Component-I (A) - Personal Details

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Component-I (B) - Description of Module

Items	Description of Module
Subject Name	**Geography**
Paper Name	Climatology
Module Name/Title	HEAT BUDGET, HEAT BALANCE AND GREENHOUSE CONDITIONS
Module Id	CL-06
Pre-requisites	
Objectives	• define incoming and outgoing radiation; • define and distinguish heat budget and heat balance; • describe heat absorption, emission, reflection and re-radiation; • explain the horizontal transport of heat; • discuss the spatial pattern of heat budget; and • explain the greenhouse conditions in the atmosphere.
Keywords	

Contents

Introduction

The meaning of heat is condition of being hot or existence of degree of hotness in the form of temperature. But have you ever thought that wherefrom the heat is coming from or what is the source of heat, for earth-atmosphere system?You must have observed that the days are hot and nights are cool. It is quite obvious that the sun is the prime source of energy on our earth. Though a little energy reaches to the earth surface or to the atmosphere when there is volcanic eruption. Some energy is also released by the endogenic forces creating irregularity like plate movement or mountain building. But these are very-very scanty in comparison to the energy received from the sun. Therefore, predominantly the sun is responsible for energizing earth-atmosphere system. With this background in our mind, here, an attempt has been made to study the heat budget, heat balance and the conditions of the atmosphere which keep the earth livable.

The livable conditions are basically associated with the warming of the surrounding. So, an evaluation is also tried to see, how natural greenhouse effect is good for the earth or how bad the human enhanced greenhouse effect is.

Concept of Heat Budget

Simply the meaning of budget is an estimate of your income and the expenditure of the same over a certain period of time. Heat is a sort of energy which our earth receives from the sun. Therefore, the energy received (your income) from the sun and its utilization (your expenditure) by/in the atmosphere as well as the surface (land and water surface) of the earth is basically heat budget. In this context, the heat budget has two main components incoming shortwave solar radiation and outgoing longwave terrestrial radiation. Let us study them in brief:

Incoming Shortwave Solar Radiation

By now, you must have studied the Module 5 on insolation in which its factors and distribution has been explained. I will not go much in detail about the insolation here, but let us see a few points concerning this module.

You know it very well, and also mentioned above that the sun is the prime source of almost all energy on the earth. This energy coming from the sun is known as solar radiation. Since the sun is extremely hot, it emits shortwave radiationin the form of electromagnetic waves. You have already studied about the electro-magnetic spectrum of solar radiation consisting of different types of shortwaves like x-rays, ultraviolet, visible and near infrared. You also have the idea about their wavelengths. It is noteworthy that most of the shortwave energy from the sun is not directly absorbed by the atmosphere.

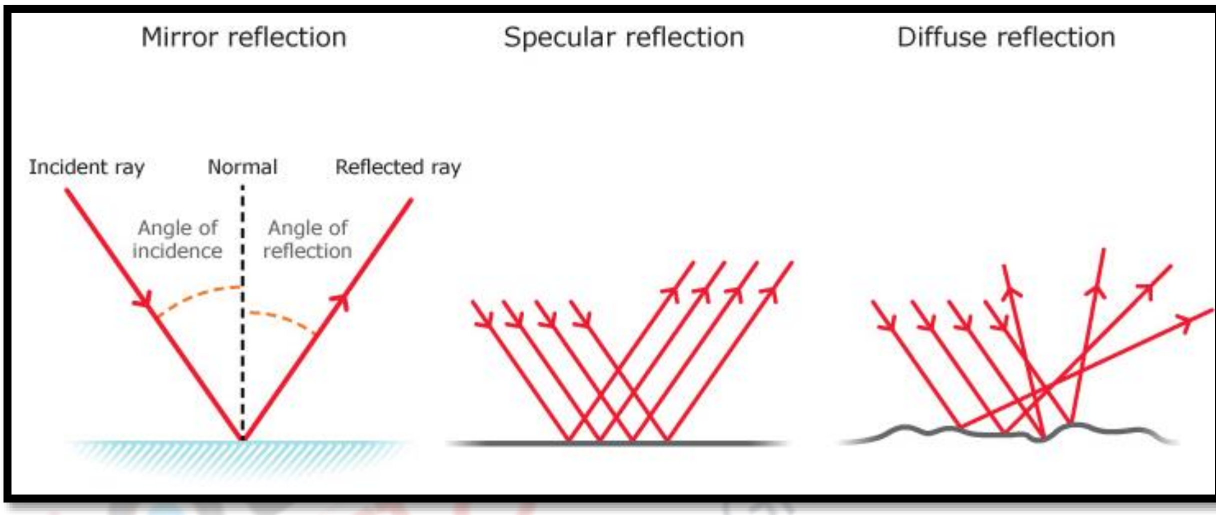
Processes Involved with Incoming Radiation

The uppermost atmosphere of earth receives about one part of energy out of two billion parts radiated from the entire sun's surface. This much tiny energy is the cause of various interactions in the atmospheric systems. Now, let us through some light on the processes involved with incoming radiations: There are three processes operating with the incoming solar radiation. They are:

- Reflection
- Diffusion and scattering
- Absorption

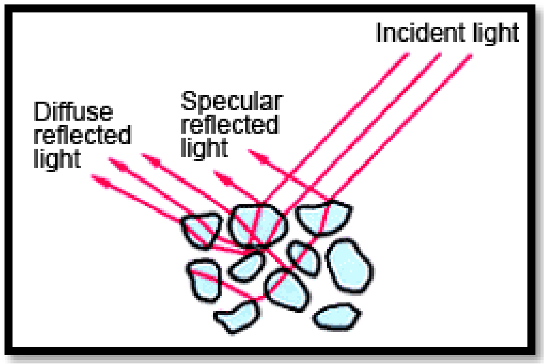
Reflection: The meaning of reflection is returning something back from where something was coming. You also know it well, as you bring a mirror to the sunlight, a bright beam of light is thrown away from the surface of the mirror. The angle of the reflection of light is dependent on the angle of the incidence. Refer the Figure 1A and you find that the angle of incidence and angle of reflection is equal. The smooth surface like a mirror or relatively smooth surface shows specular reflection while on rough and undulated surface, it is diffused reflection. The certain amount of incoming energy is lost and it does not participate in the heating process of atmosphere or the earth's surface. It is generally expressed in percentage of the incident radiation reflected. It is also called as albedo or coefficient of reflection.

