## 1. Details of Module and its structure

| Module Detail | |
|---|---|
| Subject Name | Geography |
| Course Name | Geography 01 (Class XI, Semester - 1) |
| Module Name/Title | Solar Radiation and Heat Budget – Part 1 |
| Module Id | kegy_10901 |
| Pre-requisites | Basic understanding of the composition and structure of the atmosphere |
| Objectives | After reading this lesson, learners will be able to know about:<br>• Explain the importance of insolation and establish relationship between angle of incidence of sun's rays and the intensity of heat received from them at a place;<br>• Explain the different processes involved in heating and cooling of the atmosphere (conduction, convection, radiation and advection).<br>• Explain the heat budget with the help of a diagram;<br>• Differentiate between solar radiation and terrestrial radiation. |
| Keywords | Insolation, Radiation, Conduction, Convection, Latent heat, Adiabatic changes in temperature |

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## Introduction

The earth receives almost all of its energy from the sun. The earth in turn radiates back to space the energy received from the sun. As a result, the earth neither warms up nor does it get cooled over a period of time. Thus, the amount of heat received by different parts of the earth is not the same. This variation causes pressure differences in the atmosphere. This leads to transfer of heat from one region to the other by winds. This chapter explains the process of heating and cooling of the atmosphere and the resultant temperature distribution over the earth's surface.

## Solar Radiation

The earth's surface receives most of its energy in short wavelengths. The energy received by the earth is known as incoming solar radiation which in short is termed as insolation. As the earth is a geoid resembling a sphere, the sun's rays fall obliquely at the top of the atmosphere and the earth intercepts a very small portion of the sun's energy. On an average the earth receives 1.94 calories per sq. cm per minute at the top of its atmosphere.

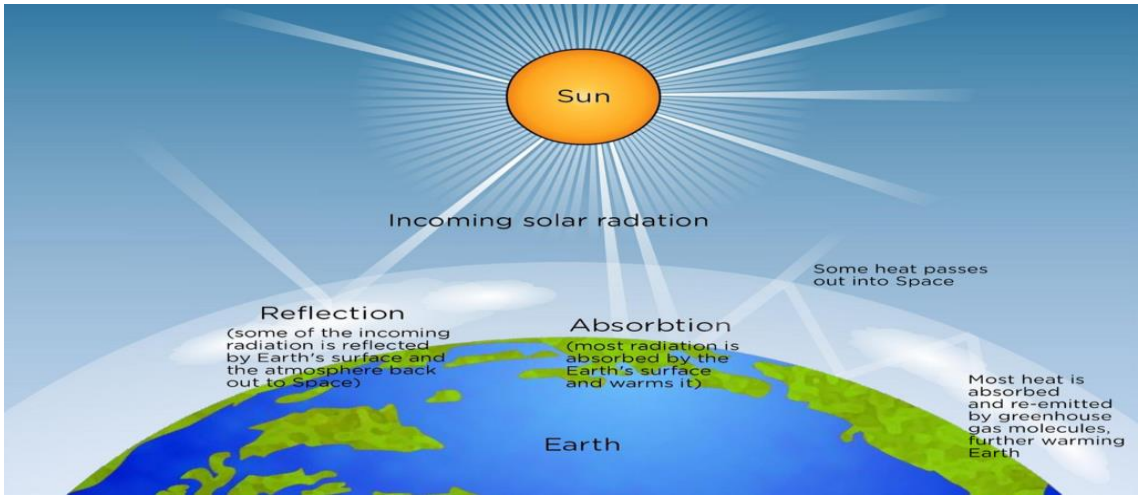


Fig. No.01 Solar Radiation

Source:-https://www.flickr.com/photos/121935927@N06/13580531193

The solar output received at the top of the atmosphere varies slightly in a year due to the variations in the distance between the earth and the sun. During its revolution around the sun, the earth is farthest from the sun (152 million km) on 4th July. This position of the earth is called aphelion. On 3rd January, the earth is the nearest to the sun (147 million km). This position is called perihelion. Therefore, the annual insolation received by the earth on 3rd January is slightly more than the amount received on 4th July. However, the effect of this variation in the solar output is masked by other factors like the distribution of land and sea and the atmospheric circulation. Hence, this variation in the solar output does not have great effect on daily weather changes on the surface of the earth.

**Variability of Insolation at the Surface of the Earth**

The amount and the intensity of insolation vary during a day, in a season and in a year. The factors that cause these variations in insolation are : (i) the rotation of earth on its axis; (ii) the angle of inclination of the sun's rays; (iii) the length of the day; (iv) the transparency of the atmosphere; (v) the configuration of land in terms of its aspect. The last two however, have less influence

1. **The rotation of earth on its axis**; The fact that the earth's axis makes an angle of 66½ with the plane of its orbit round the sun has a greater influence on the amount of insolation received at different latitudes. Note the variations in the duration of the day at different latitudes on solstices

| Latitude | 0° | 20° | 40° | 60° | 90° |
|---|---|---|---|---|---|
| December | 12h 00m | 10h 48m | 9h 8m | 5h 33m | 0 |
| June 21 | 12 h | 13h 12m | 14h 52m | 18h 27m | 6 months |

Table 9.1 : Length of the Day in Hours and Minutes on Winter and Summer Solstices in the Northern Hemisphere

2. **The Angle of Incidence or the Inclination of sun rays:**

The angle of incidence, or the angle which the sun's rays make with the earth's surface, determines the amount of solar radiation which a particular place on the earth will receive. A smaller angle means that a given amount of radiation will have to serve a larger area on the earth and the intensity will be less concentrated. A larger angle means the sun's rays will be

nearly vertical over the place and the same amount will serve a smaller area. As a result, the radiation received will be more concentrated and the intensity will be greater. This depends on the latitude of a place. The higher the latitude the smaller the angle, and the more slanting the solar radiation. The area covered by vertical rays is always less than that covered by slanting rays. If more area is covered, the energy gets distributed and the net energy received per unit area decreases. Not only are slanting rays distributed over a larger area, they also have a longer path through the atmosphere. Therefore more of their energy is absorbed, scattered and diffused within the atmosphere.

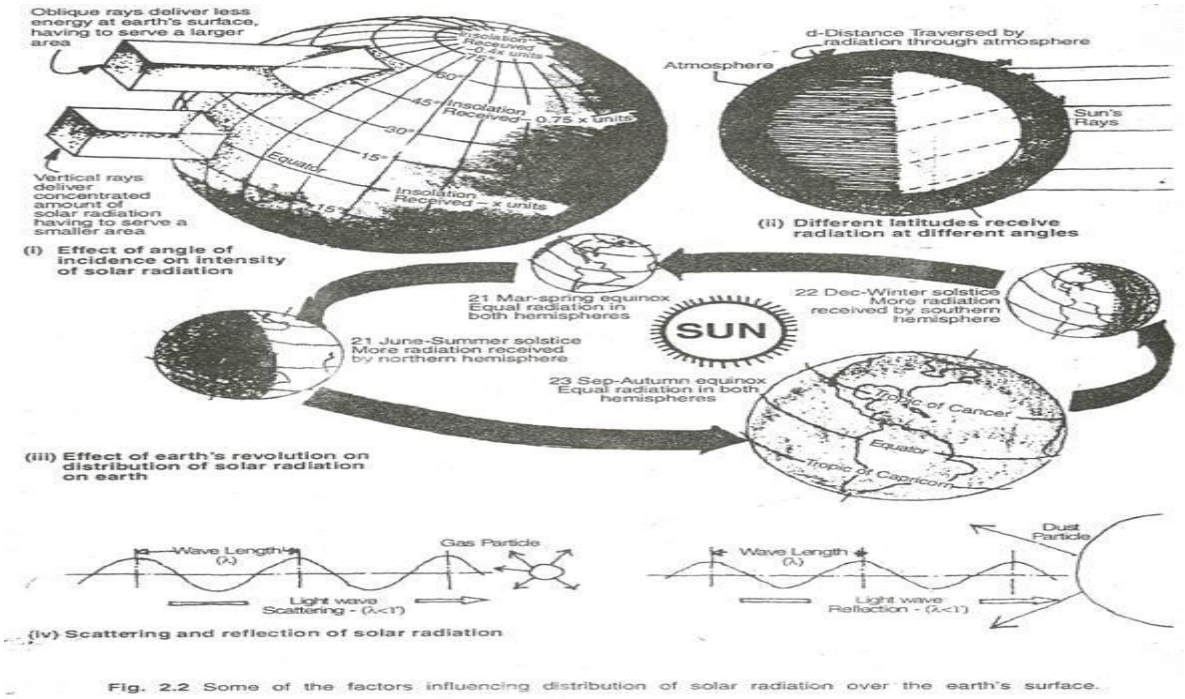


Fig. 2.2 Some of the factors influencing distribution of solar radiation over the earth's surface.

Fig.02 **.** The Angle of Incidence or the Inclination of sun rays

Source https://upload.wikimedia.org/wikipedia/commons/4/40/Figure_of_Sun_ray.jpg

As a result, at 45° latitude, the amount of radiation received is only 75% of what is received at the equator. At the Arctic and Antarctic Circles and at the poles, this figure is 50% and 40% respectively (see figs.).

