Lecture Notes
on
Overview of Physical Climatology
For
Integrated Meteorological Training Course

By

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Section 1: Earth-Sun Relationship, Elliptic and Equatorial Plane, Rotation and Revolution of Earth, Equinoxes, Solstices, Perihelion, Aphelion, Causes of Seasons, Seasonal and Latitudinal variation of solar insolation

1. Features of the Sun

The sun, having a mass about 330,000 times that of the earth and a radius about 110 times that of the earth's, is at a mean distance of about 1.5 x 10^8 km with the earth and other planets in orbit around it. Only the solar atmosphere, representing a tiny fraction of its mass and volume, is accessible to observation, yet there are distinct layers in this atmosphere. The photosphere, having a depth of about 0.0005 solar radius, covers the normally visible disk and is the direct source of practically all the observed solar radiation. Surrounding it to an additional thickness of about 0.02 solar radius is the *chromosphere* consisting of relatively transparent gases in a more or less homogeneous layer from which emerge spikes of spicules. Beyond it and extending outward without fixed limits is the corona, a pearly veil of extremely hot gas, mostly in highly ionized, atomic form, seen only at times of eclipse or with a coronagraph, which is an instrument especially designed to display the corona without the aid of an eclipse.

While the temperature at the center of the sun is estimated to be around 15 million Kelvin, the photosphere, from which most of the detectable radiation is emitted, has a temperature ranging from 7300 K at the bottom to 4500 K at the top. The effective blackbody temperature, which is the temperature a perfect radiator would have in order to produce the measured luminance, is about 5800 K.

The sun emits radiation through the entire electromagnetic spectrum from x-rays and cosmic rays to radio waves up to wavelengths of 15 m or more. The Human eyes are constructed to make maximum use of the sun; we see in the part of the spectrum where the sun emits its maximum energy.

A layout of the electromagnetic spectrum, on a logarithmic scale, is displayed in Fig. 1.

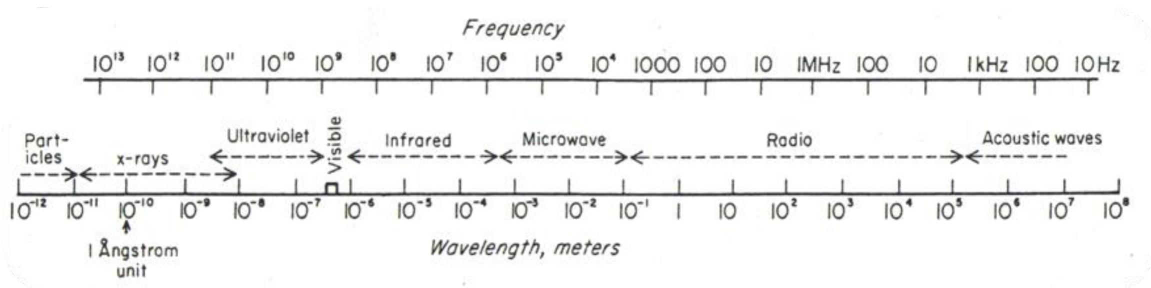

Fig. 1: The Electromagnetic Spectrum

Some of the radiation is in what is called the visible range; that is, it can be detected by the human eye. That of a wavelength too short to be observed by eye may be classed as ultraviolet radiation, and the long-wave type as infrared radiation. Just as in the case of light radiation, all radiant energy travels in straight paths through space and, at all wavelengths, with the speed of light. The wavelengths of solar and terrestrial radiation are of the order of 10^{-6} m, called microns (abbreviated μm), but sometimes given in 10^{-9} m (nanometers, nm) or in a special radiation unit of 10^{-10} m called angstrom (Å). The visible range lies between about 0.4 and 0.7 μm (400 to 700 nm, 4000 to 7000 Å). In the main body of the atmosphere, the wavelengths of about 0.1 to 30 μm are the practically important ones, but in the high atmosphere, photons in the ultraviolet, x-rays, and particle radiations produce important reactions.

2. Motions of the Earth

The most important movements of the earth are its rotation about an axis through the poles and its revolution in an orbit around the sun. Both these motions are in a counterclockwise direction if viewed from over the North Pole; that is, the rotation is from west to east, as is also the revolution. The 24-hr day on the earth and timepieces are based on the time required for the earth to make one rotation with respect to the sun. This unit of time is called the solar day. The earth rotates upon an imaginary axis, the ends of which are the North and South Poles. The time required for the earth to rotate once with respect to the sun determines the length of a day. During that time, places on the sphere are turned alternately toward and away from the sun. They go through a period of light and a period of darkness, and they are swept over twice by the circle of illumination (i.e. boundary between light and dark); at dawn and again at twilight. The direction of earth rotation is toward the east. This not only determines the direction from which the sun, moon, and stars appear to rise, but is related to other earth phenomena of far-reaching consequence, such as the prevailing directions of winds and ocean currents.

The rotating earth revolves in a slightly elliptical orbit about the sun. The time required for the earth to pass once completely around its orbit fixes the length of the year. During the time of one revolution, the turning earth rotates on its axis approximately 365ŏ times with respect to the sun, thus determining the number of days in the year. The calendars on the earth are formulated on the basis of the period of the earth's orbit around the sun i. e. 365.242 solar days.

The rotation and revolution of the earth are the motions of most significance in meteorology. The rotation indirectly accounts for the diurnal changes in the weather, such as the warming up during the daytime and the cooling off at night. Furthermore, the rotation imposes on the earth and in the atmosphere an acceleration second in importance only to the gravitational acceleration, namely, the centripetal acceleration.