Figure 1A: Reflection and Diffuse Reflection on the Surface



Diffusion and Scattering: The term diffusion refers to the spreading of something more widely from its centre to all directions. In scattering, sun energy or light is forced to deviate from the direction of propagation. When the sun energy passes through the atmosphere, it has to travel through numerous solid minute particles of aerosols and gases.In this process of passing through, the energy and light is diffused and scattered. Refer to the Figure 1B. The smaller suspended particles in the atmosphere also reflect and diffuse the sun's electromagnetic radiation. Because of this reason, we find the twilight before the sunrise or even after the sunset. More and more scattering and diffusion is possible when the wavelength is smaller. Violet visible rays have much smaller wavelength than the red visible light. The blue colour of the sky is due to selective scattering of sun light. Before dawn or after the sunset, the sky is red and it is due to diffusion and scattering of red visible light.

Figure 1B: Reflection and Diffuse Reflection in the Atmosphere



Absorption: The term absorption refers to a state of being engrossed or being captivated. Therefore, it is a process by which something is absorbed by another thing. With reference to the absorption of solar radiation, it is done so by the atmosphere or the earth surface. Incoming solar radiationisabsorbed by the different elements of atmosphere present at a particular point of time. These elements are gas molecules, water vapour, smoke and dust particles. They trap a part of solar energy during transmission through the atmosphere. In fact, the absorption is a function of the nature of the absorbing particles/ surface and the wavelength of the energy. For example, shortwave radiation is absorbed by oxygen and ozone but for relatively longer waves, they behave as transparent body.

Outgoing Longwave Terrestrial Radiation

The received energy from the sun heats the earth surface. Heated earth surface is not that hot hence, it re-emits the energy. This remittance energy is in the form of longwave radiation. In this process, the longwave energy is absorbed by the atmosphere. And the atmosphere is warmed up. Now, let us study the heat budget by different heads of incoming (income) and outgoing (expenditure) radiations.

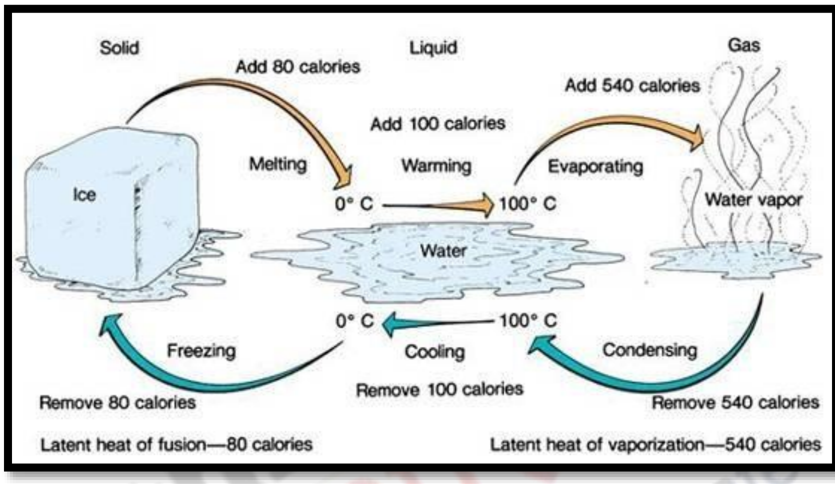
Processes Involved with Outgoing Radiation

The received energy by the earth as well as by the atmosphere is re-emitted back. It happens through different processes. Therefore, the outgoing energy involves following processes:

- Latent heat transfer
- Sensible heat transfer
- Emission by vapour and clouds
- Longwave radiation

Latent Heat Transfer: Latent heat is the energy absorbed or released from a substance due to changing phases. For example, when solid to liquid or from liquid to gas or even from solid to gas and vice versa. If a substance is changing from solid to liquid, it absorbs the energy from the surroundings so that its molecules are spread out. If the liquid is again changing its state to gas, it further requires more energy for the same reason. When the process is reversed, the energy utilized for changing the state of the substance, the same amount of energy is returned to the surroundings. Figure 2 undoubtedly explains the changing state of water and energy retained or released.

Figure 2: Relationship of Changing State of Water and Energy Use or Release



Source: https://qph.ec.quoracdn.net/main-qimg-36a6e3973562f9f51f02b4c061f940e2-c

Sensible Heat Transfer: Sensible heat is the energy needed to alter the temperature of a substance without any change in the state. It is possible by absorption of sunlight by the land surface or even the air is warmed up by gaining heat. Release of latent heat or the cool air coming in contact of warm air also cause the temperature to rise. Therefore, both the methods latent and sensible heat are responsible for gain or release of energy in the atmosphere.

Emission by Vapour and Clouds: Emission means discharge or release of something. Huge amount of terrestrial energy is released through the vapour and clouds. In fact, the energy due to which the atmosphere was heated up, in general, is released through vapour and clouds as well.

