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	INSOLATION: FACTORS AND DISTRIBUTION
Module Id	CL-05
Pre-requisites	
Objectives	• define insolation; • explain the source of energy on the earth surface; • enlist different factors affecting insolation on earth's surface; • explain the various factors affecting insolation; • discuss the distribution of solar energy on the earth's surface; and • establish the relationship between the factors of insolation and its distribution.
Keywords	

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Introduction

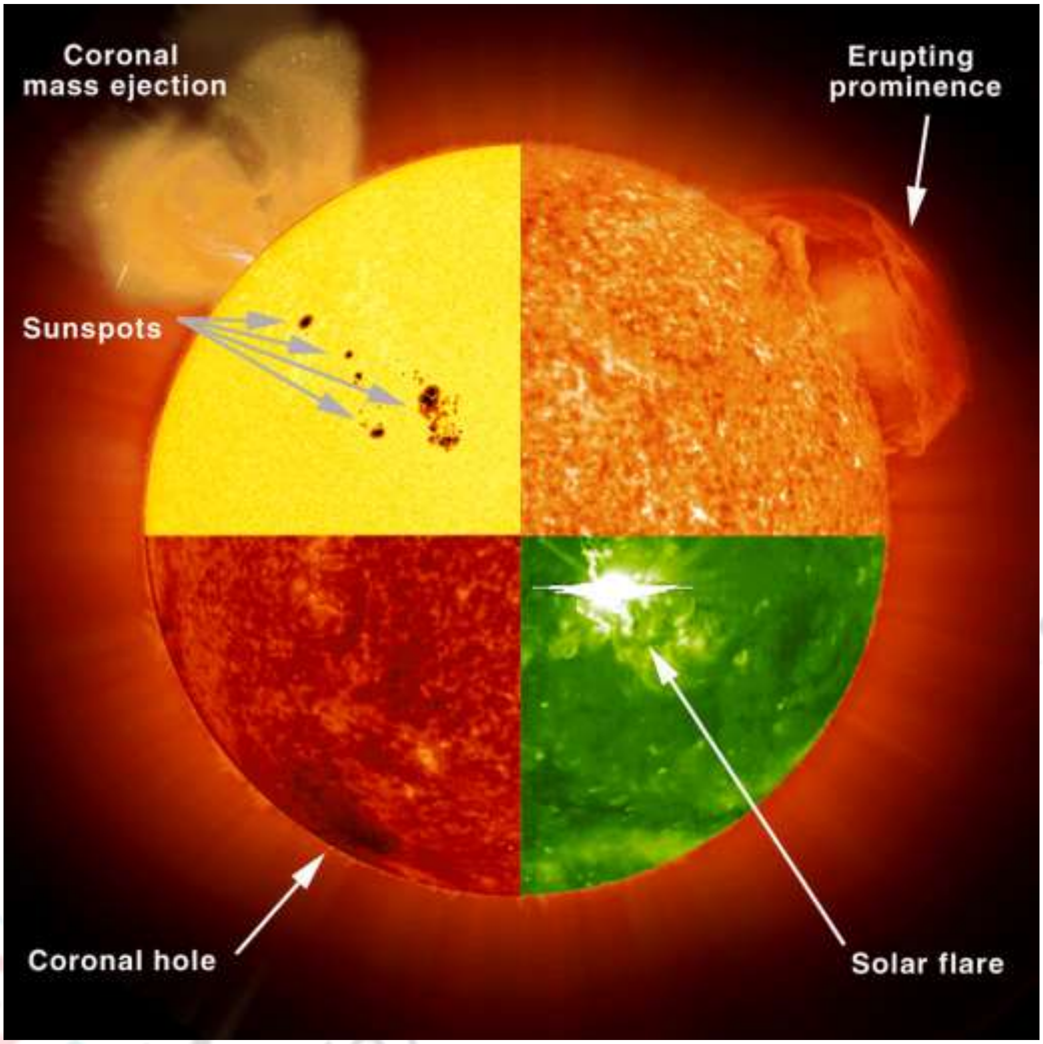
You must have travelled different places and observed about the temperature as well precipitation conditions of those places. You are also aware that the mountains are cool to cold and plains are warmer if they exist on the same latitude. You must have observed that there is season change and with this, the temperature and moisture also changes. Based on temperature, the air pressure is also greatly affected. Differences in the pressure results in the wind patterns. But have you ever thought as to why it is happening so. For this, there are several factors responsible. The changes are seen with reference to latitude, altitude, sun's position with reference to earth, nature of sky etc. In this module, an attempt has been made to discuss the insolation in general and its factors as well as its distribution over the globe in particular.