Because of the large distance of the sun from the earth, the rays of sunlight reaching the top of the atmosphere are essentially parallel. Since the surfaces of both the earth and the outer limits of its atmosphere are spherically shaped, the parallel rays of the sun will be inclined at different angles at different latitudes. Where the noon sun is directly overhead, the beam of solar energy is vertical (i.e. perpendicular to the surface) and the intensity of the solar energy is a maximum. At latitudes where the noon sun is not directly overhead, the solar rays are oblique and the solar radiation is spread over a greater surface area. The farther a given latitude is from the latitude at which the noon sun is directly overhead, the greater is the obliquity of the sun's rays and the weaker is the intensity of the solar radiation. In addition, an oblique ray passes through a thicker layer of atmosphere, which absorbs and reflects some of the radiation, thus further reducing the intensity of the solar radiation received at ground level.

Because the length of the day and the angle of the sun's rays are equal along all parts of the same parallel, it follows that all places on a parallel receive the same amount of solar energy (except for differences in cloudiness and in transparency of the atmosphere). By the same reasoning, different parallels (i.e. latitudes) receive varying amounts of solar energy which decrease from equator to poles for the year as a whole. If the earth's axis were not tilted, the angle of the sun's rays and the length of day and night along a given parallel would not change during the year. However, because of the tilt of the axis, both the angle of the sun's rays and the length of day change as the earth revolves around the sun.

An imaginary plane passing through the sun and extending outward through all points in the earth's orbit is called the plane of the ecliptic. The axis of the earth's rotation is inclined about 66½º from the plane of the ecliptic (or 23½º from an imaginary line vertical to it). This position is constant, and therefore at any time during the yearly revolution the axis is parallel to the position that it occupies at any other time (Fig. 2).