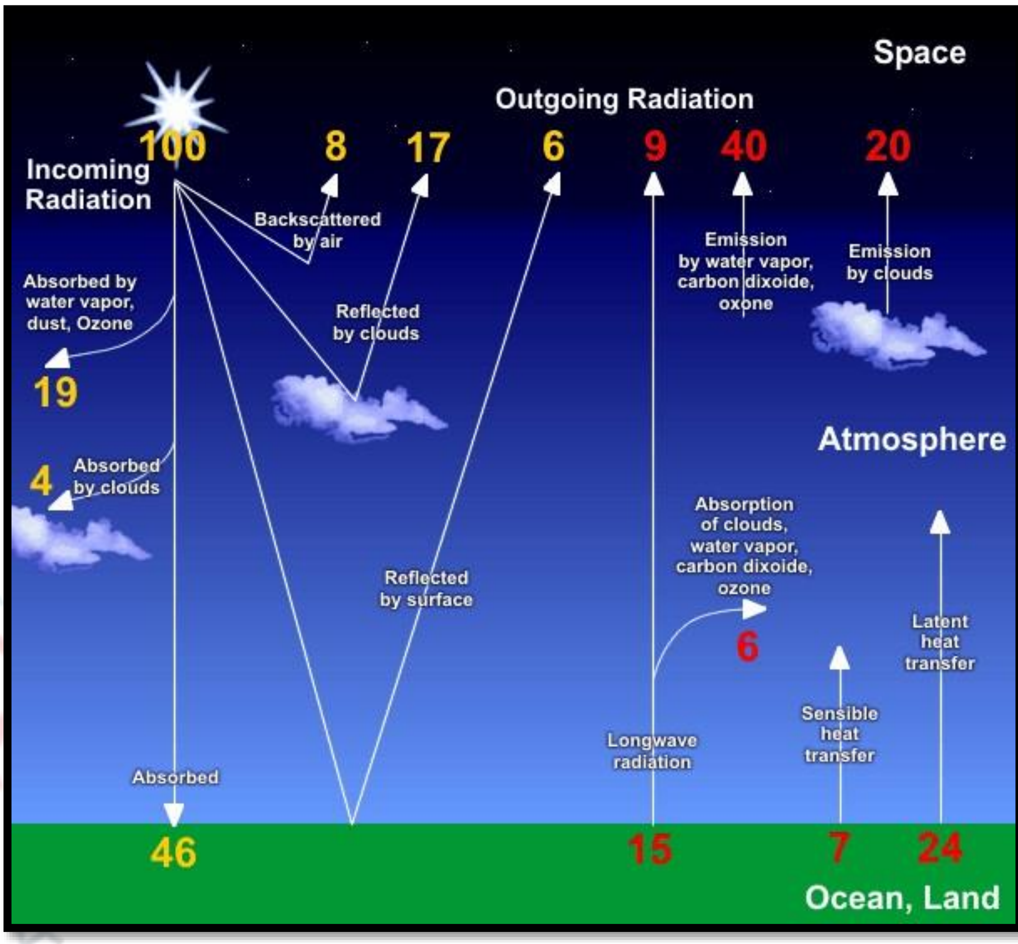
Longwave Radiation: Little amount of energy is directly released to the space by direct longwave radiation. It means that this amount of energy is not trapped by the atmosphere.

Heat Budget

The ideal heat budget of the earth is supposed to be a perfect balance between the incoming solar radiation and outgoing terrestrial radiation. Therefore, no negative or no positive between the two has to be maintained. In other words, it has to be a zero outcome of the two.

The total incoming shortwave radiation reaching at the top of the atmosphere is considered to be 100 percent. The distributed and re-distributed of this 100% or 100 units energy is termed as heat budget of the earth. Out of these 100 units, 17 units are reflected back to the space by cloud cover. Air molecules scatter 8 units of the energy back to the space. Energy reached on earth surfaceis also reflected by some surfaces like show cover, deserts or other bright surfaces. Their contribution in reflection is 6 units. Hence, the total reflection, from atmosphere (17 units), from air molecules (8 units) and from surface (6 units) is 31 units. This much of energy is not at all used in the heating of the atmosphere or the earth surface. Refer to Figure 3.

Figure 3: Heat Budget of the Earth



Source:http://www.geocoops.com/heat-budget--insolation.html

Remaining 69 units areinvolved in heating of the atmosphere and the earth surface. Out of these 69 units, 9 units are trapped by the water vapour, dust particles and ozone and heats up the atmosphere. Four units are absorbed by clouds and the rest 46 units reach directly to the earth surface. The 31 units directly reflected back to space, 23 units utilized in the atmosphere and 46 units reaching the earth make the total 100 units of incoming solar radiation.

Out of 46 units received by the earth, 9 units are directly released back to space by longwave radiation without heating the atmosphere. Six units of the longwave radiation are absorbed by clouds, water vapour, carbon dioxide and ozone. The total energy used up in heating the atmosphere is 60 units; 37 units released by the earth surface (7 units – sensible heat; 24 – units latent heat and 6 units absorbed by clouds, water vapour, carbon dioxide and ozone) and 23 units already absorbed during transmission of the solar energy (19 – units absorbed by water vapour, dust particles and ozone and 4 units – absorbed by clouds).The details of the heat budget of the earth are compiled in Table 1.

Table 1: Details of the Heat Budget

Units	Sector	Detail description
Incoming solar radiations (100 units)		
17		Reflected by clouds
8		Backscattered by air
6		Reflected back by earth surface
	31	**Returned to space (Albedo)**
19		Absorbed by water vapour, dust particles and ozone
4		Absorbed by clouds
	23	**Incoming energy absorbed in the atmosphere on the way to earth**
	46	**Reaches to the earth surface**
	100	**Total incoming radiation**
Outgoing terrestrial radiation(46+19+4=69)		
9		**Escaped to space by longwave radiation**
6		Absorbed by clouds, water vapour, carbon dioxide and ozone
7		Transfer by sensible heat
24		Transfer by latent heat
	46	**Returned to atmosphere and space**
	37	**Re-emitted energy from the earth heating the atmosphere**
	23	**Incoming energy absorbed in the atmosphere on the way to earth**
	60	**Total energy utilized in heating the atmosphere**

The total energy released to the space after being utilized by atmosphere as well as the earth is 69 units. So these 69 units as well as 31 units directly returned to space make 100 units and that was the total incoming radiation. The sectoral heat budget and their description are presented in Table 2.