### 3. Length of Day or Duration of Sunshine:

The amount of solar radiation received obviously depends on the length of time that the sun shines over a particular place. The length of day varies with latitude and with season. At the equator, where the duration of sunshine is 12 hours daily throughout the year, the amount of radiation received is more compared to other places on the earth. At ***winter solstice (22 December),*** the southern hemisphere receives more sunshine as it is summer there, while at ***summer solstice (21 June),*** the northern hemisphere receives more sunshine as it is summer timet.

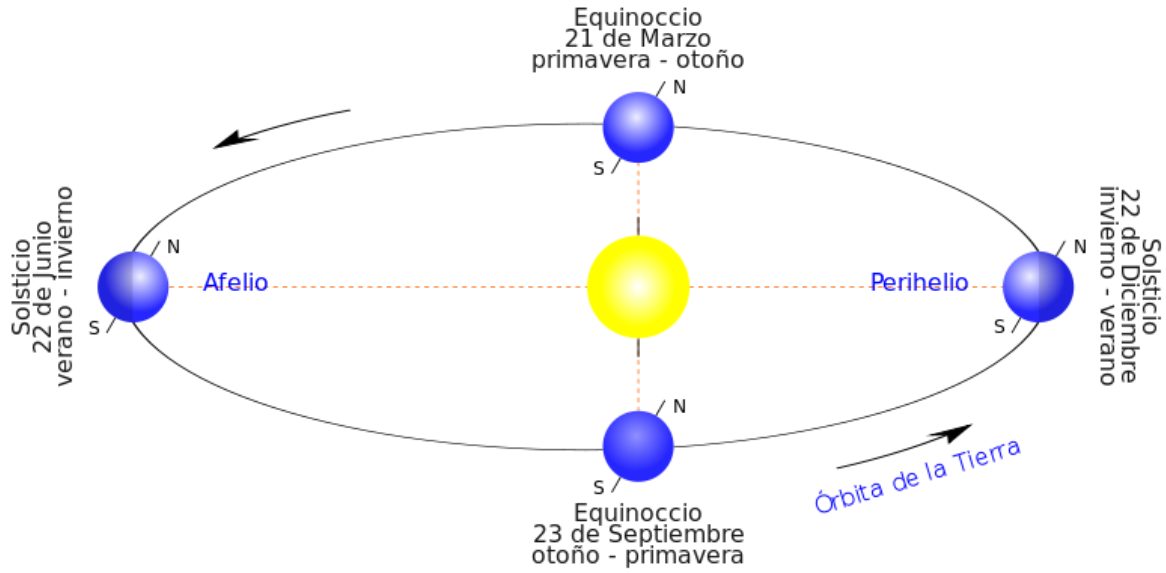


Fig .No 03 Shows the 4 most important points through which the Earth in its journey around the Sun, the two equinoxes and the 2 solstices, aphelion and perihelion concepts and how the Earth is illuminated by the Sun in either the North or South Pole as his career and since the tilt of its axis to the plane of the Sun.

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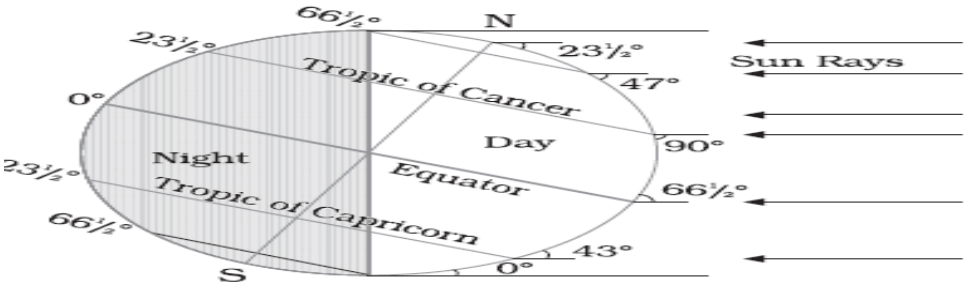


Figure 9.1 : Summer Solstice

Table 9.1 : Length of the Day in Hours and Minutes on Winter and Summer Solstices in the Northern Hemisphere

| Latitude | 0 | 20 | 40 | 60 | 90 |
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| December 22 | 12h 00m | 10h 48m | 9h 8m | 5h 33m | 0 |
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**Table:** Length of the Day in Hours and Minutes on winter and Summer Solstices in the Northern Hemisphere

**4. Transparency of Atmosphere:**

The atmosphere is largely transparent to short wave solar radiation. Incoming solar radiation passes through the atmosphere before striking the earth's surface. The amount of cloud cover and its thickness, dust and water vapour, which determine the transparency of the atmosphere, affect the reflection, absorption and transmission of solar radiation.

**5. Altitude and Aspect:**

Places at a higher altitude receive more insolation as the density of the atmosphere decreases with height. Less energy is therefore lost to the atmosphere. The direction of the slope and its angle control the amount of solar radiation received locally. Slopes more exposed to the sun receive more solar radiation than those away from the sun's direct rays. South facing slopes receive more insolation in the Northern Hemisphere. In the Southern Hemisphere, it is the north-facing slopes that receive more insolation.

**Spatial Distribution of Insolation at the Earth's Surface**

The insolation received at the surface varies from about 320 Watt/m2 in the tropics to about 70 Watt/m2 in the poles. Maximum insolation is received over the subtropical deserts, where the cloudiness is the least. Equator receives comparatively less insolation than the tropics. Generally, at the same latitude the insolation is more over the continent than over the oceans. In winter, the middle and higher latitudes receive less radiation than in summer

**Heating and Cooling of Atmosphere**

There are different processes by which heat is gained and lost, and transferred within the atmosphere and between the atmosphere and the Earth. These processes are:

The earth after being heated by insolation transmits the heat to the atmospheric layers near to the earth in long wave form. The air in contact with the land gets heated slowly and the upper layers in contact with the lower layers also get heated. This process is called conduction. Conduction takes place when two bodies of unequal temperature are in contact with one another, there is a flow of energy from the warmer to cooler body. The transfer of heat continues until both the bodies attain the same temperature or the contact is broken. Conduction is important in heating the lower layers of the atmosphere.

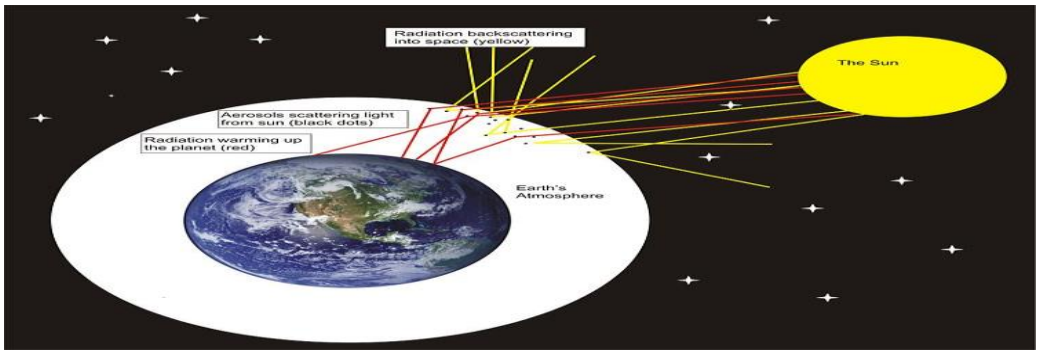


Fig. 04 show how aerosols can reflect solar radiation back into space altering the earth's radiation balance ,this affect is measured by rephelometters.

The air in contact with the earth rises vertically on heating in the form of currents and further transmits the heat of the atmsphere. This process of vertical heating of the atmosphere is known as convection. The convective transfer of energy is confined only to the troposphere.