Sources of Solar Energy

The sun is the source of almost all the energy for our Earth except geothermal energy. The sun is a biggest star in our solar system and reigns as the centre of our solar system. It provides all the light and heat for the surface of the various celestial bodies in our planetary system. The sun's average diameter is 13,91,000 km which is 109 times bigger than our earth (NASA). Sun is a self-luminous sphere of gases that emits radiant energy. This emitted energy comes from the fusion reactions (thermonuclear) take place inside the sun. Under high pressure, two or more hydrogen atoms fuse together to form one helium atom. In this process, hydrogen bomb explosion type energy is generated. The fusion process is a continuous affair with the sun. Thus, the chain reactions and continuous explosion release tremendous amounts of energy that radiate out from the sun in all directions, usually associated with terms such as coronal mass ejection, solar flare and sun spots. The outflow of energy is observed to be at the speed of light.

Earth's upper level atmosphere receives about 1/2,000,000,000 (one part out of two billionth) of the radiation given off by the sun. But even this tiny amount affects the biological and physical characteristics of earth's surface. From the outermost layer of the sun, ionized gases acquire enough velocity to escape the gravitational pull of the sun and become solar wind. These solar winds produced by streams of extremely hot protons and electrons. Occasionally, these solar winds approach earth and intensify the auroras. The intensity of solar winds is influenced by the sunspots (Figure 1).

Figure 1: Solar Flares, and Sunspot

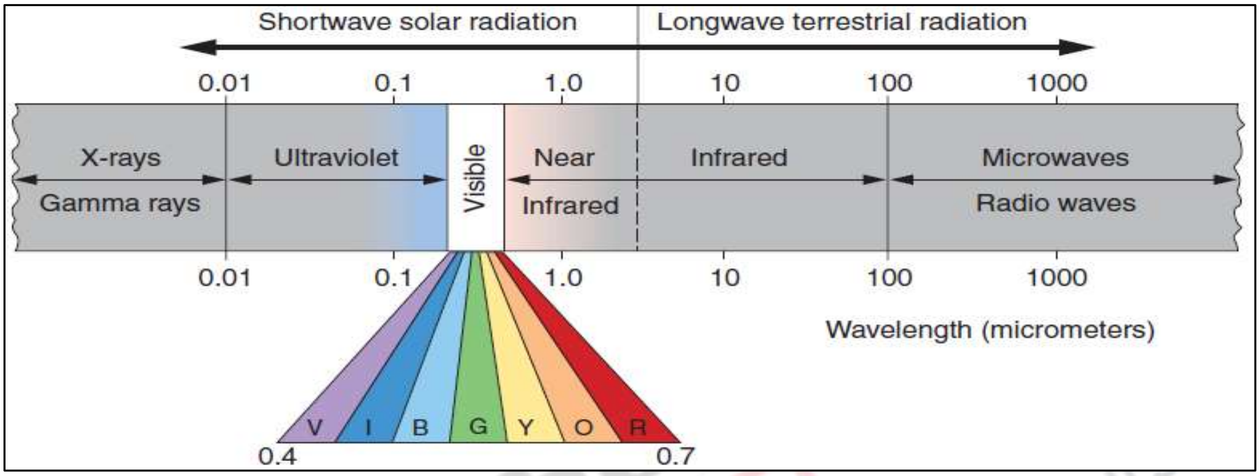


Source: http://www.geomag.bgs.ac.uk/research/space_weather/sci_intro.html

Energy is emitted by the sun in the form of electromagnetic energy,which travels at the speed of light in a spectrum of varying wavelengths. It takes about 8.3 minutes of time for these waves to reach earth. About 41% of this spectrum comes in the form of visible light rays, but much of the sun's energy cannot be seen by the human eye. About half (50%) of the sun's radiant energy is in wavelengths that are longer than visible light rays, including some infrared waves.

Although these wavelengths cannot be seen, they can sometimes be sensed by human skin. The longer waves in the infrared part of the spectrum are felt as heat. The remaining 9 per cent of solar energy is made up of X-rays, gamma rays, and ultraviolet rays, all of which are shorter in wavelength than visible light. These also cannot be seen but can affect other tissues of the human body (thus, absorbing too much X-rays can be dangerous, and excessive ultraviolet waves gives us sunburned skin). Collectively, visible light, ultraviolet rays, X-rays, and gamma rays are known as shortwave radiation. We have learned to harness some energy waves for communications (radio, microwave transmission, television), health (X-rays), and use in the field of remote sensing (photography, radar, visible and infrared imagery) (figure 2).

Figure 2: Electro-magnetic Spectrum



Source: Gabler, Petersen and Trapasso (2007)

Receipt of Energy

The earth's surface and the atmosphere receive maximum energy from the sun in a form of solar energy to run their systems such as hydrological cycleorother atmosphere dynamics. The term **insolation(in + sol + ation)**is derived from the words **in**coming **sol**ar radi**ation**. Insolation specifically applied to radiation which is arriving at earth's atmosphere first and then earth surface.The heat is derived from solar energy, normally called solar radiation. Similarly, solar energy received by the earth is called insolation. It is the amount of incoming solar radiation that is received over a unit area of the earth's surface. Solar energy received over the planet's surface varies according to season, latitude, transparency of the atmosphere, and aspect or ground slope.