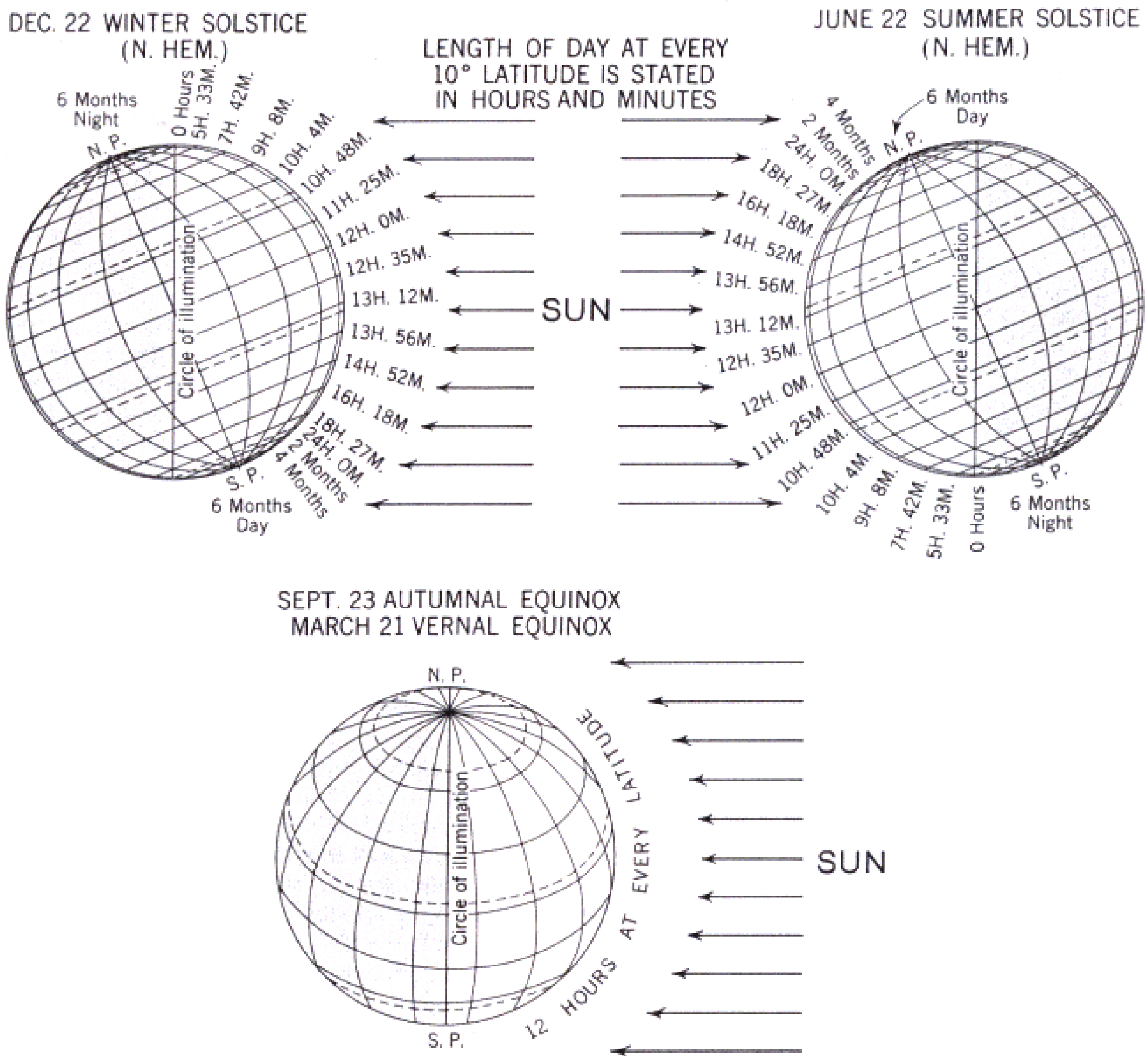

Fig. 2: Solstices and Equinoxes

3. The Seasons

The revolution of the earth is associated with the seasonal changes. If the plane of the orbit were in the plane of the earth's equator, there would be very little seasonal change. At perihelion, when the earth describing its ellipse in space reaches the major axis at the end nearest the sun, the greatest intensity of solar radiation would be received; and when the earth is at aphelion, which is the farthest end of the major axis, a minimum of solar heating would be experienced. This difference in amount of solar radiation received over the earth as a whole is extremely small compared with the seasonal variations known to exist from a different cause.

A study of Fig. 3 further reveals the explanation of the seasons.

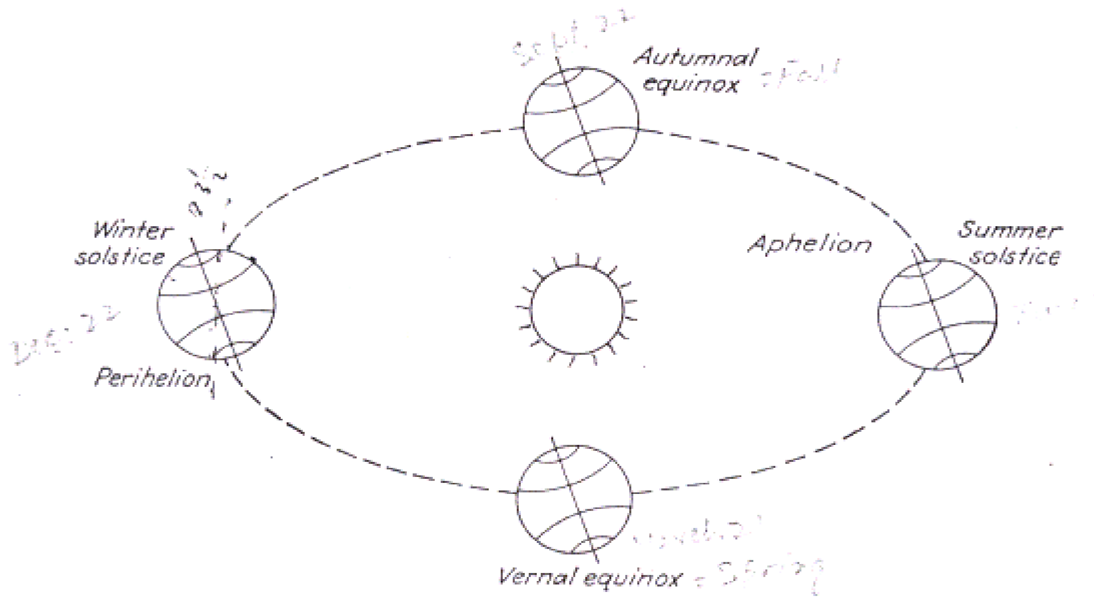

Fig. 3: The Revolution of the Earth around the Sun

The plane of the equator is inclined at an angle of 23½° from the plane of the earth's orbit. This means that the axis is inclined at an angle of 23½° from the perpendicular to the plane of the orbit. The direction toward which the axis is inclined is very nearly in the major axis of the ellipse. Therefore, the solstices, the places where this inclination is toward the sun, are very near the points of perihelion and aphelion. The winter solstice, when the Southern Hemisphere has its maximum exposure to the sun, occurs just a few days before perihelion. At the winter solstice, the sun is directly overhead at noon in latitude 23½°S. The summer solstice, when the Northern Hemisphere has its maximum exposure to the sun, occurs just a few days before aphelion. At that time the sun is directly overhead at noon at lat 23½°N.

On about June 22, the earth is midway in its orbit between the equinoctical positions, and the North Pole is inclined 23½° towards the sun (Fig. 2). As a result of the axial inclination, the sun's rays are shifted northward by that same amount (23½°), so that the noon rays are vertical at the Topic of Cancer (23½°N), and the tangent rays in the Northern Hemisphere pass over the pole and reach the Arctic Circle (66½°N) on the opposite side of it. In the Southern Hemisphere, the tangent rays do not reach the pole but terminate at the Antarctic Circle, 23½° short of the pole. Thus, while all parts of the earth north on the Arctic Circle are in constant daylight, similar latitudes in the Southern Hemisphere (pole ward from the Antarctic Circle) are entirely without sunlight. All parallels except the equator are cut unequally by the circle of illumination. Those in the Northern Hemisphere have the larger parts of their circumferences toward the sun, so that days are longer than nights. Longer days, plus more nearly vertical rays of the sun, result in a maximum receipt of solar energy in the Northern Hemisphere at this time (Fig. 4).

