Lecture Notes on Climatology

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Earth – Sun Relationship

Generally the manner of the division of the year into seasons varies with latitude. In middle latitudes, the year is divided into ‘autumn’, ‘winter’, ‘spring’ and ‘summer’. The terms ‘summer’ and ‘winter’ are not so significant in tropics, rather division into seasons is usually made in terms of rainfall amount as ‘rainy season’ and ‘dry season’ or in terms of the associated wind direction into ‘south-west monsoon’ and ‘north-east monsoon’ as in India. In the continental subtropical regions the natural seasons are usually defines in terms of temperature (hot or cold), or rainfall (rainy and dry), or both. In polar regions, the transition from summer to winter and vice versa is so sudden that spring and autumn largely disappear.

Solar radiation is one of many sources of energy, and probably one of the most important sources, that drive environmental processes acting at the surface of the Earth. The amount and intensity of solar radiation reaching the Earth is affected by the geometric relationship of the Earth with respect to the Sun. The variations in the amount and intensity of solar radiation reaching the earth are affected by latitude, the rotation of the earth and its revolution around the sun. The study of the geometric relationship of the earth with respect to the sun explains why we have seasons.

I. Earth Rotation and Revolution

The term earth rotation refers to the spinning of the earth on its axis passing through the north and south poles. Turning in an eastward direction the earth rotates at a uniform rate once every 24 hours approximately, which is called a mean solar day.

The orbit of the earth around the sun is called earth revolution. The earth's orbit around the sun is not circular, but elliptical (Fig. 1) with sun at its focus. An elliptical orbit causes the earth's distance from the sun to vary annually. The average distance of the earth from the sun is about 150 million kilometers. On 3rd January the earth is closest to the sun at an approximate distance of 147.5 million km, and this position is called as perihelion. On 4th July the earth is farthest from the sun at an approximate distance of 152.5 million km, and this position is called as aphelion. These annual variations in the earth-sun distance influence a slight change in the receipt of solar radiation. The difference in distance is not the cause of different seasons. Instead, seasons are caused by the tilt of earth's axis of rotation.

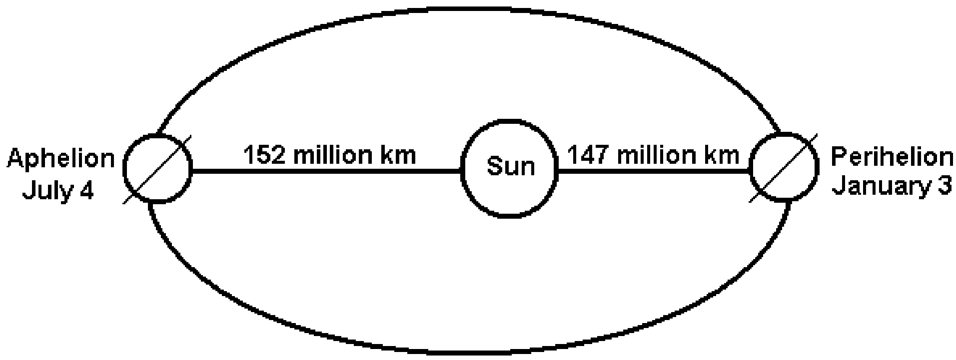


Fig. 1 : Earth's elliptical orbit

II. <u>Tilt of the earth's axis</u>

The **plane of the ecliptic** is the plane of the Earth's orbit around the sun. The Earth's axis is tilted by 23½º from the perpendicular to the plane of the ecliptic. In other words it makes an angle of 23½º with the plane of elliptic as shown in Fig 2. The axis of rotation remains pointing in the same direction as it revolves around the Sun. As a result, the earth's axis of rotation remains parallel to its position at any other time as it orbits the sun, a property called **parallelism of axes**.

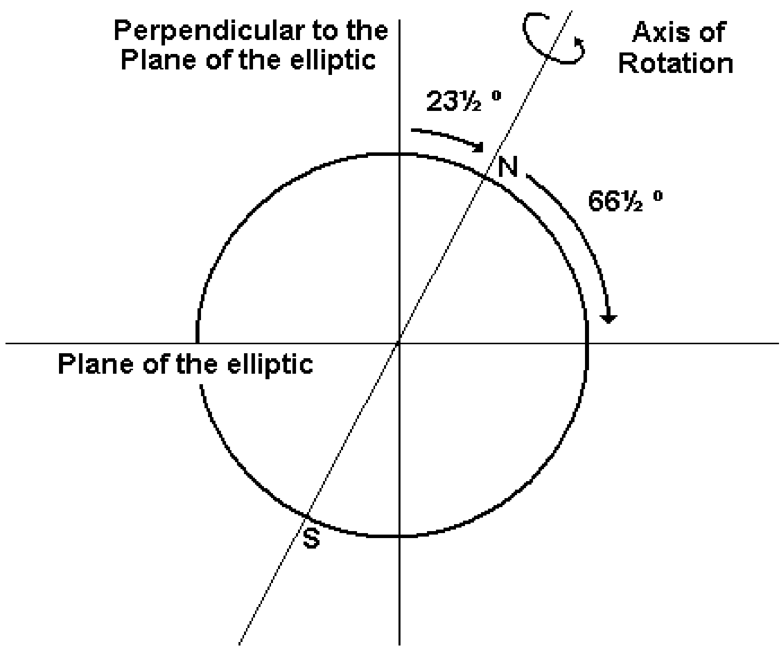
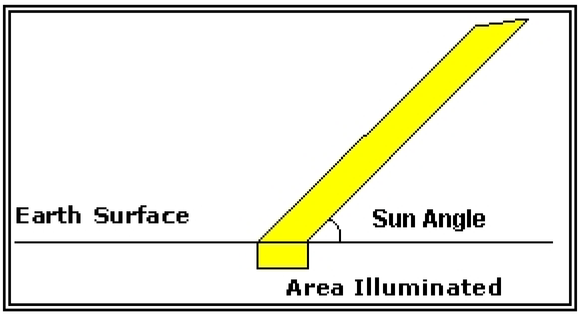


Fig. 2 : Earth's elliptical orbit

The constant tilt and parallelism causes changes in the angle that a solar rays makes with respect to a point on earth during the year, called the "**sun angle**". The most intense incoming solar radiation occurs where the sun's rays strike the earth at the highest angle. As the sun angle decreases, the beam of light is spread over a larger area and decreases in intensity due to the thickness of the atmosphere, increase in reflection and scattering of light.



III. Solstices

On June 21 or 22, the axis of rotation of the earth is inclined towards the sun (Fig. 3). The **subsolar point**, the place where the sun lies directly overhead at noon, is located at 23½ º north latitude. This date is known as the **summer solstice** and marks the first day of the summer in the northern hemisphere.

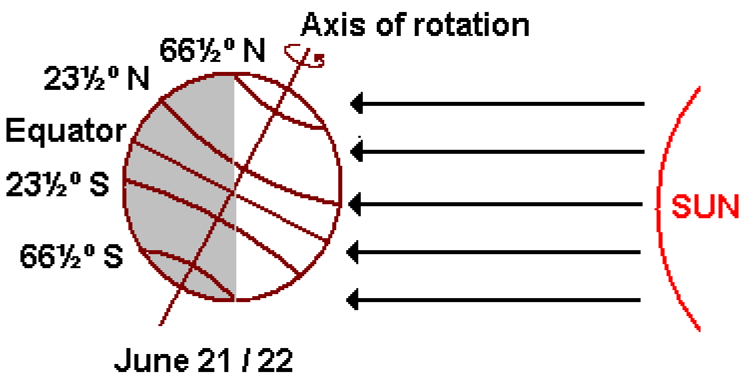


Fig. 3 : Summer Solstice

This is the longest day of the year for places located north of Tropic of Cancer (23½º N latitude). As the noon's rays are vertical over 23½º N, the tangent rays in the northern hemisphere pass over the pole. This phenomenon keeps all places north of latitude of 66½º N in 24 hours of sunlight (polar day), while locations below latitude of 66½º S are in darkness (polar night).

The **winter solstice** occurs on December 21 or 22 when the earth has oriented itself so the North Pole is facing away from, and the South Pole into the Sun (Fig. 4). The Sun lays directly overhead at noon at 23½º S latitude, called as Tropic of Capricorn. The places poleward of 66½º S latitude receives 24 hours of daylight and the places poleward of 66½º N are in the darkness. The winter solstice refers to the first day of winter in the northern hemisphere.

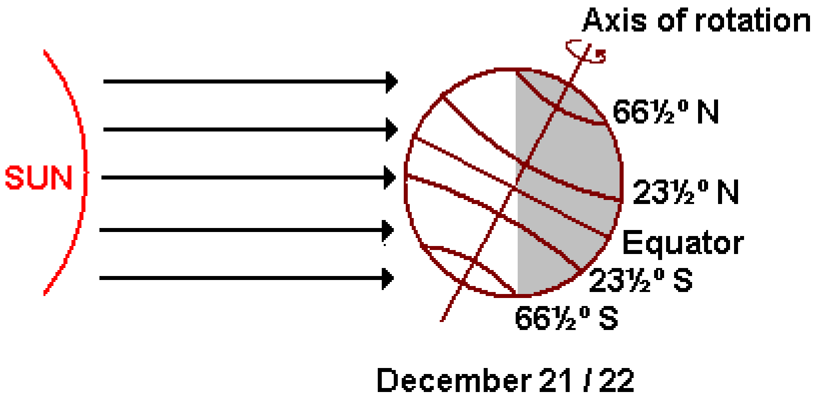


Fig. 4 : Winter Solstice

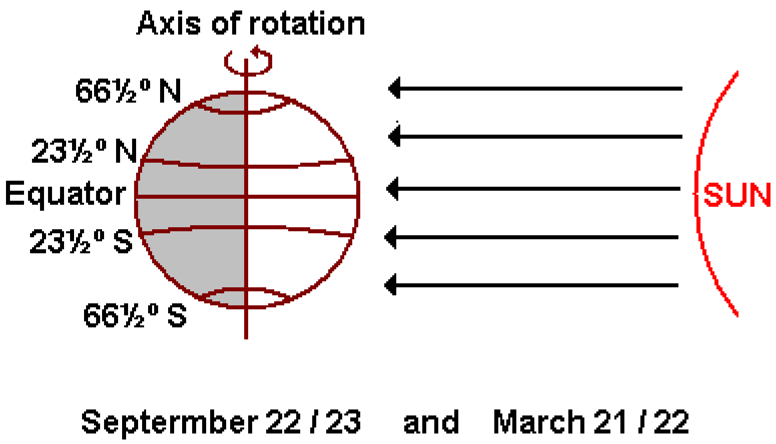


Fig. 5 : Autumnal and Spring Equinox

IV. <u>Equinoxes</u>

Midway between the solstices are two dates when the sun shines directly on the equator. The axis of rotation is still inclined but it is tilted sideways with respect to the sun rather than towards or away from the sun. at these times, the tangent rays strike the poles so that the days and nights are equal over the entire earth (Fig. 5). The period between summer and winter is called as autumn. The **autumnal equinox** on September 22 or 23 indicates the beginning of autumn season in the northern hemisphere. March 21 or 22 is the first day of the spring season and as such this date is called as the **spring equinox**. Equinoxes mark the seasons of autumn and spring and are a transition between the two more extreme seasons, summer and winter.

V. The Seasons

During the summer months the earth is inclined toward the Sun yielding high sun angles whereas during the winter, the earth is oriented away from the Sun creating low sun angles. The tilt of the earth and its impact on sun angle is the reason the northern and southern hemispheres have opposite seasons. Summer occurs when a hemisphere is tipped toward the Sun and winter when it is tipped away from the Sun.