Methods of Solar Energy Receipt

The solar radiation received by the earth's atmosphere and surface by direct radiation or diffuse energy. There are five way of solar radiations. They are:

- Transmission,
- Scattering,
- Refraction,
- Absorption, and
- Reflection

Transmission

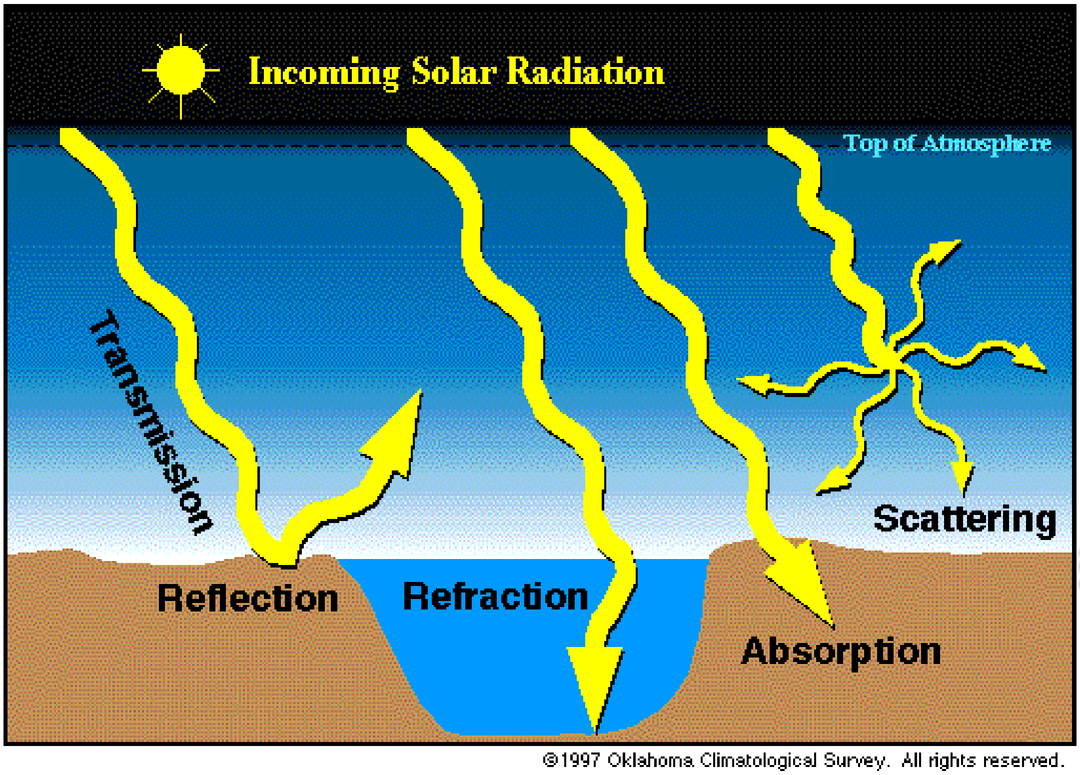
When the solar radiation reaches to the earth surface through a medium is known as transmission of solar radiation. The dictionary meaning of transmission is the passage of shortwave and longwave energy (electro-magnetic energy) through either the atmosphere or water (figure3) but the sun's energy is reaching to the earth without any medium from the space. It is also known as radiation. The atmospheric energy comprises shortwave radiation inputs (ultraviolet light, visible light, and near-infrared wavelengths) and longwave radiation outputs (thermal infrared) that pass through the atmosphere by transmission. In our atmosphere, all the radiation is not reaching to the earth surface or in other word, atmosphere is not opaque for all the radiation. For example, ultraviolet energy is absorbed by ozone layer in the atmosphere, which is coming from the sun. The transmission of short wavelength and long wavelength can be understood by the example of car with closed glass window where shortwave radiation transmit into the car and warm inside the car and does not transmit back through the glass causing very high temperature inside the car. Similarly, our earth atmosphere easily transmits incoming shortwave solar radiation but is a poor transmitter of outgoing longwave emitted energy by earth's surface. This differential transmission causes the greenhouse effect in the atmosphere. Due to greenhouse effect of the atmosphere, the earth's atmospheric temperature is hospitable. Without this effect, the living conditions could not be created. The average global temperature of 15 ^{o}C is possible only due to greenhouse effect otherwise, without this effect, the average temperature would come down to -17 ^{o}C.

Scattering

Atmospheric gases and dust particles physically interact with incoming solar radiations through processes of scattering. A redirection of energy through refraction and reflection is called scattering. The solid particles of dust, smoke, aerosols, sea salts sprays, pollutants atmospheric humidity, smoke shoots etc. available in the atmosphere are responsible for scattering of sun electromagnetic energy. It changes the direction of the light's movement without altering its wavelengths. This phenomenon is known as scattering and represents 7 per cent of Earth's reflectivity, or albedo. It is 'unpredictable' because of multiple reflections of electromagnetic waves by particles and surfaces. But in reflection, the direction of reflection is predictable. Dust particles, pollutants, ice, cloud droplets, and water vapor produce further scattering. The thumb rule is the shorter the wavelength, the greater the scattering, and the longer the wavelength, the less the scattering. Small gas molecules in the air scatter shorter wavelengths of light. Thus, the shorter wavelengths of visible light (blues and violets) scatter more. It is due to greater scattering of these visible rays, the sky appears to be blue.