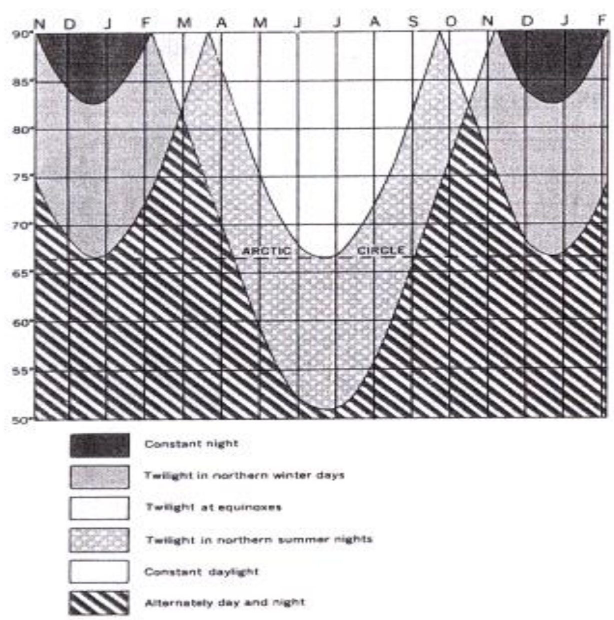

Fig. 4: The Annual march of light conditions pole ward of 50^{0}N

(After W. Meinardus)

Summer, with its associated high temperatures, is the result, and north of the equator June 22 is known as the summer solstice. In the Southern Hemisphere, all these conditions are reversed: nights are longer than days, the sun's rays are relatively oblique, solar radiation is at a minimum, and winter conditions prevail.

On about December 22, when the earth is in the opposite position in its orbit, it is the South Pole that is inclined 23½º toward the sun (Fig. 2). The noon rays are then vertical over the Tropic of Capricorn (23½ºS), and the tangent rays pass 23½º over the South Pole to the other side of the Antarctic Circle (66½ºS). Consequently, south of 66½ºS, there is constant light, while north of 66½oN there is none. All parallels of the earth except the equator are cut unequally by the circle of illumination, with days longer and the sun's rays more nearly vertical in the Southern Hemisphere. This, therefore, is summer south of the equator but winter in the Northern Hemisphere (winter solstice), where opposite conditions prevail (Fig. 4).

Twice during the yearly period of revolution, on about March 21 and September 22, the sun's noon rays are directly overhead, or vertical at the equator (Fig. 2). At these times, therefore, the circle of illumination, marking the position of the tangent rays, passes through both poles and cuts all the earth's parallels exactly in half. Consequently, one-half of each parallel (180º) is in light and the other half is in darkness, so that days and nights are equal (12 h each) over the entire earth. From this fact the two dates about March 21 (spring or vernal equinox) and about September 22 (autumnal equinox) get their names, for equinox is derived from Latin words meaning "equal night". At these seasons the maximum solar energy is received at the equator, from which it diminishes regularly toward either pole, where it becomes zero. Thus, at two points midway between the solstices, a line drawn from the sun to the earth is perpendicular to the plane of inclination of the earth's axis; so the sun shines equally in the Northern and Southern Hemispheres. These are the equinoxes, the vernal equinox occurring in the spring and the autumnal equinox in the fall of Northern Hemisphere. The approximate dates of these significant points or events are vernal equinox, March 21; summer solstice, June 22; autumnal equinox, September 22; and winter solstice, December 22. The dates vary slightly on account of our system of leap years. The time from the vernal equinox to the summer solstices is sometimes denoted as spring; from then until the autumnal equinox as summer; autumn from the autumnal equinox to the winter solstice; then winter until the next vernal equinox.

For purposes of references and computations it is convenient to assume that the earth is fixed in space and to speak of the "apparent motion" of the sun and stars. The plane in which the apparent motion of the sun is observed is called the ecliptic plane. It is obvious that this is the same as the plane of the earth's orbit. It is inclined at an angle of 23½° to the plane of the celestial equator, which is the extension into space of the earth's equatorial plane. The equinoxes are at the intersection of the two planes. The vernal equinox is found where the sun in its apparent motion in the ecliptic crosses the celestial equator going northward, and the autumnal equinox is at the intersection as the sun is going southward.

Although the changing seasons are controlled by the amount of solar radiation falling on the horizontal surface of the earth, there are local differences in the solar radiation received by land surfaces of differing slopes. For example, north of 23½°N, land surfaces which slope downward toward the south receive more solar radiation than northward-sloping land. Thus warm temperatures occur earlier in the spring on the south-facing slope of a hill than on the North Slope.

4. The Tropics and the Polar Circle

The latitude circles of 23½ºN and S are called the Tropic of Cancer and Tropic of Capricorn, respectively. They are the highest latitudes from the equator where the sun can be observed directly overhead at noon, and then only one day each during the year. As a consequence of the inclination of the earth's axis, when the sun shines directly on lat 23½º in one hemisphere, the portion of the earth pole ward from 90 - 23½º = 66½º in the other hemisphere is without sunlight. For the Northern and Southern Hemispheres these latitude circles are called the Arctic and Antarctic Circles. Every point pole ward from these circles has at least 24 hr of continuous darkness once during the year. At the poles, there are 6 months without sun and 6 months with continuous sunlight between the equinoxes.

In Fig. 3, the polar circles and the two tropics are shown, the equator being omitted. If the rays from the sun are considered as parallel lines, the darkening of the arctic regions during winter is apparent, as is also the preponderance of daylight in these latitudes during summer. It is to be noted that these conditions occur in opposite phase in the Antarctic regions.

5. Lag of the Seasons

If the temperature depended solely on the amount of radiation received from the sun at a given time, it would be highest in June and lowest in December; or to be more specific, May, June and July would be the three warmest months and November, December and January the three coldest. Actually, June, July and August are the warmest months in most Northern Hemisphere locations and December, January and February the coldest.