VI. Annual march of seasons

As seen in Fig. 6, over the course of a year, the sun's rays are perpendicular to the surface (directly overhead) at places between Tropic of Cancer 23½º N and Tropic of Capricorn 23½º S latitudes only. Places between the two tropics experience two times when the sun is directly overhead over the course of a year and the sun angle does not vary much over these places. Poleward of this region there is greater variation in the sun angle and consequently the greater variation in surface heating.

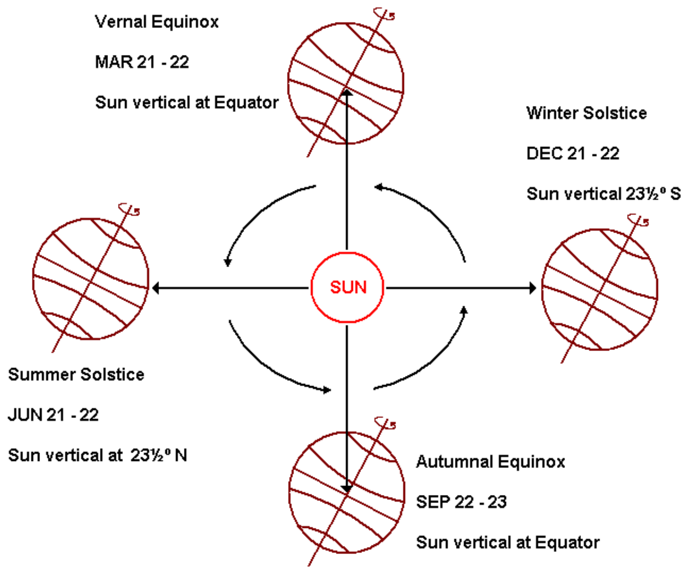


Fig. 6 : Annual March of Seasons

Solar Radiation

The weather results from the interaction of solar radiation on the earth's atmosphere and surface. The two movements (viz. rotation and revolution) explain the changing elevation of the sun as well as the latitudinal and seasonal variations in length of the day, receipt, and escape of radiation and weather.

The sun at a temperature of about 6000 Kº is the source of nearly all of our energy. The earth intercepts an infinitesimally small part of the sun's output, 5×10^{-10} %. Only a portion of the sun's radiation reaches the earth's surface as direct radiation, the remainder being reflected, absorbed, or scattered by the atmosphere. The maximum emission of solar radiation occurs at relatively short wavelengths in the visible spectrum (between 0.4 μm and 0.7 μm).

The sun radiates approximately 56 $\times 10^{26}$ cal of energy per minute. The energy per unit area incident on the earth is equal to

$$S = \frac{56 \times 10^{26} \,\mathrm{cal\,min}^{-1}}{4\pi \times (1.5 \times 10^{13}\,\mathrm{cm})^2} \quad \approx \quad 2.0 \text{ cal cm}^{-2} \text{ min}^{-1}$$

S is called as the Solar Constant. {$1.5 \times 10^{13}\,\mathrm{cm}$ is the mean distance of the earth from the sun }

The **Solar Constant** is defined as the flux of solar radiation at the outer boundary of the earth's atmosphere that is received on a surface held perpendicular to the sun's direction at the mean distance between the sun and the earth. The energy per unit area is expressed in Langleys (ly) and 1 ly = 1 cal cm^{-2}. Thus the solar constant for the earth is 2 Ly.

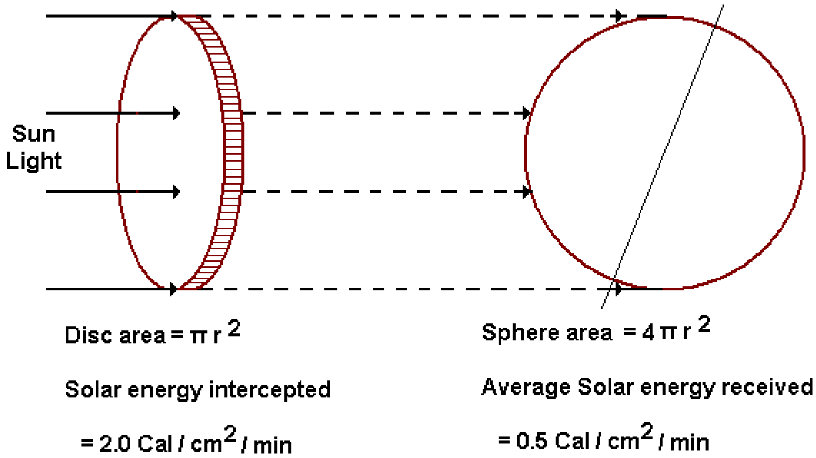


Fig. 7

If the surface, oriented perpendicular to the sun's rays, is thought of as a circular non-rotating disc with a radius r equal to the radius of the earth, the sun facing side of the disc will intercept the same amount of solar radiation as does the spherically shaped rotating earth.

Since the area of a sphere is four times the area of one side of a disc (4πr2 versus πr2), as shown in Fig. 7, the global average amount of energy received at the top of the atmosphere is 0.5 ly min-1, or one quarter of the solar constant.

Terrestrial Radiation

The absorption of solar radiation raises the temperature of the earth's surface and its atmosphere. The radiation emitted from the land and water surface of the earth is long-wave radiation, in contrast to the short-wave radiation it receives from the sun. The earth approaches an average temperature of 294 Kº, and gives out long-wave radiation in the range 4µ-80µ with a maximum at 10µ. Water vapour in the atmosphere is a strong absorber of long waves, particularly between 5.5µ and 7µ and above 27µ.

Albedo

It is defined as the ratio of the reflected radiation to the total intercepted radiation. It is described in terms of percentage of reflected radiation. The albedo of the earth-atmosphere system is 0.30. The moon has an albedo of only about 0.07, indicating that it absorbs most of the solar radiation striking its surface.

Thus, viewed from space, the earth shines more brilliantly than the moon. The major reason for this is the presence of clouds. The moon has no atmosphere and no cloud.

Some typical albedo are :

Fresh snow	0.75 – 0.90
Cloud tops	0.60 – 0.90
Old snow	0.50 – 0.70
Sand	0.15 – 0.35
Seas (high sun angle)	0.05 – 0.10
Forests	0.03 – 0.10

Terrestrial heat balance

The mean temperature of the earth undergoes fluctuations of varying periods. Averaging over a period of number of years can smooth the more rapid fluctuations out. The remaining slower variations provide evidence of a net gain or loss of energy during the period of averaging. The changes occur so slowly, however, that the net energy change per year is very small. In general, there seems to be no over all significant trend in the mean temperature of the earth or its atmosphere during the interglacial periods. Thus a long-term mean heat balance exists at each point of the earth and its atmosphere.

The total amount of solar radiation received on a horizontal surface is about 0.5 ly min^{-1}. In this explanation, the figures represent estimates for the northern hemisphere but the difference between the northern and southern hemisphere are presumed to be not large.

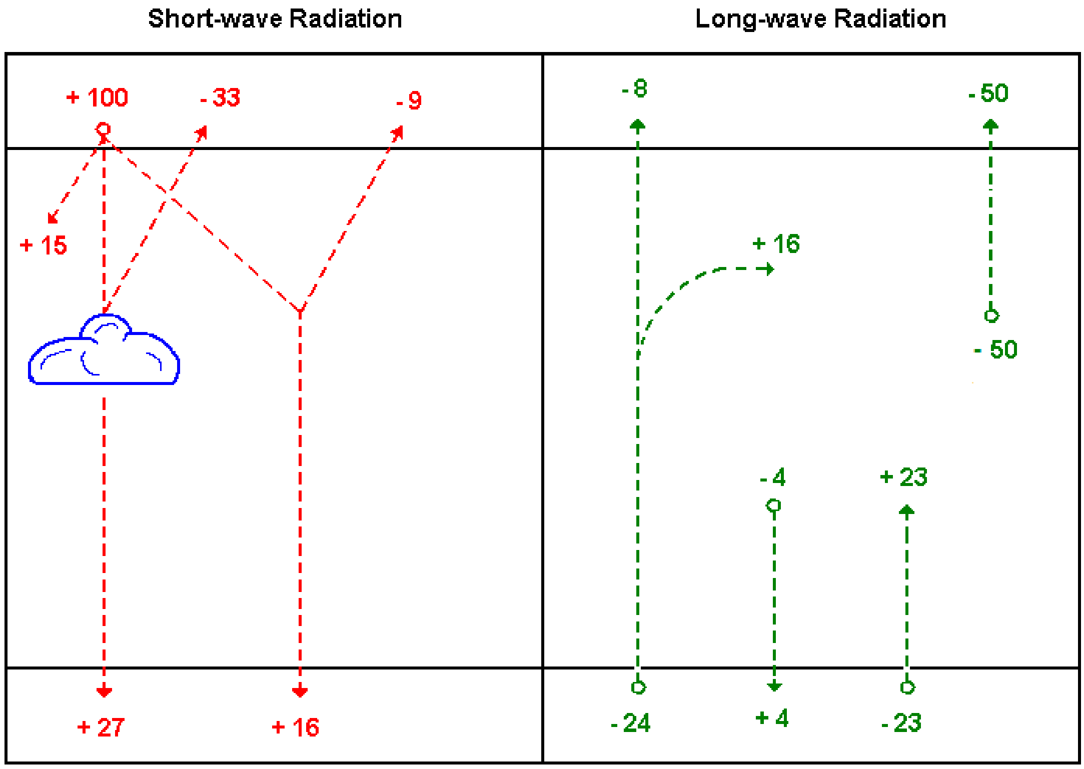


Fig. 8 : Mean heat balance in the northern hemisphere

Out of these 27 % penetrates directly to the earth's surface and 16 % arrives as the diffuse sky radiation. So that 43 % reaches the ground together. The atmosphere including clouds absorbs 15 %. The remaining 42 % is reflected back into space, which represents the albedo of the earth-atmosphere system. It is composed of the reflection on clouds and on the ground, which accounts for 33 % and the diffuse reflection, which makes up the remaining 9 %.

It is noticed that the diffuse radiation towards the ground (16 %) is considerably greater than that returned to space (9 %). This difference is due to the fact that the larger dust particles scatter more radiation in the direction away from the sun than in the direction towards the sun.

In the Fig. 8, the radiation received by the earth and the atmosphere is counted positive and the radiation emitted or reflected and scattered to space is denoted by negative.

The 42 % of the incoming solar radiation is returned directly back to the space and the remaining 58 % is absorbed by the ground and the atmosphere. This 58 % must be radiated back to space since the yearly mean temperature of the earth as a whole remains the same. The radiation from the ground upwards is called the 'effective radiation'.

The 24 % represents the difference between the actual radiation from the ground and the radiation from the atmosphere to the ground. Out of this 24 %, 16 % is reabsorbed in the atmosphere while 8 % returns directly to the space. The other 50 % is radiated back to space by the atmosphere.

When the heat transports by turbulence and by condensation are taken into consideration, a heat balance exists also for the earth's surface and the atmosphere separately. This transport of heat is estimated at 4 % and 23 % respectively.

The following is the summary of the separate heat balance of the earth:

The surface of the earth

Receives		Loses	
By direct radiation	27 %	By radiation	24 %
By diffuse radiation	16 %	By condensation (evaporation)	23 %
By turbulent transfer	4 %		
Total =	**47 %**	**Total =**	**47 %**

The atmosphere

Receives		Loses	
By absorption of solar radiation	15 %	By radiation	50 %
By absorption of ground radiation	16 %	By turbulent transfer	4 %
By condensation	23 %		
Total =	**54 %**	**Total =**	**54 %**

Distribution of solar radiation

The unequal distribution of solar radiation over the earth is the primary cause of weather and climate. The rate of receipt of solar energy varies with latitudes, seasons and time of the day i.e. the angle of sun's rays with the surface of the earth.

