GEOGRAPHY

A. Physical Geography

I. Introduction:

1. Evolution of the Universe: About 11 to 15 billion years ago all of the matter and energy in the Universe was concentrated into an area the size of an atom. At this moment, matter, energy, space and time did not exist. Then suddenly, the Universe began to expand at an incredible rate and matter, energy, space and time came into being (the Big Bang). As the Universe expanded, matter began to coalesce into gas clouds, and then stars and planets. Our solar system formed about 5 billion years ago when the Universe was about 65% of its present size (Figure 2). Today, the Universe continues to expand.

Figure 1: Hubble Space Telescope view of a distant cluster of galaxies near the beginning of time.

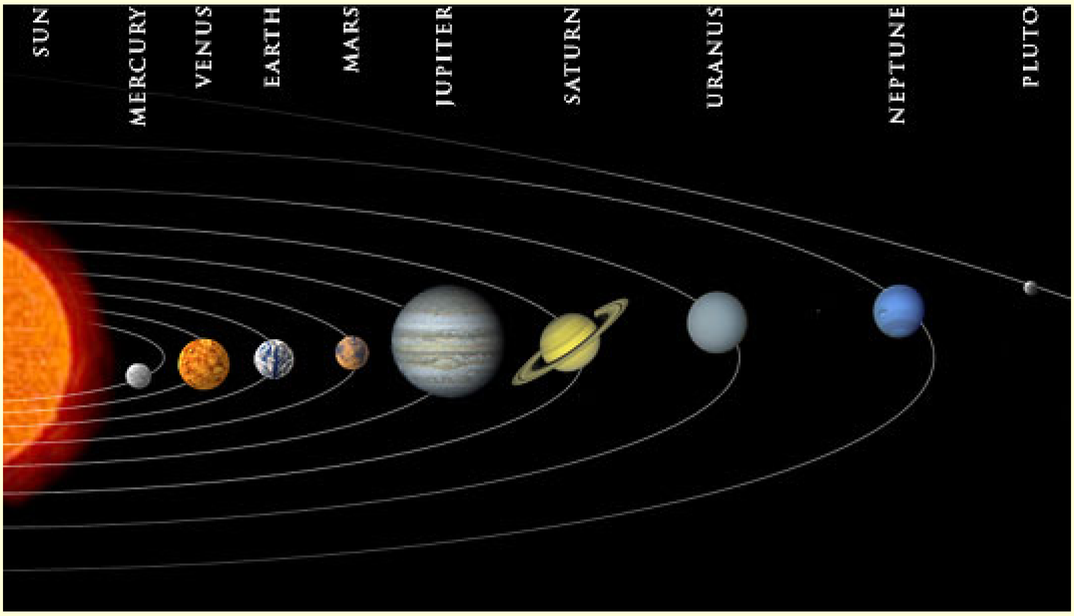

Figure 2: Our solar system began forming about 5 billion years ago as gas clouds coalesce into planets and a star. Today, the solar system contains nine commonly recognized planets and the Sun.

Why do Most Scientists Accept the Big Bang Theory?

The acceptance of this theory by the scientific community is based on a number of observations. These observations confirm specific predictions of the Big Bang theory. In a previous section, we learned that scientists test their theories through deduction and falsification. Predictions associated with the Big Bang theory that have been tested by this process are:

1. If the Big Bang did occur, all of the objects within the Universe should be moving away from each other. In 1929, Edwin Hubble documented that the galaxies in our Universe are indeed moving away from each other.
2. The Big Bang should have left an "afterglow" from the explosion. In the 1960s, scientists discovered the existence of cosmic background radiation, the so-called "afterglow" after the Big Bang explosion. Our most accurate measurements of this cosmic radiation came in November 1989, by the Cosmic Background Explorer (COBE) satellite. The measurements from this satellite tested an important prediction of the Big Bang theory. This prediction suggests that the initial explosion that gave birth to the Universe should have created radiation with a spectrum that follows a blackbody curve. The COBE measurements indicated that the spectrum of the cosmic radiation varied from a blackbody curve by only 1%. This level of error is considered insignificant.
3. If the Universe began with a Big Bang, extreme temperatures should have caused 25 percent of the mass of the Universe to become helium. This is exactly what is observed.
4. Matter in the Universe should be distributed homogeneously. Astronomical observations from the Hubble Space Telescope do indicate that matter in the Universe generally has a homogeneous distribution.

How will the Universe End?

Cosmologists have postulated two endings to the Universe. If the Universe is infinite or has no edge, it should continue to expand forever. A Universe that is finite or closed is theorized to collapse when expansion stops because of gravity. The collapse of the Universe ends when all matter and energy is compressed into the high energy, high-density state from which it began. This scenario is of course called the Big Crunch. Some theorists have suggested that the Big Crunch will produce a new Big Bang and the process of an expanding Universe will begin again. This idea is called the oscillating Universe theory.

2. **The Earth:** Scientists believe the Earth began its life about 4.6 billion years ago. The Earth formed as cosmic dust lumped together to form larger and larger particles until 150 million years had passed. At about 4.4 billion years, the young Earth had a mass similar to the mass it has today. The continents probably began forming about 4.2 billion years ago as the Earth continued to cool. The cooling also resulted in the release of gases from the lithosphere, much of which formed the Earth's early atmosphere. Most of the Earth's early atmosphere was created in the first one million years after solidification (4.4 billion years ago). Carbon dioxide, nitrogen, and water vapor dominated this early atmosphere. Table 1 below describes the three major stages of development of the atmosphere.

Table 1: Evolution of the Earth's atmosphere

Name of Stage	Duration of Stage (Billions of Years Ago)	Main Constituents of the Atmosphere	Dominant Processes and Features
Early Atmosphere	4.4 to 4.0	H_2O, hydrogen cyanide (HCN), ammonia (NH_3), methane (CH_4), sulfur, iodine, bromine, chlorine, argon	Lighter gases like hydrogen and helium escaped to space. All water was held in the atmosphere as vapor because of high temperatures.
Secondary Atmosphere	4.0 to 3.3	At 4.0 billion H_2O, CO_2, and nitrogen (N) dominant. Cooling of the atmosphere causes precipitation and the development of the oceans. By 3.0 billion CO_2, H_2O, N_2 dominant. O_2 begins to accumulate.	Continued release of gases from the lithosphere. Water vapor clouds common in the lower atmosphere. Chemosynthetic bacteria appear on the Earth some time between 3.9 and 3.5 billion years ago. Life begins to modify the atmosphere.
Living Atmosphere	3.3 to Present	N_2 - 78%, O_2 - 21%, Argon - 0.9%, CO_2 - 0.036%	Development, evolution and growth of life increases the quantity of oxygen in the atmosphere from <1% to 21%. 500 million years ago concentration of atmospheric oxygen levels off. Humans begin modifying the concentrations of some gases in the atmosphere beginning around the year 1700.

As the Earth continued to cool, the water vapor found in the atmosphere condensed to form the oceans and other fresh water bodies on the continents. Oxygen began accumulating in the atmosphere through photo-dissociation of O2 from water, and by way of photosynthesis (life). The emergence of living organisms was extremely important in the creation of atmospheric oxygen and ozone. Without ozone, life could not exist on land because of harmful ultraviolet radiation.

Most of the build up of oxygen in the atmosphere occurred between 2.1 and 1.5 billion years ago as a direct result of photosynthesis from ocean based plants like algae. At about 450 million years ago, there was enough oxygen in the atmosphere to allow for the development of a stratospheric ozone layer that was thick enough to keep terrestrial life protected from ultraviolet radiation. As a result, terrestrial life began its development and expansion at this time. Table 2 describes the timing of the evolutionary development of some of the Earth's dominant forms of life before and after 450 million years before present (BP).

Table 2: Approximate origin time of the major plant and animal groups.

Organism Group	Time of Origin
Marine Invertebrates	570 Million Years Ago
Fish	505 Million Years Ago
Land Plants	438 Million Years Ago
Amphibians	408 Million Years Ago
Reptiles	320 Million Years Ago
Mammals	208 Million Years Ago
Flowering Plants (Angiosperms)	140 Million Years Ago

Facts about the Earth: The Earth, the largest of the inner planets of the Solar System and the third closest planet to the Sun, is the sole home of human life in the entire Solar System and is the fifth largest planet. It is at a distance of 149,597,900 km from the Sun.

The Earth is a unique planet. The shape of the Earth approximates an oblate spheroid, a sphere flattened along the axis from pole to pole such that there is a bulge around the equator. This bulge results from the rotation of the Earth, and causes the diameter at the equator to be 43 km larger than the pole-to-pole diameter. Earth is a terrestrial planet, meaning that it is a rocky body, rather than a gas giant like Jupiter. It is the largest of the four solar terrestrial planets in size and mass. Of these four planets, Earth also has the highest density, the highest surface gravity, the strongest magnetic field, and fastest rotation. It is the only planet containing ample water and air around it. The temperature on the Earth is also suitable for human life.

Mass of Earth :	5.9736 x 10^{24} kg
Density of Earth :	5.517 times that of water.
Volume of Earth :	1,083,208,840,000 cubic km.
Equatorial Circumference :	40,075.03 km.
Polar or Meridianal Circumference:	40,007.89 km.
Equatorial Diameter :	12,756 km.
Polar Diameter :	12,714 km

Earth's Axis is an imaginary line which runs right across and passes through the centre of the Earth. The Earth spins round its axis which always remains inclined at an angle of 66.5^0 to the plane of the Earth's orbit.

Rotation is the spinning of the Earth on its axis. The Earth rotates from west to east and takes 23 hours, 56 minutes and 4.091 seconds to complete one rotation.The velocity of the Earth's rotation varies between nearly 1690 km per hour at equator, 845 km per hour at 60° N and S and zero at the poles.At the Equator, there is a 12-hour day and a 12-hour night. North of 66.5^0 N, there is continuous daylight; south of $66V2^0$ S there is continuous night. Days become longer with increasing latitude north, shorter with increasing latitude south.

Revolution is the movement of the Earth around the Sun simultaneously with its rotation. It takes 365 days, 5 hours, 48 minutes and 45.51 seconds for it to complete one revolution.

Orbit is the elliptical path of the Earth's revolution round the Sun.

Perihelion is closest to the Sun. The Earth reaches its perihelion on January 3 approximately when it is 147.3 million kilometres from the Sun.

Aphelion is the point in the Earth's or other planet's orbit which is farthest from the Sun. The Earth reaches its aphelion on July 4 when it is nearly 152 million kilometres away from the Sun.

Leap Year is the year in which the month of February has 29 days. Leap year occurs once in four years. The Earth actually takes 365 days, 5 hours, 48 minutes and 45.51 seconds to complete one revolution round the Sun. For the sake of convenience, the year is rounded off as 365 days. The remaining one-fourth of the day has to be accounted for, since a year represents the time taken by the Earth to complete one revolution round the Sun. Therefore, once in four years one day is added to the year in the month of February, thus, making it a leap year except centesimal years not divisible by 400. For instance, between 2000 and 2400, 2000 and 2400 are leap years but 2100, 2200 and 2300 are not leap years being indivisible by 400.

Moon- earth's satellite The Moon is the only natural satellite of the Earth. It is over one quarter size of the Earth with diameter of 3,476 km. It is also the nearest neighbour of the Earth at a mean distance of 384,400 km centre to centre, 376,284 km surface to surface. Its average orbital speed is 3,680 km per hour. The Earth is being orbited by the Moon. The period of rotation of the Moon is equal to its period of revolution around the Earth. This period is 27 days, 7 hours, 43 minutes and 11.47 seconds. Over 59 percent of the Moon's surface is directly visible from the Earth. Six American spacecraft from 1969 to 1972 brought 12 astronauts to walk on the surface of the Moon.

Land and Sea Surface: The estimated total surface area of the Earth is 510,066,100 sq km, of which the sea or hydrosphere covers five-sevenths or, more accurately, 70.92% and the land or lithosphere two-sevenths or 29.08 %. The mean depth of the hydrosphere is 3,554 metres.

Map Reading

Equator represents the imaginary line passing round the Earth midway between the north and south poles. It, thus, divides the Earth into two equal halves (the Northern and Southern hemispheres).

Meridians represent the imaginary lines drawn out on the global map, from pole to pole and perpendicular to the Equator.

Prime Meridian is the 0° meridian which passes through Greenwich, a place near London. It is also known as the Greenwich Meridian.

Longitudes are the equidistant lines drawn east and west of the Greenwich Meridian. They denote angular distances of a place due east or west of the Greenwich Meridian. They converge at the two poles.

Latitudes are parallel lines drawn north and south of the Equator. They indicate angular distance of a place in relation to the Equator.

Tropics are literally turning points. They refer to those parallels where the Sun is imagined to halt its movement and turn about northward or southward as the case may be. The 23'/2° PARALLEL AS THE Tropic of Capricorn

Great Circles are imaginary circles whose plane passing through the centre of the Earth bisects it into two equal halves. For example, equator is a great circle. Parts of opposite meridian also constitute great circles. The number of great circles which can be drawn on a sphere is limitless. They are used to determine shortest distance between any two points on the surface of the Earth, cutting down the travelling costs by aircraft and ships.

Small Circles are similar to the great circles. However, they differ from great circles in the sense that their plane does not pass through the Earth's centre. All the parallels of latitude north and south of the Equator make small circles.

Contour Lines join places of equal height above sea level on a map.

Map Projection is the method by which the curved surface of the Earth is depicted on a flat surface of plane. In other words, it represents the projection of curved lines of latitude and longitude on a global map.

Zenithical Projection is adopted to construct equal area or equidistant maps. Equal area projection is frequently shown as a polar projection. Here, concentric parallels are drawn with the pole at the centre and with meridians as straight lines converging on the pole.

Conical Projection represents a part of the globe, projected upon a tangent cone, which in effect is opened up and laid flat.

Cylindrical Projection represents the globe as projected upon a surrounding cylinder, which, in effect, is opened up and laid out. Here, the lines of latitude and longitude are drawn as straight lines intersecting at right angles.

Mercator Projection represents the map of global area in a cylindrical type of projection, where the lines of latitude and longitude are drawn as straight lines intersecting at right angles instead of the curved lines they ought to be. This projection can give correct shapes only for very small areas and their comparative size will be wrong.

3. **Earth Sun Geometry:** The term Earth rotation refers to the spinning of our planet on its axis. Because of rotation, the Earth's surface moves at the equator at a speed of about 467 m per second or slightly over 1675 km per hour. If you could look down at the Earth's North Pole from space you would notice that the direction of rotation is counter-clockwise (Figure 3). The opposite is true if the Earth is viewed from the South Pole. One rotation takes exactly twenty-four hours and is called a mean solar day. The Earth's rotation is responsible for the daily cycles of day and night. At any one moment in time, one half of the Earth is in sunlight, while the other half is in darkness. The edge dividing the daylight from night is called the circle of illumination. The Earth's rotation also creates the apparent movement of the Sun across the horizon.