The lag is accounted for on the basis of the time required for heating and cooling. One may have a roaring fire in a stove to heat a room in the early morning on a cold day, but the temperature in the room will not reach its highest point until later on, even through the fire may have died down by that time. Conditions in the heating of the earth by the sun are somewhat analogous. The same lag is also noticed in the diurnal period of solar heating. The highest temperatures occur not at noon when the sun is most intense but a few hours later.

Any object, including the earth, can give off heat as well as receive it. If the heat coming in equal that going out, there will be no temperature change. If they do not balance, the temperature will increase or decrease. For the earth as a whole, there is no net gain or loss of heat, but there are gains and losses through the year at a given latitude. For example, in the Northern Hemisphere, outside the tropics, the heat received exceeds the heat lost until sometime in August, when the heat lost begins to exceed that received. Cooling then predominates until sometime in February, when the heat gained begins to exceed the heat lost. The process is complicated somewhat by the transport of heat and cold from various regions by the winds.

Another factor contributing to the lag of the seasons in high latitudes and high elevations is the freezing and thawing of ice. Heat added to ice causes it to melt while its temperature remains at $0^{o}C$. Until the required amount of heat is added to the frozen mass in the spring, its temperature will not rise above the melting point, and similarly in the fall, there is a lag in the cooling while the freezing proceeds.

Section 2: Weather, Climate, Elements of Weather, Climate Controls, Weather Phenomena, Semi-Diurnal Variation of Pressure, Diurnal Variation of Temperature

Weather is the sum total of the atmospheric variables at a given place for a brief period of time; it is an everyday experience. Climate, on the other hand, refers to a more enduring regime of the atmosphere; it is an abstract concept. It represents a composite of the day-to-day weather conditions, and of the atmospheric elements, within a specified area over a long period of time. It is more than "average weather," for no adequate concept of climate is possible without an appreciation of seasonal and diurnal change and of the succession of weather episodes generated by mobile atmospheric disturbances. While in a study of climate emphasis may be given to the average, still, departures, variations, and extremes are also important.

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 sunshine (solar energy), atmospheric pressure, temperature, moisture (humidity and precipitation), and winds. The atmospheric pressure, 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, favours fair skies.

Climate, as the cumulative expression of the daily weather conditions, is most frequently described by employing averages of the climatic elements, or variables, particularly temperature and precipitation, but also sunshine and winds.

1. Controls of Weather and Climate

Weather varies from day to day and climate differs from region to region because of variations in the amount, intensity, and spatial distribution over the earth of the elements of weather and climate set forth in the previous section. The climatic elements vary temporally and regionally because of the operation of the climatic controls. Moreover, each of the climatic elements (solar energy, temperature, precipitation, and winds) also functions as a climatic control and influences each of the other elements, but there are other controls in addition.

The most fundamental control of both weather and climate is the unequal or differential 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. This 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.

1.1. Latitudinal Variation of 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.

1.2. 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.

1.3. 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, since it serves as a transporter of heat from regions of net heat gain to regions of net loss.

The scales of atmospheric pressure and atmospheric motion 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 wind systems are important factors in determining climate. Some pressure and wind systems, especially the High Pressure Areas over the subtropical oceans, tend to be semi-permanent in position, and they too are of great climatic importance.

1.4. Ocean Currents

Ocean currents, both warm and cold, which are largely induced by the major wind systems, also serve as 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.

1.5 Major Terrain eatures

Since within the troposphere, the temperature normally decreases which increasing altitude, places at higher elevations are likely to have lower temperatures (and often also more precipitation) than adjacent lowlands. Thus, altitude is an important 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.

1.6 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.

In summary, the climates of the earth are determined by the interaction of a complex set of controls. The great difference in heating between low and high latitudes is of fundamental importance, as it induces atmospheric and oceanic flows which transport heat from low toward higher latitudes. However, the patterns of flow are greatly modified by the latitudinal shifting of the zone of maximum heating which occurs with the progression of the seasons, by the distribution of continents and oceans, and by the location of major terrain obstacles. In addition, many local geographical features leave delicate, although often important, imprints on climate.

Section 3: General Circulation of Atmosphere over the globe, Pressure and Wind Belts, Distribution of pressure and temperature over the surface of the earth, Equatorial Trough and ITCZ

The general circulation of the atmosphere – the largest and most persistent scale of motion – represents the atmosphere's response to its global setting. The most prominent features of this setting are: (1) the large latitudinal variation of atmospheric heating, (2) the northward and southward displacement of the zone of maximum heating during the course of a year, (3) the strengthening of the north-south gradient of heating in the winter hemisphere and its weakening in the summer hemisphere, (4) the distribution of continents and oceans, and (5) the rotation of the earth.

Although the distribution of continents and oceans leads to important east-west heating contrasts in some regions of the world, the north-south heating differences are dominant for the earth as a whole. While the north-south variation of heating initiates northward or southward atmospheric motions (meridional flow), the earth's rotation is very effective in turning the flow toward the east or west (zonal flow). Consequently, the general circulation is principally characterized by extensive zonal wind systems.

Because the general circulation of the atmosphere and oceans represents the time-averaged large-scale motion, it must somehow provide a pole ward transport of energy, for if it did not, high latitudes would grow continually colder and low latitudes continually warmer. In addition, the time-averaged atmospheric flow must transport momentum from the tropics, where the winds are easterly, to higher latitudes, where they are westerly.