The angle of the sun's rays determines the thickness of atmosphere they must pass through to reach the surface. Therefore, direct rays from overhead (90^{o}) has less scattering and absorption than low oblique-angle rays because it travels farther through the atmosphere. Insolation from low-angle (30^{o}) of Sun experiences more scattering of shorter wavelengths, leaving only residual orange and red region wavelength appears orange to red at sunrise or sunset. Incoming insolation is diffused by clouds and atmosphere and is transmitted to Earth, that energy is known as diffuse radiation, where light is scattered to appear white clouds. This light is multi-directional and thus casts shadow-less light on the ground.

Figure3: Processes of Insolation



Source: http://okfirst.mesonet.org/train/meteorology/graphics/RadiationFate.gif

Refraction

Refraction means bending of light. As solar radiation enters the atmosphere, it passes from one medium to another of atmosphere, from virtually empty space into atmospheric gases. The atmosphere itself is made up of different layers. The different layers have different density and change in density of the atmosphere causes the bending of incoming solar radiations at different angles. This refraction could also be seen with water as well. It is known as refraction of incoming radiation. For example, prism refracts light passing through it, bending different wavelengths to different angles, separating the light into different component of colours to display the spectrum. In nature, rainbow is created when visible light passes through many raindrops and is refracted and reflected toward the viewer at a precise angle. Mirage is another example, where an image that appears near the horizon where light waves are refracted by different layers of air of different temperatures (and consequently of different densities) in summers hot day.

Reflection

The reflection is an ability of the material where a portion of arriving energy strikes. Depending upon the surface characteristics, where it strikes, the quantum of reflectivity is determined. It might be completely bounced directly back into space with or without being absorbed. This returned energy is called reflection especially specular reflectance where angle of incidence and angle of reflectance is same. A mirror is one of the example of reflecting more than 90 per cent of the visible light incidence upon it. The term albedo is used to describe the amount of energy reflected back in percentage. Albedo is the reflective quality of a surface. It is an important control over the amount of insolation that is available for absorption by a surface. So, the proportion of insolation that is reflected back from the atmosphere, from the tops of the clouds, and earth surface including land and water both, without heating the receiving surface, is an albedo.

Of the total insolation about 30 per cent average, but varies widely according to the material and their characteristic of the surface as well as the angle and wavelength of the incident radiation. The albedo from green grass and forest is 8–27 per cent, more than 30 per cent for yellowing deciduous forest in autumn; for cities and rock surfaces, 12–18 per cent, more than 40 per cent from chalk and light-coloured rock and buildings; for sand up to 40 per cent; for fresh, flat snow up to 90 per cent; and for calm water very little, that is only 2 per cent in the case of vertically incident radiation but up to 78 per cent where there is a low angle of incidence. The albedo for cloud surfaces averages 55 per cent, but it can be up to 80 per cent for thick stratocumulus cloud.

Absorption

In our earth's atmosphere due to the different composition, act as a barrier to the insolation or it absorbed some solar radiation, may be assimilated by the object is generally termed as atmospheric absorption. The different material on earth has different absorptive capabilities with different wavelength of solar radiation. It is happening in all electromagnetic radiations at certain spectral bands by the composition present in the atmosphere. The most efficient absorbers of solar radiation in this regard are water (H_2O), carbon dioxide (CO_2) ozone (O_3), Oxygen (O_2) nitrous oxide (NO_2). The cumulative effect of the absorption by the various constituents can cause the atmosphere to close down completely in certain regions of the spectrum that leads to an increase in temperature. Generally, a good radiator is also a good absorber and a poor radiator is a poor absorber. As colour is concern, dark-colour surface are much more efficient absorbers of radiation in the visible portion of the spectrum than light-colour surface (figure 4).

Figure 4: Impact of Colour on Absorption and Reflection

Source: Hess (2014)

Factors Affecting Insolation

The actual amount of insolation received by the earthvaries according to the conditions of the atmosphere as well as the seasons. The various astronomical and geographical factors determine the amount of insolation received at any point on the earth's surface. They are:

- Solar output/constant,
- Angle of incidence,
- Length of day,
- Earth distance from sun,
- Transparency of the atmosphere

Solar output /constant

At the top of the earth's atmosphere receives insolation is expressed as the solar constant.It received at the top of the atmospheric surface (thermopause) on a perpendicular plane to the solar beam. The average insolation received at the thermopause i.e. 1368 Wm^2(Watt per square metre)energy (solar constant) in the form of short wave. Thus, it is termed as solar constant for that mean distance from the sun. These solar constant is varying over 1 Wm^2 by periodic disturbances and explosions in the solar surface basically related to sun spot. Sun spots are dark and cooler areas visible on the sun's surface. The recent researches have shown that more and more energy is released when the sunpots are in large number. The number of sunspots also increases or decreases on a regular basis, creating a cycle of 11 years. When sunspots are maximum, the solar radiations is also maximum. Increase or decrease in sunspots are directly and positively correlated with the received radiation on the earth. It is assumed that our earth is behaving as black body, a persistent anomaly of 1 per cent in the solar constant could change the mean temperature of earth's surface by as much as 0.6 ºC.The solar constant is reduced by half or more through reflection, scattering and absorption of the shortwave radiation in the atmosphere.