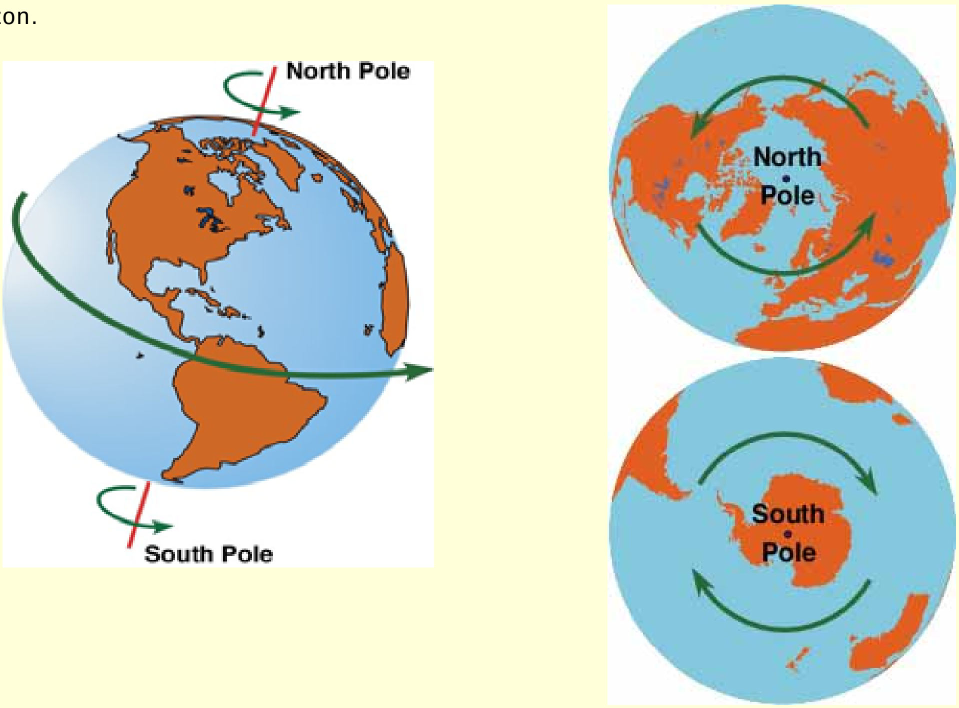

Figure 3: The movement of the Earth about its axis is known as rotation. The direction of this movement varies with the viewer's position. From the North Pole the rotation appears to move in a counter-clockwise fashion. Looking down at the South Pole the Earth's rotation appears clockwise.

The orbit of the Earth around the Sun is called an Earth revolution. This celestial motion takes 365.26 days to complete one cycle. Further, the Earth's orbit around the Sun is not circular, but oval or elliptical (see Figure 4). An elliptical orbit causes the Earth's distance from the Sun to vary over a year. Yet, this phenomenon is not responsible for the Earth's seasons! This variation in the distance from the Sun causes the amount of solar radiation received by the Earth to annually vary by about 6%. Figure 4 illustrates the positions in the Earth's revolution where it is closest and farthest from the Sun. On January 3, perihelion, the Earth is closest to the Sun (147.3 million km). The Earth is farthest from the Sun on July 4, or aphelion (152.1 million km). The average distance of the Earth from the Sun over a one-year period is about 149.6 million km.

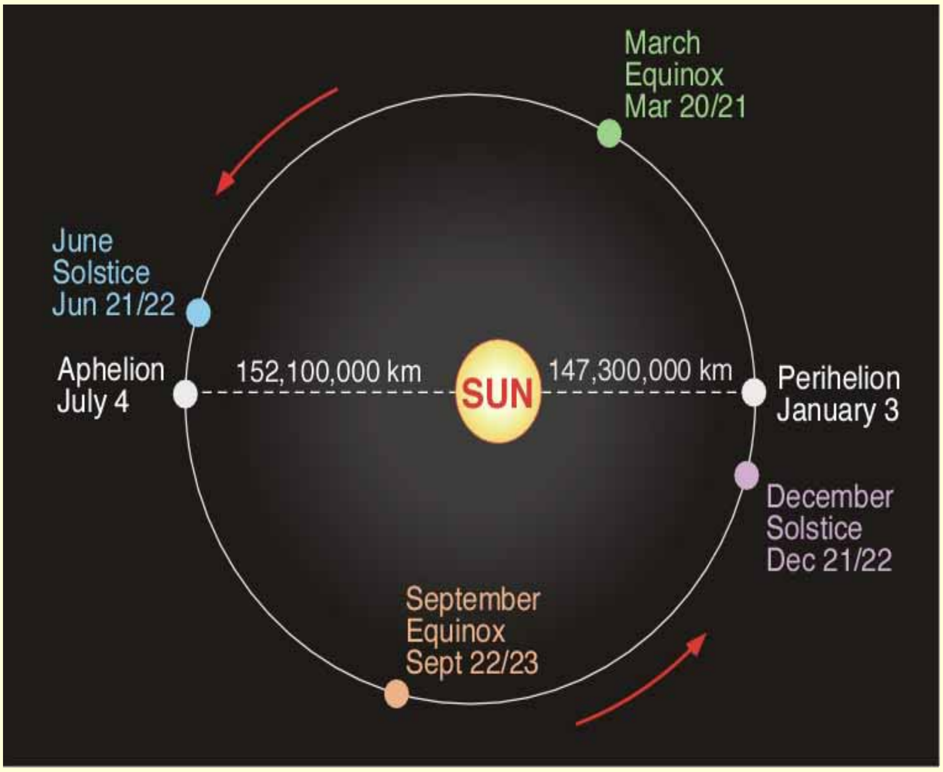

Figure 4: Position of the equinoxes, solstices, aphelion, and perihelion relative to the Earth's orbit around the Sun.

Tilt of the Earth's Axis: The ecliptic plane can be defined as a two-dimensional flat surface that geometrically intersects the Earth's orbital path around the Sun. On this plane, the Earth's axis is not at right angles to this surface, but inclined at an angle of about 23.5° from the perpendicular. Figure 5 shows a side view of the Earth in its orbit about the Sun on four important dates: June solstice, September equinox, December solstice, and March equinox. Note that the angle of the Earth's axis in relation to the ecliptic plane and the North Star on these four dates remains unchanged. Yet, the relative position of the Earth's axis to the Sun does change during this cycle. This circumstance is responsible for the annual changes in the height of the Sun above the horizon. It also causes the seasons, by controlling the intensity and duration of sunlight received by locations on the Earth. Figure 6 shows an overhead view of this same phenomenon. In this view, we can see how the circle of illumination changes its position on the Earth’s surface. During the two equinoxes, the circle of illumination cuts through the North Pole and the South Pole. On the June solstice, the circle of illumination is tangent to the Arctic Circle (66.5° N) and the region above this latitude receives 24 hours of daylight. The Arctic Circle is in 24 hours of darkness during the December solstice.

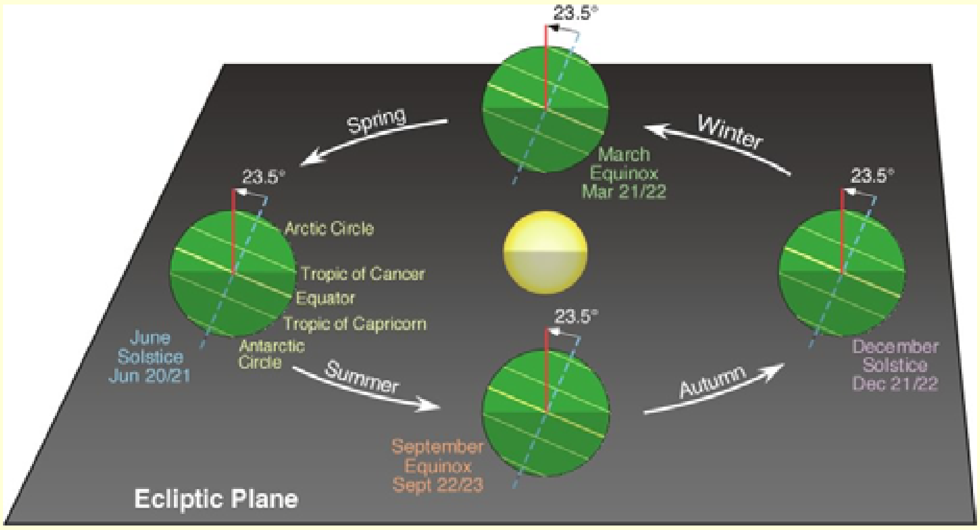

Figure 5: The Earth's rotational axis is tilted 23.5° from the red line drawn perpendicular to the ecliptic plane. This tilt remains the same anywhere along the Earth's orbit around the Sun. Seasons are appropriate only for the Northern Hemisphere.

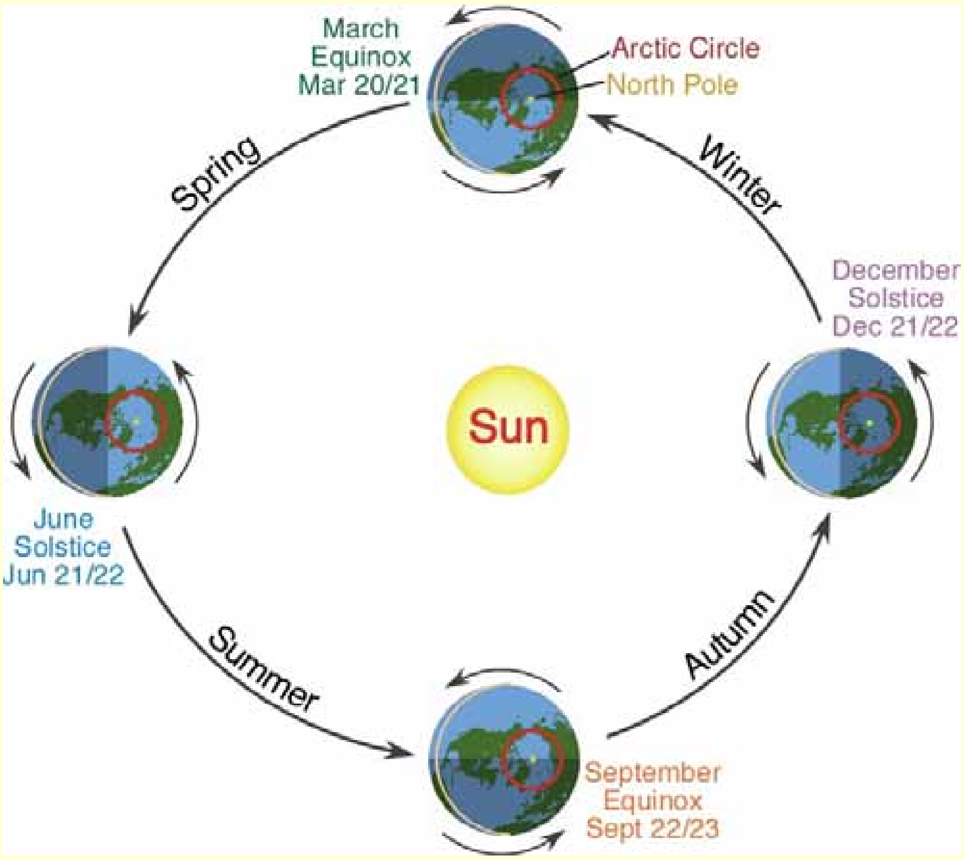

Figure 6: Annual change in the position of the Earth in its revolution around the Sun. In this graphic, we are viewing the Earth from a position in space that is above the North Pole (yellow dot) at the summer solstice, the winter solstice, and the two equinoxes. Note how the position of the North Pole on the Earth's surface does not change. However, its position relative to the Sun does change and this shift is responsible for the seasons. The red circle on each of the Earths represents the Arctic Circle (66.5 degrees N). During the June solstice, the area above the Arctic Circle is experiencing 24 hours of daylight because

the North Pole is tilted 23.5 degrees toward the Sun. The Arctic Circle experiences 24 hours of night when the North Pole is tilted 23.5 degrees away from the Sun in the December solstice. During the two equinoxes, the circle of illumination cuts through the polar axis and all locations on the Earth experience 12 hours of day and night. Seasons are appropriate only for the Northern Hemisphere.

On June 21 or 22 the Earth is positioned in its orbit so that the North Pole is leaning 23.5° toward the Sun. During the June solstice (also called the summer solstice in the Northern Hemisphere), all locations north of the equator have day lengths greater than twelve hours, while all locations south of the equator have day lengths less than twelve hours . On December 21 or 22 the Earth is positioned so that the South Pole is leaning 23.5 degrees toward the Sun. During the December solstice (also called the winter solstice in the Northern Hemisphere), all locations north of the equator have day lengths less than twelve hours, while all locations south of the equator have day lengths exceeding twelve hours.

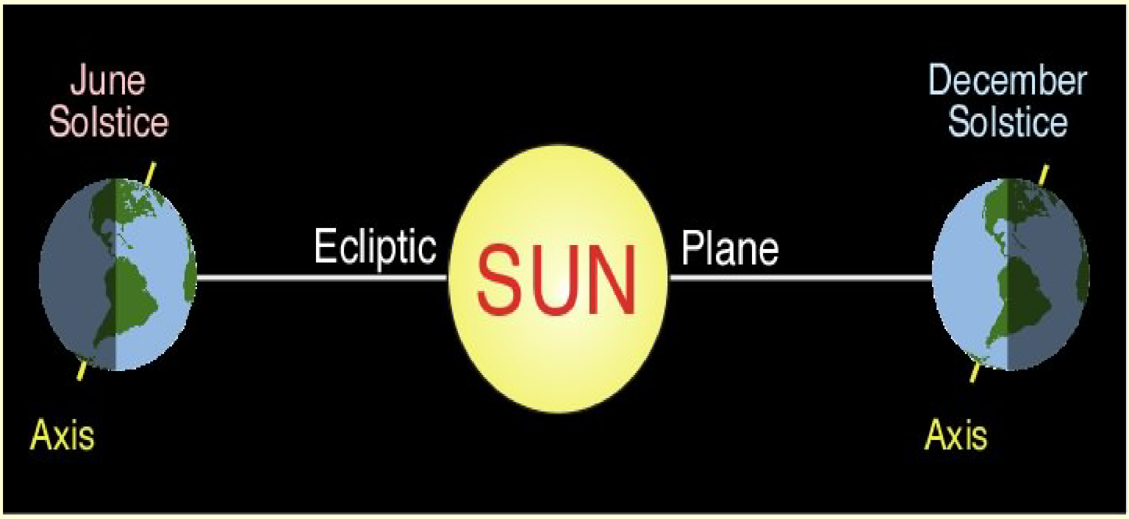

Figure 7: During the June solstice the Earth's North Pole is tilted 23.5 degrees towards the Sun relative to the circle of illumination. This phenomenon keeps all places above a latitude of 66.5degrees N in 24 hours of sunlight, while locations below a latitude of 66.5 degrees S are in darkness. The North Pole is tilted 23.5 degrees away from the Sun relative to the circle of illumination during the December solstice. On this date, all places above a latitude of 66.5 degrees N are now in darkness, while locations below a latitude of 66.5 degrees S receive 24 hours of daylight.

On September 22 or 23, also called the autumnal equinox in the Northern Hemisphere, neither pole is tilted toward or away from the Sun. In the Northern Hemisphere, March 20 or 21 marks the arrival of the vernal equinox or spring when once again the poles are not tilted toward or away from the Sun. Day lengths on both of these days, regardless of latitude, are exactly 12 hours.

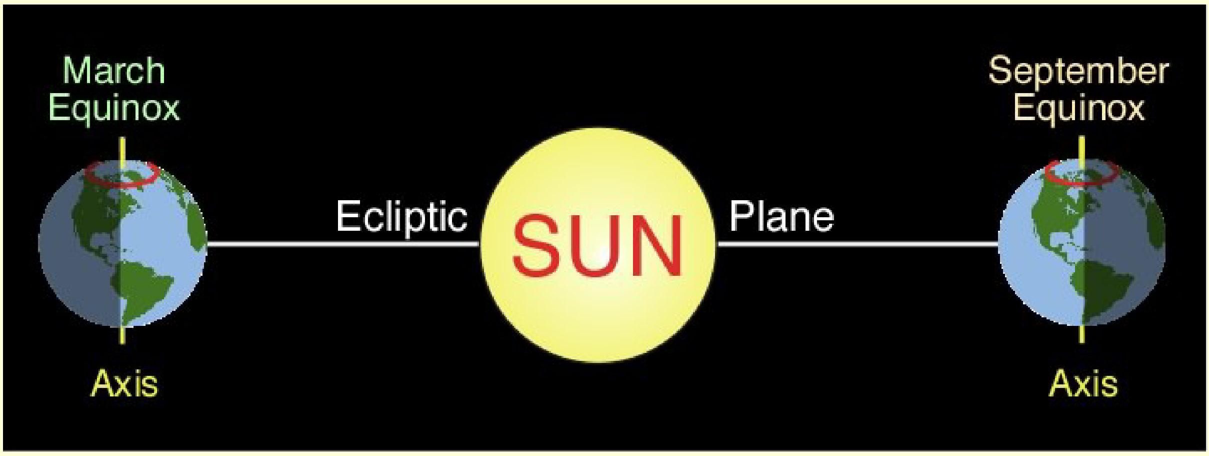

Figure 8: During the equinoxes, the axis of the Earth is not tilted toward or away from the Sun and the circle of illumination cuts through the poles. This situation does not suggest that the 23.5 degree tilt of the Earth no longer exists. The vantage point of this graphic shows that the Earth's axis is inclined 23.5 degrees toward the viewer for both dates . The red circles shown in the graphic are the Arctic Circle.