1. Theories of the General Circulation of the Atmosphere

For nearly three centuries, scientists have sought to explain the cause of the atmosphere's general circulation, yet even today it is not fully understood. \One of the early theories was put forth by George Hadley, a British lawyer, who in 1735, attempted to explain the existence of the persistent northeast winds in the tropics north of the equator.These steady winds were known as the trade *winds* because their steadiness favored commerce during the era of the sailing ship.

Hadley concluded that strong solar heating in equatorial latitudes causes a general rising motion of air along the equator, with this air flowing pole ward at high elevations. As the pole ward-flowing air cools, it becomes heavier and sinks. At low elevations, air then flows equator ward to replace the rising warm air, thus forming a continuous circulation cell oriented north-south along the meridians. Such a meridional cell is known as a Hadley cell. It is a direct circulation – rising warm and sinking cold air.

Hadley explained the northeast and southeast trade winds as resulting from the fact that on the rotating earth a point on the equator has a greater eastward velocity than a point at higher latitudes. He thus concluded that as air in the lower branch of a meridional cell flows equator ward, it travels into a region of the earth that is moving more rapidly eastward. This gives the air an easterly component (relative to the earth), which added to its equator ward motion produces the northeast trade winds of the Northern Hemisphere and the southeast trade winds of the Southern Hemisphere.

A current view of some of the major features of the general circulation is shown schematically in Fig. 1.

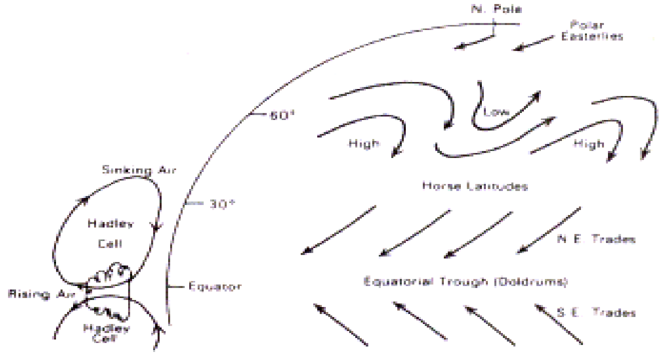

Fig 1: A schematic of General Circulation of the atmosphere

Between the equator and about latitudes 30ºN and 30ºS, the general circulation is similar to Hadley's description, while pole ward of these latitudes, is the polar vortex with its wavelike structure. Because of the strong solar heating in equatorial latitudes, air is warmed, rises and flows pole ward in each hemisphere. As it moves away from the equator at high elevations, the air loses heat through long-wave radiation, so that by the time it reaches 30ºN or 30ºS, it has cooled sufficiently to sink. The sinking branch of the Hadley cell coincides with the subsidence that is observed in the subtropical anticyclones. Air in the equator ward moving return branches of the Hadley cells is turned by the Coriolis force, to the right in Northern Hemisphere and to the left in the Southern Hemisphere. This leads to tropical easterlies or trades. On the other hand, the Coriolis force turns air in the upper pole ward-flowing branches toward the east, producing the westerlies which are found above the pole ward portions of the tropical easterlies (Fig. 2).

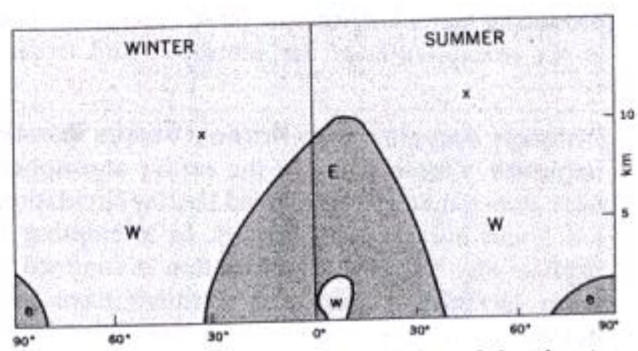

Fig 2: A pole ward cross-section of the planetary winds up to

about 15 kms above the earth's surface.

[E: Tropical Easterlies or trades, W: Westerlies, z: average location of the Jet Stream, w: Equatorail westerlies, e:polar easterlies]

Thus, it is the earth's rotation that causes the general circulation to be mainly zonal. Although the zonal flow predominates, averages also reveal a meridional component to the flow as shown in the Hadley cells of Fig. 1.

The Hadley cells accomplish certain major atmospheric processes: (1) Their upper-level branches transport energy from equatorial latitudes to about 30^{o}N and 30^{o}S latitude; (2) their lower branches transport moisture evaporated from the subtropical latitudes to equatorial latitudes, where it contributes to the heavy equatorial rains; and (3) the rising of warm air in equatorial latitudes and sinking of cooler air in the subtropics (a direct circulation) is a process which transforms total potential energy into kinetic energy, thereby making the Hadley cells a major source of the atmosphere's kinetic energy in low latitudes.

Although zonal averages reveal the existence of the Hadley cells, there are large longitudinal and seasonal variations in the strength and location of these circulations. Over some longitudes the meridional components are pronounced, while in others they are weak or absent. Averaged over all longitudes, the Hadley cell is stronger in the winter hemisphere than in the summer hemisphere. Moreover, the rising branch of the cell migrates southward and northward with the changing seasons, reaching, for example, as far pole ward as about 30^{o}N over southern Asia in July.