A) Distribution of solar radiation without atmosphere

The annual march of the solar radiation at the top of the atmosphere is shown Fig. 9.

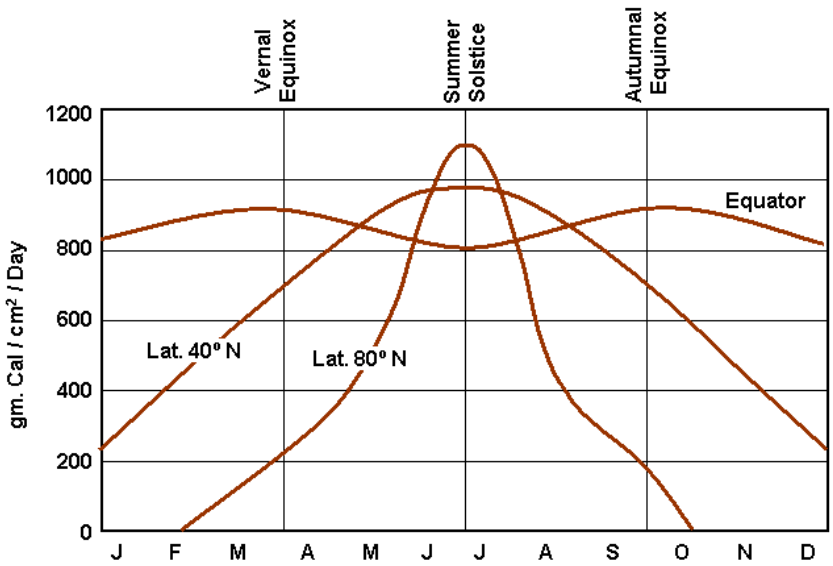


Fig. 9 : Annual solar radiation at the outer limit of the atmosphere

In tropics, the intensity of solar radiation remains quite high throughout the year with little seasonal variation. The noon rays are vertical twice a year at all places situated between two tropics. As a result the solar radiation curve shows two maxima and two minima for the low latitudes.

The mid latitude curve (40º) is broadly representative of the belts lying between 23½º and 66½º in each hemisphere. It shows a single strong maximum and a single minimum, both of which coincide with the solstice. The curves show a large seasonal variation.

The high latitude (80º), which represents belts poleward of Arctic and Antarctic circles, resembles that of middle latitudes. The only difference in this curve is that it reaches zero during winter when there is no solar radiation.

B) Distribution of solar radiation with atmosphere (without clouds)

The distribution of solar radiation with atmosphere but without clouds is shown in Fig. 10.

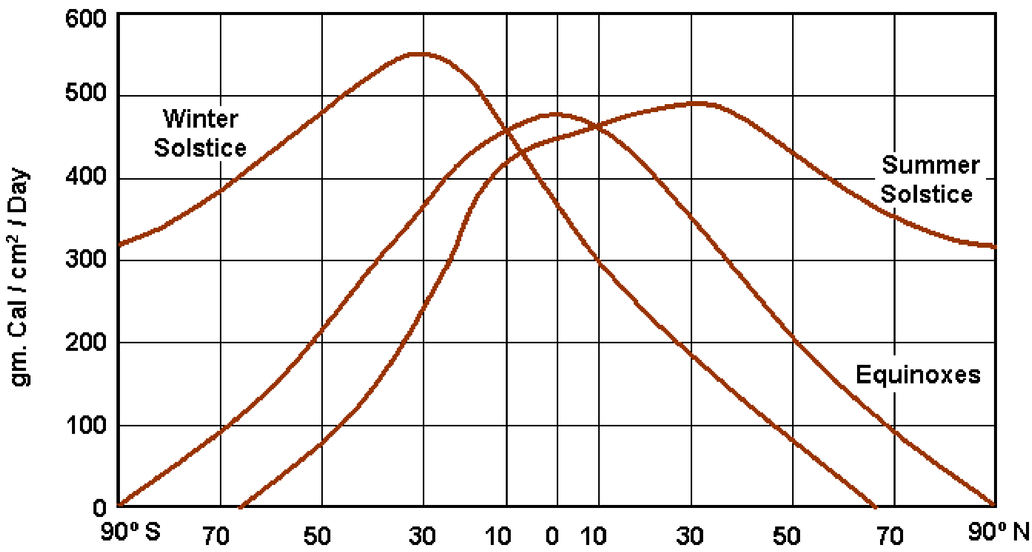


Fig. 10 : Latitudinal distribution of solar energy at the earth's surface (with atmosphere but without clouds)

A solar beam, while passing through the atmosphere (without clouds), is depleted by scattering, reflection and absorption. Thus the amount of radiation reaching the surface of the earth is less than that received at the outer limits of the atmosphere. The depletion is maximum at high latitudes due to higher obliquity of the solar beam resulting in the path of the beam passing through much greater thickness of the atmosphere than in the lower latitudes.

At the time of the equinoxes the latitudinal distribution of solar radiation is symmetrical about the equator with the amount decreasing to zero at each pole.

During summer solstice the more nearly vertical solar beam and larger days combined together produce a broad maximum in middle latitudes of northern hemisphere. The same feature is observed in the middle latitudes of southern hemisphere during the winter solstice.

Latitudinal variation of radiation is small in summer hemisphere compared to the winter hemisphere.

C) Distribution of solar radiation with atmosphere and clouds

The clouds reflect a large amount of solar radiation reducing the amount of it reaching the surface of the earth. The maximum total annual radiation (Fig. 11) is not found at the equator but rather at about latitude 20ºN and 20ºS. the lesser amount near the equator in the southern hemisphere is due to greater cloudiness and more ocean surface in the southern hemisphere.

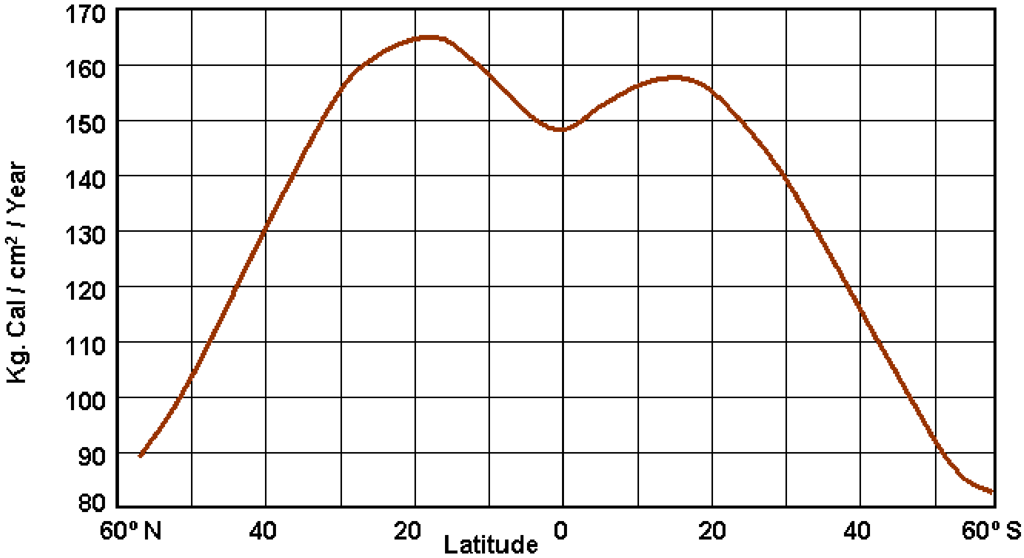


Fig. 11 : Total annual solar radiation received at the earth's surface by latitude belts

In the equatorial belt, area of least solar radiation coincides with the warm continents, where convective clouds are in abundant. Maximum solar radiation is received in the sub-tropics, which are relatively less cloudy region. In the high latitudes, the lowest annual radiation values are over oceans because of abundant cloudiness

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Weather, Climate and Climatic Elements

Weather is the instantaneous state of the atmosphere, or the sequence of the states of the atmosphere as time passes. The difference between climate and weather is usefully summarized by the popular phrase "Climate is what you expect, weather is what you get". Weather and climate are meteorological terms that are related but not interchangeable

Climate is usually defined as the average weather plus the extremes for a given time period and a given location. More technically, for a given location and time period the climate is the probability distribution of each variable that characterizes the local weather. Climate changes from one location to another, and in a given location climate can change from one time period to another. Weather is the sum total of the atmospheric variables at a given place for a brief period of time; it is an everyday experience. Thus we speak of today's weather, or of last week's. Climate, on the other hand, refers to a more enduring regime of the atmosphere.

According to The Meteorological Glossary, published by the UKMO, 'climate' is defined as 'the synthesis of the day-to-day values of the meteorological elements that affect its locality'. Synthesis here means more than simple averages as the climate also involves extreme values, and the ranges within which phenomena occur, and the frequencies of weather types with associated values of elements

Climatic data are usually expressed in terms of an individual calendar month or season and are determined over a period of about 30 years. This is long enough to ensure that representative values for the month or season are obtained and freaks or abnormal values do not exert too strong an influence.

II Elements of Climate and Weather

Although weather and climate are not identical both are described by combinations of the same atmospheric variables, called the elements of weather and climate. Primarily these elements are Pressure, Temperature, Precipitation, Humidity, Wind and Cloudiness. The atmospheric pressure is of particular importance in determining the characteristics of the other variables. It is atmospheric pressure that to an important degree determines the direction and speed of the wind, and it is the wind that in turn moves air masses of contrasting temperature and moisture from one locality to another. While air movement is predominantly in a horizontal direction, there is also some slight upward or downward movement. Where the motion is upward, cloud and precipitation are likely, while downward air movement, or subsidence, favors fair skies.

Controls of Climate

Climatic Controls are the factors affecting the climate of particular place. The most fundamental control of both weather and climate is the unequal heating and cooling of the atmosphere in different parts of the earth. While the earth as a whole loses as much heat to space as it gains from the sun, some parts experience a net gain and others a net loss. The unequal heating occurs on a wide variety of geographic scales, the largest and most important of which is the differential between high and low latitudes. But heating and cooling differences also exist between continents and oceans, between snow-covered and snow-free areas, between forested and cultivated land, and even between cities and their surrounding country sides. These heating and cooling differences, and the air movements (winds) they induce, represent the overall general background control of weather and climate. The more specific controls are derived from various geographic factors.

A) Latitudinal Variations in Solar Radiation

Latitudinal differences in the amounts of solar energy received are the most basic climatic control. In low latitudes the sun is high in the sky, the solar radiation is intense, and the climate is warm and tropical; in high latitudes the sun is lower in the sky, the solar radiation is weaker, and the climate is colder. The zone of maximum solar radiation shifts northward and southward during the year, thereby producing the seasons. The effectiveness of solar heating also varies with the nature of the surface on which the sunshine falls. Thus a strongly reflecting snow surface is heated much less than a land surface lacking snow.

B) Altitudes

Since within the troposphere temperature normally decreases with increasing Altitude, places at higher elevations are likely to have lower temperatures (and often also more precipitation) than adjacent lowlands. Thus altitude is a climatic control. Where a high mountain chain lies athwart the path of prevailing winds, it acts to block the movement of air and hence the transfer of warm or cold air masses. In addition, the upward thrust of air on a mountain's windward side and the downward movement of air on its lee side tend to make for increased precipitation in the former instance and a decrease in the latter.

C) Distribution of Continents and Oceans

Continents heat and cool more rapidly than do oceans. Consequently non coastal continental areas experience more intense summer heat and winter cold than do oceanic and coastal areas.