Table 2: Sector-wise Description of Heat Budget

Units	Detail description
Incoming solar radiations (23+8+23+46=**100**)	
17+6=**23**	Reflection
8	Diffusion and scattering
19+4=**23**	Absorption
46	Received at the earth surface
Absorption by atmosphere (both incoming and outgoing; 19+4+6=**29**)	
19	Incoming by water vapour, dust particles and ozone
4	Incoming by clouds
6	Outgoing by clouds, water vapour, carbon dioxide and ozone
Released by the earth but atmosphere is heated (6+7+24=**37**)	

6	Longwave radiation absorbed by clouds, water vapour, carbon dioxide and ozone
7	Sensible heat transfer, utilized in the atmosphere
24	Latent heat transfer, utilized in the atmosphere
Outgoing total energy from the earth and atmosphere(9+20+40=**69**)	
9	Directly released to space by the earth
20	Emission by clouds
40	Emission by water vapour, carbon dioxide and ozone

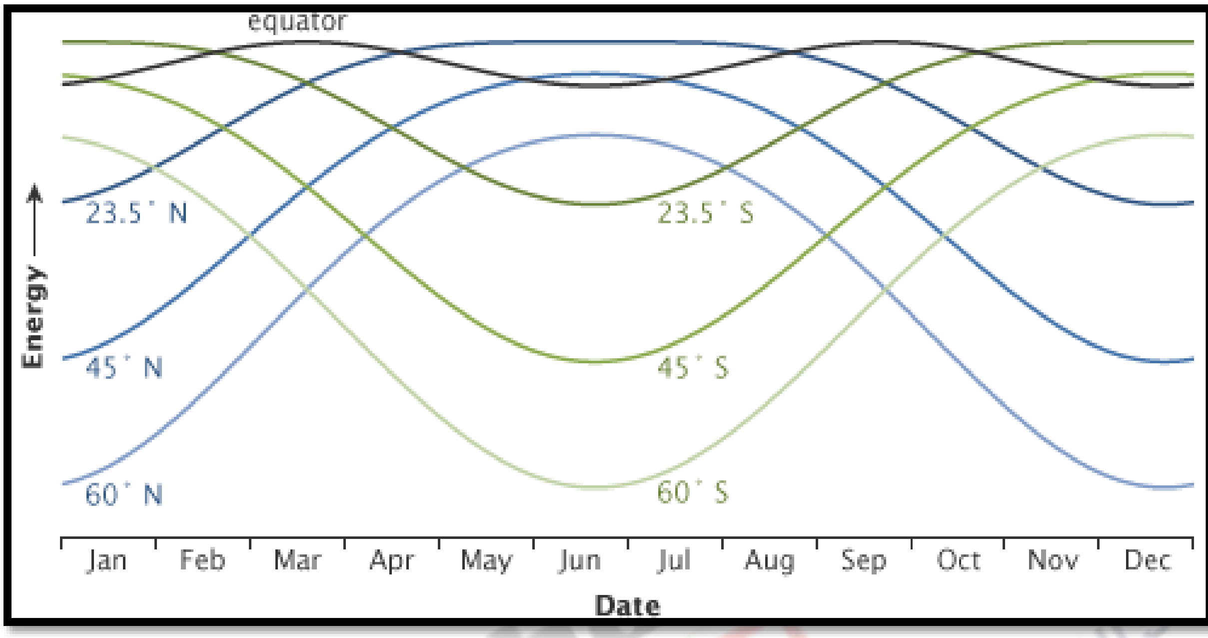
Heat Balance

Heating is the process of transfer of energy from a body of higher temperature to another body of lower temperature. The distribution heat energy is not uniform over the earth surface. It has numerous factors to affect,about which you have already studied in Module 5. Its distribution is most affected by the curvature of the earth/ incidence of sun rays. Therefore, the maximum energy is received near the equator throughout the year. The seasonal variations of energy received are considerable with increasing latitudes.

Latitude-wise Temporal Variation in Received Energy

Refer the Figure 4. On vertical axis, the energy is increasing upward. You can very well observe that the grey line is on the top showing very high received energy in all months (throughout the year) and it is equator. Blue lines are for different latitudes of northern hemisphere. Sun is vertical in the northern hemisphere from third week of March and reaches on peak in the third week of June. Hence, from January to June the energy received on the northern latitudes increases. After that, it keeps on declining and the lowest most reaches in December/January. The reverse case is seen in the context of southern hemisphere. The latitudes of southern hemisphere are shown in green colour. The complete reversal of the distribution of energy is primarily caused by the change in incidence of sun rays in an annual cycle.

