure. The thinner air means that gas molecules are less likely to collide into each other, resulting in lower temperatures.[2]

e. Hence, <u>this explains why some locations within the tropics may experience lower average annual temperatures compared to other locations at similar latitudes</u>. For instance, the

[2] Temperature is not the same as heat energy. Temperature is affected by the pressure exerted on the medium.

summit of Mount Kilimanjaro is 4°S of the equator but is permanently ice-capped, forming an exception to the tropical rainforest climate which is dominant at that latitude in Africa.

5. Cloud Cover

a. The amount of cloud cover affects the diurnal temperature range of a particular area as clouds influence the amount of insolation received during the day and the amount of counter-radiation received at night for a particular place.

b. During the day, clouds reflect and scatter insolation and reduce the amount of insolation received at the earth's surface. As such, areas with low cloud cover, such as the deserts, generally receive higher levels of insolation at the surface and experience higher daytime temperatures.

c. In contrast, areas with more cloud cover experience more reflection and receive lower levels of insolation at the surface and experience lower daytime temperatures.

d. During the night, clouds reflect outgoing terrestrial long-wavelength radiation back to earth in a process known as counter-radiation. As such, areas with low cloud cover generally receive lower levels of counter-radiation at night and experience lower night-time temperatures.

e. In contrast, areas with more cloud cover receive higher levels of counter-radiation and experience higher night-time temperatures.

f. Thus, cloud cover influences the diurnal temperature range of a location. For example, rainforest climates with thick cloud cover experience daytime temperatures of 30°C and night time temperatures of about 20°C. In deserts where there is very little cloud cover, temperatures may reach 40°C during the day and drop to freezing point at night.

g. Hence, <u>this explains why tropical climates such as the sub-tropical steppe (BSh) and hot low latitude desert (BWh) climates have a high diurnal temperature range.</u>

6. **Continental / Maritime Effect** [affected by cloud cover and ocean currents]

a. Continental and maritime effects may influence the (i) average annual temperature, (ii) seasonality of temperature, as well as the (iii) diurnal temperature range of a location due to the different specific heat capacities[3] of continents and oceans.

b. Water has a higher heat capacity than land. So it takes more heat to raise the temperature of one gram of water by one degree than it does to raise the temperature of land. 1 calorie of solar energy (any type of energy really) will warm one gram of water by 1 degree Celcius, while the same calorie would raise the temperature of a gram of granite by more than 5 degrees C.

c. Land has a lower specific heat capacity compared to oceans. Water has 4 times the heat capacity of clay and thus land surfaces heat up and cool more rapidly than the oceans. Consequently, temperatures above continents are more responsive to changes in heat and display (i) greater average annual temperatures, and a (ii) greater difference between the maximum and minimum monthly temperatures, as well as a (iii) greater diurnal temperature range compared to maritime locations.

d. In contrast, the reverse occurs for locations near the oceans, due to the greater heat capacity of the ocean, leading to the ***maritime effect***.

e. Hence, this explains the differences between the (i) average annual temperature, (ii) seasonality of temperature, as well as the (iii) diurnal temperature range of continental and maritime locations.

f. Oceanic and coastal areas also tend to have ***denser cloud cover***, which serve to reduce insolation and increase counter-radiation, thereby resulting in diurnal lower temperature ranges (lower daytime temperatures and higher night-time temperatures).

g. Offshore ***oceanic currents*** also affect the temperatures of their adjoining land masses. Cold currents such as the Benguela Current lower the temperatures of the Atlantic coast of South Africa and Namibia by bringing cool waters from the poles which cool the air above the ocean over these areas.

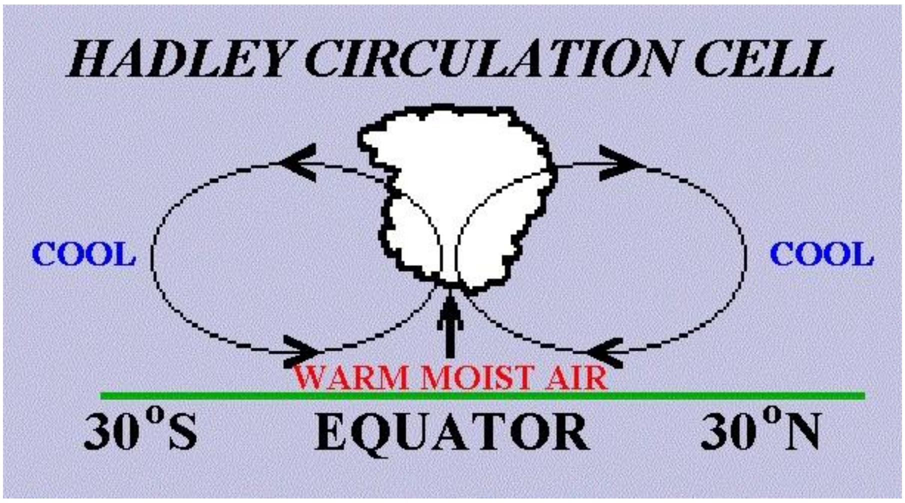
See: https://www.youtube.com/watch?v=p4pWafuvdrY