D) Pressure and Wind Systems

Differences in heating and cooling between high and low latitudes, between land and water areas, and between snow-covered and bare land surfaces lead not only to regional temperature contrasts but also to differences in atmospheric pressure which in turn induce air movements (winds). Air in motion, which in itself is an important element of weather and climate, also operates as a control, for it serves as a transporter of heat from regions of net heat gain to regions of net loss. And just as there is a great variety of geographic scales of differential heating and cooling of terrestrial surfaces, so there is a great variety of scales relating to atmospheric pressure and atmospheric motion. They range from those of hemispheric magnitude, such as the belts of westerly winds in middle latitudes and the belts of easterlies that encircle the low latitudes, to the small but extremely violent tornado.

The mobile low-and high-pressure systems which bring day-to-day weather changes and are conspicuous features on daily weather maps are of a common scale of atmospheric motion. The frequency of occurrence and the paths followed by these transient mobile pressure and winds systems are important factors in determining climate. Some pressure and wind systems, especially the highs over the subtropical oceans, tend to be semi permanent in position, and they too are of great climatic importance.

E) Ocean Currents

Ocean currents, both warm and cold, which are largely induced by the major wind systems, are also an important climatic control. They are highly important in transporting warmth and chill in a north-south direction, and in so doing give some coastal regions distinctive climates. (Fig. 12).

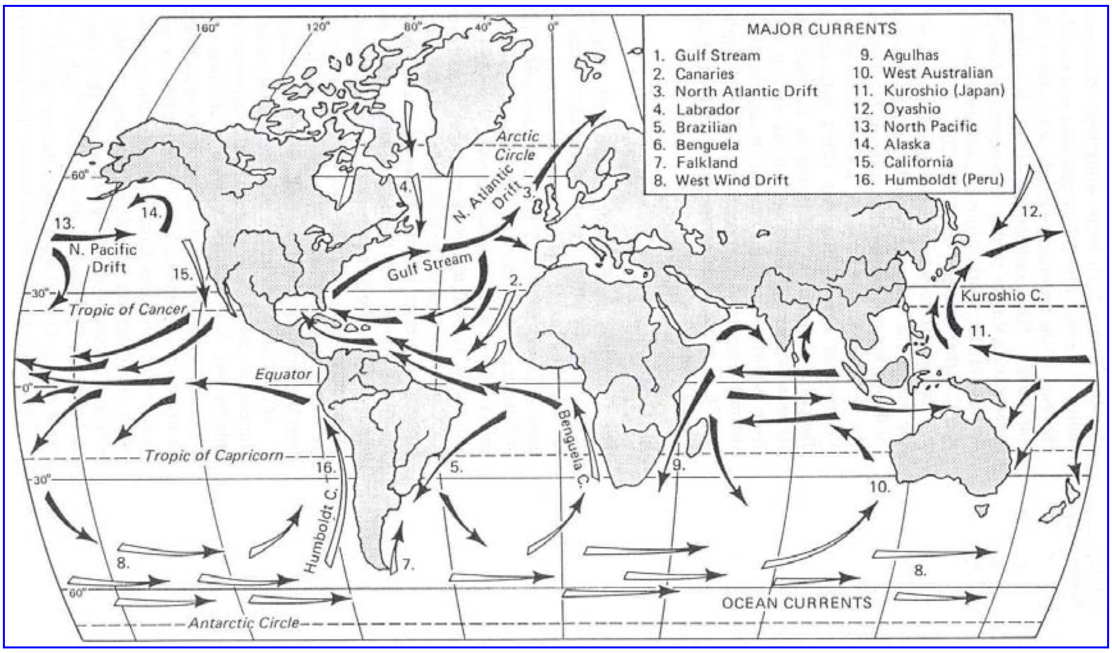

Fig. 12 : Major Ocean Currents. (Warm Currents are shown by dark arrows and Cold Currents by open arrows)

F) Local Features

Finally, the climate of a place is affected by a variety of local features, such as its exposure, the slope of the land, and the characteristics of vegetation and soil. In the Northern Hemisphere south-facing slopes receive more direct sunlight and have a warmer climate than those with a northern exposure, which not only face away from the sun, but are also more open to cold northerly winds. Areas with sandy, loosely packed soil, because of their low heat conductivity, are inclined to experience more frosts than do areas with hard packed soils; valleys normally have more frequent and severe frosts than the adjacent slopes; and cities are usually warmer than the adjacent country sides.

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General Circulation of the atmosphere

The simplest observed global characteristic of the atmosphere is that the tropics are much warmer than the poles. As discussed earlier, this is a straightforward consequence of the geometry of the earth. The annually averaged incoming solar radiation per unit area of the earth's surface is much greater at the equator than at the poles (Fig. 13). The difference arises because of the fact that the polar regions are covered in ice and snow and therefore reflect much of the incoming radiation back to space. Another fact is that the tropical regions actually receive more energy from the sun than they emit back to space, while the converse is true in high latitudes.

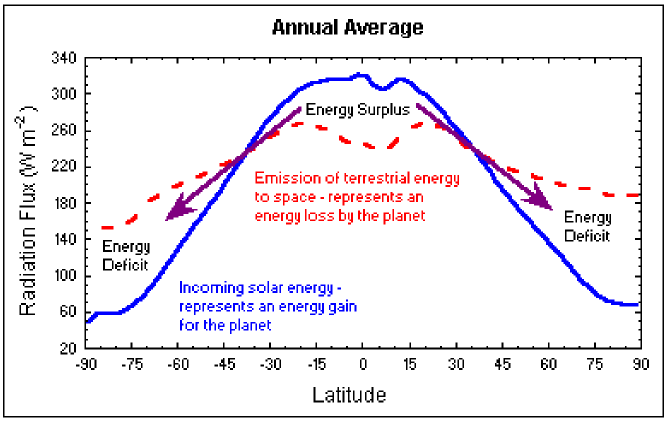

Fig. 13 : Latitudinal variation in annual average of radiation

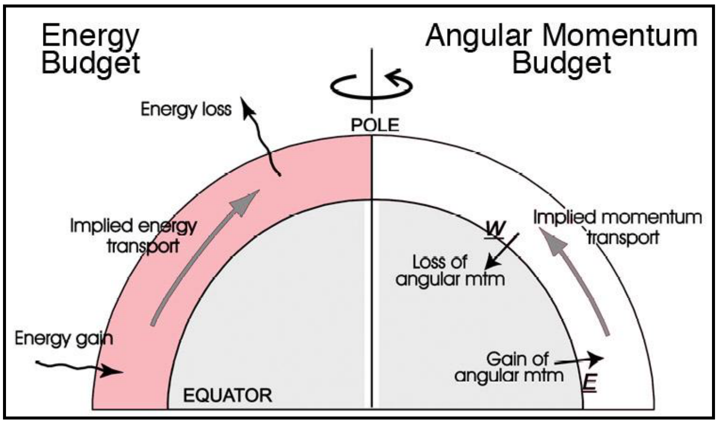

Fig. 14 : Latitudinal transport of heat and angular momentum

Over the globe, the energy balance is nearly balanced when averaged over a year (incoming equals outgoing). Hence, there must be a process acting to transport excess energy from the tropics to make up the deficit in high latitudes, as depicted schematically in (Fig. 14). To compensate for the surplus and deficit of radiation in different regions of the globe, atmospheric and oceanic transport processes distribute the energy equally around the earth. This transport is accomplished by atmospheric winds and ocean currents.

Single-Cell Model of the General Circulation

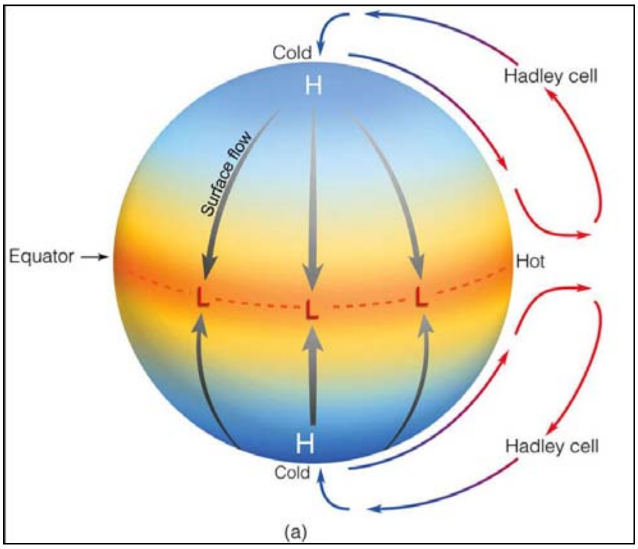

Fig. 15 : Single-Cell Model of General Circulation

If the Earth's surface were smooth, uniform, and stationary, atmospheric circulation would be very simple. The atmosphere would act as a contained fluid and movements within this fluid would be the convective currents caused by temperature and density differences.

The latitudinal transfer of heat would result in a single circulation cell, where the surface air converges and rises at the equator, spreads laterally toward the poles, descends and flows back toward equator at the surface.

This creates the single cell circulation model (Fig. 15) possible only on a non-rotating Earth and sun being directly over the equator.

Three-Cell Model of the General Circulation

This model represents the average circulation of the atmosphere and is used to describe the atmospheric transport of energy. It considers effects of coriolis force due to the Earth's rotation. In this circulation model, the Northern and Southern Hemisphere are each divided into three cells of circulation, each spanning 30 degrees of latitude. The latitudes that mark the boundaries of these cells are the Equator, 30° North and South, and 60° North and South (Fig. 16).

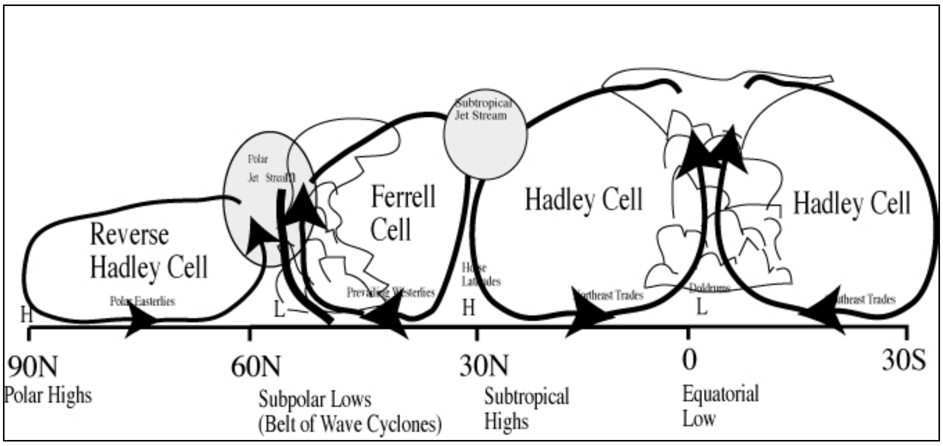

Fig. 16 : Three-Cell Model of General Circulation

Hadley Cell

George Hadley, an English meteorologist, theorized this first circulation cell in 1735. The Hadley cell is the strongest of the three cells of circulation and is formed as warm air rises above the Equator and starts to flow northward.

The rising air cools condenses and forms a region of intense clouds and heavy precipitation. This area is called the Inter-Tropical Convergence Zone (ITCZ) and corresponds regions over which the tropical rain forests are found. The ITCZ moves north and south following the sun during the year. Because the stratosphere is stable, rising air that reaches the tropopause, moves poleward. By the time the air moving northward reached about 30° N it has become a westerly wind (it is moving to the east) due to the Coriolis force. Because of conservation of angular momentum, the poleward moving air increases speed. The increased speed and the Coriolis force are responsible for the subtropical jet.

This poleward moving air leads to the formation of semi-permanent high pressure belt at the surface that results from the sinking air at 30°.

Once the sinking air reaches the ground, some flows to the equator, turning west (in the northern hemisphere) as it goes due to the Coriolis force. This surface air forms the trade winds which blow steadily from the northeast in the northern hemisphere and southeast in the southern hemisphere.