Figure 4: Selected Latitude-wise Trend of Daily Received Energy at Local Noon



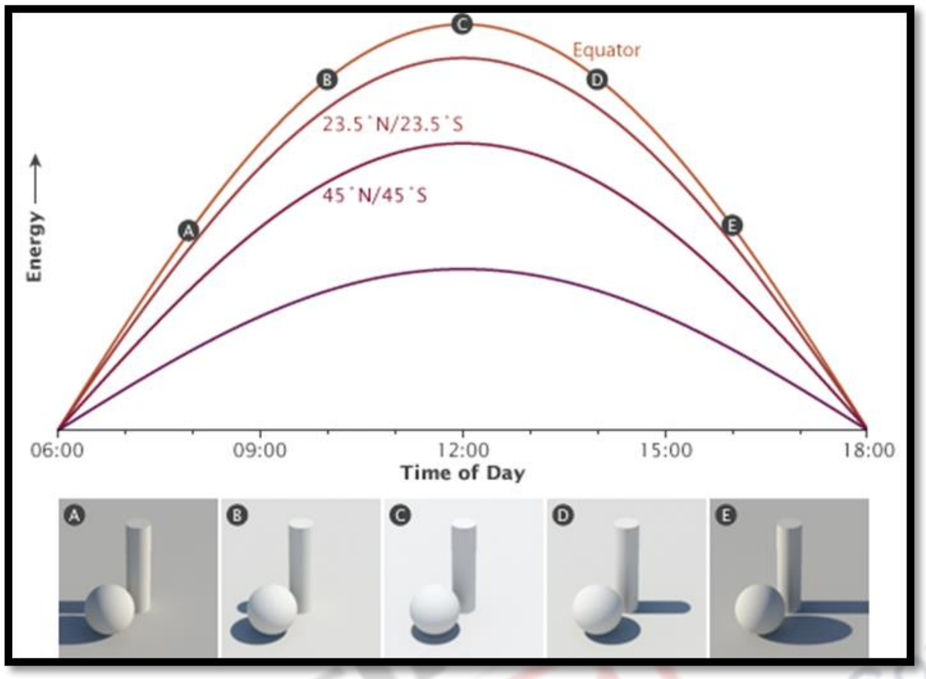
Source: https://earthobservatory.nasa.gov/Features/EnergyBalance/page3.php

Diurnal and Horizontal Variations in Irradiance

The maximum irradiance (flux of radiant energy per unit area) from the sun is when the incidence of rays is vertical or near to vertical. It happens around noon at any place on the earth. Inclination of sun rays causes the variations. In general, it is the highest at the equator and lowest at the poles. At equator, it is perpendicular to the propagation of sun rays. With progressive increase in latitudes, the angle of solar illumination reduces, consequently, the solar irradiance decreases. It is demonstrated in Figure 5. It shows the relationship between latitudes, time and solar energy during the equinoxes. Five recorded times are taken here for the illustration from 6am to 6pm at the interval of three hours.

The length of shadow of the objects shows the inclination of sun light and the intensity is affected by the duration of the day. The shadow of the objects decreases from sunrise to the noon. When the sun is directly overhead along the equator, there is no shadow. After the noon, it keeps on increasing until the sunset. At this time, the shadow is the longest as it happens at the sunrise. Further after that, the sun goes beyond the horizon.

Figure 5: Diurnal and Horizontal Variations in Irradiance during Equinox



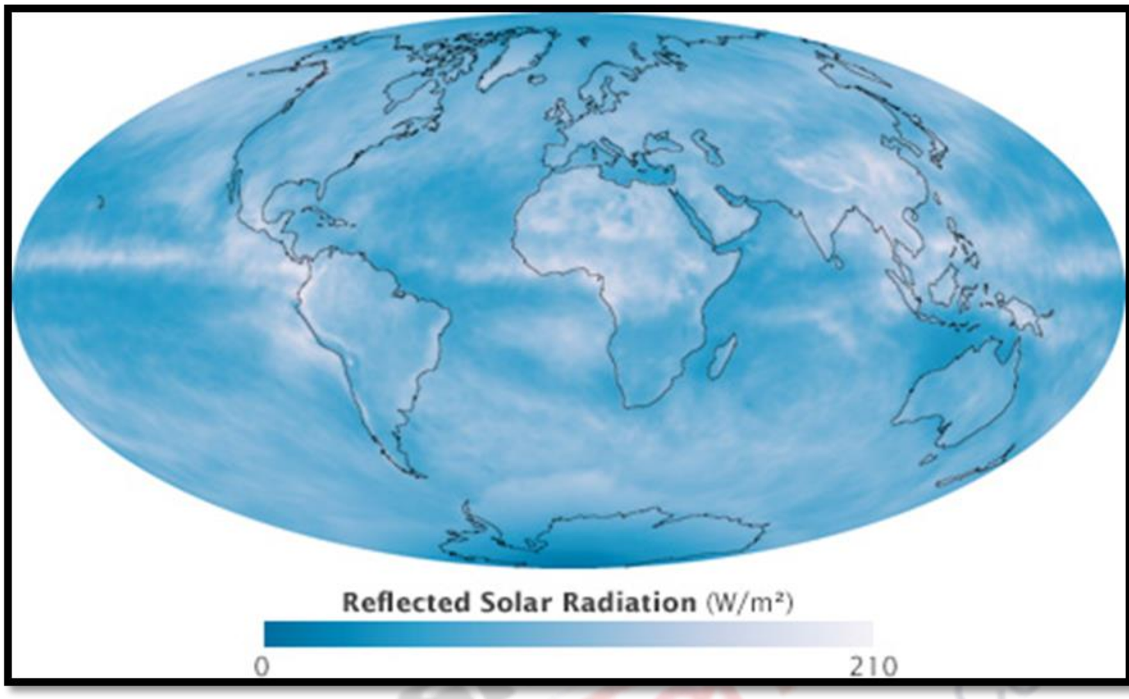
Source: https://earthobservatory.nasa.gov/Features/EnergyBalance/page2.php

Variations in Reflected Solar Radiation

During June in northern hemisphere and during December in southern hemisphere, days are longer over poles and due to this reason polar areas get more sunlight. Polar areas are cold with huge accumulation of ice. Long duration sunshine is also not very effective because of greater reflectivity of the areas. Hence, the heating in the polar areas is very low. During the same months, but in reverse hemispheres, the sunshine is absent in the polar areas. Overall, the tropics receivemore sunshine and consequently greater energy. The greater reflection means less energy available for heating the surface and lesser reflection signify the greater energy availability for heating the surface. Therefore, if other things remain the same, higher reflecting zones are cooler and lesser reflectance is associated with more heating.