Axis Tilt and Solar Altitude: The annual change in the relative position of the Earth's axis in relationship to the Sun causes the height of the Sun or solar altitude to vary in our skies. Solar altitude is normally measured from either the southern or northern point along the horizon and begins at zero degrees. Maximum solar altitude occurs when the Sun is directly overhead and has a value of 90°. The total variation in maximum solar altitude for any location on the Earth over a one-year period is 47° (Earth's tilt 23.5° x 2 = 47°). This variation is due to the annual changes in the relative position of the Earth to the Sun. At 50 degrees North, maximum solar altitude varies from 63.5 degrees on the June solstice to 16.5 degrees on the December solstice (Figure 9). Maximum solar height at the equator goes from 66.5 degrees above the northern end of the horizon during the June solstice, to directly overhead on the September equinox, and then down to 66.5 degrees above the southern end of the horizon during the December solstice (Figure 10).

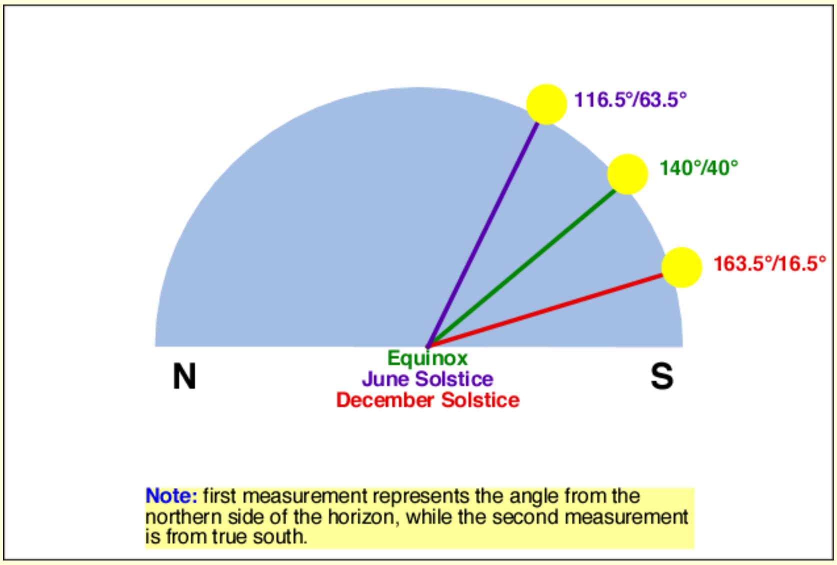

Figure 9: Variations in solar altitude at solar noon for 50 degrees North during the June solstice, equinox, and December solstice.

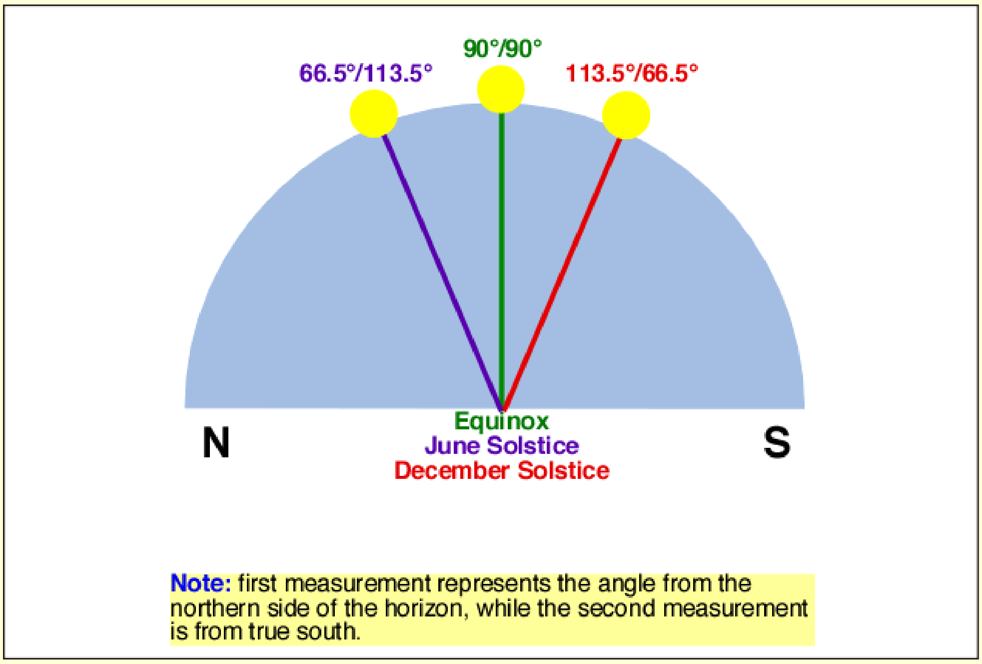

Figure 10: Variations in solar altitude at solar noon for the equator during the June solstice, equinox, and December solstice.

The location on the Earth where the Sun is directly overhead at solar noon is known as the subsolar point. The subsolar point occurs on the equator during the two equinoxes . On these dates, the equator is lined up with the ecliptic plane and the poles are in line with the circle of illumination. During the summer solstice, the subsolar point moves to the Tropic of Cancer (23.5° N) because at this time the North Pole is inclined 23.5° toward the Sun (Figures 11 and 12). Figure 12 shows how the subsolar point gradually changes from one day to the next over a period of one-year. Note that on this graph, the subsolar point is located at the Tropic of Capricorn (23.5° S) during the December solstice when the South Pole is angled 23.5° toward the Sun.

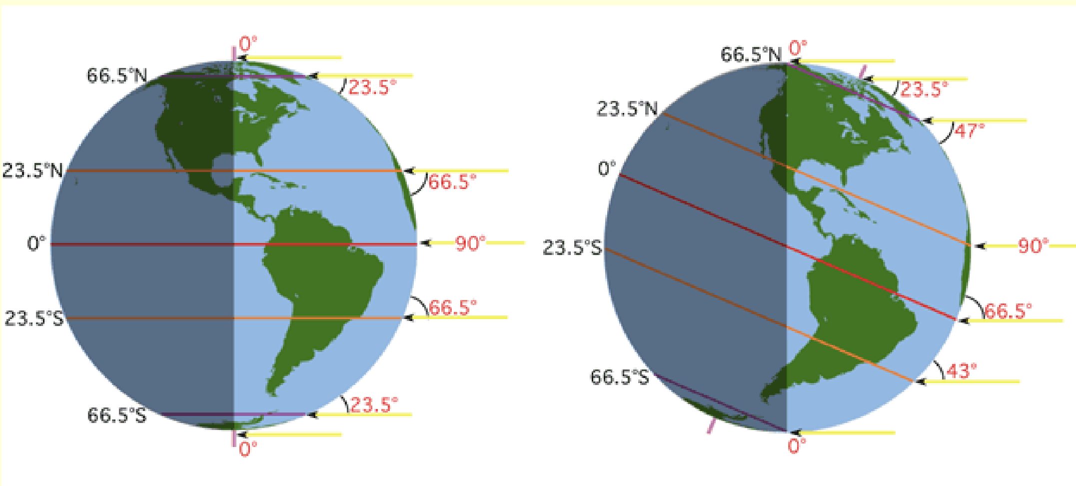

Figure 11: Relationship of maximum Sun height to latitude for the equinox (left) and June solstice (right). The red values on the right of the globes are maximum solar altitudes at solar noon. Black numbers on the left indicate the location of the Equator, Tropic of Cancer (23.5 degrees N), Tropic of Capricorn (23.5 degrees S), Arctic Circle (66.5 degrees N), and the Antarctic Circle (66.5 degrees S). The

location of the North and South Poles are also identified. During the equinox, the equator is the location on the Earth with a Sun angle of 90 degrees for solar noon. Note how maximum Sun height declines with latitude as you move away from the Equator. For each degree of latitude traveled maximum Sun height decreases by the same amount. At equinox, you can also calculate the noon angle by subtracting the location's latitude from 90. During the summer solstice, the Sun is now directly overhead at the Tropic of Cancer. All locations above this location have maximum Sun heights that are 23.5 degrees higher from the equinox situation. Places above the Arctic Circle are in 24 hours of daylight. Below the Tropic of Cancer the noon angle of the Sun drops one degree in height for each degree of latitude traveled. At the Antarctic Circle, maximum Sun height becomes 0 degrees and locations south of this point on the Earth are in 24 hours of darkness.

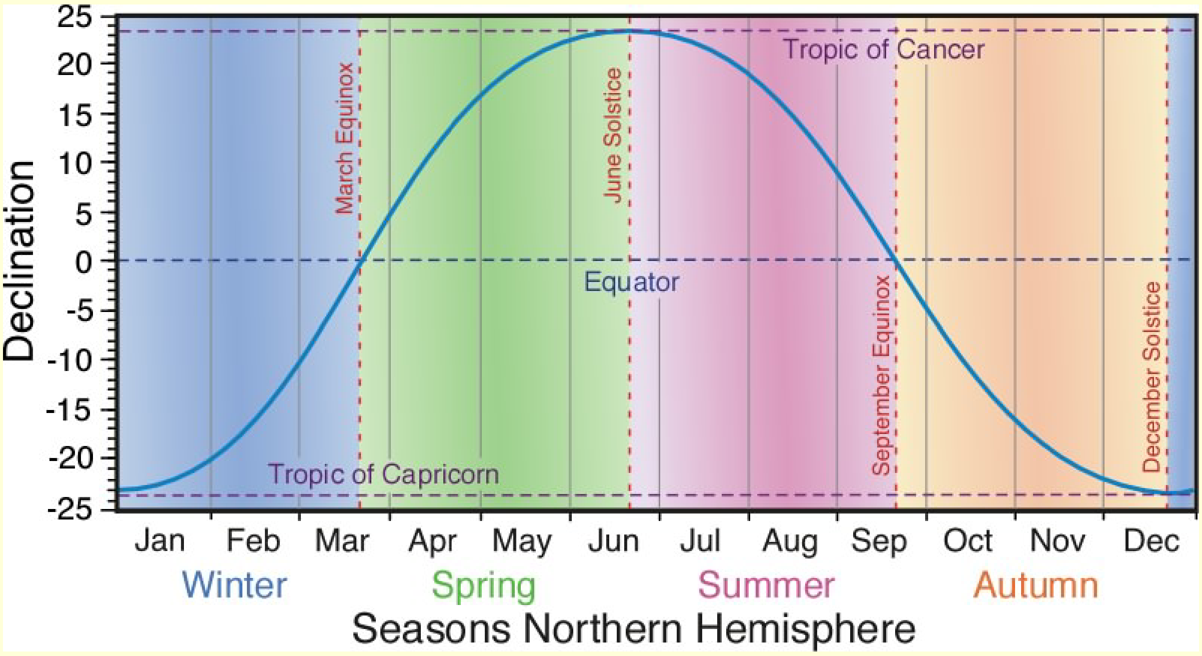

Figure 12: Angle of the Sun's declination and latitude of the subsolar point throughout the year. Seasons are for the Northern Hemisphere.

The following table describes the changes in solar altitude at solar noon for the two solstices and equinoxes. All measurements are in degrees (horizon has 180 degrees from True North to True South) and are measured from either True North or True South (whatever is closer).

Table 3: Maximum Sun altitudes for selected latitudes during the two solstices and equinoxes.

Location's Latitude	March Equinox March 20/21	June Solstice June 21/22	September Equinox September 22/23	December Solstice December 21/22
90 N	0 degrees	23.5 degrees	0 degrees	- 23.5 degrees
70 N	20 degrees	43.5 degrees	20 degrees	-3.5 degrees
66.5 N	23.5 degrees	47 degrees	23.5 degrees	0 degrees
60 N	30 degrees	53.5 degrees	30 degrees	6.5 degrees
50 N	40 degrees	63.5 degrees	40 degrees	16.5 degrees
23.5 N	66.5 degrees	90 degrees	66.5 degrees	43 degrees
0 degrees	90 degrees	66.5 degrees	90 degrees	66.5 degrees
23.5 S	66.5 degrees	43 degrees	66.5 degrees	90 degrees
50 S	40 degrees	16.5 degrees	40 degrees	63.5 degrees
60 S	30 degrees	6.5 degrees	30 degrees	53.5 degrees
66.5 S	23.5 degrees	0 degrees	23.5 degrees	47 degrees
70 S	20 degrees	-3.5 degrees	20 degrees	43.5 degrees
90 S	0 degrees	- 23.5 degrees	0 degrees	23.5 degrees

Finally, the altitude of the Sun at solar noon can also be calculated with the following simple equation:

Altitude A = 90 - Latitude L +/- Declination D

In this equation, L is the latitude of the location in degrees and D is the declination. The equation is simplified to A = 90 - L if Sun angle determinations are being made for either equinox date. If the Sun angle determination is for a solstice date, declination (D) is added to latitude (L) if the location is experiencing summer (northern latitudes = June solstice; southern latitudes = December solstice) and subtracted from latitude (L) if the location is experiencing winter (northern latitudes = December solstice; southern latitudes = June solstice). All answers from this equation are given relative to True North for southern latitudes and True South for northern latitudes. For our purposes only the declinations of the two solstices and two equinoxes are important. These values are: June solstice D=23.5, December solstice D=23.5, March equinox D=0, and Septemeber equinox D=0. When using the above equation in tropical latitudes, Sun altitude values greater than 90 degrees may occur for some calculations. When this occurs, the noonday Sun is actually behind you when looking towards the equator. Under these circumstances, Sun altitude should be recalculated as follows:

Altitude A = 90 - (originally calculated Altitude A - 90)

4. **The Natural Spheres:** From the standpoint of Physical Geography, the Earth can be seen to be composed of four principal components:

1. Lithosphere: describes the solid inorganic portion of the Earth (composed of rocks, minerals and elements). It can be regarded as the outer surface and interior of the solid Earth. On the surface of the Earth, the lithosphere is composed of three main types of rocks:

- Igneous - rocks formed by solidification of molten magma.
- Sedimentary - rocks formed by the alteration and compression of old rock debris or organic sediments.
- Metamorphic - rocks formed by alteration of existing rocks by intense heat or pressure.

2. Atmosphere: is the vast gaseous envelope of air that surrounds the Earth. Its boundaries are not easily defined. The atmosphere contains a complex system of gases and suspended particles that behave in many ways like fluids. Many of its constituents are derived from the Earth by way of chemical and biochemical reactions.

3. Hydrosphere: describes the waters of the Earth (see the hydrologic cycle). Water exists on the Earth in various stores, including the atmosphere, oceans, lakes, rivers, soils, glaciers, and groundwater. Water moves from one store to another by way of: evaporation, condensation, runoff, precipitation, infiltration and groundwater flow.

4. Biosphere: consists of all living things, plant and animal. This zone is characterized by life in profusion, diversity, and ingenious complexity. Cycling of matter in this sphere involves not only metabolic reactions in organisms, but also many abiotic chemical reactions.
All of these spheres are interrelated to each other by dynamic interactions, like biogeochemical cycling, that move and exchange both matter and energy between the four components.