There are also east-west-oriented circulations, particularly in the subtropics and tropics, which are apparently related to the distribution of continents and oceans. In some longitudes, particularly during the Northern Hemisphere summer, these mean east-west circulations are quite prominent. They appear to play a crucial role in producing major longitudinal (east-west) differences in the precipitation of the subtropics and tropics.

2. The Observed General Circulation of the Atmosphere

If the earth's surface were completely homogeneous (for example, entirely water), the general circulation of the atmosphere might be characterized by rather ideal, clearly recognizable flow patterns, symmetrical with respect to the equator. But the real earth has an irregular pattern of continents and oceans, particularly in the Northern Hemisphere. This basic irregularity, which is further complicated by seasonal differences in the heating and cooling patterns, results in a circulation which departs from an ideal, symmetrical pattern.

2.1 The Averaged Pressure and Wind

January and July distribution of Sea-Level Pressure: Figure 3 depicts January and July profiles of the zonally averaged (i.e., averaged over all longitudes) sea-level pressure, while Figs. 4 and 5 are map portrayals of average sea-level pressure.

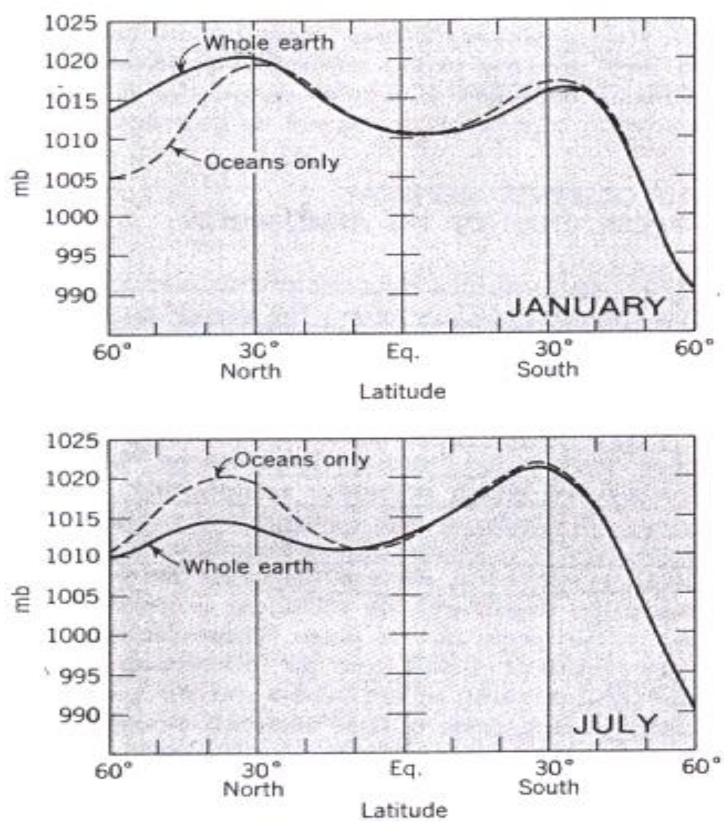

Fig. 3: Profiles of Sea Level Pressure from 600 N to 600 S, averaged for all longitudes, at the time of extreme seasons.