[3] Specific heat capacity refers to the amount of energy required to increase the temperature of a unit mass of a substance by 1°C.

7. **Re-distribution of surplus solar radiation by the Hadley Cell** (Just know, to be revisited in next lecture)

   a. A **Hadley Cell** is a thermally-direct cell found between the equator and 30^0 north and south of the equator in both the northern and southern hemisphere.

   b. The Hadley Cell encompasses latitudes from the equator to about 30 degrees. At the equator, air is warm due to the concentration of insolation from the sun. The air flowing northwards from the equator high up in the atmosphere is warm and moist compared to the air nearer to the poles. Heat from the equator generally sinks around 30 degrees latitude where the Hadley Cells end. As a result, the warmest air does not reach the poles. This helps to redistribute the surplus solar radiation from the equator towards 30 degrees latitude north and south of the equator. This prevents the equator from becoming hotter and hotter. (think like a natural air conditioning system)



LINKS BETWEEN THE FACTORS INFLUENCING THE TEMPERATURE AND THE CHARACTERISTICS OF THE 5 CLIMATE ZONES IN THE TROPICS

Climatic Zones Summary Table					
Climate	**Tropical Rainforest**	**Tropical Monsoon**	**Tropical Savanna**	**Sub-Tropical Steppe**	**Hot Low Latitude Desert**
Köppen classification	Af	Am	Aw	BSh	BWh
Temperature Characteristics	**Average annual temperature:** Above 18°C (between 26°C to 28°C) **→ Due to low latitude**	**Average annual temperature:** Above 18°C **→ Due to low latitude**	**Average annual temperature:** Above 18°C **→ Due to low latitude**	**Average annual temperature:** Above 18°C **→ Due to relatively low latitude**	**Average annual temperature:** Above 18°C **→ Due to relatively low latitude**
	Annual temperature range: Small (less than 3°C) due to equal length of day and night (lack of seasonality) in a year **→ Influence of axial tilt is minimal due to the very low latitude of locations with this climate**	**Annual temperature range:** Small but larger than tropical rainforest (3°C to 6°C) **→ Due to axial tilt**	**Annual temperature range:** Small but larger than tropical rainforest and tropical monsoon (3°C - 10°C) **→ Due to axial tilt**	**Annual temperature range:** Large (20°C - 30°C) **→ Due to axial tilt**	**Annual temperature range:** Large (20°C - 30°C) **→ Due to axial tilt**
	Diurnal temperature range: Small (10°C), with average high of 32°C in the day and average low of 22°C at night **→ Due to extensive cloud cover throughout the year**	**Diurnal temperature range**: Variable depending on season (10°C - 25°C). May exceed 25°C during dry season when cloud cover is absent. Lower during wet season. **→ Due to varying cloud cover across the year (more during the wet season)**	**Diurnal temperature range**: Variable depending on season (10°C - 25°C). May exceed 25°C during dry season when cloud cover is absent. Lower during wet season. **→ Due to continentality and varying cloud cover across the year (more during the wet season)**	**Diurnal temperature range**: Very large (ranging from 20°C to 50°C), due to high daily temperatures which can exceed 40°C and low nighttime temperatures which can drop below 0°C. **→ Due to continentality and minimal cloud cover throughout the year**	**Diurnal temperature range**: Very large (ranging from 20°C to 50°C), due to high daily temperatures which can exceed 40°C and low nighttime temperatures which can drop below 0°C. **→ Due to continentality and minimal cloud cover throughout the year**

Note: Bear the other factors such as altitude, continental / maritime effect and ENSO in mind when considering factors that may affect temperature, when answering Data Response Questions and Structured Essay Questions.]