II. **Atmosphere:** Atmosphere is the mass of air that extends outward from the surface of the Earth into space. The entire atmosphere is mixture of gases and weighs 5,700 trillion tonnes. A column of air weighing about one tonne is pressing downwards on our shoulders, but we do not feel this pressure as it is counter-balanced by the same pressure from within our bodies.The atmospheric air is composed of about 78% nitrogen and 21% oxygen. Besides, there are minute proportions* of other gases, including argon, carbon dioxide, helium, methane, hydrogen, ozone, neon, xenon, etc. The amount of carbon dioxide varies from place to place, being greatest around the cities and smallest in the countryside. Atmosphere also contains tiny particles of dust and some other substances. There are also varying amounts of water vapour, evaporated from the surface of the Earth and the oceans.

About 5/6th of the total mass of atmosphere and almost all the water vapour is confined to the lowest layer of atmosphere, called the troposphere. It contains 90% of the air and the tallest mountains. Most of the weather-related phenomena that we experience, originate from this zone. The temperature in die troposphere decreases upward till the ttopopause, which is the upper limit of the troposphere. Above this, there is lower stratosphere where conditions are relatively calm and, therefore, the jet aircrafts often fly there. However, in the upper stratosphere, strong winds blow. Beyond stratosphere is the ionosphere where temperature decreases sharply; it is -70°C at a height of about 80 km above the sea level. Then, the temperature starts rising sharply, reaching almost 2,000°C at a height of 400 km above the sea level. The ionosphere is so named because die thinly distributed gas molecules are ionised or electrically charged.

The atmosphere is essential for life on the Earth. Oxygen and carbon dioxide in the atmosphere are necessary for animal and plant life. The ozone layer in the stratosphere protects life on the Earth by absorbing most of the Sun's harmful radiation. The general circulation of atmosphere redistributes heat on the globe, thus performing the functions of a giant thermostat.

1. **Atmospheric Composition:** Table 1 lists the eleven most abundant gases found in the Earth's lower atmosphere by volume. Of the gases listed, nitrogen, oxygen, water vapor, carbon dioxide, methane, nitrous oxide, and ozone are extremely important to the health of the Earth's biosphere.

The table indicates that nitrogen and oxygen are the main components of the atmosphere by volume. Together these two gases make up approximately 99% of the dry atmosphere. Both of these gases have very important associations with life. Nitrogen is removed from the atmosphere and deposited at the Earth's surface mainly by specialized nitrogen fixing bacteria, and by way of lightning through precipitation. The addition of this nitrogen to the Earth's surface soils and various water bodies supplies much needed nutrition for plant growth. Nitrogen returns to the atmosphere primarily through biomass combustion and denitrification.

Oxygen is exchanged between the atmosphere and life through the processes of photosynthesis and respiration. Photosynthesis produces oxygen when carbon dioxide and water are chemically converted into glucose with the help of sunlight. Respiration is a the opposite process of photosynthesis. In respiration, oxygen is combined with glucose to chemically release energy for metabolism. The products of this reaction are water and carbon dioxide.

The next most abundant gas on the table is water vapor. Water vapor varies in concentration in the atmosphere both spatially and temporally. The highest concentrations of water vapor are found near the equator over the oceans and tropical rain forests. Cold polar areas and subtropical continental deserts are locations where the volume of water vapor can approach zero percent. Water vapor has several very important functional roles on our planet:

- It redistributes heat energy on the Earth through latent heat energy exchange.
- The condensation of water vapor creates precipitaion that falls to the Earth's surface providing needed fresh water for plants and animals.
- It helps warm the Earth's atmosphere through the greenhouse effect.

The fifth most abundant gas in the atmosphere is carbon dioxide. The volume of this gas has increased by over 35% in the last three hundred years. This increase is primarily due to human induced burning from fossil fuels, deforestation, and other forms of land-use change. Carbon dioxide is an important greenhouse gas. The human-caused increase in its concentration in the atmosphere has strengthened the greenhouse effect and has definitely contributed to global warming over the last 100 years. Carbon dioxide is also naturally exchanged between the atmosphere and life through the processes of photosynthesis and respiration.

Methane is a very strong greenhouse gas. Since 1750, methane concentrations in the atmosphere have increased by more than 150%. The primary sources for the additional methane added to the atmosphere (in order of importance) are: rice cultivation; domestic grazing animals; termites; landfills; coal mining; and, oil and gas extraction. Anaerobic conditions associated with rice paddy flooding results in the formation of methane gas. However, an accurate estimate of how much methane is being produced from rice paddies has been difficult to ascertain. More than 60% of all rice paddies are found in India and China where scientific data concerning emission rates are unavailable. Nevertheless, scientists believe that the contribution of rice paddies is large because this form of crop production has more than doubled since 1950. Grazing animals release methane to the environment as a result of herbaceous digestion. Some researchers believe the addition of methane from this source has more than quadrupled over the last century. Termites also release methane through similar processes. Land-use change in the tropics, due to deforestation, ranching, and farming, may be causing termite numbers to expand. If this assumption is correct, the contribution from these insects may be important. Methane is also released from landfills, coal mines, and gas and oil drilling. Landfills produce methane as organic wastes decompose over time. Coal, oil, and natural gas deposits release methane to the atmosphere when these deposits are excavated or drilled.

The average concentration of the greenhouse gas nitrous oxide is now increasing at a rate of 0.2 to 0.3% per year. Its part in the enhancement of the greenhouse effect is minor relative to the other greenhouse gases already mentioned. However, it does have an important role in the artificial fertilization of ecosystems. In extreme cases, this fertilization can lead to the death of forests, eutrophication of aquatic habitats, and species exclusion. Sources for the increase of nitrous oxide in the atmosphere include: land-use conversion; fossil fuel combustion; biomass burning; and soil fertilization. Most of the nitrous oxide added to the atmosphere each year comes from deforestation and the conversion of forest, savanna and grassland ecosystems into agricultural fields and rangeland. Both of these processes reduce the amount of nitrogen stored in living vegetation and soil through the decomposition of organic matter. Nitrous oxide is also released into the atmosphere when fossil fuels and biomass are burned. However, the combined contribution to the increase of this gas in the atmosphere is thought to be minor. The use of nitrate and ammonium fertilizers to enhance plant growth is another source of nitrous oxide. How much is released from this process has been difficult to quantify. Estimates suggest that the contribution from this source represents from 50% to 0.2% of nitrous oxide added to the atmosphere annually.

Ozone's role in the enhancement of the greenhouse effect has been difficult to determine. Accurate measurements of past long-term (more than 25 years in the past) levels of this gas in the atmosphere are currently unavailable. Moreover, concentrations of ozone gas are found in two different regions of the Earth's atmosphere. The majority of the ozone (about 97%) found in the atmosphere is concentrated in the stratosphere at an altitude of 15 to 55 kilometers above the Earth's surface. This stratospheric ozone provides an important service to life on the Earth as it absorbs harmful ultraviolet radiation. In recent years, levels of stratospheric ozone have been decreasing due to the buildup of human created chlorofluorocarbons in the atmosphere. Since the late 1970s, scientists have noticed the development of severe holes in the ozone layer over Antarctica. Satellite measurements have indicated that the zone from 65° North to 65° South latitude has had a 3% decrease in stratospheric ozone since 1978.

Ozone is also highly concentrated at the Earth's surface in and around cities. Most of this ozone is created as a by product of human created photochemical smog. This buildup of ozone is toxic to organisms living at the Earth's surface.

Table 1: Average composition of the atmosphere up to an altitude of 25 km.

Gas Name	Chemical Formula	Percent Volume
Nitrogen	N_2	78.08%
Oxygen	O_2	20.95%
***Water**	H_2O	0 to 4%
Argon	Ar	0.93%
***Carbon Dioxide**	CO_2	0.0360%
Neon	Ne	0.0018%
Helium	He	0.0005%
***Methane**	CH_4	0.00017%
Hydrogen	H_2	0.00005%
***Nitrous Oxide**	N_2O	0.00003%
***Ozone**	O_3	0.000004%

* variable gases

2. **The Layered Atmosphere:** The Earth's atmosphere contains several different layers that can be defined according to air temperature, Figure 1 displays these layers in an average atmosphere.

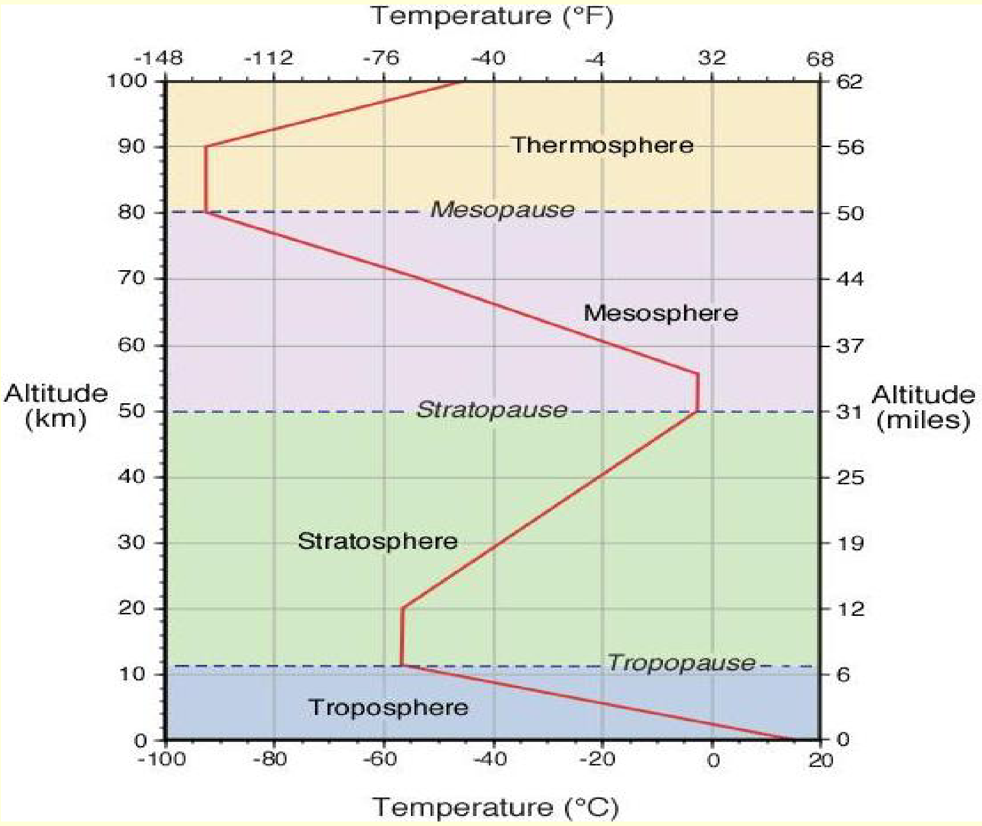

Figure 1: Vertical change in average global atmospheric temperature. Variations in the way temperature changes with height indicates the atmosphere is composed of a number of different layers (labeled

above). These variations are due to changes in the chemical and physical characteristics of the atmosphere with altitude.

According to temperature, the atmosphere contains four different layers (Figure 1). The first layer is called the troposphere. The depth of this layer varies from about 8 to 16 kilometers. Greatest depths occur at the tropics where warm temperatures causes vertical expansion of the lower atmosphere. From the tropics to the Earth's polar regions the troposphere becomes gradually thinner. The depth of this layer at the poles is roughly half as thick when compared to the tropics. Average depth of the troposphere is approximately 11 kilometers as displayed in Figure 1.

About 80% of the total mass of the atmosphere is contained in troposphere. It is also the layer where the majority of our weather occurs (Figure 2). Maximum air temperature also occurs near the Earth's surface in this layer. With increasing height, air temperature drops uniformly with altitude at a rate of approximately 6.5° Celsius per 1000 meters. This phenomenon is commonly called the Environmental Lapse Rate. At an average temperature of -56.5° Celsius, the top of the troposphere is reached. At the upper edge of the troposphere is a narrow transition zone known as the tropopause.

Figure 2: Most of our planet's weather occurs in the troposphere. This image shows a view of this layer from an airplane's window

Above the tropopause is the stratosphere. This layer extends from an average altitude of 11 to 50 kilometers above the Earth's surface. This stratosphere contains about 19.9% of the total mass found in the atmosphere. Very little weather occurs in the stratosphere. Occasionally, the top portions of thunderstorms breach this layer. The lower portion of the stratosphere is also influenced by the polar jet stream and subtropical jet stream. In the first 9 kilometers of the stratosphere, temperature remains constant with height. A zone with constant temperature in the atmosphere is called an isothermal layer. From an altitude of 20 to 50 kilometers, temperature increases with an increase in altitude. The higher temperatures found in this region of the stratosphere occurs because of a localized concentration of ozone gas molecules. These molecules absorb ultraviolet sunlight creating heat energy that warms the stratosphere. Ozone is primarily found in the atmosphere at varying concentrations between the altitudes of 10 to 50 kilometers. This layer of ozone is also called the ozone layer. The ozone layer is important to organisms at the Earth's surface as it protects them from the harmful effects of the Sun's ultraviolet radiation. Without the ozone layer life could not exist on the Earth's surface.

Separating the mesosphere from the stratosphere is transition zone called the stratopause. In the mesosphere, the atmosphere reaches its coldest temperatures (about -90° Celsius) at a height of approximately 80 kilometers. At the top of the mesosphere is another transition zone known as the mesopause.

The last atmospheric layer has an altitude greater than 80 kilometers and is called the thermosphere. Temperatures in this layer can be greater than 1200° C. These high temperatures are generated from the absorption of intense solar radiation by oxygen molecules (O_2). While these temperatures seem extreme, the amount of heat energy involved is very small. The amount of heat stored in a substance is controlled in part by its mass. The air in the thermosphere is extremely thin with individual gas molecules being separated from each other by large distances. Consequently, measuring the temperature of thermosphere with a thermometer is a very difficult process. Thermometers measure the temperature of bodies via the movement of heat energy. Normally, this process takes a few minutes for the conductive transfer of kinetic energy from countless molecules in the body of a substance to the expanding liquid inside the thermometer. In the thermosphere, our thermometer would lose more heat energy from radiative emission then what it would gain from making occasional contact with extremely hot gas molecules.

3. Atmospheric Pressure:

Introduction: Air is a tangible material substance and as a result has mass. Any object with mass is influenced by the universal force known as gravity. Newton's Law of Universal Gravitation states: any two objects separated in space are attracted to each other by a force proportional to the product of their masses and inversely proportional to the square of the distance between them. On the Earth, gravity can also be expressed as a force of acceleration of about 9.8 meters per second per second. As a result of this force, the speed of any object falling towards the surface of the Earth accelerates (1st second - 9.8 meters per second, 2nd second - 19.6 meters per second, 3rd second - 29.4 meters per second, and so on.) until terminal velocity is attained.

Gravity shapes and influences all atmospheric processes. It causes the density and pressure of air to decrease exponentially as one moves away from the surface of the Earth. Figure 3 below models the average change in air pressure with height above the Earth's surface. In this graph, air pressure at the surface is illustrated as being approximately 1013 millibars (mb) or 1 kilogram per square centimeter of surface area.