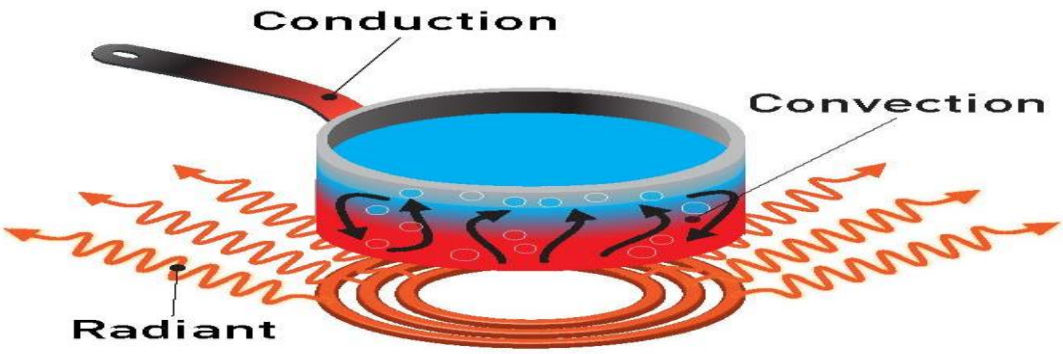


Fig05 ;-Conduction

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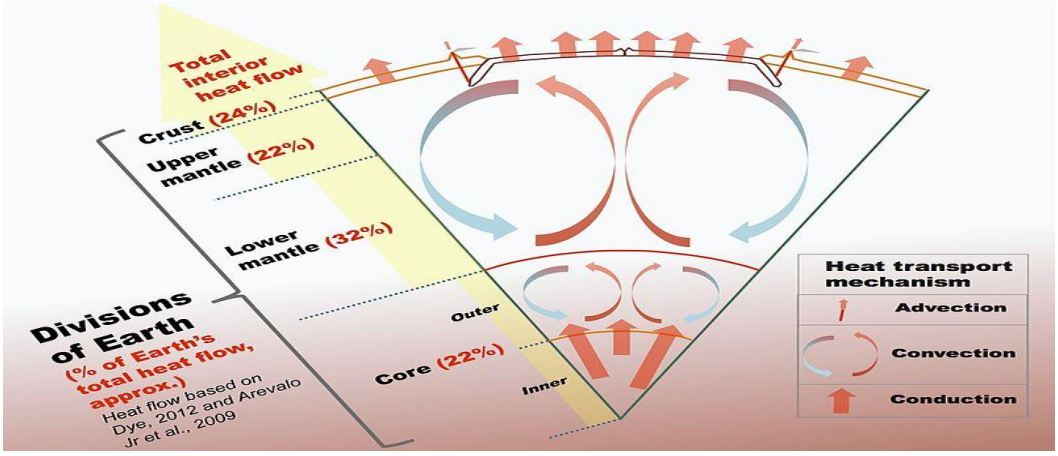


Fig06 ;-Heat flow of the inner earth

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The transfer of heat through horizontal movement of air is called advection. Horizontal movement of the air is relatively more important than the vertical movement. In middle latitudes, most of dirunal (day and night) variation in daily weather are caused by advection alone. In tropical regions particularly in northern India during summer season local winds called ‘loo’ is the outcome of advection process.

## Terrestrial Radiation

The insolation received by the earth is in short waves forms and heats up its surface. The earth after being heated itself becomes a radiating body and it radiates energy to the atmosphere in long wave form. This energy heats up the atmosphere from below. This process is known as terrestrial radiation. The long wave radiation is absorbed by the atmospheric gases particularly by carbon dioxide and the other green house gases. Thus, the atmosphere is indirectly heated by the earth's radiation. The atmosphere in turn radiates and transmits heat to the space. Finally the amount of heat received from the sun is returned to space, thereby maintaining constant temperature at the earth's surface and in the atmosphere.

## Heat Budget of the Earth

The heat budget of the planet earth. The earth as a whole does not accumulate or loose heat. It maintains its temperature. This can happen only if the amount of heat received in the form of insolation equals the amount lost by the earth through terrestrial radiation. Consider that the insolation received at the top of the atmosphere is 100 per cent. While passing through the atmosphere some amount of energy is reflected, scattered and absorbed. Only the remaining part reaches the earth surface. Roughly 35 units are reflected back to space even before reaching the earth's surface. Of these, 27 units are reflected back from the top of the clouds and 2 units from the snow and ice-covered areas of the earth. The reflected amount of radiation is called the albedo of the earth. The remaining 65 units are absorbed, 14 units within the atmosphere and 51 units by the earth's surface. The earth radiates back 51 units in the form of terrestrial radiation. Of these, 17 units are radiated to space directly and the remaining 34 units are absorbed by the atmosphere (6 units absorbed directly by the atmosphere, 9 units through convection and turbulence and 19 units through latent heat of condensation). 48 units absorbed by the atmosphere (14 units from insolation +34 units from terrestrial radiation) are also radiated back into space. Thus, the total radiation returning from the earth and the atmosphere respectively is 17+48=65 units which balance the total of 65 units received from the sun. This is termed the heat budget or heat balance of the earth. This explains, why the earth neither warms up nor cools down despite the huge transfer of heat that takes place.

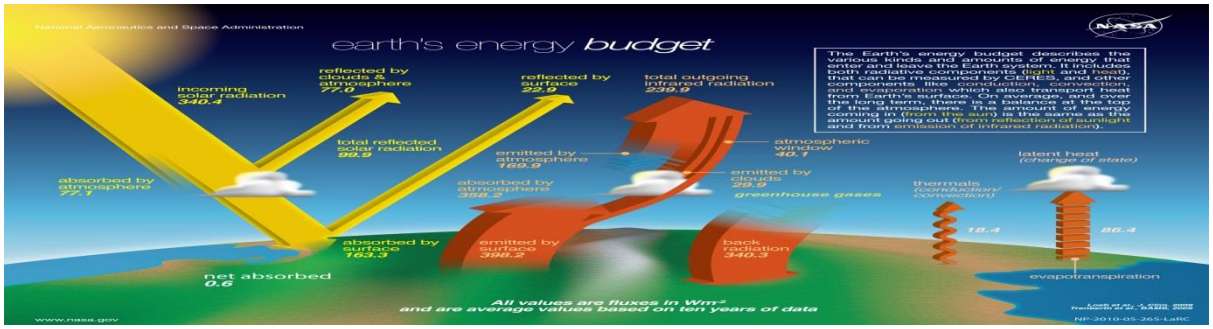



Fig No. 07 Earth's energy budget, with incoming and outgoing radiation (Values are shown in W/m$^2$). Satellite instruments (CERES) measure the reflected solar and emitted infrared radiation fluxes. The energy balance determines Earth's climate

https://upload.wikimedia.org/wikipedia/commons/b/bb/The-NASA-Earth%27s-Energy-Budget-Poster-Radiant-Energy-System-satellite-infrared-radiation-fluxes.jpg

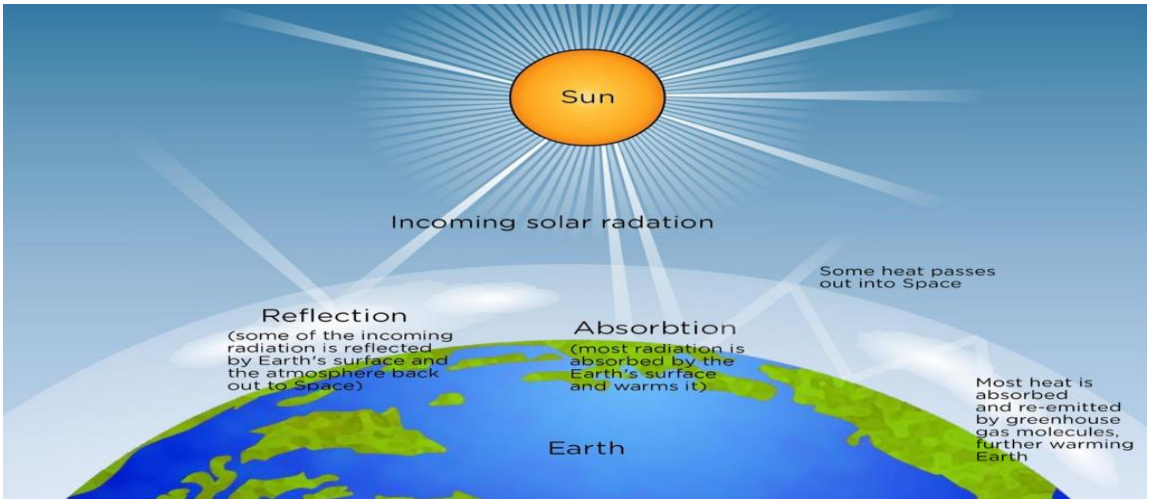
**Variation in the Net Heat Budget at the Earth's Surface**

As explained earlier, there are variations in the amount of radiation received at the earth's surface. Some part of the earth has surplus radiation balance while the other part has deficit. The latitudinal variation in the net radiation balance of the earth — the atmosphere system. The figure shows that there is a surplus of net radiation balance between 40 degrees north and south and the regions near the poles have a deficit. The surplus heat energy from the tropics is redistributed pole wards and as a result the tropics do not get progressively heated up due to the accumulation of excess heat or the high latitudes get permanently frozen due to excess deficiency.

The earth receives almost all of its energy from the sun. The earth in turn radiates back to space the energy it receives. As a result, the temperature of the earth neither increases nor decreases in the long term. However, the amount of heat received by different parts of the earth is not the same. This variation causes temperature and pressure differences in the atmosphere which lead to transfer of heat from one region to another by winds and ocean currents. This unit explains the process of heating and cooling of the atmosphere and the resultant distribution of energy over the earth's surface.

**Solar Radiation**

The sun is a perpetual source of energy for the earth. The earth receives one out of every two billion parts of the sun's energy output, but even this amount is very large. More energy reaches the earth in one hour than all of the energy currently consumed on the planet in one year. Energy is emitted by the sun in the form of electromagnetic radiation which includes visible light, radio waves, infrared rays, x-rays, and ultraviolet rays. A large amount comprises short wave radiation.