Refer to the Figure 6. The amount of sunlight absorbed on the earth surface depends on the reflectiveness of the atmosphere as well as the earth surface. From this figure, it is obvious that the amount of solar radiation(in watts per square meter) reflected by clouds is high, at equinox, in tropical areas. The cloud free deserts also reflect substantial amount of energy. During September for which this map is, the poles are not getting sufficient sunlight, the reflectance is less and darker blue colour is assigned. Reflected solar radiation is the function of the state of atmosphere as well as the nature of the surface of the earth.

Figure 6: Variations in Reflected Solar Radiation during September 2008



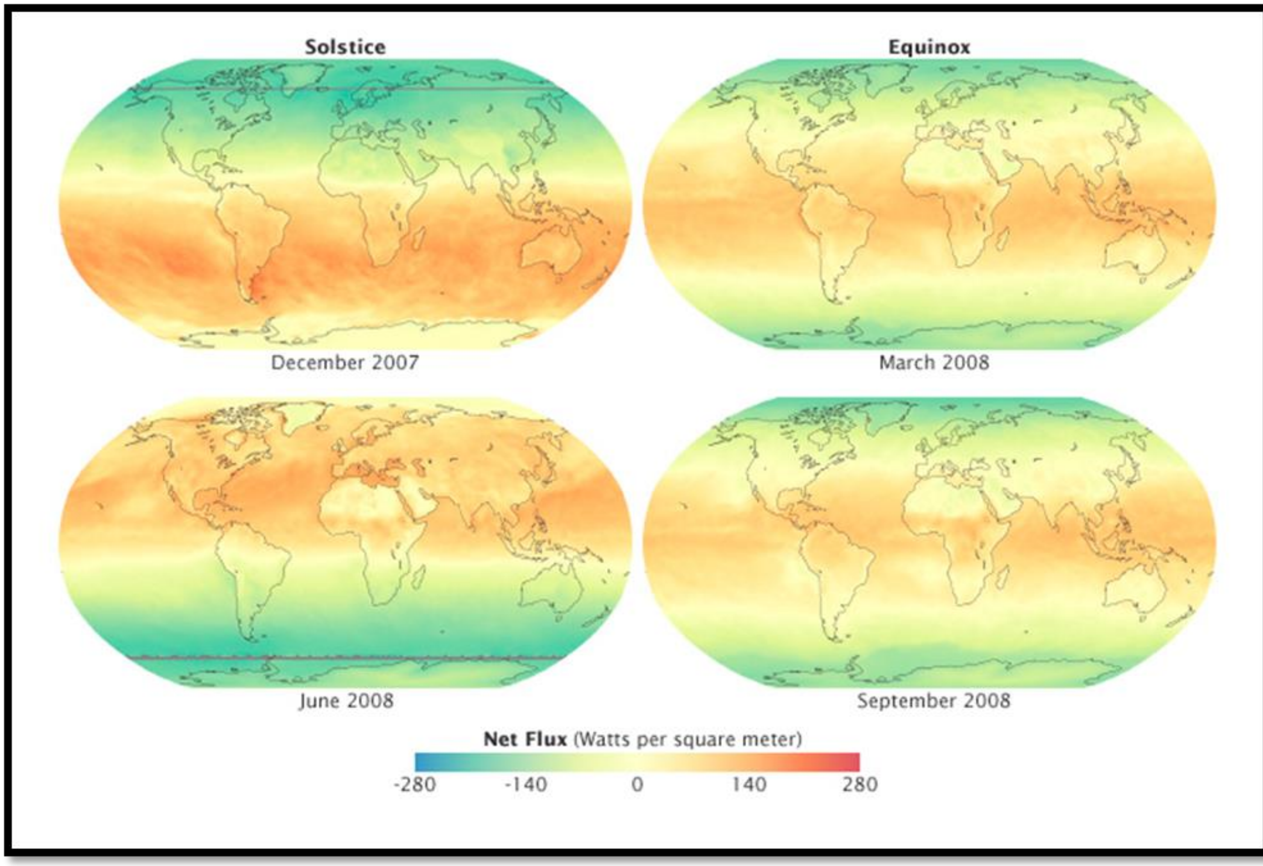
Source: https://earthobservatory.nasa.gov/Features/EnergyBalance/page3.php

Net Radiation

The difference in reflectiveness and solar illumination over the earth determines the heating imbalances. These imbalances give birth to several changes and variations in the earth systems. As discussed above, the net radiation is the result the difference between the amount of incoming energy and the amount of the energy radiated back to space. In the tropics, there is a surplus energy because the amount of sunlight absorbed is more than the amount of heat radiated. Contrary to this, the higher latitude areas have annual energy deficit as the amount of absorbed energy is less than the radiated energy.

Refer to the Figure 7. It is quite obvious that during equinox, the net radiation is more in the tropics but the higher latitude areas have deficit radiation. At this time the sun is overhead at the equator. On entire earth, the days and nights are almost equal. Poles are getting oblique sun rays and that are not effective. On the other hand, during solstice in December, the sun is vertical in the southern hemisphere and therefore, gets very high net radiation. During the same period, the northern hemisphere is away from the sun and gets less net radiation. During June, when the sun is vertical in the northern hemisphere, its net radiation is very high and while the southern hemisphere gets very low net radiation.