Angle of incidence

The angle at which sun rays strike on earth surface is called angle of incidence. It controls the amount of insolation received at the earth's surface. The amount of insolationis determined by time of the day (morning, noon and evening), the latitude (equator to poles) and season (summer, autumn, winter and spring). When the sun rays strike vertically or sun isdirectly overhead, the rays angle of incidence is 90 degree. The beam of rays spread on a smaller area in comparison to oblique/ slanting beam of sun rays as you can see the Figure 5, when sun is in a vertical position, the beam of light will spread over one mile but in the oblique position (with $30^0$of angle) of the sun the same beam of light will spread over two miles. Therefore, per unit of area received energy is greater in case of vertical beam with reference to oblique/ slanting beam on earth surface (Figure 6).When sun rays are oblique (incidence angle is less than 90º), it is spread over a relatively larger surface on the earth, then energy per unit area is decreased. In addition, the oblique rays have to traverse a larger distance through the atmosphere before they strike the surface of the earth. The longer their path, the larger the amount of energy lost by various processes of reflection, absorption, and scattering, etc. Thus, it is clear that the larger amount of radiant energy is lost in case of slanting rays than in vertical rays. Therefore, on an average, equatorial areas receive approximately 2.4 times more insolation than polar areas.

Figure 5: Angle of incidence and insolation

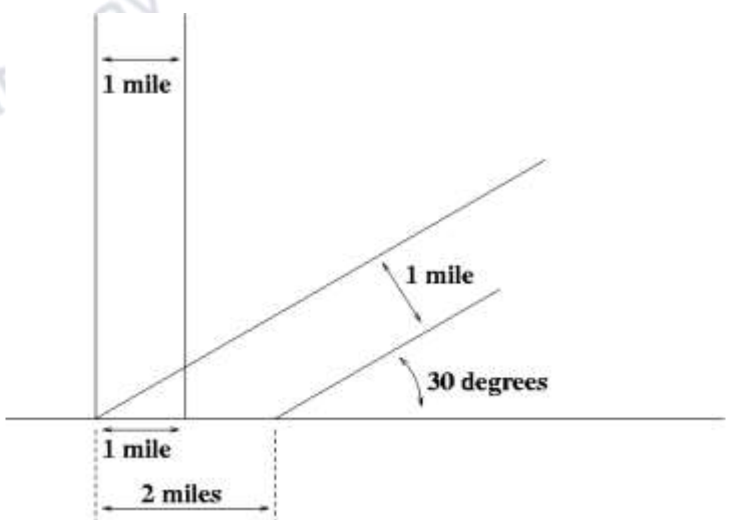
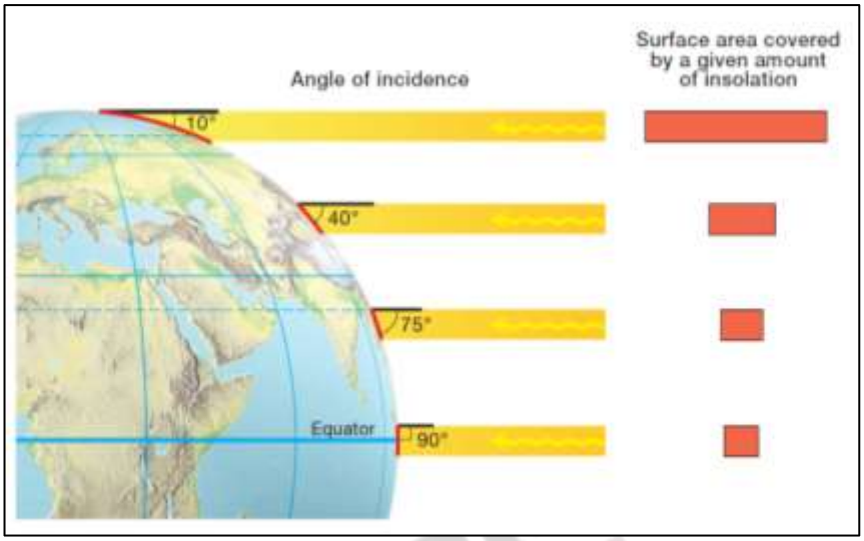


Figure 6: Sun Ray's Angle of Incidence and Energy Effectiveness



Source: Hess, 2014

Length of day

The length of the day determines the duration of sunlight which affects the amount of solar radiation received by the earth's surface. The longer period of sunshine, greater the quantity of solar radiation will be received by a portion of earth.For example, at the equator the length of days and nights is 12 hours in all the months but the tropics of Arctic and Antarctic sunshine duration varies between 0 and 24. See the Table1 showing length of day at different latitudes. On the autumn and spring equinoxes (September 23 and March 21 respectively), the sun is overhead at the equator at noon. The night and day all over the earth are equal on these days and maximum amount of insolation is received at the equator (Table 2), and the amount of insolation decreasing towards the poles.It is caused by vertical sunshine at equator but with increasing latitudes, the rays become more and more slanting. Therefore, poleward, the received energy keeps on declining.