Polar Cell

This is the northernmost cell of circulation and its mean position is between 60°N and the North Pole. At the pole, cold, dense air descends, causing an area of subsidence and high pressure. As the air sinks, it begins spreading southward. Since the coriolis force is strongest at the poles, the southward moving air deflects sharply to the right. This wind regime is called the surface polar easterlies, although the upper winds are still predominantly from the southwest. Near 60ºN, the southeasterly moving air moving along the surface collides with the weak, northwesterly surface flow that resulted from spreading air at 30°N. This colliding air rises, creating a belt of low pressure near 60°N.

Ferrel Cell

The mid-latitude circulation cell between the Polar cell and the Hadley cell is called the Ferrel cell. The Ferrel cell circulation is not as easily explained as the Hadley and Polar cells. Unlike the other two cells, where the upper and low-level flows are reversed, a generally westerly flow dominates the Ferrel cell at the surface and aloft. It is believed the cell is a forced phenomena, induced by interaction between the other two cells. The stronger downward vertical motion and surface convergence at 30°N coupled with surface convergence and net upward vertical motion at 60°N induces the circulation of the Ferrel cell. This net circulation pattern is greatly upset by the exchange of polar air moving southward and tropical air moving northward.

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Distribution of Wind and Pressure over the surface of the earth

In subtropical region, the northeast trade winds and southeast trade winds prevail in the northern and southern hemisphere respectively. They are separated near the equator by a zone of prevailing calms known as 'doldrums'. However, the doldrums are frequently absent in one part or the other of the equatorial zone. Then the northeast trades and southeast trades meet directly at a surface of discontinuity on which strong rainsqualls may develop. The zone of doldrums is largely north of equator. Over some parts of the earth it even extends into southern hemisphere. Where the zone of doldrums is displaced far north from its symmetrical position at the equator, the southeast trade winds may reach into the northern hemisphere and get deflected into southwest winds under the influence of the coriolis force.

Beyond the trade wind regions of each hemisphere are the zones of 'prevailing westerlies'. These westerlies are better developed in the southern hemisphere than in the northern hemisphere. These zones of westerlies are the regions of the migrating cyclones and anticyclones.

Poleward from the region of westerlies, beyond 65 to 75 latitude easterly winds with a component towards the equator prevail.

The wind distribution as described is closely connected with the general pressure distribution shown in Figures 17 and 18.

Near the equator, a zone of low pressure is found. It is followed in both hemispheres by zone of high pressure called 'subtropical' high-pressure belts. In summer hemisphere, these high-pressure belts do not extend continually around the earth but are interrupted over the continents since the land is hotter than the oceans. The central regions of the high-pressure belts have frequent calms.

In the region of the westerlies even the mean pressure distribution is rather irregular because of the migrating pressure centers. On the whole, the pressure decreases here toward the pole.

In the surface layers of the arctic and of the Antarctic zone, the pressure distribution is anticyclonic, because of the low temperature of the air in the surface layers. Since Greenland and Antarctica are not symmetrical with respect to the poles, the zones of the easterly winds in the polar regions are not symmetrical to the poles.

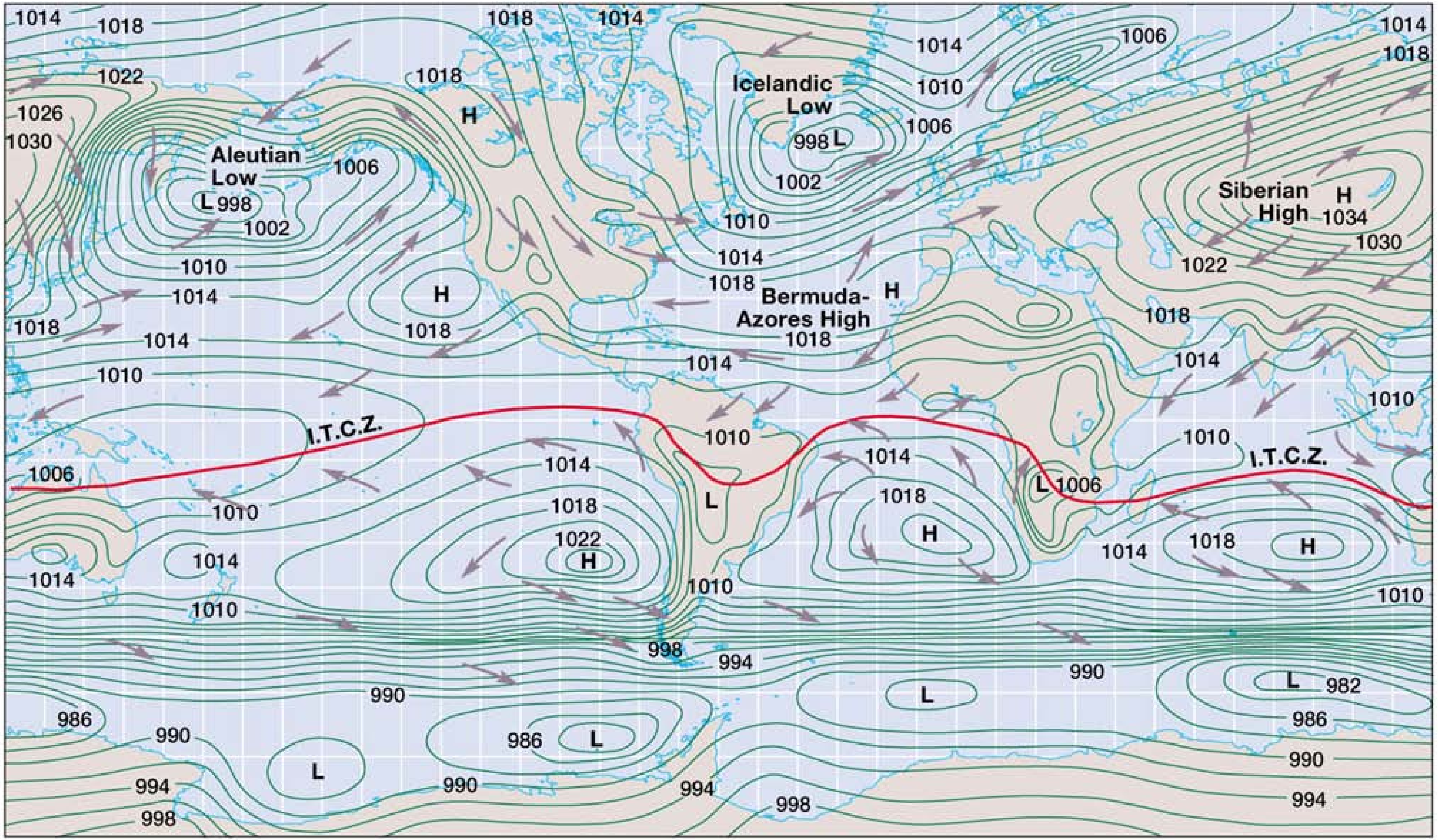

Fig. 17 : Mean Sea Level Pressure (hPa) in January

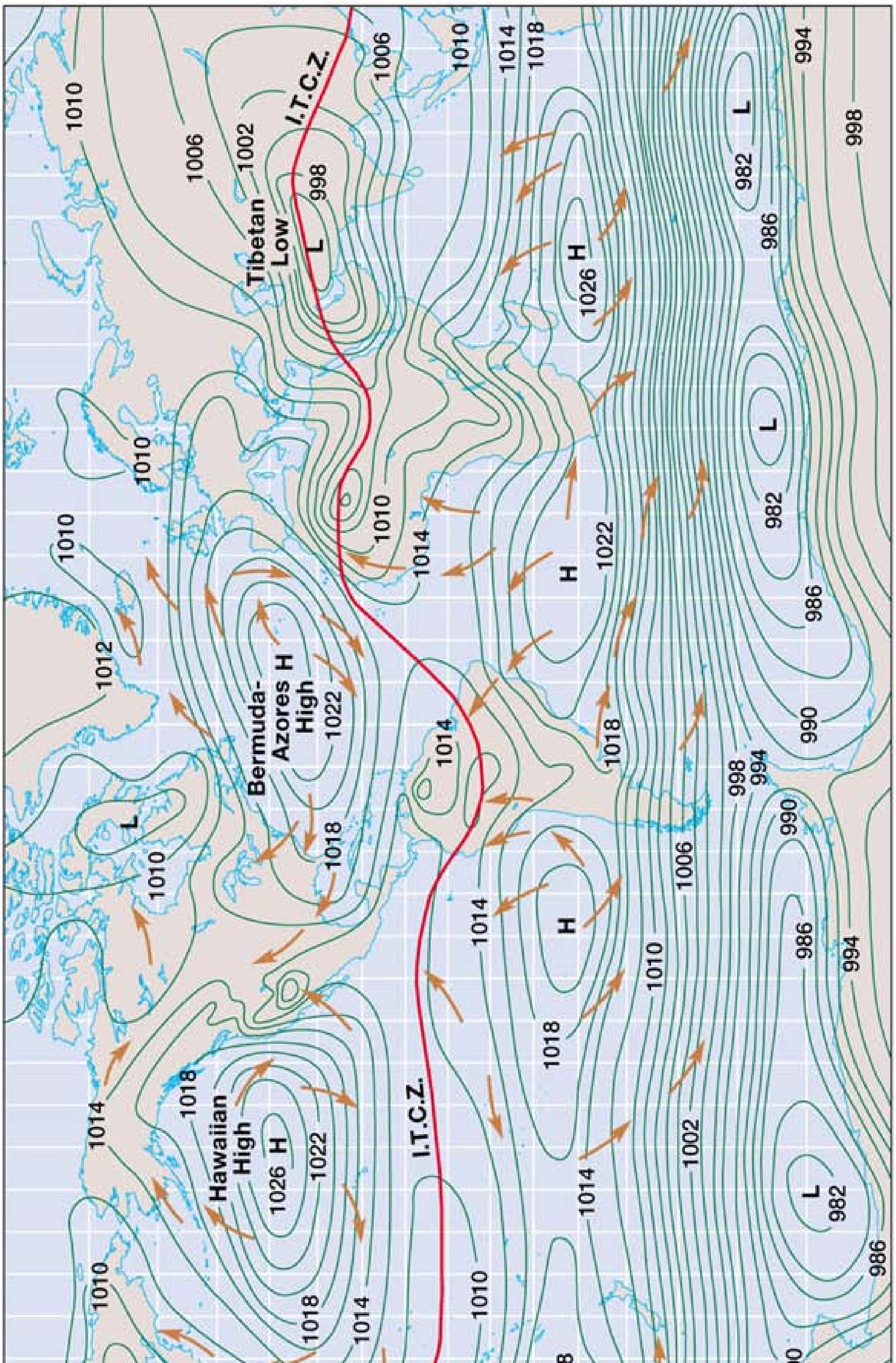

Fig. 18 : Mean Sea Level Pressure (hPa) in July

Effect of land and sea on the on the wind and pressure distribution

The unequal heating of water and land produces considerable modifications of the pressure and wind distribution. These deviations are more noticeable during the extreme months of January and July.

During July, the large continental mass of the northern hemisphere is much warmer than the surrounding oceans. Hence a low pressure is found over the continents, which interrupt the high-pressure belt. The continental low is in direct connection with the equatorial low-pressure zone of doldrums. The southern hemisphere has winter in July so that here the land is colder than the water. But the disturbance of the pressure distribution is much less because of the smaller land area in the southern hemisphere.

Over the continents, in the northern hemisphere during July, the northeast trade winds are absent. Instead, the southwest winds that are observed are continuation of the southeast trade winds of the southern hemisphere, which are deflected to southwest as they cross the equator. The deflection of the southeast trades into the southwest monsoon is especially pronounced over India and the Indian Ocean.