Figure 7: Net Radiation during Solstice and Equinox



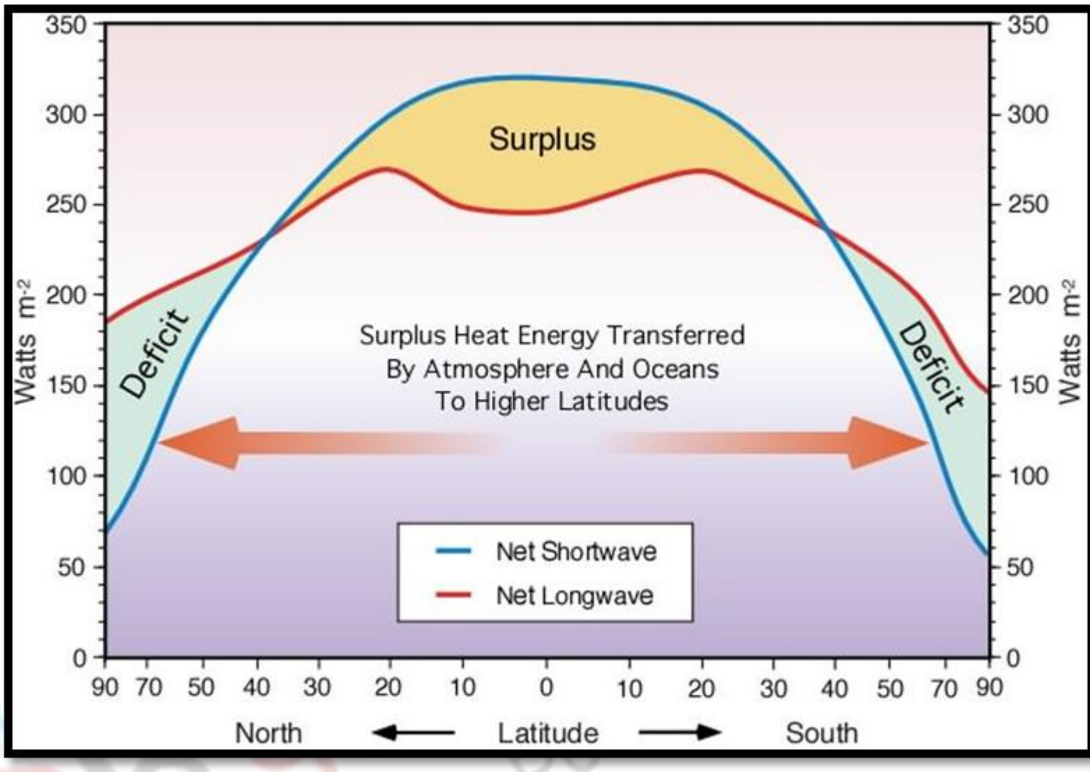
Source: https://eoimages.gsfc.nasa.gov/images/imagerecords/77000/77849/netflux_cer_2007-08.jpg

The positive values on the map denote that the received energy is more than the radiated. Conversely, the negative values of net radiation show that the terrestrial radiation is more than incoming solar radiation. Dark green and bluish shades towards higher latitudes reflect increased intensity of this trend.

Incoming and Outgoing Radiation across the Latitudes

You are well aware that the maximum solar radiation is received in the tropics. The heat from the tropics is transported to the higher latitudes by atmospheric circulations (prevailing winds, cyclones and air masses) and oceanic circulations (mainly ocean currents. From Figure 8, it is evident that approximately between 35^0 N and 35^0 S latitudes, the energy received is surplus. More energy is received (shortwave) than lost (longwave). Blue colour line represents the incoming radiation while red colour line shows the outgoing. The areas with higher incoming and lesser outgoing radiation are shown as heat surplus areas and reverse situation represents heat deficit areas. Because of the transport of radiation in the form of heat energy, higher latitudes are relatively warmer than what they wouldhave been otherwise. Heat is also lowered in the tropics due to transport, and hence, it is relatively cooler than what it wouldhave beenin the absence of latitudinal heat transfer.

Figure 8: Latitudinal Variation of the Radiation Balance

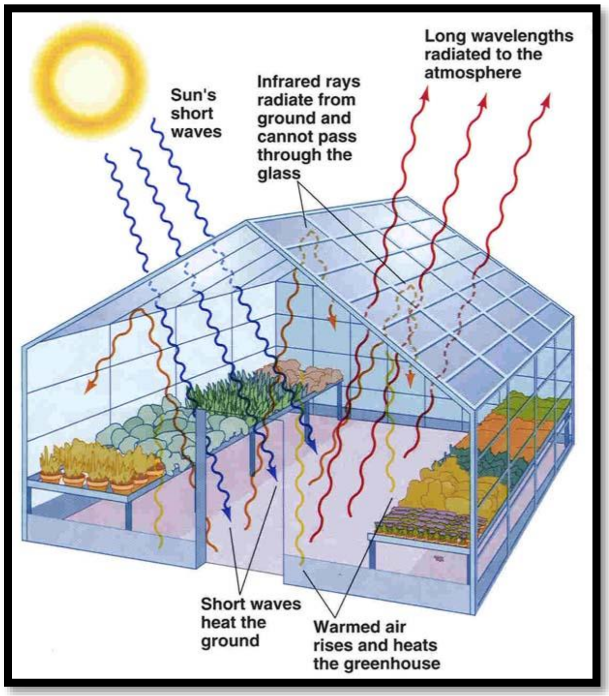


Source: http://www.physicalgeography.net/fundamentals/images/rad_balance_ERBE_1987.jpg

Greenhouse Conditions

Major gases in the composition of the atmosphere are nitrogen and oxygen accounting for nearly 99 percent share of the total. These gases are transparent to both incoming as well as outgoing radiation. As against this, gases such as carbon dioxide, methane, water vapour and other trace gases are opaque to several wave lengths of thermal radiation.They allow solar radiation to come but when the earth re-emit the same energy by longwave radiation, they do not allow to escape. They behave like a house made up of glass which allows the sun energy to enter but holds back when the house itself releases the energy. The result is the rise of the temperature of the glass house (Figure 9).