Table1: Length of Day at Different Latitudes

Latitude (in degree)	Length of the day		
	March 21 / Sept 22	June 21	December 21
0	12 hours	12 hours	12 hours
10	12 hours	12 hours, 35 min.	11 hours, 25 min.
20	12 hours	13 hours, 12 min.	10 hours, 48 min.
23.5	12 hours	13 hours, 35 min.	10 hours, 41 min.
30	12 hours	13 hours, 56 min.	10 hours, 04 min.
40	12 hours	14 hours, 52 min.	09 hours, 08 min.
50	12 hours	16 hours, 18 min.	07 hours, 42 min.

60	12 hours	18 hours, 27 min.	05 hours, 33 min.
66.5	12 hours	24 hours	0 hours
70	12 hours	24 hours	0 hours
80	12 hours	24 hours	0 hours
90	12 hours	24 hours	0 hours

Source: after Gabler, Petersen and Trapasso, 2007

Table 2: Daily Solar Radiation on a Horizontal Surface outside the Atmosphere (in Wm^{-2})

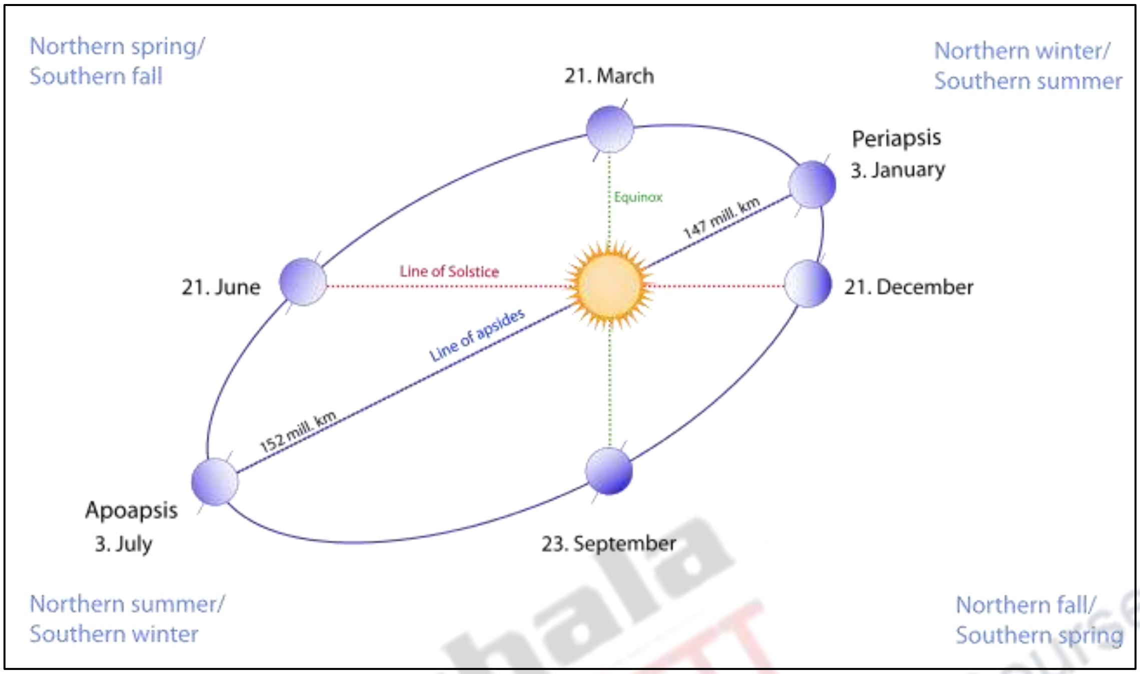
Date	90^{o}N	70^{o}	50^{o}	30^{o}	0^{o}	30^{o}	50^{o}	70^{o}	90^{o}S
21 Dec.	0	0	86	227	410	505	514	526	559
21 Mar	0	149	280	378	436	378	280	149	0
22 Jun	524	492	482	474	384	213	80	0	0
23 Sep	0	147	276	373	430	372	276	147	0

Source: after Barry and Chorley, 2003

Earth distance from sun

Theearth is revolving around the sun in an elliptical orbit, resulting continuous change in the distance between sun and the earth on annual basis. It leads to seasonal variation in solar energy received by the earth. The mean distance between the earth and sun is about 149,600,000 kilometers (92,900,000 miles).When earth position is farthest (152 million km) from sun is known as ‘aphelion’ on July 4. It is perihelion(147 million km) occurs on January 3 each year which is the closest distance. During aphelion the northern hemisphere is facing the sun and therefore receives energy about 7 percent less than the perihelion (southern hemisphere). It is apparent from the Figure 8. It means the earth is relatively closer to the sun during the northern hemisphere winter or southern hemisphere summer that produce an increase in the effective January world surface temperature of about $4^{o}C$ over those of July. Consequently, northern hemisphere winter is warmer than southern hemisphere winter and southern hemisphere summer is warmer than northern hemisphere summer.Moreover, southern summer (22 September – 21 March) is five days less than northern summer (21 March – 21 September).