During January in the northern hemisphere, the continent is much colder than the adjoining oceans where a strong high is developed. On the south side of the continental anticyclone, the winds are northeasterly. The centers of low pressure over the oceans are considerably intensified during the winter so that the cyclonic activity is now at a maximum. On the north side of the continental anticyclone, the winds are westerly. Thus the belts of westerlies surround the northern hemisphere completely, but are displaced more northward over the continents.

The southern hemisphere has its summer during January. Thus the pressure over the continents is now lower than over the adjoining oceans. As a result, the zone of doldrums with its low pressure shows a southward bulge over the continent. But the interruption of the southern subtropical high-pressure belt by the continents during January is only slight.

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Distribution of Temperature over the surface of the earth

The atmospheric temperature is controlled principally by the incoming soalr radiation. Hence its distribution depends largely on the latitude. Also, it is affected by the nature of the surface of the earth especially by the differences between water and land, by the altitude, and by the prevailing winds.

Considering the mean temperature of each latitude (Table 1), the latitudinal control of temperature is found more dominant.

Table 1. : Latitudinal distribution of temperature (ºF)

Latitude	Year	January	July	Range
90º N	-8.9	-42.0	30.0	72.0
80º N	-1.0	-26.0	35.6	61.6
70º N	12.7	-15.3	45.1	60.4
60º N	30.0	3.0	57.4	54.4
50º N	42.5	19.2	64.6	45.4
40º N	57.4	41.0	75.2	34.2
30º N	68.7	58.1	81.1	23.0
20º N	77.5	71.2	82.4	11.2
10º N	80.1	78.4	80.4	2.5
Equator	79.2	79.5	78.1	1.8
10º S	77.5	79.3	75.0	4.3
20º S	73.2	77.7	68.0	9.7
30º S	61.9	71.4	58.5	12.9
40º S	53.4	60.1	48.2	11.9
50º S	42.4	46.6	38.1	8.5
60º S	25.9	35.8	15.6	20.2
70º S	7.5	25.7	-9.4	35.1
80º S	-16.6	12.6	-39.1	51.7
90º S	-27.6	7.7	-54.0	62.0

The yearly averages show that the warmest latitude is not at the equator but at 10º N. Equator is the hottest circle of latitude only during January. In the month of July, the warmest parallel latitude is somewhat north of 20º N.

The northern hemisphere as a whole has a higher annual mean temperature than the southern hemisphere. Also on the yearly average, each latitude of the northern hemisphere is warmer than the corresponding latitude in the southern hemisphere. The temperature decrease with latitude is very small in tropical and sub-tropical latitudes.

During January the northern hemisphere has its winter. The temperature decrease from the equator toward either pole is considerably greater in winter than in summer (due to the seasonal variation of radiation). The greatest surplus of radiation during January occurs at about 30º south, while the temperature maxima is found at the equator. This is because of the fact that the temperature does not depend on the radiative balance alone.

The meridional temperature gradient acts as a regulator of the intensity of the general circulation; hence the general circulation is considerably more intense during the winter season than during the summer season.

The annual range of temperature is the difference between the mean temperature of the warmest and of the coldest month. It is notices that at the equator and at 10º N latitude the range is not equal to the difference between the mean temperatures of July and January because of the reason that at these latitudes the monthly maxima and minima are not reached in July and in January.

The annual temperature range is very small in tropical latitudes and increases towards both poles since the yearly variation of incoming solar radiation is larger at poles than at the equator. South of 30º S latitude the annual temperature range decreases to a secondary minimum at 50º south. This drop is due to the sharp decrease of continental area beyond 30º S latitude.

Table 2 shows the mean temperature during January and july and during the whole year for each hemisphere separately and for the whole earth.

Table 2. : Mean temperatures (ºF)

Part of he globe	Year	January	July	Annual Range
Northern hemisphere	59.3	46.5	72.3	25.8
Southern hemisphere	56.0	62.7	49.5	13.2
Whole earth	57.7	54.6	60.8	6.2

It is seen that northern hemisphere has higher annual mean temperature and large annual range than the southern hemisphere. The higher annual range is due to the much larger continental areas in the northern hemisphere. Land surfaces are heated much more strongly in summer and cooled to much lower temperatures in winter than the water surfaces.

The greater land covers in the northern hemisphere is not the only factor responsible for its higher mean temperature. The oceans are also warmer in the northern than in the southern hemisphere. This is due to

a) the transport of warm equatorial waters from the southern hemisphere into the northern hemisphere by the southeast trades, which cross the equator and
b) the partial protection of its oceans from the cold polar waters and from the Arctic ice by land barriers, there being no such barrier between the Antarctic Ocean and the southern oceans in more equatorial latitudes.

Effect of land and sea on the temperature distribution

The effect of land and water on the temperature distribution can be seen in Fig.19 and Fig. 20, which show the sea-level isotherm during the months of January and July.

As seen in Fig. 19, over large part of the globe the January isotherms are not parallel to the latitude circles. In the northern hemisphere, the isotherms are deflected toward lower latitudes over the continents, indicating that the continents are colder than the oceans. The coldest region is found in Siberia.

During January a sweep of isotherms over eastern part of the north Atlantic is seen. This is due to the combination of the effects of north Atlantic drift and the prevailing westerly winds.

The prevailing winds everywhere in temperate latitudes are westerly. Consequently, during the winter the west coasts of the temperate zones are warmer than the east coasts.

In the southern hemisphere, January is the summer month when the continents are warmer than the oceans.

On the whole the isotherms in the southern hemisphere follows the parallels of latitude more closely than in the northern hemisphere since the earth's surface is more uniform.

During July (Fig. 20), the continents of the northern hemisphere are warmer than the adjoining oceans. Over north Africa, the Arabian peninsula and southwestern Asia, regions surrounded by closed 90º F isotherms is found. In the southern hemisphere, which now has its winter, the isotherms again have a much more regular shape than the isotherms over the northern hemisphere owing to the smaller continental areas.

The meridional temperature gradient is much greater during winter than during the summer.