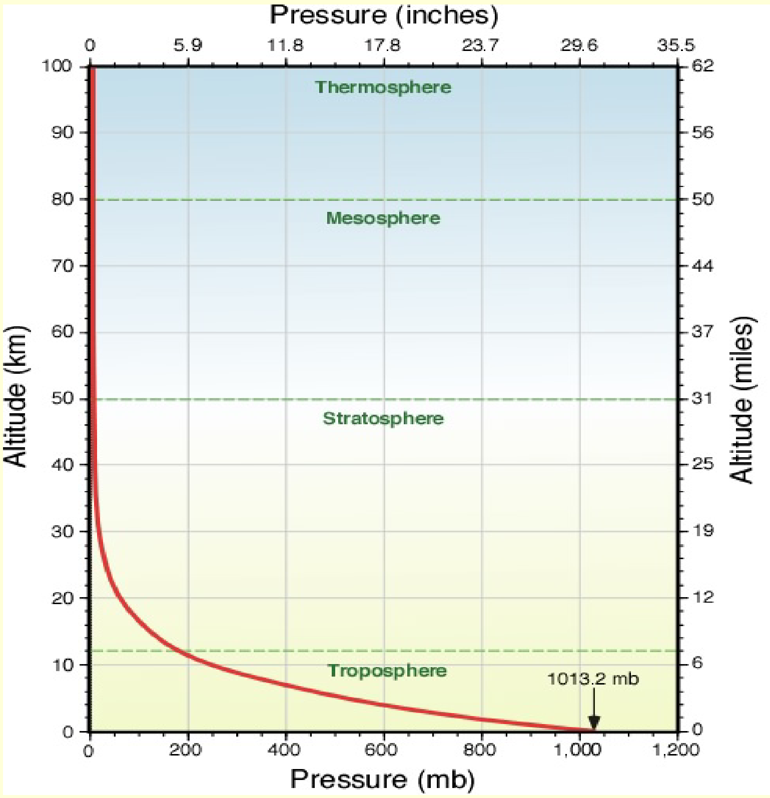

Figure 3: Change in average atmospheric pressure with altitude.

Measuring Atmospheric Pressure: Any instrument that measures air pressure is called a barometer. The first measurement of atmospheric pressure began with a simple experiment performed by Evangelista Torricelli in 1643. In his experiment, Torricelli immersed a tube, sealed at one end, into a container of mercury (see Figure 4 below). Atmospheric pressure then forced the mercury up into the tube to a level that was considerably higher than the mercury in the container. Torricelli determined from this experiment that the pressure of the atmosphere is approximately 30 inches or 76 centimeters (one centimeter of mercury is equal to 13.3 millibars). He also noticed that height of the mercury varied with changes in outside weather conditions.

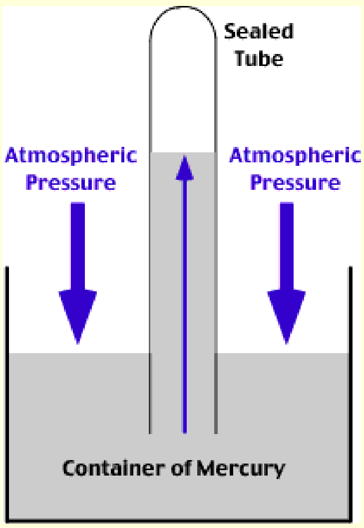

Figure 4: Diagram showing the construction of Torricelli's barometer.

The most common type barometer used in homes is the aneroid barometer (Figure 5). Inside this instrument is a small, flexible metal capsule called an aneroid cell. In the construction of the device, a vacuum is created inside the capsule so that small changes in outside air pressure cause the capsule to expand or contract. The size of the aneroid cell is then calibrated and any change in its volume is transmitted by springs and levers to an indicating arm that points to the corresponding atmospheric pressure.

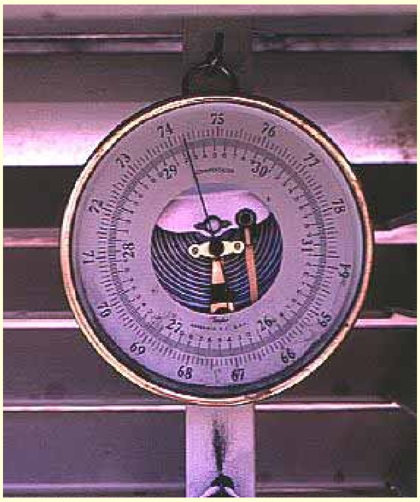

Figure 5: Aneroid barometer.

For climatological and meteorological purposes, standard sea-level pressure is said to be 76.0 cm or 29.92 inches or 1013.2 millibars. Scientists often use the kilopascal (kPa) as their preferred unit for measuring pressure. 1 kilopascal is equal to 10 millibars. Another unit of force sometimes used by scientists to measure atmospheric pressure is the newton. One millibar equals 100 newtons per square meter (N/m2).

Atmospheric Pressure at the Earth's Surface: Surface air pressure varies both spatially and temporally. During the winter months (December to February), areas of high pressure develop over central Asia (Siberian High), off the coast California (Hawaiian High), central North America (Canadian High), over Spain and northwest Africa extending into the subtropical North Atlantic (Azores High), and over the oceans in the Southern Hemisphere at the subtropics. Areas of low pressure occur just south of the Aleutian Islands (Aleutian Low), at the southern tip of Greenland (Iceland Low), and latitudes 50 to 80° South.

During the summer months (June to August), a number of dominant winter pressure systems disappear. Gone are the Siberian High over central Asia and the dominant low pressure systems near the Aleutian Islands and at the southern tip of Greenland. The Hawaiian and Azores High intensify and expand northward into their relative ocean basins. High pressure systems over the subtropical oceans in Southern Hemisphere also intensity and expand to the north. New areas of dominant high pressure develop over Australia and Antarctica (South Polar High). Regions of low pressure form over central Asia and southwest Asia (Asiatic Low). These pressure systems are responsible for the summer monsoon rains of Asia.

4. The Concept of Temperature:

Temperature and Heat: Temperature and heat are not the same phenomenon. Temperature is a measure of the intensity or degree of hotness in a body. Technically, it is determined by getting the average speed of a body's molecules. Heat is a measure of the quantity of heat energy present in a body. The spatial distribution of temperature in a body determines heat flow. Heat always flows from warmer to colder areas.

The heat held in a object depends not only on its temperature but also its mass. For example, let us compare the heating of two different masses of water (Table 2). In this example, one mass has a weight of 5 grams, while the other is 25 grams. If the temperature of both masses is raised from 20 to 25° Celsius, the larger mass of water will require five times more heat energy for this increase in temperature. This larger mass would also contain contain 5 times more stored heat energy.

Table 2: Heat energy required to raise two different quantities of water 5° Celsius.

Mass of the Water	Starting Temperature	Ending Temperature	Heat Required
5 grams	20° Celsius	25° Celsius	25 Calories of Heat
25 grams	20° Celsius	25° Celsius	125 Calories of Heat

Temperature Scales: A number of measurement scales have been invented to measure temperature. Table 3 describes important temperatures for the three dominant scales in use today.

Table 3: Temperature of absolute zero, the ice point of water, and the stream point of water using various temperature measurement scales

Measurement Scale	Steam Point of Water	Ice Point of Water	Absolute Zero
Fahrenheit	212	32	-460
Celsius	100	0	-273
Kelvin	373	273	0

The most commonly used scale for measuring temperature is the Celsius system. The Celsius scale was developed in 1742 by the Swedish astronomer Anders Celsius. In this system, the melting point of ice was given a value of 0, the boiling point of water is 100, and absolute zero is -273. The Fahrenheit system is a temperature scale that is used exclusively in the United States. This system was created by German physicist Gabriel Fahrenheit in 1714. In this scale, the melting point of ice has a value of 32, water boils at 212, and absolute zero has a temperature of -460. The Kelvin scale was proposed by British physicist Lord Kelvin in 1848. This system is often used by scientists because its temperature readings begin at absolute zero and due to the fact that this scale is proportional to the amount of heat energy found in an object. The Kelvin scale assigns a value of 273 for the melting temperature of ice, while the boiling point of water occurs at 373.

Measurement of Air Temperature: A thermometer is a device that is used to measure temperature. Thermometers consist of a sealed hollow glass tube filled with some type of liquid. Thermometers measure temperature by the change in the volume of the liquid as it responds to the addition or loss of heat energy from the environment immediately outside its surface. When heat is added, the liquid inside the thermometer expands. Cooling cause the liquid to contract. Meteorological thermometers are often filled with either alcohol or mercury. Alcohol thermometers are favored in very cold environments because of this liquid's low freezing point (-112° Celsius).

By international agreement, the nations of the world have decided to measure temperature in a similar fashion. This standardization is important for the accurate generation of weather maps and forecasts, both of which depend on having data determined in a uniform way. Weather stations worldwide try to determine minimum and maximum temperatures for each and every day. By averaging these two values, daily mean temperatures are also calculated. Many stations also take temperature readings on the hour. Temperature measurements are determined by thermometers designed and approved by the World Meteorological Organization. These instruments are housed in specially designed instrument shelters that allow for the standardization of measurements taken anywhere on the Earth (Figure 6 and Figure 7).

Figure 6: Well ventilated instrument shelters are used to protect thermometers from precipitation, direct Sun, and other physical elements. Construction standardization of these shelters, by international agreement, guarantees that measurements are comparable in any of the over 15,000 weather stations found worldwide.

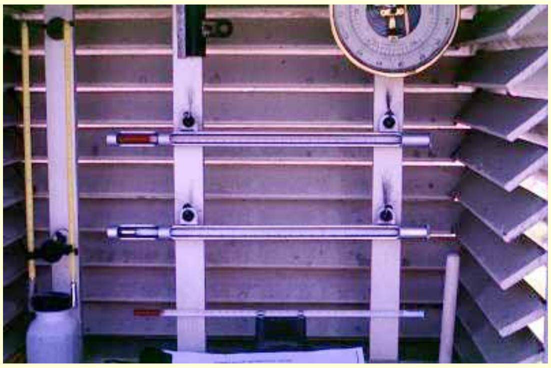

Figure 7: Thermometers found inside the instrument shelter are mounted approximate 1.5 meters above the ground surface. The top thermometer contains alcohol and is used to determine daily minimum temperatures. The lower thermometer uses mercury to determine the daily maximum temperature.

5. **Global Surface Temperature Distribution:** If the Earth was a homogeneous body without the present land/ocean distribution, its temperature distribution would be strictly latitudinal (Figure 8). However, the Earth is more complex than this being composed of a mosaic of land and water. This mosaic causes latitudinal zonation of temperature to be disrupted spatially

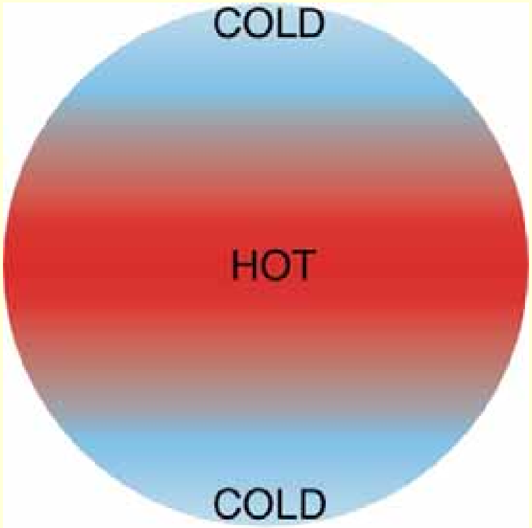

Figure 8: Simple latitudinal zonation of temperature.

The following two factors are important in influencing the distribution of temperature on the Earth's surface:

- The latitude of the location determines how much solar radiation is received. Latitude influences the angle of incidence and duration of daylength.
- Surface properties - surfaces with high albedo absorb less incident radiation. In general, land absorbs less insolation that water because of its lighter color. Also, even if two surfaces have the same albedo, a surface's specific heat determines the amount of heat energy required for a specific rise in temperature per unit mass. The specific heat of water is some five times greater than that of rock and the land surface (see Table 4 below). As a result, water requires the input of large amounts of energy to cause a rise in its temperature.

Table 4: Specific Heat of Various Substances.

Substance	Specific Heat
Water	1.00
Air	0.24
Granite	0.19
Sand	0.19
Iron	0.11

Mainly because of specific heat, land surfaces behave quite differently from water surfaces. In general, the surface of any extensive deep body of water heats more slowly and cools more slowly than the surface of a large land body. Other factors influencing the way land and water surfaces heat and cool include:

- Solar radiation warms an extensive layer in water, on land just the immediate surface is heated.
- Water is easily mixed by the process of convection.
- Evaporation of water removes energy from water's surface.

The following images illustrate the Earth's temperature distribution patterns for an average January and July based on 39 years of data (Figures 9 and 10). Note that the spatial variations of temperature on these figures is mostly latitudinal. However, the horizontal banding of isotherms is somewhat upset by the fact that water heats up more slowly in the summer and cools down more slowly in the winter when compared to land surfaces. During January, much of the terrestrial areas of the Northern Hemisphere are below freezing (Figure 9). Some notable Northern Hemisphere cold-spots include the area around Baffin Island Canada, Greenland, Siberia, and the Plateau of Tibet. Temperatures over oceans tend to be hotter because of the water's ability to hold heat energy.

In the Southern Hemisphere, temperatures over the major landmasses are generally greater than 20° Celsius with localized hot-spots in west-central Australia, the Kalahari Desert in Africa, and the plains of Bolivia, Paraguay, and Argentina (Figure 9). Subtropical oceans are often warmer than landmass areas near the equator. At this latitude, land areas receive less incoming solar radiation because of the daily convective development of cumulus and cumulonimbus clouds. In the mid-latitudes, oceans are often cooler than landmass areas at similar latitudes. Terrestrial areas are warmer because of the rapid heating of land surfaces under frequently clear skies. Antarctica remains cold and below zero degrees Celsius due to the presence of permanent glacial ice which reflects much of the solar radiation received back to space.

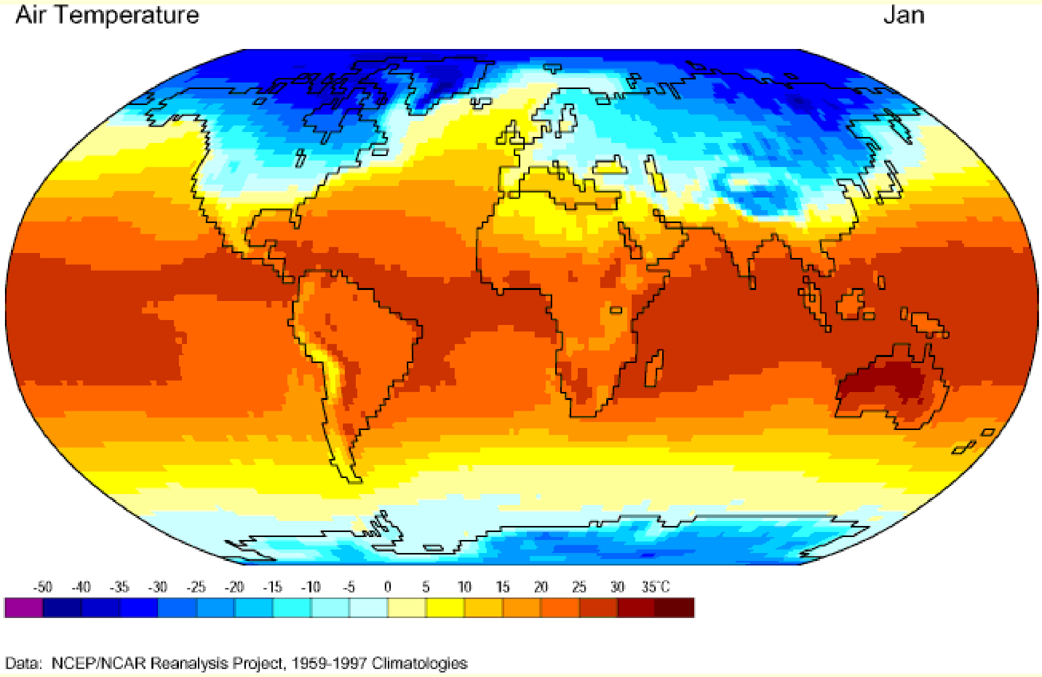

Figure 9: Mean January air temperature for the Earth's surface, 1959-1997.

In July, the Northern Hemisphere is experiencing its summer season because the North Pole is now tilted towards the Sun (Figure 10). Some conspicuous hot-spots include the south-central United States, Arizona and northwest Mexico, northern Africa, the Middle East, India, Pakistan, and Afghanistan. Temperatures over oceans tend to be relatively cooler because of the land's ability to heat quickly. Two terrestrial areas of cooler temperatures include Greenland and the Plateau of Tibet. In these regions, most of the incoming solar radiation is sent back to space because of the presence of reflective ice and snow.