The energy received by the earth is known as ***incoming solar radiation*** which is termed ***insolation.*** As the earth is a geoid resembling a sphere, the sun's rays fall obliquely at the top of the atmosphere and the earth intercepts a very small portion of the sun's energy. On an average the earth receives 1.94 calories per sq.cm per minute at the top of its atmosphere. The solar output received at the top of the atmosphere varies slightly in a year due to variation in the distance between the earth and the sun. During its revolution around the sun, the earth is farthest from the sun (152 million km) on ***4th July.*** This position of the earth is called ***aphelion.*** On ***3rd January***, the earth is nearest to the sun (147 million km). This position is called ***perihelion.*** Therefore, the annual insolation received by the earth on 3rd January is slightly more than the amount received on 4th July. The amount of energy radiated by the sun too is not constant. However, the effect of this variation in solar output is modified by other factors and therefore does not have a great effect on daily weather changes.

**Variability of Insolation at the Surface of the Earth**

The amount and intensity of insolation vary during a day, in a season and in a year. The amount of insolation reaching the earth's surface and its effectiveness per unit area depends on the following factors:

**1. The Angle of Incidence or the Inclination of sun rays:**

The angle of incidence, or the angle which the sun's rays make with the earth's surface, determines the amount of solar radiation which a particular place on the earth will receive. A smaller angle means that a given amount of radiation will have to serve a larger area on the earth and the intensity will be less concentrated. A larger angle means the sun's rays will be nearly vertical over the place and the same amount will serve a smaller area. As a result, the radiation received will be more concentrated and the intensity will be greater. This depends on the latitude of a place. The higher the latitude the smaller the angle, and the more slanting the solar radiation. The area covered by vertical rays is always less than that covered by

slanting rays. If more area is covered, the energy gets distributed and the net energy received per unit area decreases. Not only are slanting rays distributed over a larger area, they also have a longer path through the atmosphere. Therefore more of their energy is absorbed, scattered and diffused within the atmosphere.

See Fig. 2.2 (i)

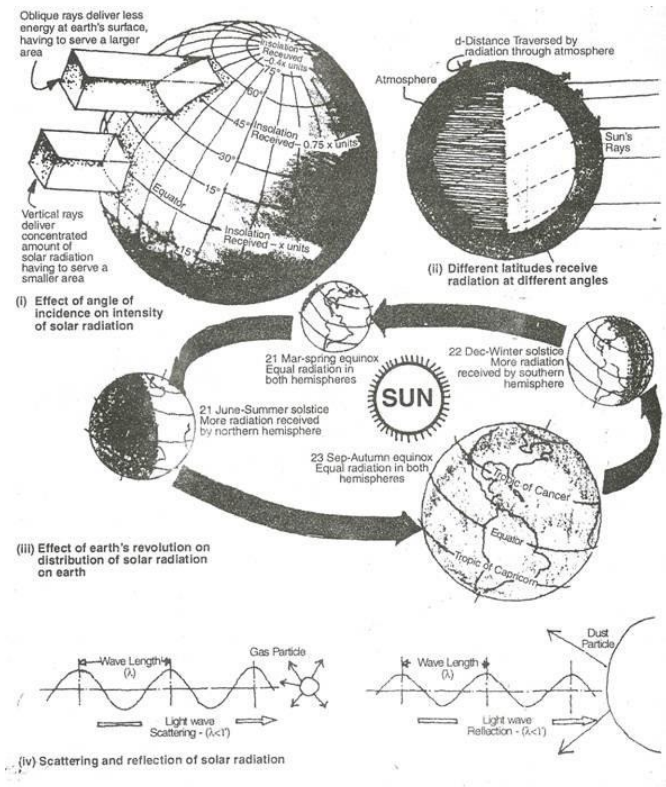
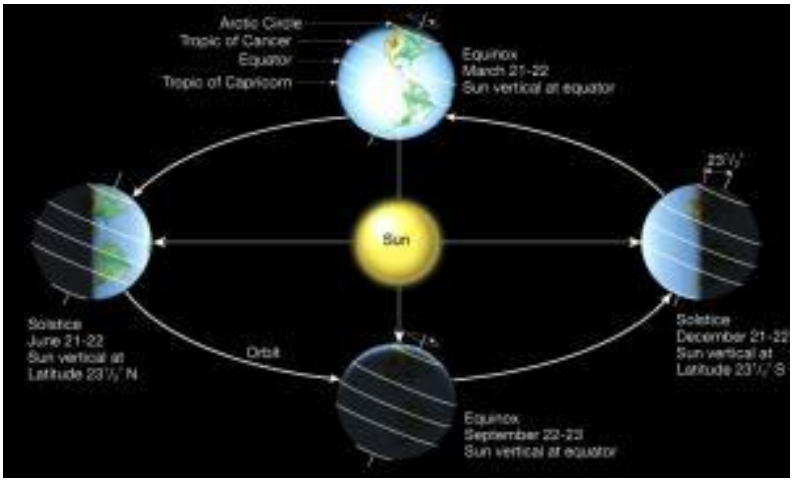



Fig. 2.2 Some of the factors influencing distribution of solar radiation over the earth's surface.

As a result, at 45° latitude, the amount of radiation received is only 75% of what is received at the equator. At the Arctic and Antarctic Circles and at the poles, this figure is 50% and 40% respectively (see figs.).

**2. Length of Day or Duration of Sunshine:**

The amount of solar radiation received obviously depends on the length of time that the sun shines over a particular place. The length of day varies with latitude and with season. At the equator, where the duration of sunshine is 12 hours daily throughout the year, the amount of radiation received is more compared to other places on the earth. At ***winter solstice (22 December),*** the southern hemisphere receives more sunshine as it is summer there, while at ***summer solstice (21 June),*** the northern hemisphere receives more sunshine as it is summer time there. [Fig. 2.2 (iii)]



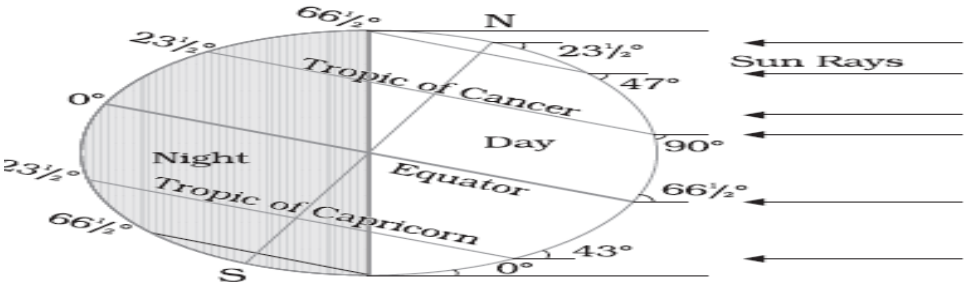




**Figure 9.1 : Summer Solstice**

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receive more insolation in the Northern Hemisphere. In the Southern Hemisphere, it is the north-facing slopes that receive more insolation.