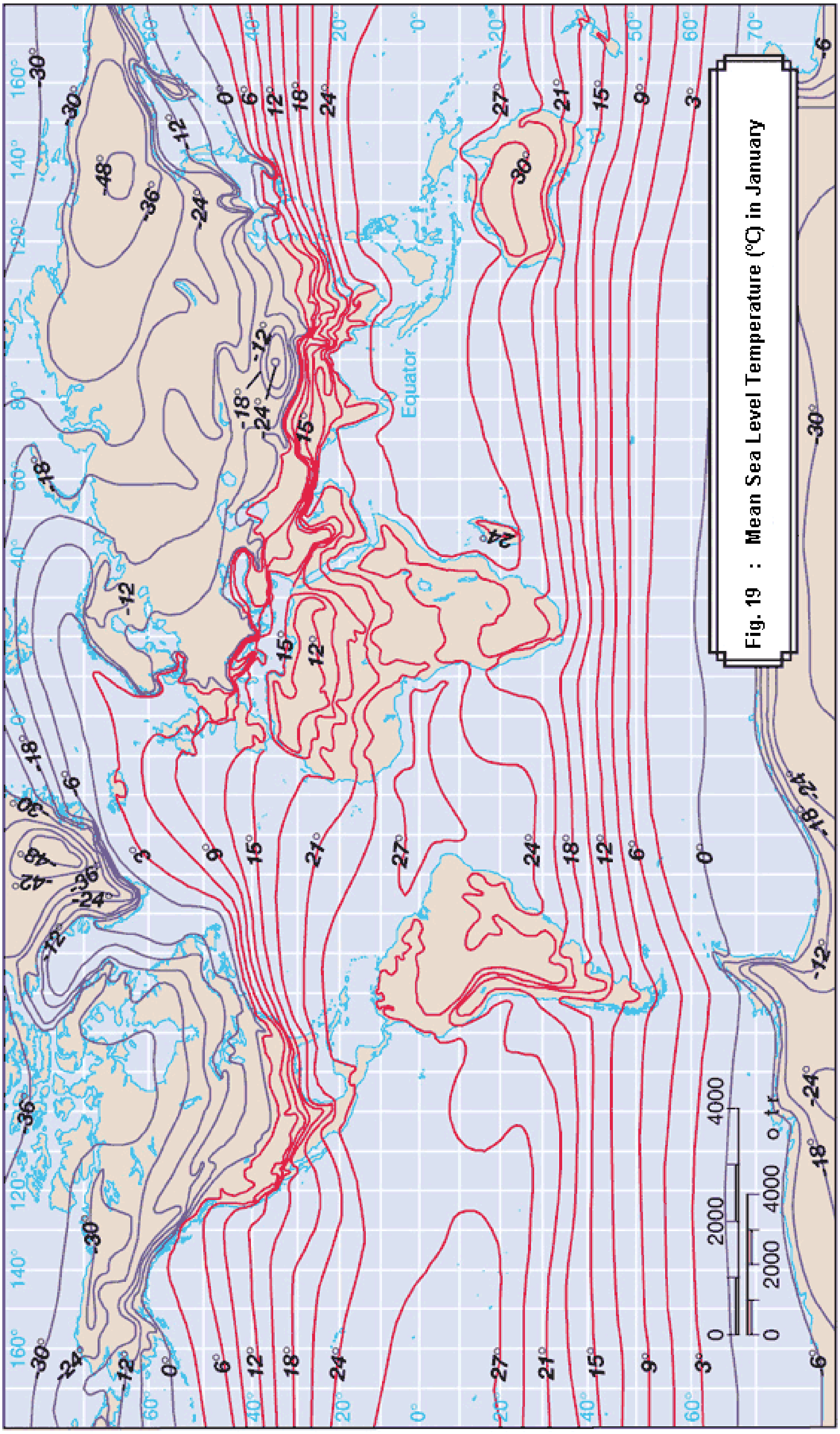

Fig. 19 : Mean Sea Level Temperature (°C) in January

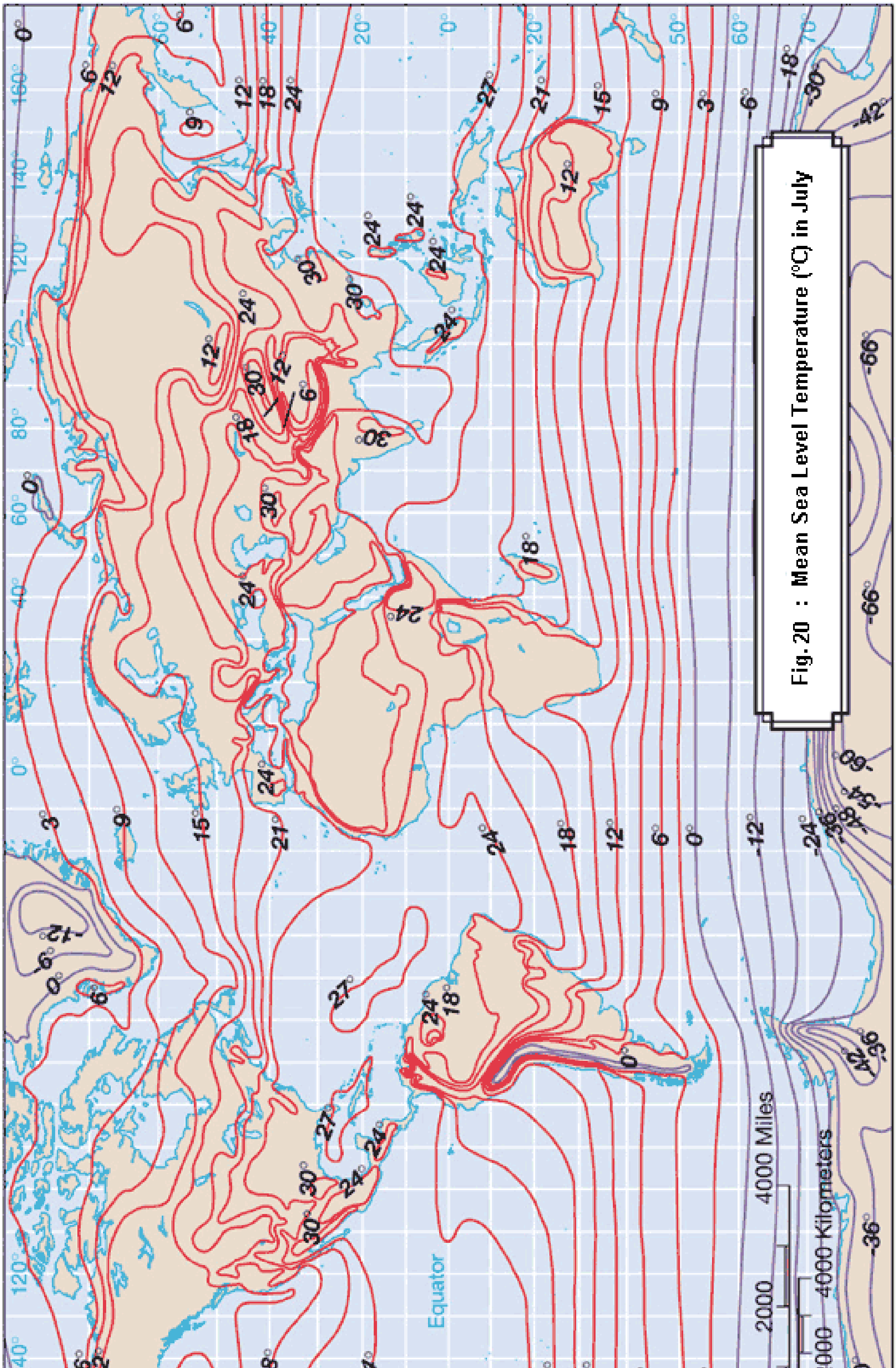

Fig. 20 : Mean Sea Level Temperature (°C) in July

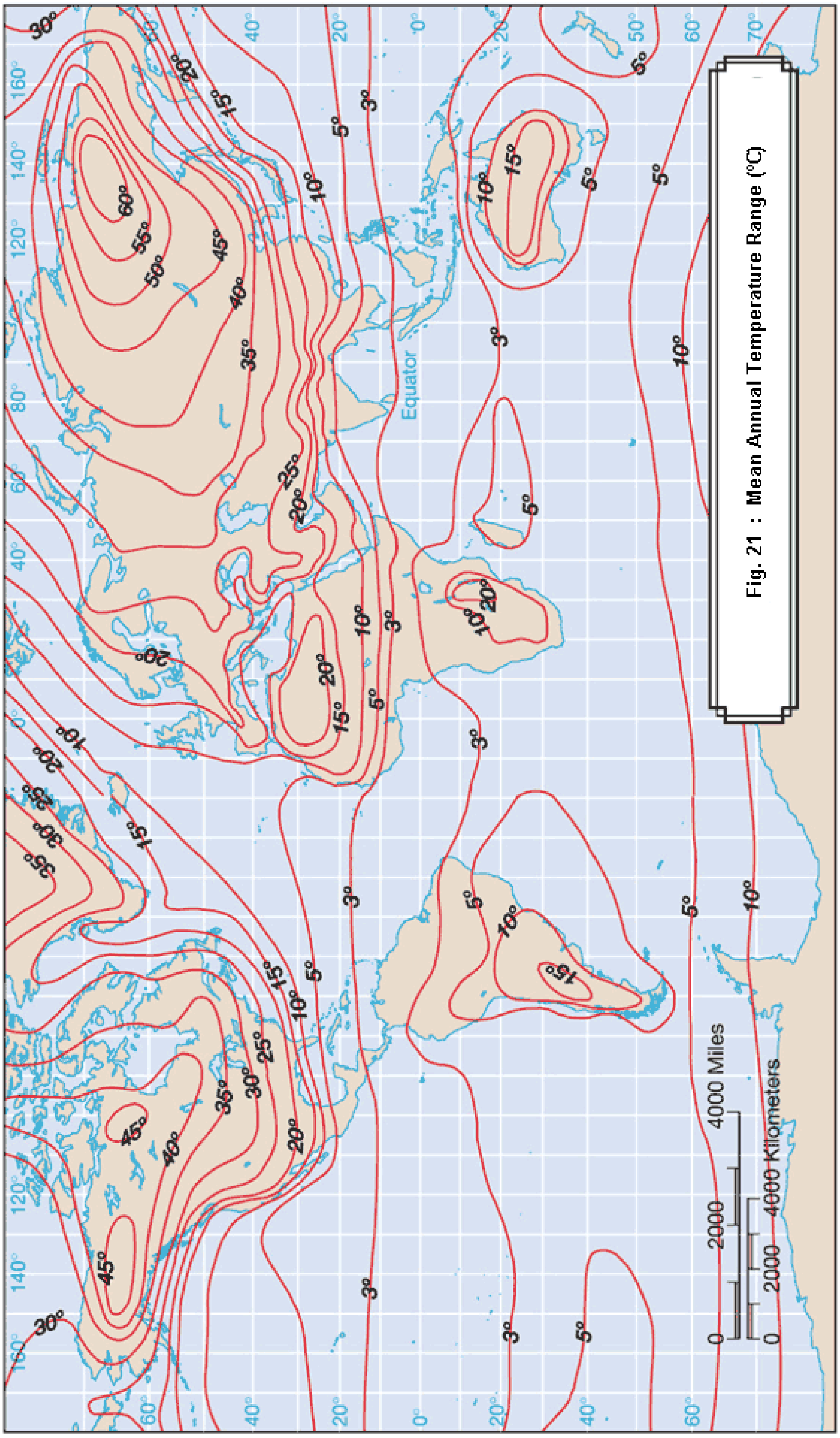

Fig. 21 : Mean Annual Temperature Range (°C)

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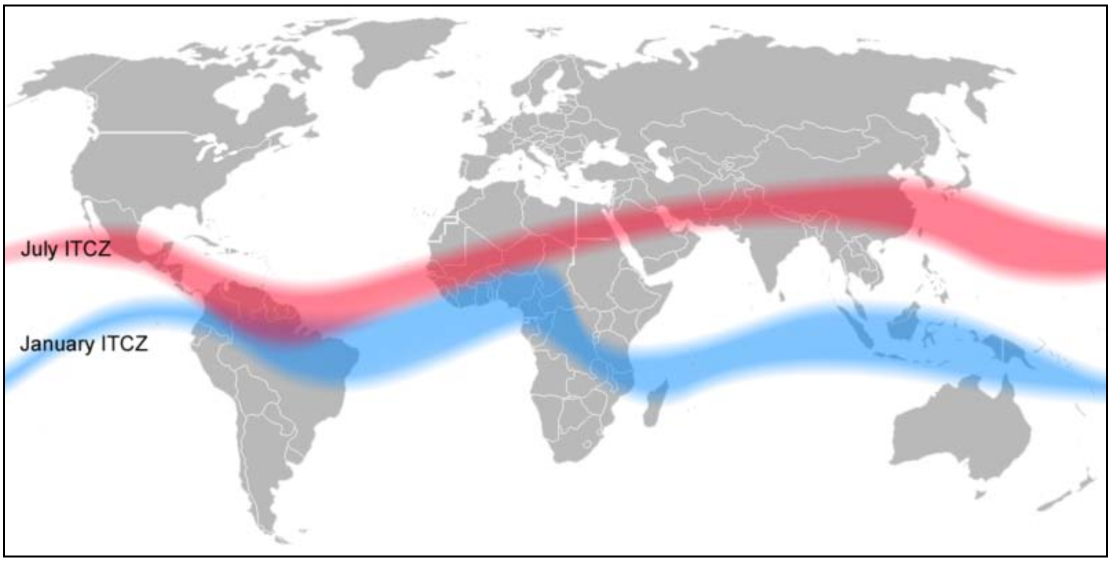
Equatorial Trough and Inter Tropical Convergence Zone (ITCZ)

On or near the equator, where average solar radiation is greatest, air is warmed at the surface and rises. This creates a band of low air pressure, centered on the equator. This rising air comprises one segment of a circulation pattern called the Hadley Cell. The rising air is replaced by the Trade winds approaching the equator from north and south. As the trade winds meet near the equator, surface convergence and uplift take place. Equatorial Trough is the quasi-continuous belt of low pressure lying between the subtropical high pressure belts of the Northern and Southern Hemispheres. This entire region is one of very homogeneous air, probably the most ideally barotropic region of the atmosphere. Yet humidity is so high that slight variations in stability cause major variations in weather. The position of the equatorial trough is fairly constant in the eastern portions of the Atlantic and Pacific, but it varies greatly with season in the western portions of those oceans and in southern Asia and the Indian Ocean. It moves into or toward the summer hemisphere. The equatorial trough would be said to contain regions of doldrums; portions of it could be described as intertropical convergence zone (ITCZ).



The convergence of the Southeast and Northeast Trade Winds, within the doldrums, creates a zone of Cumulus clouds and attendant shower activity. Under certain circumstances, tropical depressions on the ITCZ intensify to hurricanes. It may seem puzzling that the ITCZ can produce cyclones, when the Coriolis force is at its weakest near the equator. The answer to this puzzle lies in the fact that the ITCZ is not stationary on the equator, but migrates north and south with the seasons. These movements are not perfectly symmetrical above and below the equator, because of the influence of land masses, among other factors.

Climatic Zones

- The Köppen Climate Classification System is the most widely used for classifying the world’s climates.
- Köppen's scheme to classify world climates was devised in 1918 by Wladimir Köppen of the University of Graz in Austria.
- It is based on the concept that native vegetation is the best expression of climate, climate zone boundaries having been selected with vegetation limits in mind.
- Among the various types of classification of climate, Köppen's classification system is the most widely used for teaching and studying of Geography.
- A unique and distinctive feature of the system is the employment of an ingenious symbolic nomenclature in designating the climatic types.
- The classification may be applied to present-day climatic conditions. Alternatively, it also may be used to develop a future climatology that is implied by the output of a numerical climate model.
- Köppen recognizes five principal groups of world climates that are intended to correspond with five principal vegetation groups. These five climatic groups may be described as tropical rainy, dry, warm temperate rainy, cold snow-forest, and polar.
- Each type of climate is described by a formula consisting of a combination of letters, and each of which has a precise meaning.
- Each of these climates is further divided into sub-divisions based upon differences in the seasonal distribution of temperature and precipitation.
- This is the most widely used systems for classifying climate because it is easy to use and data requirements are minimal.
- The classification is based on the 26 values of monthly and annual average precipitation and temperature:

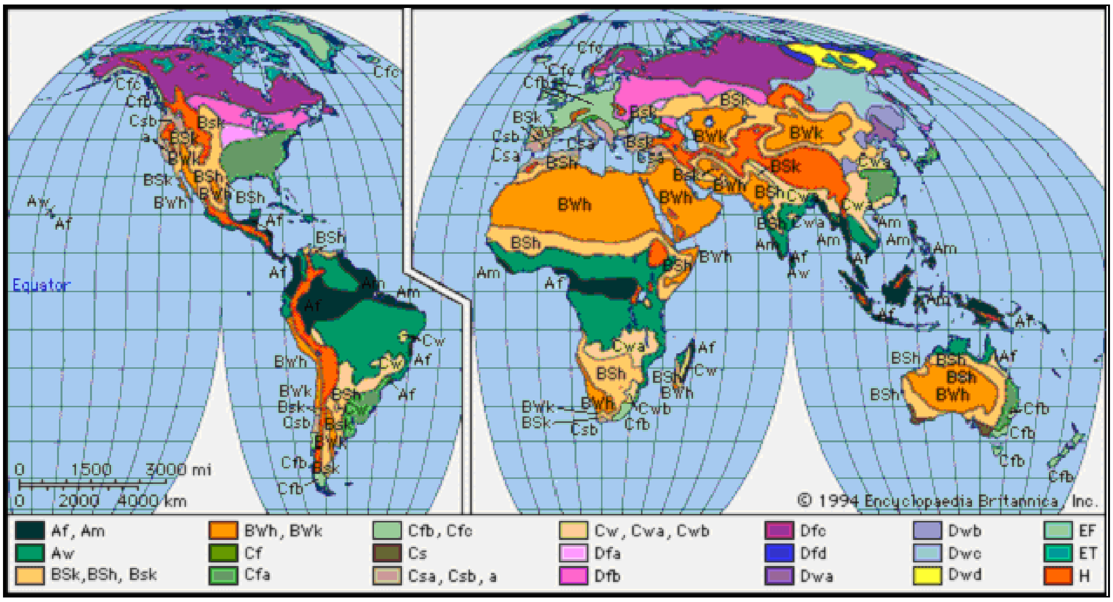
Precipitation (mm) : Jan to Dec (12 monthly values), r (annual mean)

Temperature (ºC) : Jan to Dec (12 monthly values), t (annual mean)

- The Köppen classification includes five major categories which are designated by capital letters as :

A	:	Tropical rainy Climates
B	:	Dry Climates
C	:	Warm temperate rainy Climates
D	:	Cold snow-forest Climates
E	:	Polar Climates

Köppen's Climate Group and Types



Definition and description of climate types in Köppen's scheme

A : Tropical rainy climate

: The average temperature of the coldest month is 18 ºC or higher.

In tropical rainy climates certain plants, known as megatherms, do not thrive with monthly temperatures lower than 18 ºC. The megatherms need continuously high temperatures and relatively abundant precipitation. Within the A group of climates three main types are recognised.

Af : Tropical rain forest climate

: when precipitation in driest month is 6 cm or more

Within this climate there is minimum of seasonal variation in temperature and precipitation, both remaining high throughout the year. These are mainly located within the equatorial rain belt. Among the regions whose climate of this type are the Amazon Valley in South America, the Congo Basin, the Guinea coast in Africa, and the East Indies.

Am : Tropical monsoon climate

: when precipitation in driest month is less than 6 cm and more than (10 – r/25)

This climate is characterized by the short dry season, but with total rainfall so great that ground remains sufficiently wet throughout the year to support rainforest. These are found mainly in the coastal regions where a monsoon wind blows against a mountain range during part of the year.

Aw : Tropical savanna climate

: when precipitation in driest month is less than (10 – r/25)

This savanna type of climate differs from the tropical type in that it has a distinct dry season in winter. These are developed over the regions that are reached by migrating equatorial rain belt only during the season when the sun is high. This type of climate is found in some parts of Colombia, Venezuela, Brazil, Sudan, South Africa, northern Australia, India, Burma and Indo-china.

B : Dry climate

: The annual precipitation (r) in cm should be less than (2t + 14) where t is the average annual temperature in ºC.

In dry climates there is an excess of evaporation over precipitation. The amount of precipitation that falls is not sufficient in providing moisture in the ground for plants. Since the aridity depends not only on the smallness of precipitation but also on the magnitude of potential evaporation, a combination of temperature and precipitation data is used to determine the boundary of B climates. The B climates predominantly occur in the interior of the continents, often on the lee side of mountain ranges, which prevent any moderating maritime influences. According to the degree of dryness and the resulting type of vegetation, the two main subdivisions of B climates are distinguished, the arid dessert type and semiarid steppe type; the steppe type represents the transition from dessert climates to more humid climates.

BW : Arid or Dessert type dry climate

BS : Semiarid or Steppe type dry climate

Formula for identifying BW and BS margins

	Boundary between BS and humid climates	Boundary between BW and BS
Precipitation evenly distributed	r = 2t + 14	r = ½ (2t + 14)
Precipitation maximum in summer	r = 2t	r = ½ (2t)
Precipitation maximum in winter	r = 2t + 28	r = ½ (2t + 28)

A further subdivision (by adding letter ‘h’ or ‘k’) separates the hot tropical-subtropical deserts and steppes from the cold temperate-boreal deserts and steppes.

h : when t >= 18 ºC

k : when t < 18 ºC

The *h* type of B climates owe their existence mainly o the subsiding motion in the subtropical anticyclones. As such theses are found at around 20º to 25º north and south latitudes. The *k* type of B climates are typical of the interior of the continents at higher latitudes, where any air arriving from the oceans has already become rather dry. These are found mainly in the heart of the large continental masses of the northern hemisphere.

C : Warm temperate rainy climate

: The average temperature of the coldest month is less than 18ºC but more than or equal to –3ºC.

The C climates are distinguished from the A types by the existence of a cool season during which at least 1 month has a mean temperature below 18ºC and no month has a mean temperature below –3ºC. These regions receive more precipitation than that with B climates. Over the northern boundaries of the regions of C climate, the snow and frost are quite common whereas over southern side they are very rare. The climates of C type are divided according to the seasonal variation of the precipitation and according to the temperature and the length of the summer season.

C*s* : Warm temperate rainy climate with dry summer

: when precipitation in wettest month of winter is at least three times the precipitation in the driest summer month

The summer dry type C climate occurs on the subtropical boundaries of the middle latitudes. In summer these regions are in the zone of the subtropical anticyclone and the frontal activity is weak. But in winter frontal systems are more frequent so that considerable precipitation occurs.

C*w* : Warm temperate rainy climate with dry winter

: when precipitation in wettest month in summer is at least ten times the precipitation in driest winter month

C*w* climates are located in northern India, southern china, southern Brazil, Mexico, east coast of Australia and on the plateaus of tropical and subtropical Africa. Many of these regions are considerably above sea level; and the coldest month temperature below 18 ºC is an effect of altitude rather than of the latitude. In tropical highland regions, the dry winters and warm summers reflect the shift of the zone of doldrums. At higher latitudes the moist maritime air is more frequent in summer and dry continental air is more frequent in winter.

C*f* : Warm temperate rainy climate without dry season

: when difference between driest and wettest months is less then required for ***s*** and ***w*** and the precipitation in then driest month of summer is more than 3 cm.

In some tropical stations belongs to this group, which show very small monthly variation of the precipitation. Outside the tropics the C*f* type is the typical oceanic climate covering almost 30 per cent of the whole ocean area. The C*f* climates are found mainly in the regions of westerlies where the precipitation is mainly caused by frontal lifting.

Depending on the temperature, the C climates are further subdivided into hot summer (*a*), warm summer (*b*) and cool short summer (*c*) as follows.

a : when warmest month temperature is 22 ºC or above

b : when warmest month temperature is less than 22 ºC and temperature of at least four warmest months remains greater than 10 ºC

c : when the temperature of less than four months remains more than 10 ºC

The type C*sa* is characteristic for the Mediterranean coast, the interior of southern California and for small area along the west coast of Australia. The C*sb* type occurs in more oceanic locations where the summer temperature is moderated by the sea. Since the C*s* type is found in regions dominated by subtropical high-pressure belt in summer, the type C*sc* does not occur.

A far as temperature is concerned the C*w* climate resembles C*s* types with hot and warm summers. The stations with C*wb* climate are found in the tropics if their elevation is high enough.

The type C*fa* (hot summers) is found in the eastern and central United States, on the east coast of South America, over the southern islands of Japan, on the east coast of Australia. The summers of C*fb* type of climate are cooler than those of the type C*fa*. This type is mainly found in locations under maritime influence and represents the climate of British Isles, France and Germany, northerly islands of Japan, northwestern parts of North America, southwest coast of Australia, Tasmania and New Zealand. In continental locations the type C*fa* or C*fb* changes into D*fa* or D*fb* toward the pole. In regions under maritime influence, however, the type C*fc* is found. Here the summers are short due to high latitude, but he winters are relatively mild owing to the moderating effect of water. The climate of type C*fc* is found on the west coast of Norway, over the Faeroes and the Orkney Islands, over the southern parts of Iceland, parts of Alaskan coast and over the Aleutian Islands.

D : Cold snow-forest climate

: The average temperature of the coldest month is less than –3 ºC and the average temperature of warmest month temperature is above 10 ºC.

The D climates have more severe winter than the C climates, with more occasional snow cover. These are also characterised by the hot summers, which is long and short along the poleward boundaries and relatively long in the southern regions. The D types are separated from the C type by the isotherm of –3 ºC of the coldest month and from the E climates by the isotherm of 10 ºC of the warmest month. The D climates are typical for regions in the interior of the large continental masses. They are absent in southern hemisphere and in the northern hemisphere they cover largely the continental areas from 40º to 50º latitude to the polar circle. Two principal subdivisions of D climate is recognised; D*w*, with dry season in winter and D*f*, with no dry season. The rule of summer dry climate does not extend to these locations with cold winters. A D*s* climate exists only in the interior of Oregon.

The climate type D*w* is observed only in eastern Asia. In many regions with D types of climate, the difference between the precipitation during the wettest summer month and during the driest winter month is not sufficiently great. As such D*f* type covers much larger area than D*w* type.

Other small letters used with D climate are same as that used with C climate. In addition to the the subdivisions a, b, c with hot, warm and cool summers, respectively, there occurs in Siberia a fourth subdivision d with very cold winters.

d : when the average temperature of the coldest month is –38 ºC or less.

The D regions with hot summers are found only in north America (D*fa*) and in northern China and Manchuria (Dw*a*).

In North America the D*fb* climate is found to the north of the region with the D*fa* climate or, in the western part of the country. In Europe and Asia the D*fb* climate occurs mainly in Poland, the Baltic States, and southwestern Russia. The region north of Vladivostok has the winter dry climate D*wb*, except in narrow coastal belt, where the winter dryness is less pronounced.

The D*wc* and D*fc* represent the transition to the polar climates. D*wc* type occurs only over eastern Asia.

In the northernmost part of Asia the winter is so cold that the types D*fd* and D*wd* are represented.

E : Polar Climate

: The average temperature of the warmest month remains below 10 ºC

In the higher latitudes, once the temperatures are well below freezing and the ground frozen it makes little difference to plant life how cold it gets. Rather, it is the intensity and duration of a season of warmth, which is critical. Hence the warm-month isotherm is employed as the poleward boundary of E climate. Apart from the mountain regions the polar climates occupy the most northerly and southerly zones of the earth. The following climatic subdivisions of polar climate are recognised.

ET : Polar Tundra climate

: when the average temperature of the warmest month remains below 10 ºC but above 0 ºC.

EF : Polar Frost climate

: when the average temperature of the warmest month remains below 0 ºC

The tundra climates (ET), the vegetation consists largely of mosses, lichens and grasses, some flowering plants and near the border of the tree climates, even some dwarf forms of trees are found. The ET climates are found in the north coasts of Canada, Alaska, Iceland and Eurasia and over small northern belt of Antarctic continent.

The data from the frost climates (EF), where the mean temperature even of the warmest month remains below freezing, are scanty. This type is found over the permanently continental ice plateau of Antarctica and Greenland and over the perpetually frozen ocean in the vicinity of the North Pole.

EH : Polar climate due to high altitude

Polar climates owing to the elevation of the land may occur at any latitude provided that the altitude is high enough. Since the temperature changes much more rapidly in the vertical than in the horizontal direction, transition from one climatic type to another occur very rapidly with the ascent in mountain areas.

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