In the Southern Hemisphere, temperatures over the major landmasses are generally cooler than ocean surfaces at the same latitude (Figure 10). Antarctica is bitterly cold because it is experiencing total darkness. Note that Antarctica is much colder than the Arctic was during its winter season . The Arctic consists mainly of ocean. During the summer, this surface is able to absorb considerable quantities of sunlight which is then converted into heat energy. The heat stored in the ocean is carried over into the winter season. Antarctica has a surface composed primarily of snow and ice. This surface absorbs only a small amount of the solar radiation during the summer. So it never really heats up. As a result, the amount of heat energy stored into the winter season is minimal.

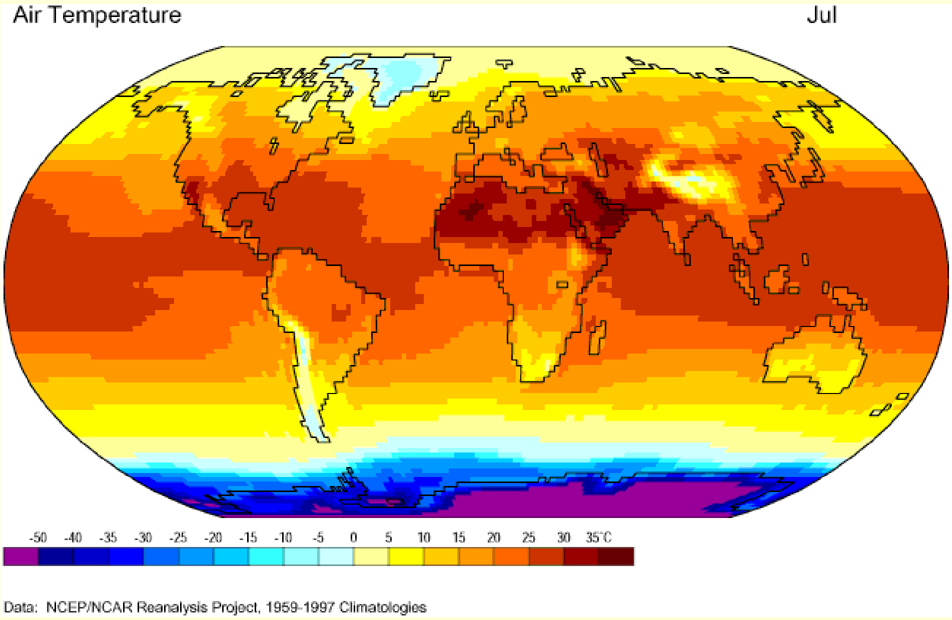

Figure 10: Mean July air temperature for the Earth's surface, 1959-1997.

6. **Forces Acting to Create Wind:** Wind can be defined simply as air in motion. This motion can be in any direction, but in most cases the horizontal component of wind flow greatly exceeds the flow that occurs vertically. The speed of wind varies from absolute calm to speeds as high as 380 kilometers per hour. Over short periods of time surface winds can be quite variable.

Wind develops as a result of spatial differences in atmospheric pressure. Generally, these differences occur because of uneven absorption of solar radiation at the Earth's surface (Figure 11). Wind speed tends to be at its greatest during the daytime when the greatest spatial extremes in atmospheric temperature and pressure exist.

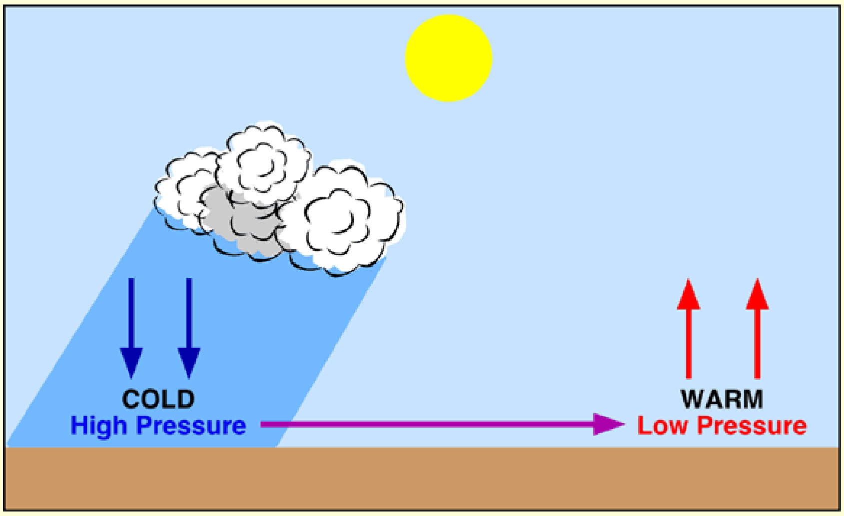

Figure 11: Formation of wind as a result of localized temperature differences.

Wind is often described by two characteristics: wind speed and wind direction. Wind speed is the velocity attained by a mass of air traveling horizontally through the atmosphere. Wind speed is often measured with an anemometer in kilometers per hour (kmph), miles per hour (mph), knots, or meters per second (mps). Wind direction is measured as the direction from where a wind comes from. For example, a southerly wind comes from the south and blows to the north. Direction is measured by an instrument called a wind vane (Figure 12). Both of these instruments are positioned in the atmospheric environment at a standard distance of 10 meters above the ground surface.

Wind speed can also be measured without the aid of instruments using the Beaufort wind scale (Table 5). This descriptive scale was originally developed by Admiral Beaufort of the British Navy in the first decade of the 17th century. The purpose for this system was to allow mariners to determine wind speed from simple observations. The Beaufort system has undergone several modifications to standardize its measurement scale and to allow for its use on land. Users of this scale look for specific effects of the wind on the environment to determine speed.

Figure 12: Meteorological instruments used to measure wind speed and direction. Wind speed is commonly measured with an anemometer. An anemometer consists of three open cups attached to a rotating spindle. The speed of roation is then converted into a measurement of wind speed. Wind direction is measured with a wind vane. On the photograph above, the wind vane instrument has a bullet shaped nose attached to a finned tail by a metal bar.

Table 5: Beaufort wind speed scale.

Beaufort Code	Speed Miles per Hour	Speed Kilometers per Hour	Description	Effects on the Environment
0	< 1	< 1	calm	smoke rises vertically
1	2 - 3	1 - 5	light air	smoke drifts slowly
2	4 - 7	6 - 11	light breeze	leaves rustle, wind can be felt, wind vanes move
3	8 - 12	12 - 19	gentle breeze	leaves and twigs on trees move
4	13 - 18	20 - 29	moderate breeze	small tree branches move, dust is picked up from the ground surface
5	19 - 24	30 - 38	fresh breeze	small trees move
6	25 - 31	39 - 51	strong breeze	large branches move, telephone and power overhead wires whistle
7	32 - 38	51 - 61	near gale	trees move, difficult to walk in the wind
8	39 - 46	62 - 74	gale	twigs break off from trees
9	47 - 54	75 - 86	strong gale	branches break off from trees, shingles blown off roofs
10	55 - 63	87 - 101	whole gale	trees become uprooted, structural damage on buildings
11	64 - 74	102 - 120	storm	widespread damage to buildings and trees
12	> 75	> 120	hurricane	severe damage to buildings and trees

Winds are named according to the compass direction of their source. Thus, a wind from the north blowing toward the south is called a northerly wind. Figure 13 describes the sixteen principal bearings of wind direction. Most meterological observations report wind direction using one of these sixteen bearings.

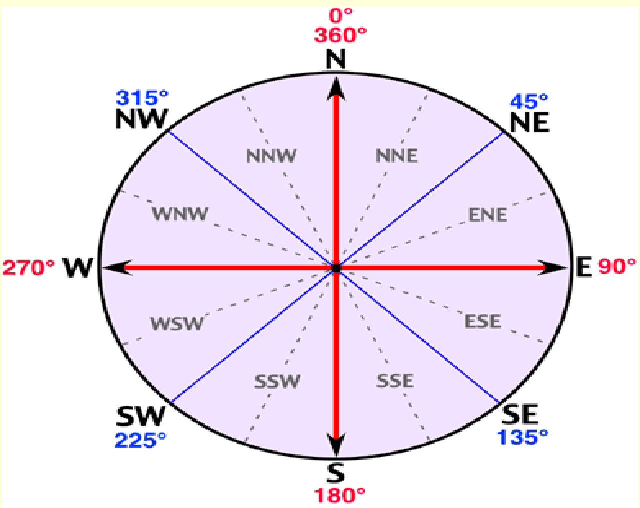

Figure 13: Wind compass describing the sixteen principal bearings used to measure wind direction. This compass is based on the 360 degrees found in a circle.

Horizontally, at the Earth's surface wind always blows from areas of high pressure to areas of low pressure (vertically, winds move from areas of low pressure to areas of high pressure), usually at speeds determined by the rate of air pressure change between pressure centers. This situation is comparable to someone skiing down a hill. The skier will of course move from the top of the hill to the bottom of the hill, with the speed of their descent controlled by the gradient or steepness of the slope. Likewise, wind speed is a function of the steepness or gradient of atmospheric air pressure found between high and low pressure systems. When expressed scientifically, pressure change over a unit distance is called pressure gradient force, and the greater this force the faster the winds will blow.

On weather maps, pressure is indicated by drawing isolines of pressure, called isobars, at regular 4 millibar intervals (e.g., 996 mb, 1000 mb, 1004 mb, etc.). If the isobars are closely spaced, we can expect the pressure gradient force to be great, and wind speed to be high (see Figure 14). In areas where the isobars are spaced widely apart, the pressure gradient is low and light winds normally exist. High speed winds develop in areas where isobars are closer.

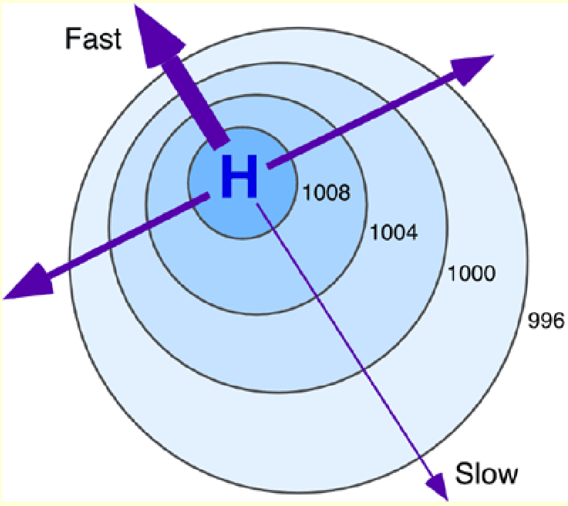

Figure 14: Association between wind speed and distance between isobars. In the illustration above thicker arrows

Pressure gradient force is the primary force influencing the formation of wind from local to global scales. This force is determined by the spatial pattern of atmospheric pressure at any given moment in time. Figure 15 illustrates two different pressure gradient scenarios and their relative effect on wind speed.

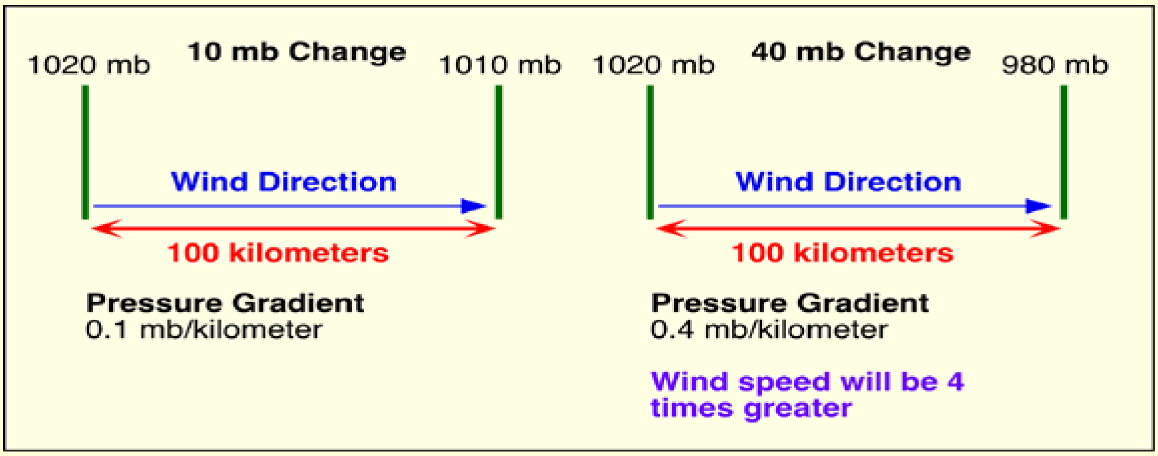

Figure 15: Effect of pressure gradient on wind speed. (The two diagrams display the relative relationship between pressure gradient and wind speed. This relationship is linear and positive. As a result, quadrupling the pressure gradient increases wind speed by a factor of four).

The rotation of the Earth creates another force, termed Coriolis force, which acts upon wind and other objects in motion in very predictable ways. According to Newton's first law of motion, air will remain moving in a straight line unless it is influenced by an unbalancing force. The consequence of Coriolis force opposing pressure gradient acceleration is that the moving air changes direction. Instead of wind blowing directly from high to low pressure, the rotation of the Earth causes wind to be deflected off course. In the Northern Hemisphere, wind is deflected to the right of its path, while in the Southern Hemisphere it is deflected to the left. The magnitude of the Coriolis force varies with the velocity and the latitude of the object (see Figure 16). Coriolis force is absent at the equator, and its strength increases as one approaches either pole. Furthermore, an increase in wind speed also results in a stronger Coriolis force, and thus in greater deflection of the wind. Coriolis force only acts on air when it has been sent into motion by pressure gradient force. Finally, Coriolis force only influences wind direction and never wind speed.

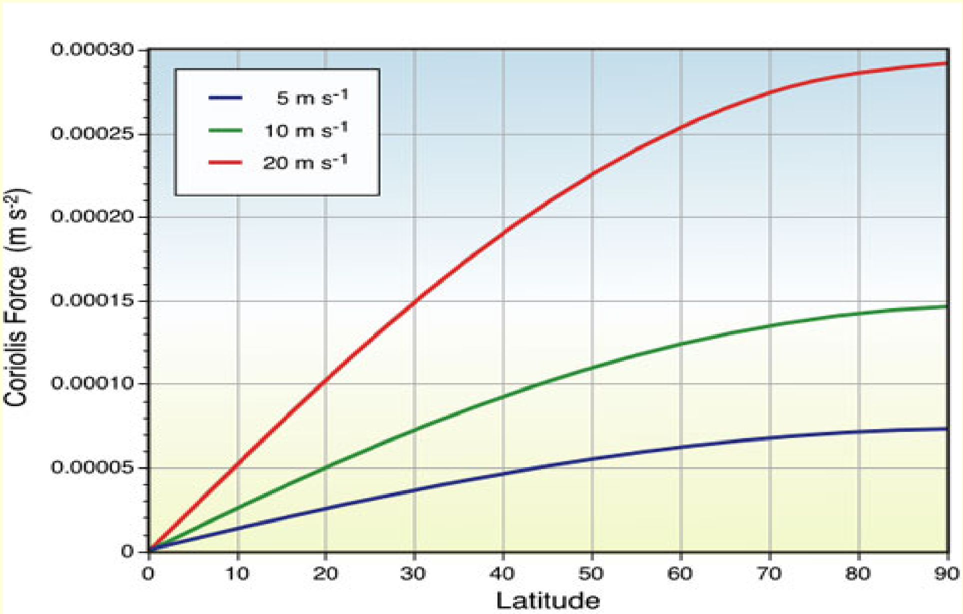

Figure 16: The strength of Coriolis force is influenced by latitude and the speed of the moving object.