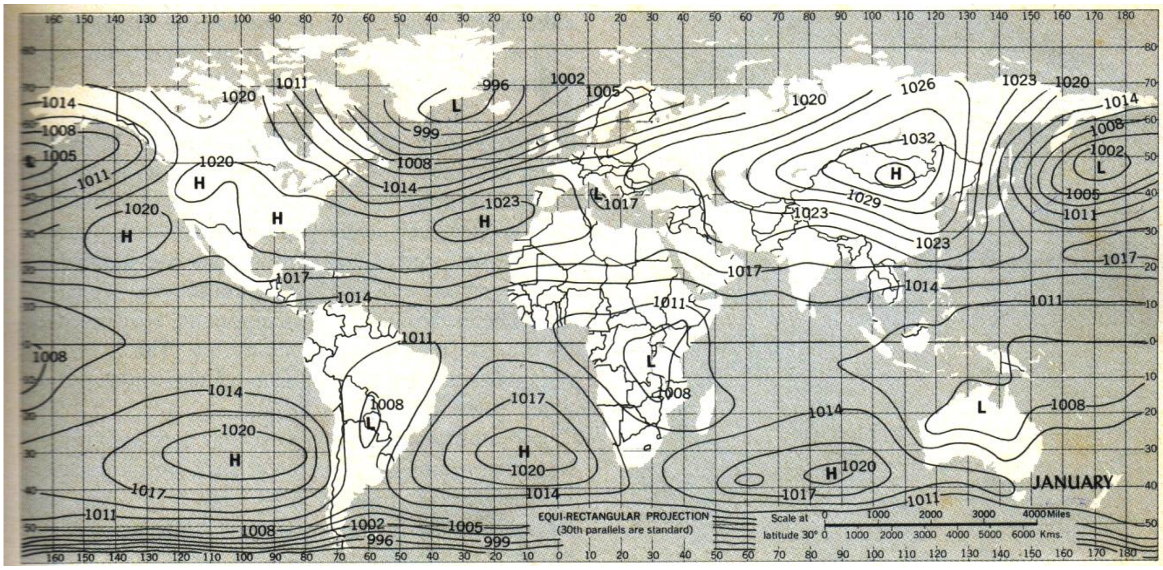

Fig 4: Distribution of Sea Level Pressure (hPa) in January

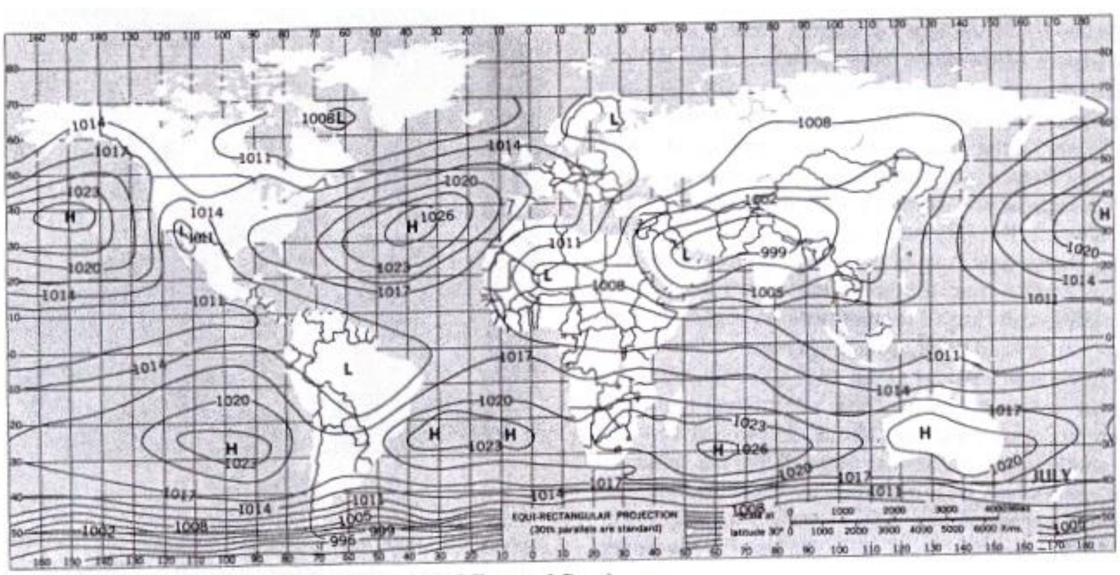

Fig 5: Distribution of Sea Level Pressure (hPa) in July

The following features are observed:

1. Pressure belts and cells, like belts of solar energy and temperature, shift generally northward in July and southward in January – a fact of crucial importance to climate. This latitudinal migration is revealed in Fig. 3. For example, the lowest pressure in the tropics is near 12^{o}N in July and about 5^{o}S in January.
2. The atmospheric pressure, averaged over an entire hemisphere, is greater in the winter hemisphere than in the summer hemisphere. This implies that during the progression of the seasons, there is a transfer of atmospheric mass across the equator from the summer to the winter hemisphere.
3. At most latitudes, the gradients of pressure are higher in the winter hemisphere than those in the summer hemisphere. This indicates that winds tend to be stronger in the winter hemisphere.
4. The subtropical belts of high pressure are most continuous in the winter hemisphere; in the summer hemisphere they are weakened by the heated continents (Figs. 4 and 5). These subtropical cells are best developed over the eastern sides of the oceans and are weaker toward the western sides. In the Northern Hemisphere in July, the subtropical highs over the eastern portions of the oceans extend well into the middle latitudes, strongly affecting the climate of the western sides of the continents.
5. In sub polar regions, sea-level pressure is low.In the higher latitudes of the Southern Hemisphere in Figs. 4 and 5, the averages for both extreme months show a deep and essentially continuous belt of low pressure. But in the Northern Hemisphere the sub polar low appear as cells over the oceans. In January a deep low-pressure cell called the Icelandic low occupies the North Atlantic, while another cell, the Aleutian low, is present in the North Pacific. In July the Icelandic low greatly weakens, and the Aleutian low disappears.
6. In January, a strong high-pressure cell forms in the higher middle latitudes of the cold Eurasian continent, and a weaker high appears over the smaller North American continent. In July, the warm continents tend to be occupied by low pressure. The low extending from Arabia to northern India is especially prominent.

3. Equatorial trough and Inter Tropical Convergence Zone [ITCZ]

In equatorial latitudes, there is a weak, usually broad trough of low pressure – the equatorial trough. In July, it is found in the low latitudes of the Northern Hemisphere; in January, it is displaced southward, lying mainly, but not entirely, in Southern Hemisphere low latitudes. For the year as a whole, its average position is a few degrees north of the equator, reflecting a slight asymmetry in the global pattern of heating. Because of the greater land mass of the Northern Hemisphere in low latitudes, the zone of annual maximum heating appears to be displaced slightly into the Northern Hemisphere. The equatorial trough more or less coincides with this zone.

In some longitudes, the equatorial trough is quite broad, with an extensive area of light and variable winds (the doldrums). At other longitudes, it is greatly restricted, with the northeast and southeast trades converging along a very narrow zone. In still other longitudes, the equatorial trough is absent.

Within the equatorial trough, is the Inter Tropical Convergence Zone (ITCZ), along which the northeast and southeast trades converge. In some longitudes, it is well defined, but in others it is weak or absent. At times, more than one convergence zone appears to exist. While the equatorial trough is, in general, characterized by weak rising motions and showery precipitation, the greatest activity is found along the ITCZ. Moreover, the heavy, convective precipitation occurs mainly in weak, ill-defined disturbances which form along the ITCZ. Because the equatorial air is very humid and relatively unstable, only slight convergence is needed to cause development of cumulus clouds and thundershowers.