Figure 8: Earth Orbit



Source: https://upload.wikimedia.org/wikipedia/commons/thumb/f/f0/Seasons1.svg/650px-Seasons1.svg.png

Transparency of the Atmosphere

Our atmosphere is not transparent for all the radiation coming from the sun because of different composition and layers. Itis also one of the controlling factors of insolation to reach earth surface.The atmosphere is composed of gases, water vapour andparticulate matters. The atmosphere is a mixture of gases, such as nitrogen (N), oxygen (O_2), Argon, carbon dioxide, Neon (Ne), Helium (He), Methane (CH_4), Krypton (Kr), Ozone (O_3), Nitrous oxide (N_2O), Hydrogen (H) and Xenon (Xe). The atmosphere also contains water vapour, water in the gaseous state. Theconcentrations of water vapour in the atmosphere are small but variable between nearly zero and about 5 per cent by volume, usually higher above large water bodies. The concentration of water vapour decreases with altitude from about 4 per cent close to the ground to more or less zero above about 12 kilometres.The atmosphere also contains a particulate matter which is suspended in atmosphere. Primarily, the particulate matters are generated by windblown minute particle from dry areas and deserts;Pollen and mould spores from vegetation; Smoke: from natural forest fires and from air pollution; and Salt spray from the oceans. All these compositions create obstacles in insolation and reinforce the pattern of solar energy distribution at earth's surface byreflection, refraction, scattering, and absorption.Reflection from dust, salt, and smoke particles in the air is an important mechanism for returning shortwave solar radiation to space.Similarly, reflection from cloud tops also depletes the amount of solar radiation that would otherwise be available to the earth. Thetransparency of the atmosphere also varies with latitude.In the higher latitudes, the sun's rays are more oblique, so that they have to pass through relatively thicker layers of the atmosphere than at lower latitudes.

Distribution of Insolation

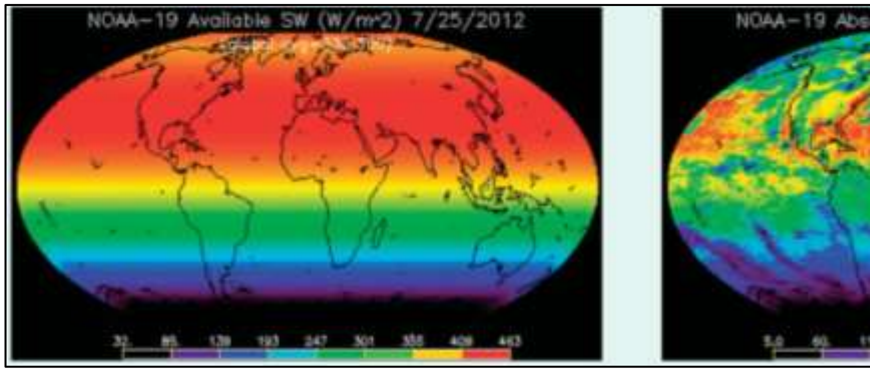
The total incoming solar radiation as known as insolation. It is always high at pole in summer solstices. There are two main factors i.e. sun angle and length of daylight that influenced the insolation in any given location the most. As shown in the Figure 9 taken by NOAA-19 satellite on July 2012. The highest average daily insolation found over the Arctic because of 24 hours daylight. The earth's surface receives different amount of insolation according to season. It receives more insolation in summer than winter because of longer day lengthin higher altitudes.The upper atmosphere over the north pole is marked maximum of solar radiation at the June solstice, but only 30 per cent of total insolation is absorbed by the surface due to high average cloudiness over the arctic in summer and very high reflectivity (albedo) from the ice surface and snow as compared with the global average of 48 per cent of insolation being absorbed at the surface.

The horizontal distribution of insolation is also varying on earth surface. The maximum temperature is found in the tropics rather than equator because apparent migration of the vertical sun is relatively rapid between 6° N to 6° S. The vertical sun rays, during autumn and spring equinoxes, lies only for 30 days, allowing very little time span for heating the earth surface very high. Contrary to this, the latitude between 17° to 23.5° N-S, the insolation occurs almost vertically for 86 consecutive days during solstice. This longer duration of insolation over tropics than at equator, makes the maximum temperature zone at tropics Figure10). The distribution of land and water also affect the temperature in this zone. In northern hemisphere, continent enhanced the rise in temperature than oceanic southern hemisphere. Another factor is cloudiness, in sub-tropical high-pressure zone, due to low cloud cover allows large annual receipts of solar radiation.