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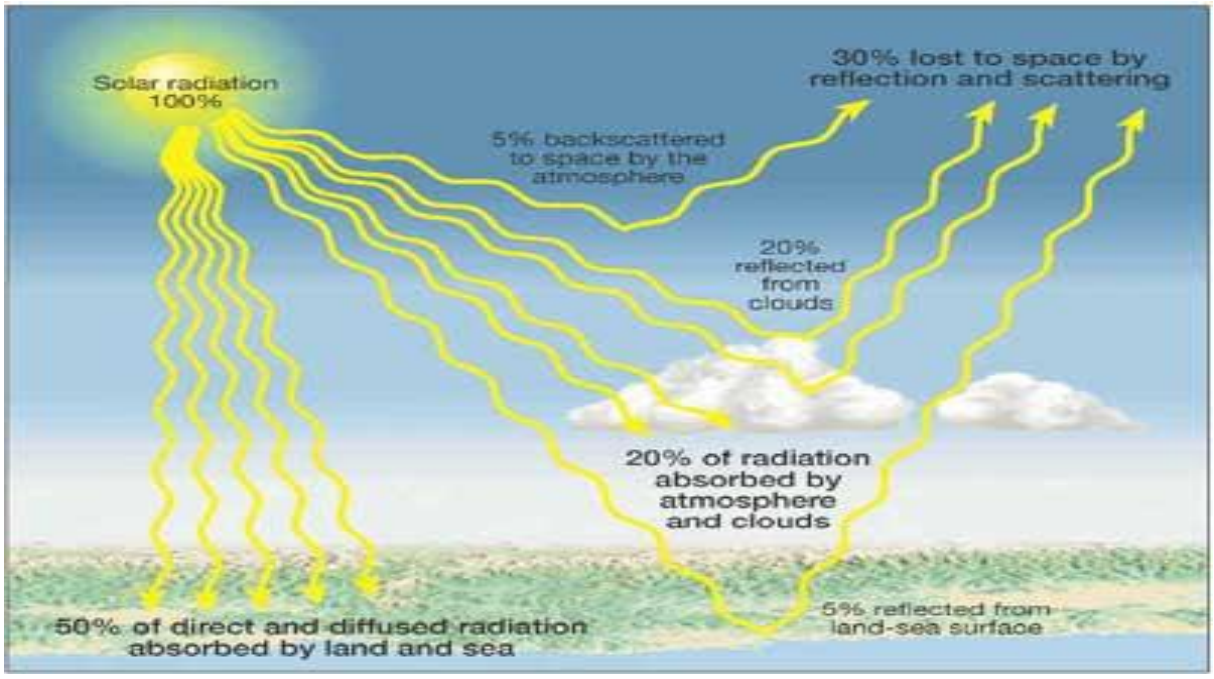
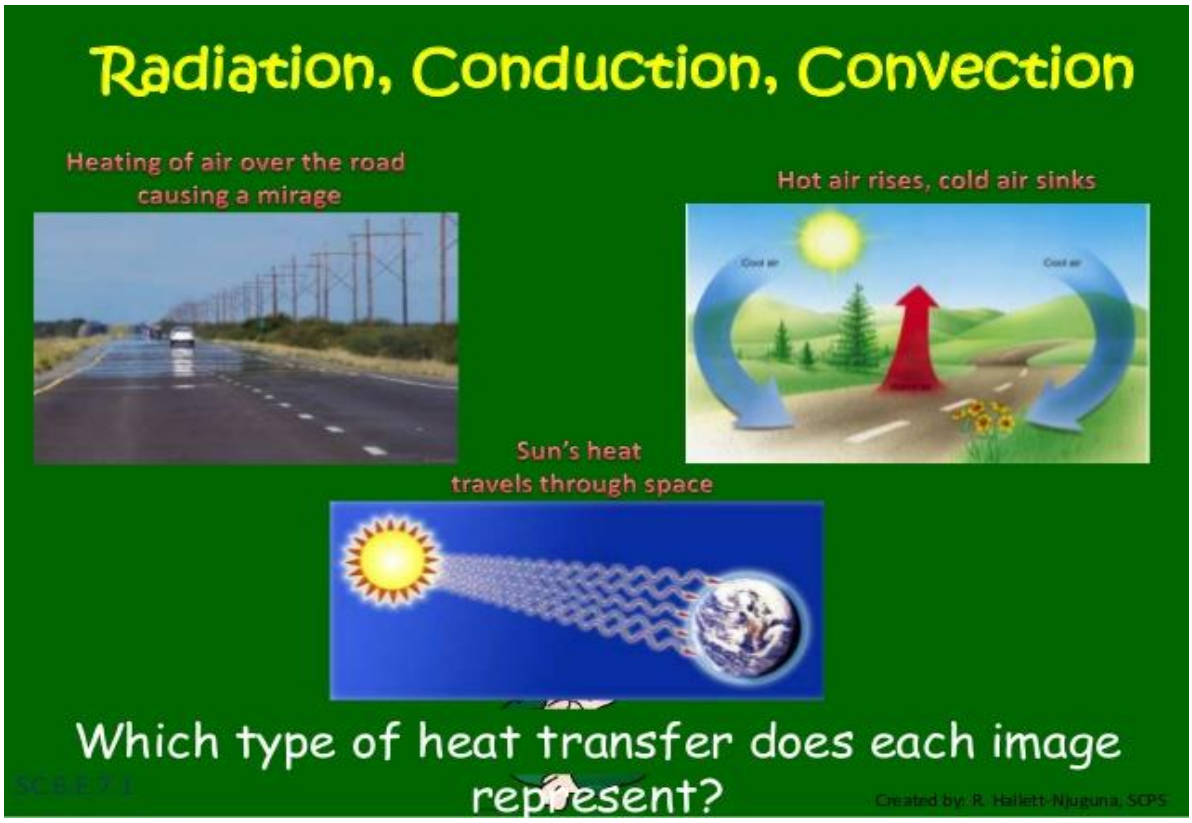
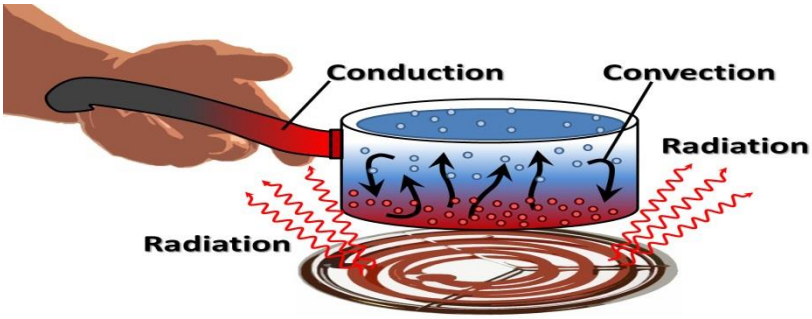


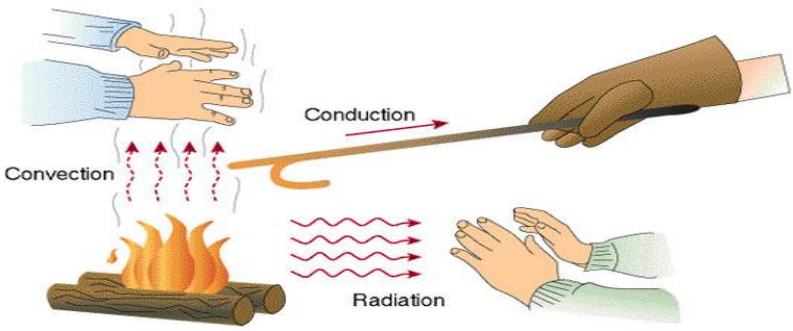



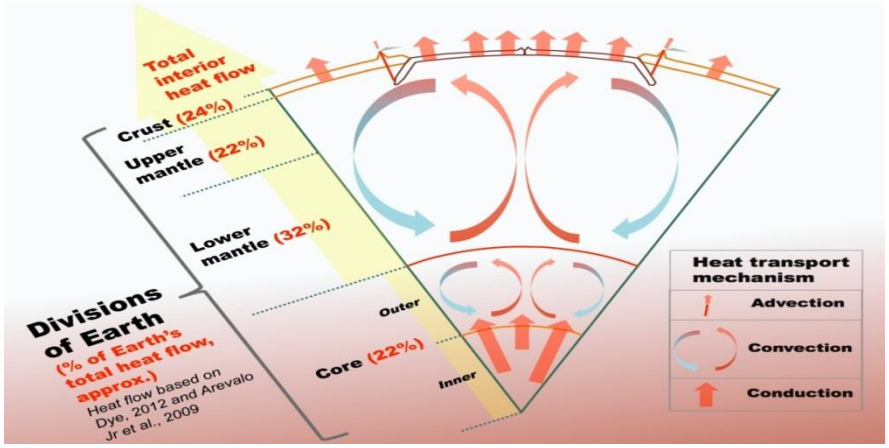
## Heating and Cooling of Atmosphere

There are different processes by which heat is gained and lost, and transferred within the atmosphere and between the atmosphere and the Earth. These processes are:

1. ***Radiation:*** All bodies radiate heat, regardless of their themperature. Radiated energy is emitted in the form of electromagnetic waves which can travel even through a vacuum. Radiation emitted by the sun has a shorter wavelength and passes easily through the atmosphere to heat up the Earth's surface. The Earth's surface emits long wave radiation which is more readily absorbed by the atmosphere. Radiation is thus the most important process by which the Earth and its atmosphere receive energy.
2. ***Conduction:*** Conduction is the process by which heat is transferred between two objects that are in contact with one another. Air in contact with the Earth's surface may be heated or cooled by the process of conduction. Conduction is important in heating the lower layers of the atmosphere. It is a slow process of heat transfer. Since air is a very poor conductor of heat, the conduction process affects only the lowermost layers of air closest to the earth's surface. As a means of heat transfer within the atmosphere as a whole, conduction is the least important process and can be neglected when considering a majority of meteorological phenomena.