Centripetal acceleration is the third force that can act on moving air. It acts only on air that is flowing around centers of circulation. Centripetal acceleration is also another force that can influence the direction of wind. Centripetal acceleration creates a force directed at right angles to the flow of the wind and inwards towards the centers of rotation (e.g., low and high pressure centers). This force produces a circular pattern of flow around centers of high and low pressure. Centripetal acceleration is much more important for circulations smaller than the mid-latitude cyclone.

The last force that can influence moving air is frictional deceleration. Friction can exert an influence on wind only after the air is in motion. Frictional drag acts in a direction opposite to the path of motion causing the moving air to decelerate. Frictional effects are limited to the lower one kilometer above the Earth's surface.

Geostrophic Wind: Air under the influence of both the pressure gradient force and Coriolis force tends to move parallel to isobars in conditions where friction is low (1000 meters above the surface of the Earth) and isobars are straight. Winds of this type are usually called geostrophic winds. Geostrophic winds come about because pressure gradient force and Coriolis force come into balance after the air begins to move (Figure17).

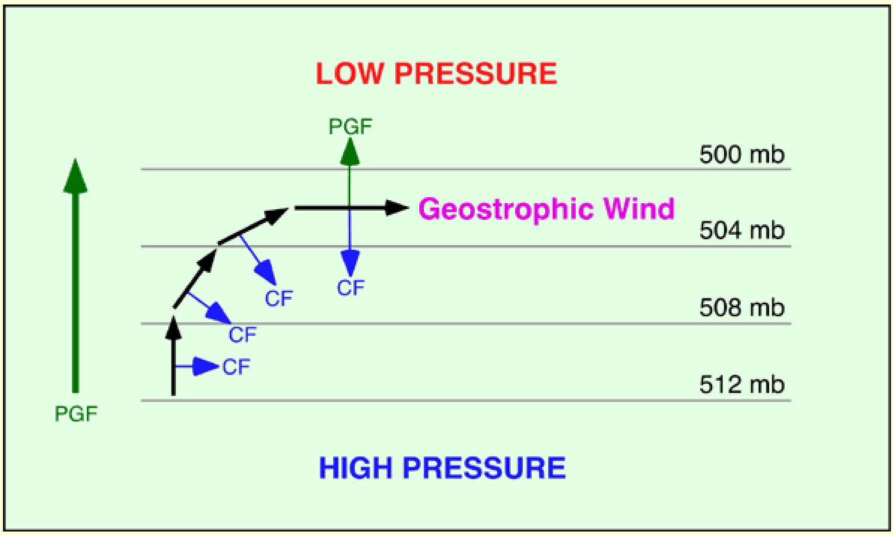

Figure 17: A geostrophic wind flows parallel to the isobars. In this model of wind flow in the Northern Hemisphere, wind begins as a flow of air perpendicular to the isobars (measured in millibars) under the primary influence of the pressure gradient force (PGF). As the movement begins, the Coriolis force (CF) begins to influence the moving air causing it to deflect to the right of its path. This deflection continues until the pressure gradient force and Coriolis force are opposite and in balance with each other.

Figure 17 models air flow in the Northern Hemisphere. In the Southern Hemisphere, Coriolis acceleration acts on moving air by deflecting it to the left instead of the right.

Finally, Buy Ballot's Law states that when you stand with your back to a geostrophic wind in the Northern Hemisphere the center of low pressure will be to your left and the high pressure to your right. The opposite is true for the Southern Hemisphere.

Gradient Wind: Wind above the Earth's surface does not always travel in straight lines. In many cases winds flow around the curved isobars of a high (anticyclone) or low (cyclone) pressure center. A wind that blows around curved isobars above the level of friction is called a gradient wind. Gradient winds are slightly more complex than geostrophic winds because they include the action of yet another physical force. This force is known as centripetal force and it is always directed toward the center of rotation. The following figure describes the forces that produce gradient winds around high and low pressure centers (Figure 18). Around a low, the gradient wind consists of the pressure gradient force and centripetal force acting toward the center of rotation, while Coriolis force acts away from the center of the low. In a high pressure center, the Coriolis and centripetal forces are directed toward the center of the high, while the pressure gradient force is directed outward.

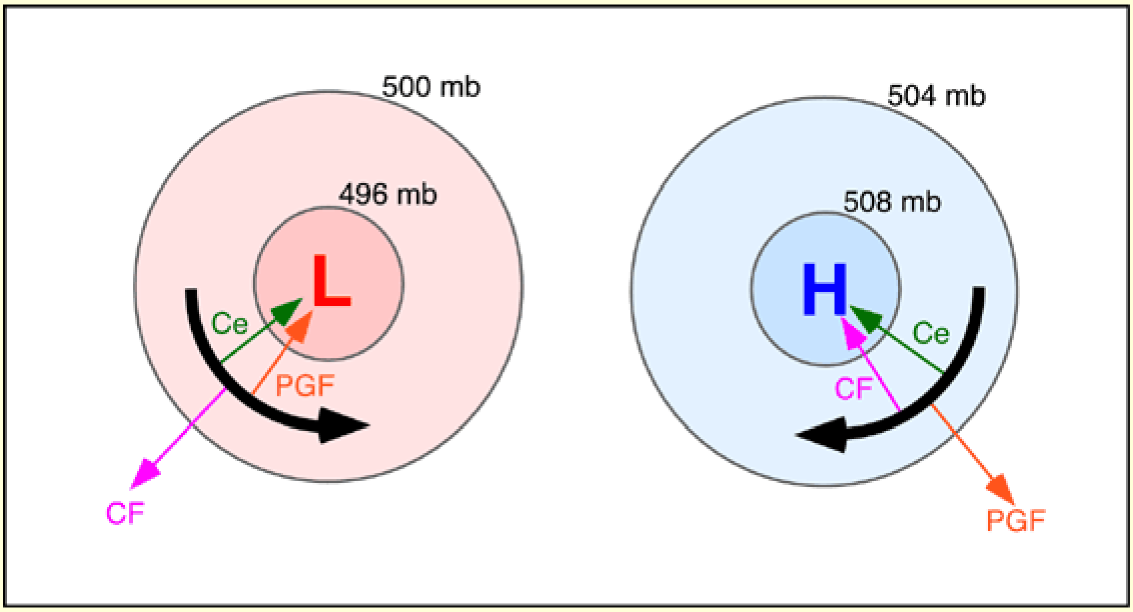

Figure 18: The balance of forces that create a gradient wind in the Northern Hemisphere (PGF = pressure gradient force; CF = Coriolis force; Ce = centripetal force). In this diagram, CF = Ce + PGF for the low, and PGF = CF + Ce for the high.

Friction Layer Wind: Surface winds on a weather map do not blow exactly parallel to the isobars as in geostrophic and gradient winds. Instead, surface winds tend to cross the isobars at an angle varying from 10 to 45°. Close to the Earth's surface, friction reduces the wind speed, which in turn reduces the Coriolis force. As a result, the reduced Coriolis force no longer balances the pressure gradient force, and the wind blows across the isobars toward or away from the pressure center. The pressure gradient force is now balanced by the sum of the frictional force and the Coriolis force. Thus, we find surface winds blowing counterclockwise and inward into a surface low, and clockwise and out of a surface high in the Northern Hemisphere. In the Southern Hemisphere, the Coriolis force acts to the left rather than the right. This causes the winds of the Southern Hemisphere to blow clockwise and inward around surface lows, and counterclockwise and outward around surface highs (see Figure 19 below).

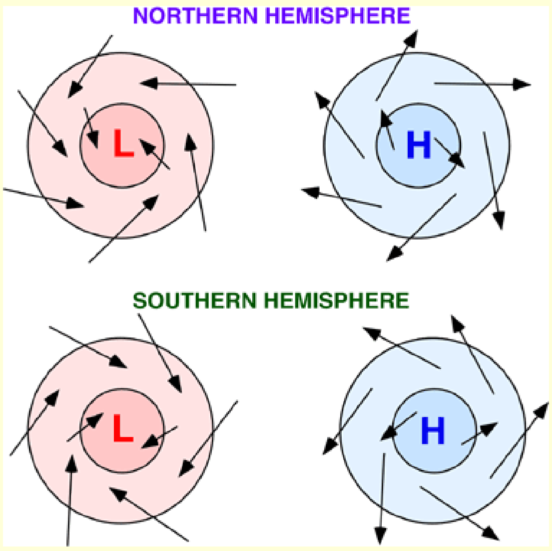

Figure 19: Circulation patterns of high and low pressure systems in the North and South Hemisphere.

7. Local and Regional Wind Systems:

Thermal Circulations: Winds blow because of differences in atmospheric pressure. Pressure gradients may develop on a local to a global scale because of differences in the heating and cooling of the Earth's surface. Heating and cooling cycles that develop daily or annually can create several common local or regional thermal wind systems. The basic circulation system that develops is described in the generic illustrations below.

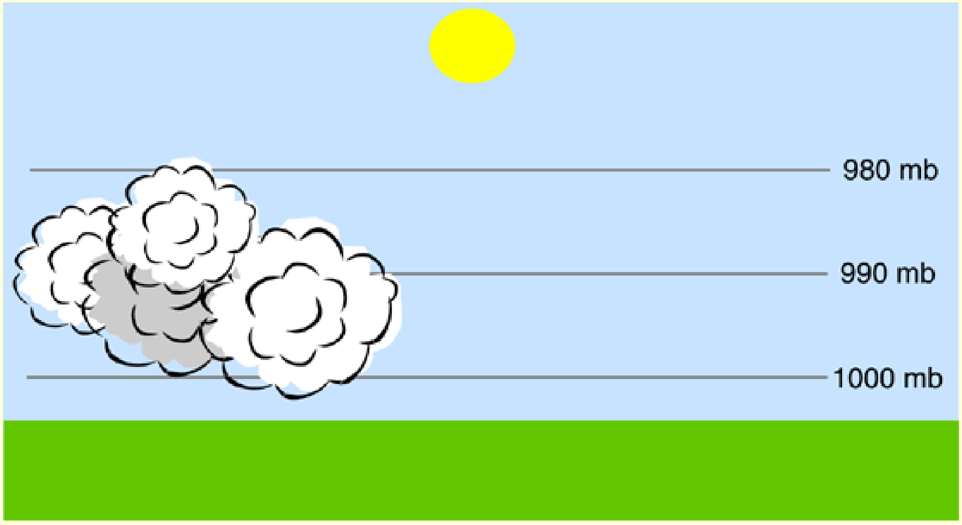

Figure 20: Cross-section of the atmosphere with uniform horizontal atmospheric pressure.

In this first diagram (Figure 20), there is no horizontal temperature or pressure gradient and therefore no wind. Atmospheric pressure decreases with altitude as depicted by the drawn isobars (1000 to 980 millibars). In the second diagram (Figure 21), the potential for solar heating is added which creates contrasting surface areas of temperature and atmospheric pressure. The area to the right receives more solar radiation and the air begins to warm from heat energy transferred from the ground through conduction and convection. The vertical distance between the isobars becomes greater as the air rises. To the far left, less radiation is received because of the presence of cloud, and this area becomes relatively cooler than the area to the right. In the upper atmosphere, a pressure gradient begins to form because of the rising air and upward spreading of the isobars. The air then begins to flow in the upper atmosphere from high pressure to low pressure.

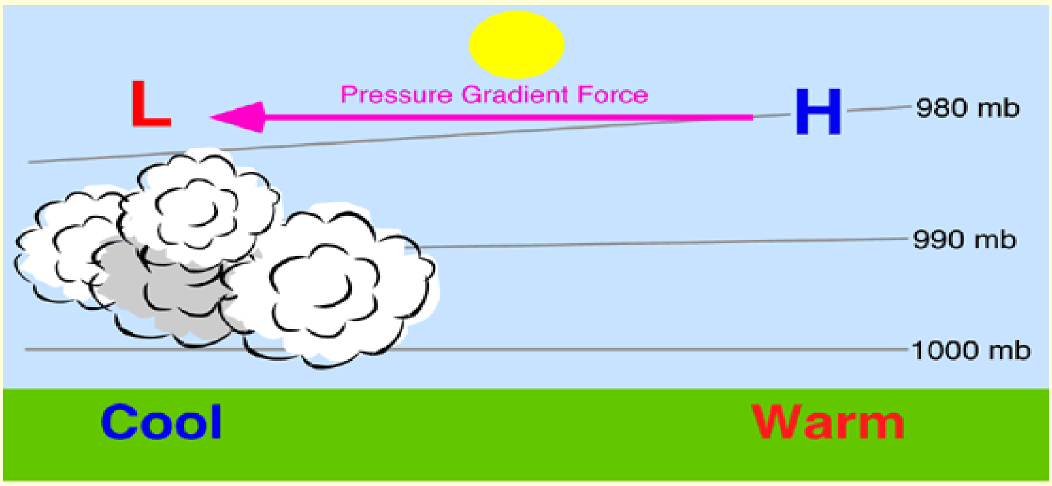

Figure 21: Development of air flow in the upper atmosphere because of surface heating.

Figure 22 shows the full circulation system in action. Beneath the upper atmosphere high is a thermal low pressure center created from the heating of the ground surface. Below the upper atmosphere low is a thermal high created by the relatively cooler air temperatures and enhanced by the descending air from above. Surface air temperatures are cooler here because of the obstruction of shortwave radiation absorption at the Earth's surface by the cloud. At the surface, the wind blows from the high to the low pressure. Once at the low, the wind rises up to the upper air high pressure system because of thermal buoyancy and outflow in the upper atmosphere. From the upper high, the air then travels to the upper air low, and then back down to the surface high to complete the circulation cell. The circulation cell is a closed system that redistributes air in an equitable manner. It is driven by the greater heating of the surface air in the right of the diagram.

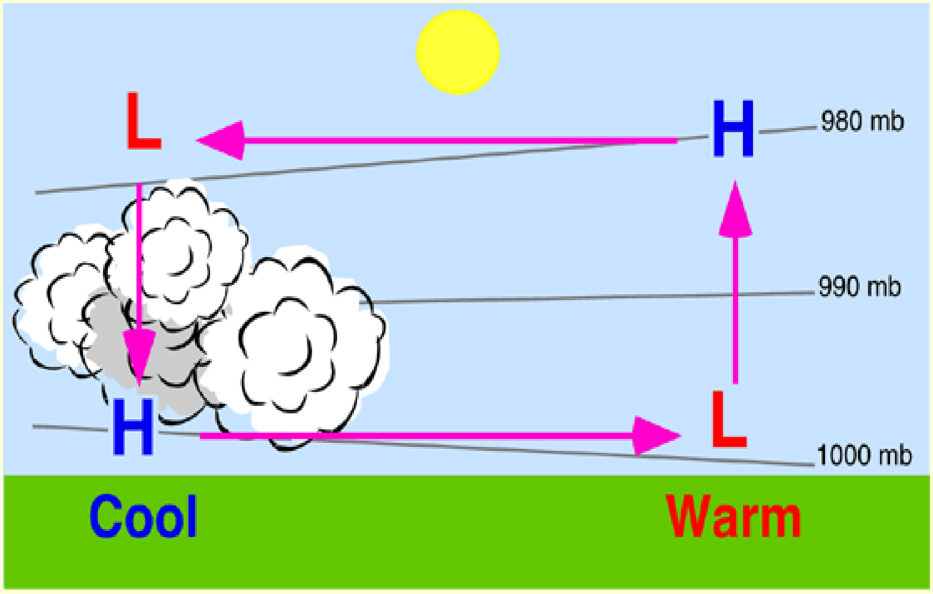

Figure 22: Development of a closed atmospheric circulation cell because of surface heating.

Sea and Land Breezes: Sea and land breezes are types of thermal circulation systems that develop at the interface of land and ocean. At this interface, the dissimilar heating and cooling characteristics of land and water initiate the development of an atmospheric pressure gradient which causes the air in these areas to flow.