Figure 9: Available Solar Energy and Energy Absorbed by the Earth

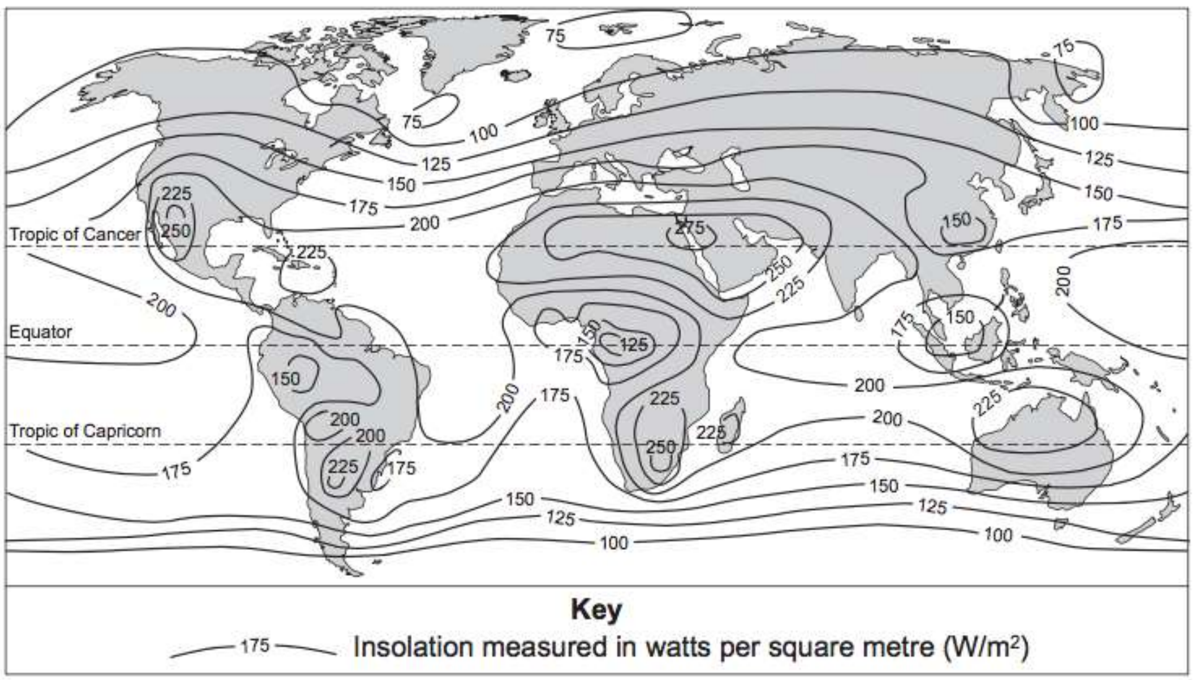
Absorbed solar radiation in W/m_2 on the same day as Figure 4-C, taken by the NOAA-19. Energy absorbed and surface characteristics (for example, land or water) determine the patterns of radiation absorption.

Available solar energy at the top of the atmosphere in W/m2, taken by the NOAA-19 satellite. Notice that the most solar energy (red and orange areas) is available in the Northern Hemisphere, where it is summer.



Source: Hess, 2014

Figure 10: Distribution of Mean Annual Global Solar Radiation



Source: Barry and Chorley, 2010

Conclusion

Insolation on the earth is received almost entirely from the sun which comes in the form electromagnetic radiation from the surface whose temperature is about 6000 K. The solar constant reaching to the earth is approximately 1368 Wm^2. The amount of energy, emitted by the sun in the form of electromagnetic radiation, received by the earth is very small in comparison to the total energy released from the sun. But it is sufficient to run the earth systems and the biotic life evolved on the earth. The sun’s energy is reaching to the earth is basically solar radiation.

There are five methods of insolation such as transmission, scattering, refraction, absorption and reflection. These mechanisms impact on the uneven distribution of insolation in the earth. There are several astronomical and geographical factors that also affecting the insolation on the earth. Important among them are solar output, incidence angle of the sun rays, length of day, variations in distance between earth and sun and transparency of the atmosphere.

The variation of insolation are also due to the solar flares and sunspotsthat periodically change the patterns. The varying incidence angle of the sun rays and length of day affects the latitudinal variation in the amount of insolation on the earth surface. Consequently, within the tropics, the total insolation is more than higher latitudes. The distance between earth and the sun as well as inclination angle of the earth determine the different season on earth. Therefore, uneven distribution of insolation is very important to understand the atmospheric dynamics and distribution of climate and vegetation on earth surface. The climatic elements such as temperature, precipitation and winds are controlled by the amount of insolation. The livelihood of the people and their comforts as well as plants life are totally depends on the available insolation on earth surface.

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