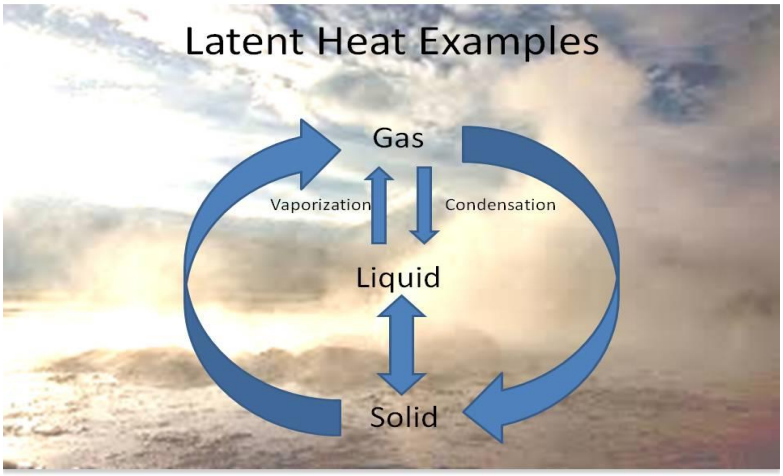


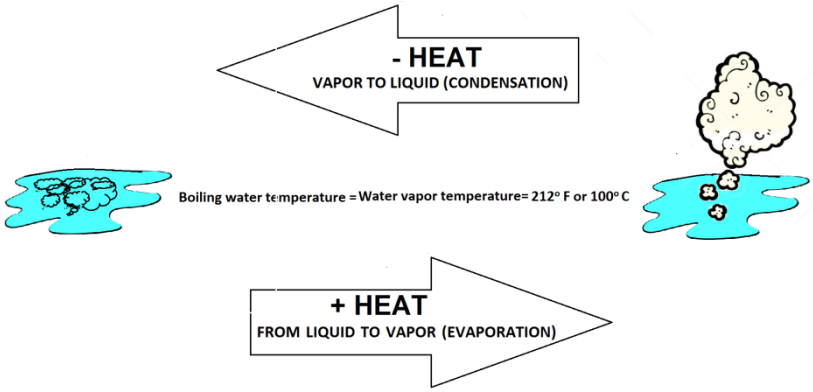

**3**. ***Convection:*** Convection involves the transfer of energy by the vertical movement of particles. This is an important process of energy transfer within fluids (liquids and gases). Since the atmosphere is a gaseous medium, convection is the most significant mechanism of heat transfer. Air in contact with a warm surface rises, setting up what is known as a convection current. The rising limb of a convection current begins to spread horizontally at some level (which may be as high as the tropopause). It displaces the colder air at this level and the colder air starts to move downward as the descending limb of the convection current. The convective transfer of energy is confined only to the troposphere. Heat gained by the layers of air at or near the earth's surface from radiation or conduction is usually transferred to the upper atmospheric layers by the process of convection.

**4.** ***Advection:*** The transfer of heat through horizontal movement of air is called *advection*. Horizontal movement of air is relatively more important than vertical movement. In fact, advection is responsible for slow heat transfer from the equatorial to polar regions.

The processes mentioned above involve the transfer of sensible heat (or heat that can be felt and recorded by an instrument). Heat may also be transferred in the latent or hidden form. When a substance changes its state (eg: from solid to liquid or liquid to gas) some energy is absorbed or released without changing the temperature of the substance. This energy is known as latent heat. When water evaporates, changing its state from liquid to gas, it absorbs latent energy (latent energy of evaporation). When it condenses (gas changes to liquid) this energy is released as latent heat of condensation. If evaporation occurs at place A and

condensation at place B, latent energy is transferred from place A to place B. This transfer of energy may take place vertically or horizontally.



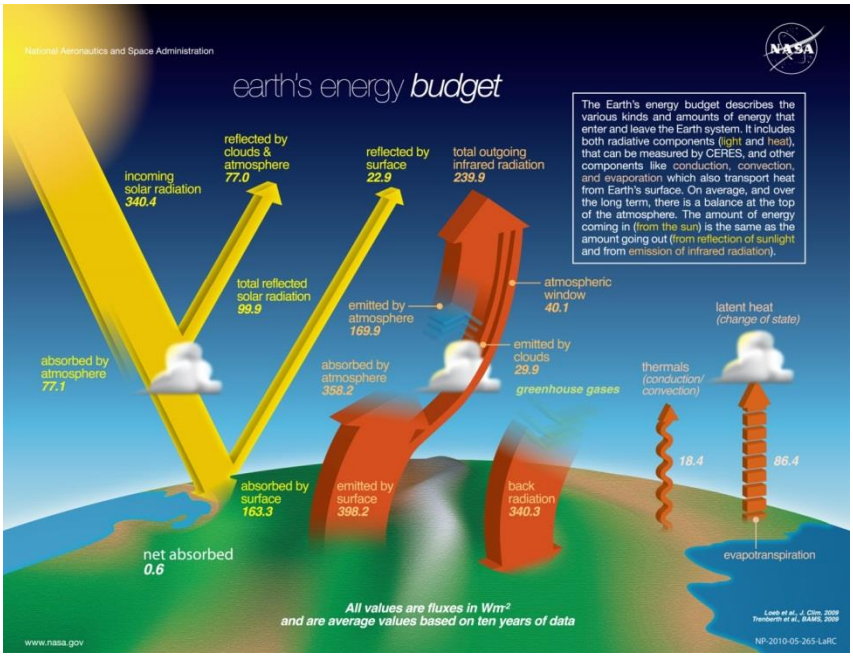




**5. *Expansion and Compression of air:*** Whenever air moves upward it passes through regions of successively lower pressure. Consequently, the rising air expands and cools adiabatically. In the same way, as the air descends, it comes under increasingly higher pressure so that it is compressed and heated. These temperature changes, caused only due to change in pressure that the rising or falling air is subjected to, are called adiabatic temperature changes. No heat is added to or removed from the moving parcel of air by any external source.

**Heat Budget of the Earth**

Earth's energy budget is an account of energy entering the earth's system and escaping from the system to space. The heat budget of the earth is thus the balance between insolation and outgoing terrestrial radiation.

The earth receives energy from the sun as insolation. Solar radiation is absorbed, scattered and reflected by components of the atmosphere.



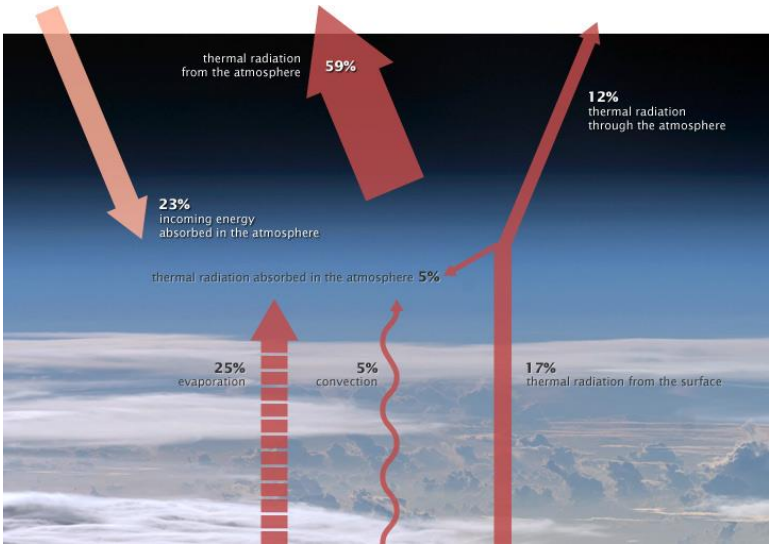




Figure no. ( ) depicts the heat budget of the earth. The earth as a whole does not accumulate or lose heat. It maintains its temperature. This can happen only if the amount of heat received in the form of insolation equals the amount lost by the earth through terrestrial radiation.

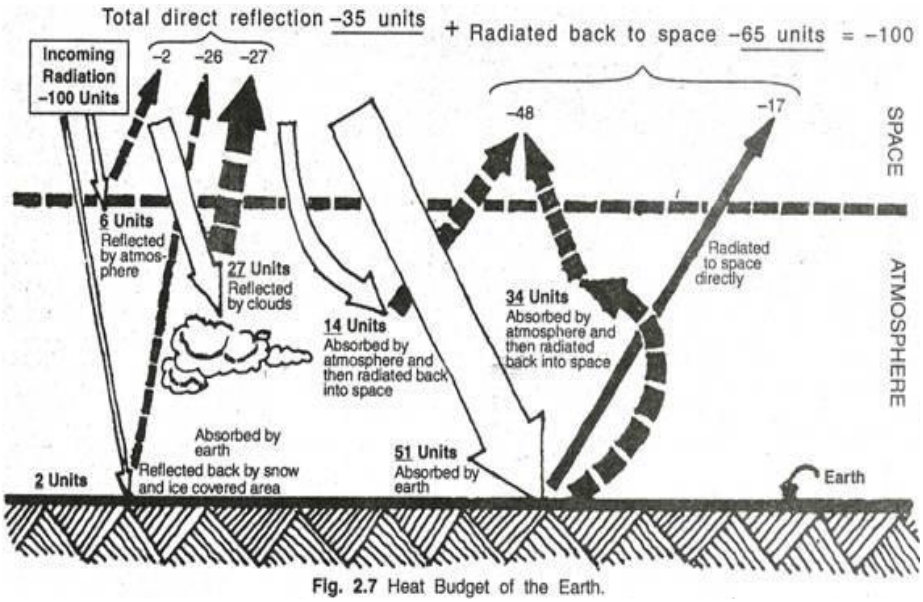
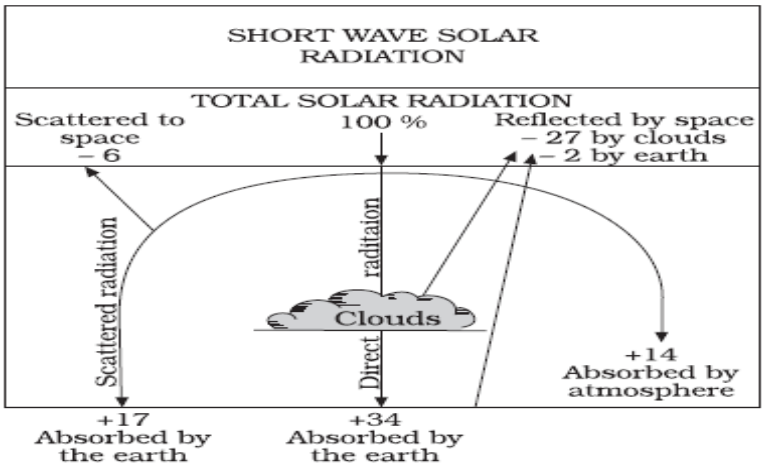
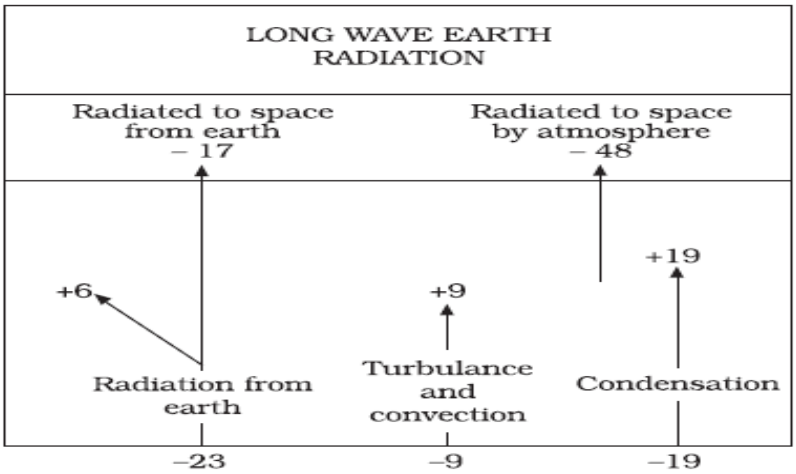