Figure 9: House made up of Glass Creates Greenhouse Condition

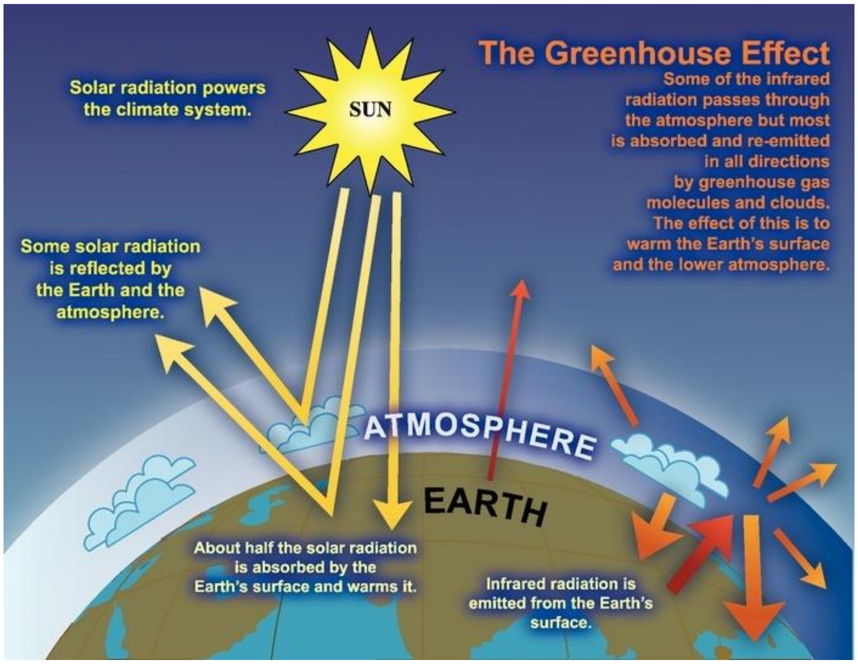


Source: http://www.earthlyissues.com/images/greenhouse.jpg

Atmospheric gases absorb only some wavelengths of energy but are transparent to others. The absorption patterns of water vapor (blue band) and carbon dioxide (pink band) overlap in some wavelengths. The carbon dioxide is not as strong a greenhouse gas as water vapor, but it absorbs energy in wavelengths (12 to 15micro meters) which water vapor does not. As such, atmospheric window, in this zone, is partially closed through which heat radiated by surface would normally escape to space.

Temperature rises when molecules of greenhouse gas absorb thermal infrared energy. These gases radiate thermal infrared energy in all directions. The upward radiated heat continues to encounter greenhouse gas molecules which also absorb the heat, resulting in temperature rise. The net result is that the amount of radiated heat increases. It is well known that atmosphere thins with altitude. The concentration of greenhouse gases is also in the lower troposphere. Since greenhouse gas molecules radiate infrared energy in all directions, some of it spreads downward also and ultimately returns to Earth's surface, where it is absorbed. The Earth's surface temperature is higher than it would have been only by direct solar heating. The additional heating is due to the effect of greenhouse conditions (Figure 10).

Figure 10: The Greenhouse Effect



Source: http://www.earthontheedge.com/wp-content/uploads/2014/10/greenhouse_effect_AR4.png

Since the earth is covered by a blanket of atmosphere that allowsshort wave solar radiation to enter and slows the rate of the long waveinfrared radiation emitted by the Earth leaves. In addition, it is important to note that ozone (O_3) in Stratosphere absorbs ultra violet rays and thus keeps Earth free from the harmful effects of UV radiation. It was detected in 1980s that ozone layer is depleting fast over poles. Montreal Protocol (1987) was signed to check the problem. Recent researches have shown that the ozone layer is improving because of the concerted cooperative efforts of the international community.

Balancing Act

The temperature on the globe remains almost constant. It happens because the incoming and outgoing energy is almost equal on an annual basis. The high energy receiving areas transfer to the low receiving and thus, uniformity is almost reached. That is why the low latitude areas are relatively cooler by transferring the energy to the deficit areas, in comparison to what it would have been otherwise. Apart from the transfer of energy, some atmospheric gases are of the nature which holds the energy released by longwave radiation. It causes the temperature to rise and maintain a moderate temperature of the entire earth which makes it habitable. In the absence of the greenhouse effect of the atmosphere the earth's temperature would have been 33^0C lower than present. Therefore, without the absorptive gases in atmosphere human life and other life forms would do not have been possible.

Summary and Conclusions

The source of almost all energy on the earth's surface and its atmosphere is sun. The incoming solar energy serves as the basis for transforming energy into heat. The distribution of heat varies significantly from equator to poles; from low altitudes to higher altitudes and from shallow to greater depths; and in land and oceans. Motions such as winds, currents, waves and processes such as conduction, convection and advection serve as the basis for the redistribution of heat in different parts of the earth surface. The absorption of heat by different surfaces gets modified under the influence of reflection, refraction and re-radiation. Heat balance is an extremely important factor in maintaining a fairly stable temperature on the earth surface.Global heat budget is the balance between incoming and outgoing solar radiation. Incoming solar energy varies at different times of year and for different locations across the globe. Insolation is the solar radiation received atthe earth surface or in its atmosphere.

The maximum solar radiation is received in the tropics and the lowest around the poles and their surroundings. Heat is always transferred from high heat concentration to the lower one. In another words, the cold is also transferred from high cold concentrated areas to low heat concentration. Therefore, the transport of energy is from the high concentration zone to low concentration zone. In this way, a sort of balance of heat is maintained by transfer particularly through winds and ocean currents.

Major gases in the composition of the atmosphere are nitrogen and oxygen accounting for nearly 99 percent share of the total. These gases are transparent to both incoming as well as outgoing radiation. As against this, gases such as carbon dioxide, methane, water vapor and other trace gases are opaque to several wave lengths of thermal radiation. Temperature rises when molecules of greenhouse gas absorb thermal infrared energy. The net result is increase in heat. Since greenhouse gas molecules radiate infrared energy in all directions, some of it spreads downward also and ultimately returns to earth's surface, where it is absorbed. The earth's surface temperature is higher than it would have been only by direct solar heating. The additional heating is due to the effect of greenhouse conditions. Therefore, greenhouse effect of the atmosphere is required for different life forms on earth but 'enhanced' greenhouse effect due to anthropogenic activities is a challenge.

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