Fig. 2.7 Heat Budget of the Earth.

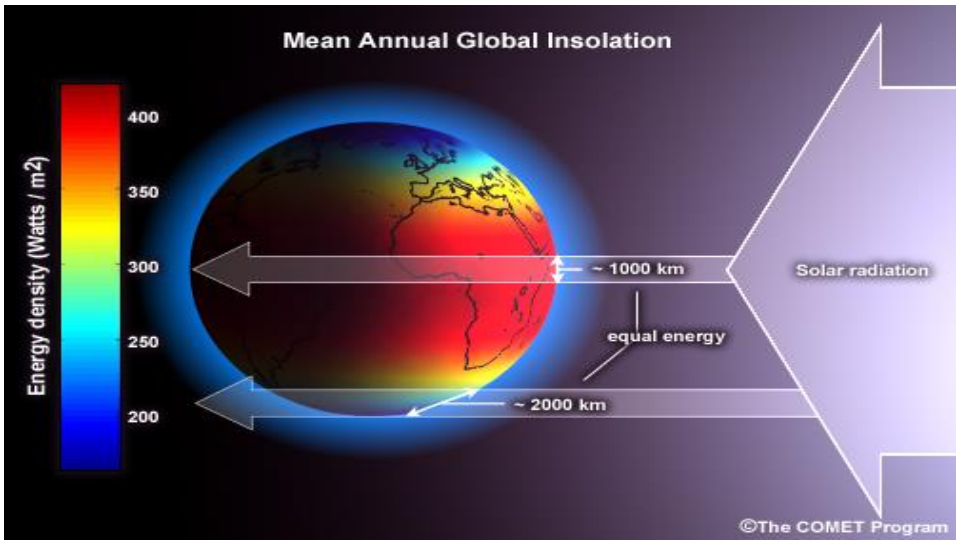
Consider the insolation received at the top of the atmosphere as 100 units. While passing through the atmosphere, roughly 35 units are reflected back or lost to space even before reaching the earth's surface, owing to the reflection from the top of the atmosphere (6 units), from the top of the clouds (27 units) and from the snow and ice-covered areas of the earth's surface (2 units). The reflected amount of radiation is called the ***albedo of the earth.*** The remaining 65 units are absorbed, 14 units of heat within the atmosphere and 51 units by the earth's surface.

The earth radiates 51units back in the form of terrestrial radiation. Of these, 17 units are radiated to space directly and the remaining 34 units are absorbed by the atmosphere (6 units absorbed directly by the atmosphere, 9 units through convection and turbulence and 19 units through latent heat of condensation). 48 units absorbed by the atmosphere (14 units from insolation+34 units from terrestrial radiation) are also radiated back into space. Thus, the total radiation returning from the earth and the atmosphere respectively is 17+48=65 units which balance the total amount of 65 units received from the sun. This is termed the heat budget or heat balance of the earth. This explains why the earth neither warms up nor cools down despite the huge transfer of heat that takes place.

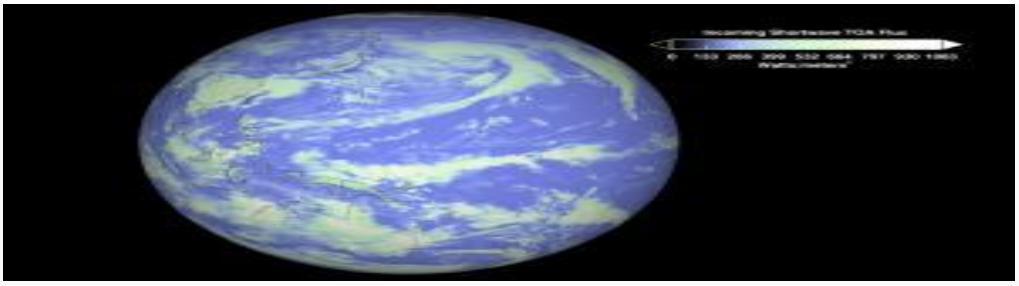


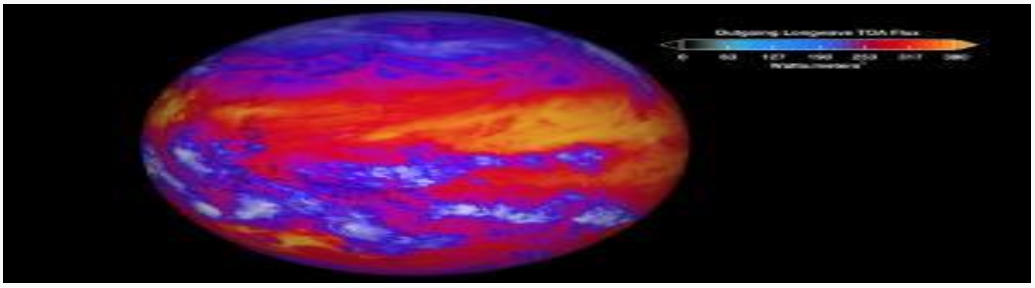

**Variation in the Net Heat Budget at the Earth's Surface**




A graphic representation of the insolation and terrestrial radiation.



*Incoming*, top-of-atmosphere (TOA) shortwave flux radiation shows energy received from the sun (Jan 26–27, 2012).

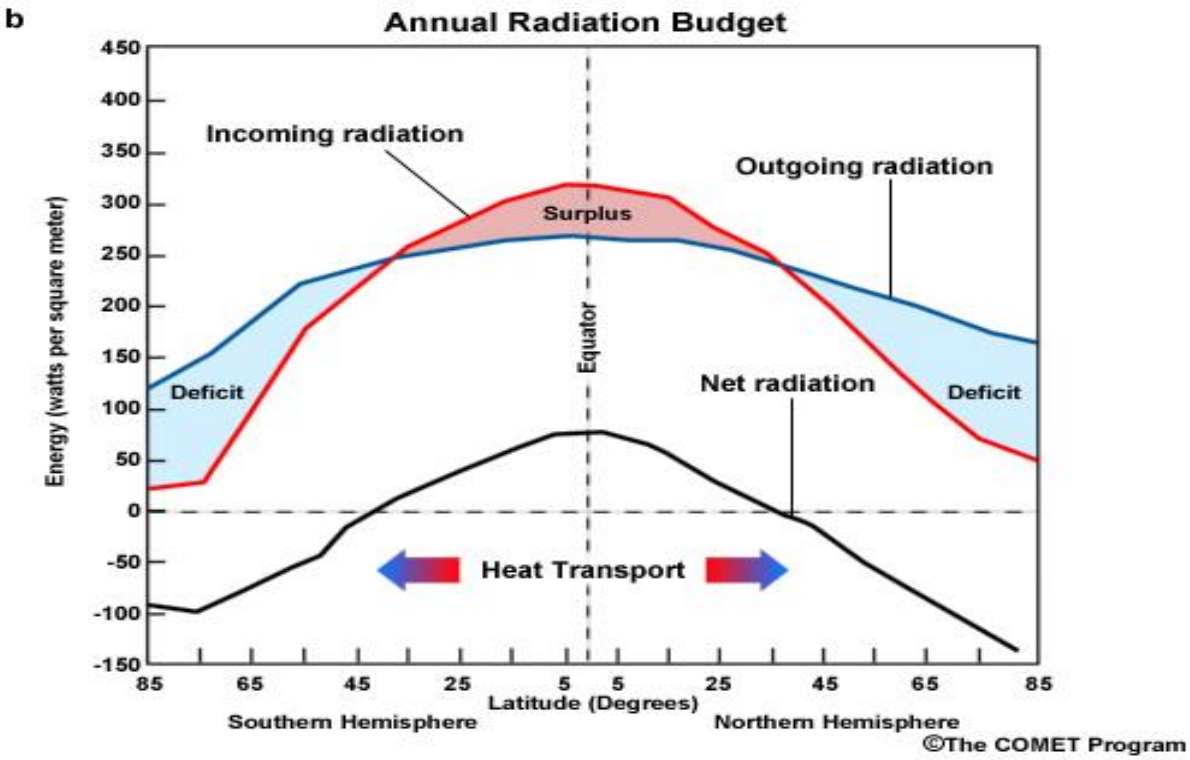


*Outgoing*, long wave flux radiation at the top-of-atmosphere (Jan 26–27, 2012).

Heat energy radiated from earth (in watts per square metre) is shown in shades of yellow, red, blue and white. The brightest yellow areas are the hottest and are emitting the most energy out to space, while the dark blue areas and the bright white clouds are much colder, emitting the least energy.

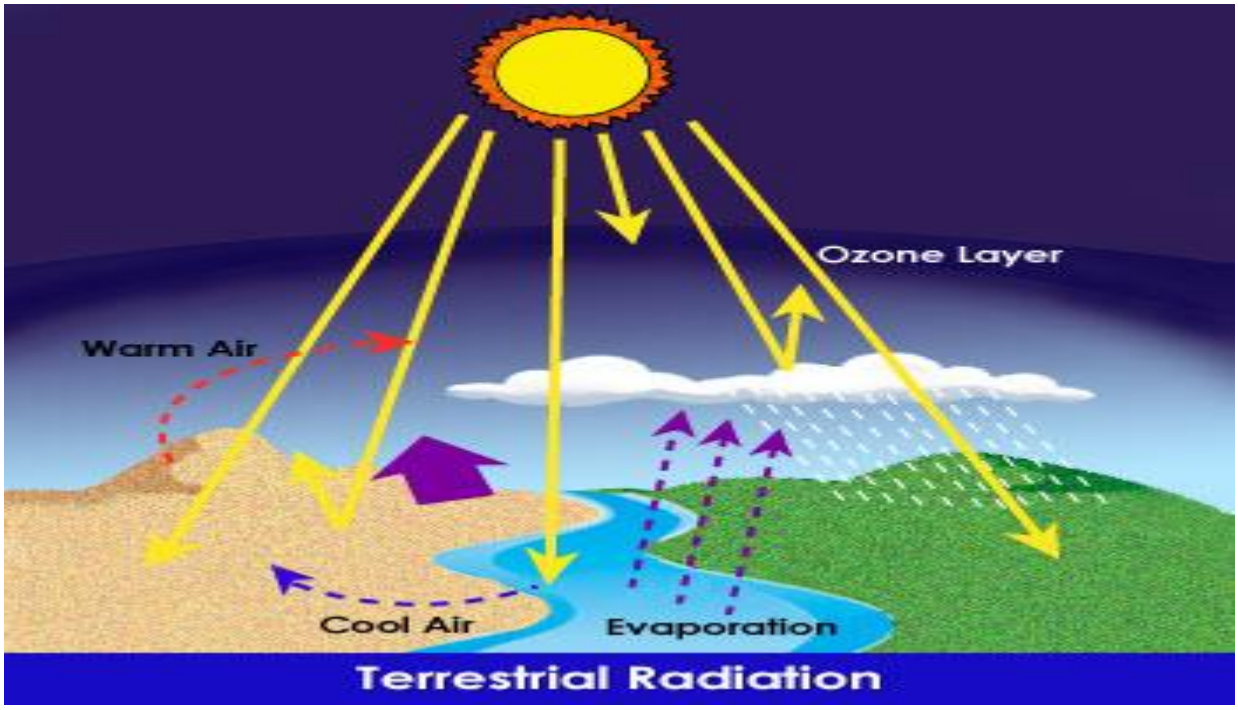
As explained earlier, there are variations in the amount of radiation received at the earth's surface. Some parts of the earth have surplus radiation while other parts have a deficit.

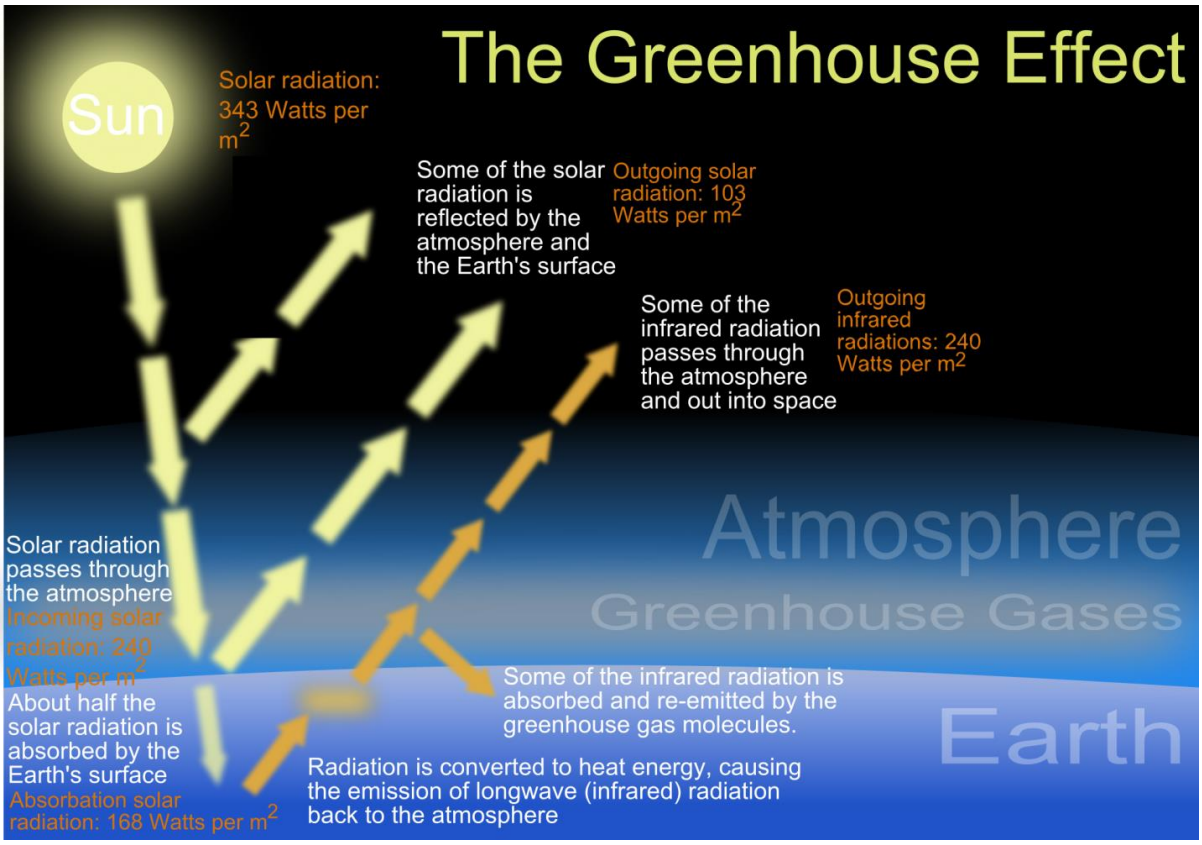
Figure no. ( ) depicts the latitudinal variation in the net radiation balance of the earth-atmosphere system. The figure shows that there is a surplus of net radiation balance between 40 degrees north and south and the regions near the poles have a deficit. The surplus heat energy from the tropics is redistributed poleward. As a result the tropics do not get progressively heated up due to the accumulation of excess heat. Similarly, higher latitudes get permanently frozen due to due to excess deficit.




Latitudinal Balance in net radiation balance

**Terrestrial Radiation**




It has already been pointed out that about two-thirds of the radiant solar energy reaches the earth's surface directly or indirectly in the form of short-wave electro-magnetic waves. This energy is converted into terrestrial heat by the earth’s surface and then radiated in the form of terrestrial radiation. The earth radiates heat in the form of long waves or infrared radiation. Most of the atmospheric gases, especially carbon dioxide and water vapour, that are almost

transparent to short-wave solar radiation, absorbing only about 19 percent of it, absorb about 85 per cent of the terrestrial long-wave or infrared radiation. Thus it is clear that the atmosphere receives a larger part of its energy supply from the earth and not directly from the sun. Since the atmosphere is almost transparent to most of the solar radiation and absorbs a large part of the terrestrial radiation, it acts to conserve the heat energy of the earth. This conservation is called ***the greenhouse effect.***