During the daytime land heats up much faster than water as it receives solar radiation from the Sun (Figure 23). The warmer air over the land then begins to expand and rise forming a thermal low. At the same time, the air over the ocean becomes a cool high because of water's slower rate of heating. Air begins to flow as soon as there is a significant difference in air temperature and pressure across the land to sea gradient. The development of this pressure gradient causes the heavier cooler air over the ocean to move toward the land and to replace the air rising in the thermal low. This localized air flow system is called a sea breeze. Sea breeze usually begins in midmorning and reaches its maximum strength in the later afternoon when the greatest temperature and pressure contrasts exist. It dies down at sunset when air temperature and pressure once again become similar across the two surfaces.

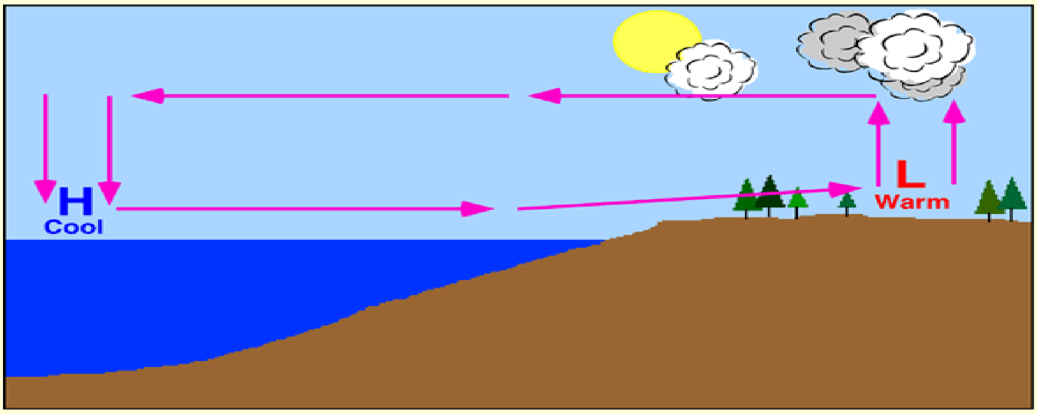

Figure 23: Daytime development of sea breeze.

At sunset, the land surface stops receiving radiation from the Sun (Figure 24). As night continues the land surface begins losing heat energy at a much faster rate than the water surface. After a few hours, air temperature and pressure contrasts begin to develop between the land and ocean surfaces. The land surface being cooler than the water becomes a thermal high pressure area. The ocean becomes a warm thermal low. Wind flow now moves from the land to the open ocean. This type of localized air flow is called a land breeze.

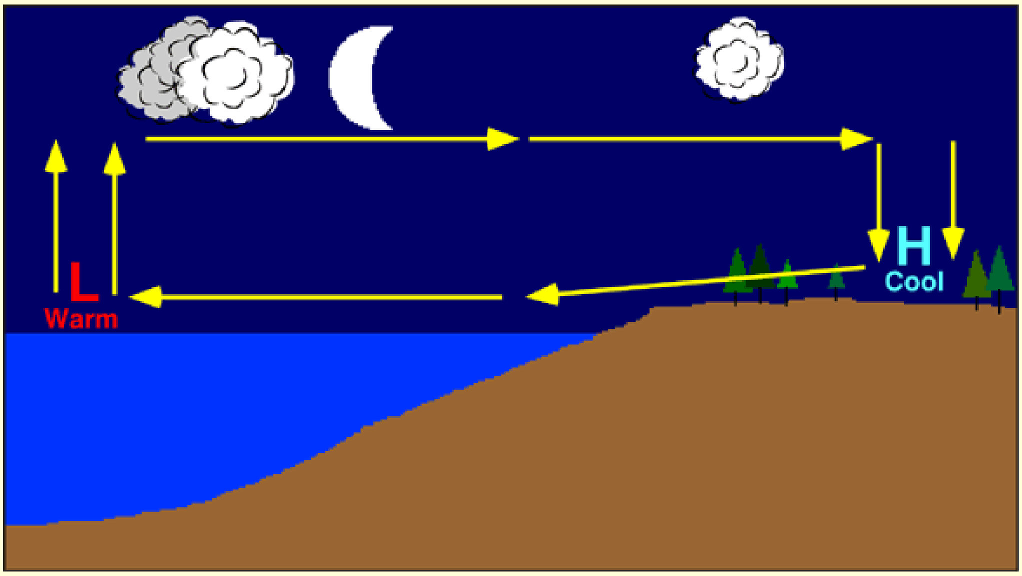

Figure 24: Nighttime development of land breeze.

Mountain and Valley Breezes: Mountain and valley breezes are common in regions with great topographic relief (Figure 25 and 26). A valley breeze develops during the day as the Sun heats the land surface and air at the valley bottom and sides (Figure 25). As the air heats it becomes less dense and buoyant and begins to flow gently up the valley sides. Vertical ascent of the air rising along the sides of the mountain is usually limited by the presence of a temperature inversion layer. When the ascending air currents encounter the inversion they are forced to move horizontally and then back down to the valley floor. This creates a self-contained circulation system. If conditions are right, the rising air can condense and form into cumuliform clouds.

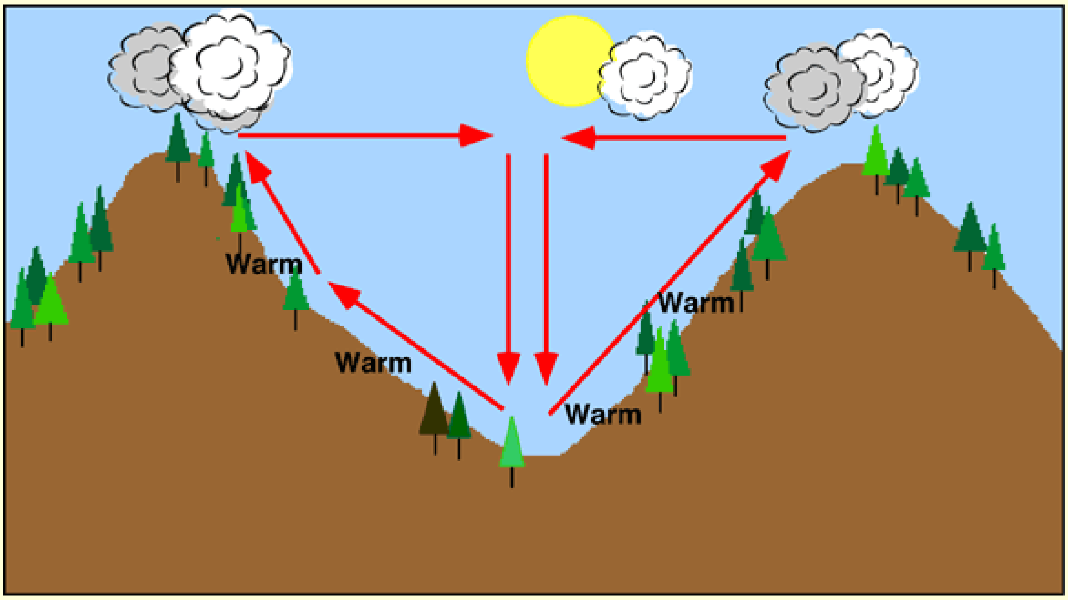

Figure 25: Daytime development of valley breeze.

During the night, the air along the mountain slopes begins to cool quickly because of longwave radiation loss (Figure 26). As the air cools, it becomes more dense and begins to flow downslope causing a mountain breeze. Convergence of the draining air occurs at the valley floor and forces the air to move vertically upward. The upward movement is usually limited by the presence of a temperature inversion which forces the air to begin moving horizontally. This horizontal movement completes the circulation cell system. In narrowing terrain, mountain winds can accelerate in speed because of the venturi effect. Such winds can attain speeds as high has 150 kilometers per hour.

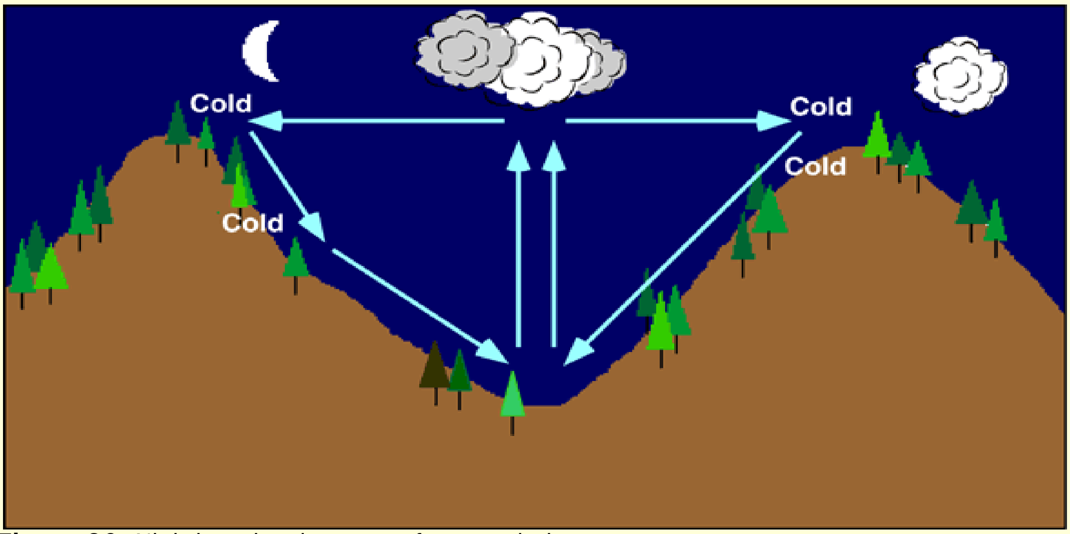

Figure 26: Nighttime development of mountain breeze.

Monsoon Winds: Monsoons are regional scale wind systems that predictably change direction with the passing of the seasons. Like land/sea breezes, these wind systems are created by the temperature contrasts that exist between the surfaces of land and ocean. However, monsoons are different from land/sea breezes both spatially and temporally. Monsoons occur over distances of thousands of kilometers, and their two dominant patterns of wind flow act over an annual time scale.

During the summer, monsoon winds blow from the cooler ocean surfaces onto the warmer continents. In the summer, the continents become much warmer than the oceans because of a number of factors. These factors include:

- Specific heat differences between land and water.
- Greater evaporation over water surfaces.
- Subsurface mixing in ocean basins which redistributes heat energy through a deeper layer.

Precipitation is normally associated with the summer monsoons. Onshore winds blowing inland from the warm ocean are very high in humidity, and slight cooling of these air masses causes condensation and rain. In some cases, this precipitation can be greatly intensified by orographic uplift. Some highland areas in Asia receive more than 10 meters of rain during the summer months.

In the winter, the wind patterns reverse as the ocean surfaces are now warmer. With little solar energy available, the continents begin cooling rapidly as longwave radiation is emitted to space. The ocean surface retains its heat energy longer because of water's high specific heat and subsurface mixing. The winter monsoons bring clear dry weather and winds that flow from land to sea.

Figure 27 illustrates the general wind patterns associated with the winter and summer monsoons in Asia. The Asiatic monsoon is the result of a complex climatic interaction between the distribution of land and water, topography, and tropical and mid-latitudinal circulation. In the summer, a low pressure center forms over northern India and northern Southeast Asia because of higher levels of received solar insolation. Warm moist air is drawn into the thermal lows from air masses over the Indian Ocean. Summer heating also causes the development of a strong latitudinal pressure gradient and the development of an easterly jet stream at an altitude of about 15 kilometers and a latitude of 25° North. The jet stream enhances rainfall in Southeast Asia, in the Arabian Sea, and in South Africa. When autumn returns to Asia the thermal extremes between land and ocean decrease and the westerlies of the mid-latitudes move in. The easterly jet stream is replaced with strong westerly winds in the upper atmosphere. Subsidence from an upper atmosphere cold low above the Himalayas produces outflow that creates a surface high pressure system that dominates the weather in India and Southeast Asia.

Monsoon wind systems also exist in Australia, Africa, South America, and North America.

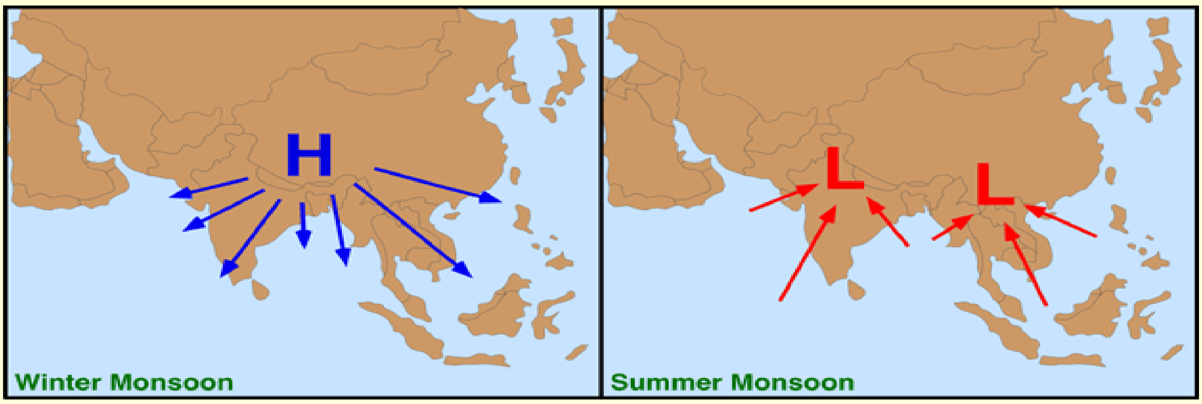

Figure 27: Winter and summer monsoon wind patterns for southeast Asia.

8. Thunderstorms, Tornadoes and Hurricanes

Thunderstorms: Thunderstorms form when moist, unstable air is lifted vertically into the atmosphere. Lifting of this air results in condensation and the release of latent heat. The process to initiate vertical lifting can be caused by:

(1). Unequal warming of the surface of the Earth.
(2). Orographic lifting due to topographic obstruction of air flow.
(3). Dynamic lifting because of the presence of a frontal zone.

Immediately after lifting begins, the rising parcel of warm moist air begins to cool because of adiabatic expansion. At a certain elevation the dew point is reached resulting in condensation and the formation of a cumulus cloud. For the cumulus cloud to form into a thunderstorm, continued uplift must occur in an unstable atmosphere. With the vertical extension of the air parcel, the cumulus cloud grows into a cumulonimbus cloud. Cumulonimbus clouds can reach heights of 20 kilometers above the Earth's surface. Severe weather associated with some these clouds includes hail, strong winds, thunder, lightning, intense rain, and tornadoes.

Figure 28: Multiple lightning strikes from a thunderstorm occurring at night.

Generally, two types of thunderstorms are common:

1) Air mass thunderstorms which occur in the mid-latitudes in summer and at the equator all year long.
2) Thunderstorms associated with mid-latitude cyclone cold fronts or dry lines. This type of thunderstorm often has severe weather associated with it.

The most common type of thunderstorm is the air mass storm. Air mass thunderstorms normally develop in late afternoon hours when surface heating produces the maximum number of convection currents in the atmosphere. The life cycle of these weather events has three distinct stages. The first stage of air mass thunderstorm development is called the cumulus stage (Figure 29). In this stage, parcels of warm humid air rise and cool to form clusters of puffy white cumulus clouds. The clouds are the result of condensation and deposition which releases large quantities of latent heat. The added heat energy keeps the air inside the cloud warmer than the air around it. The cloud continues to develop as long as more humid air is added to it from below. Updrafts dominate the circulation patterns within the cloud.

Figure 29: Developing thunderstorm cloud at the cumulus stage.

When the updrafts reach their maximum altitude in the developing cloud, usually 12 to 14 kilometers, they change their direction 180° and become downdrafts. This marks the mature stage (Figure 30). With the downdrafts, precipitation begins to form through collision and coalescence (Figure 31). The storm is also at its most intense stage of development and is now a cumulonimbus cloud The top of the cloud takes on the familiar anvil shape, as strong stratospheric upper-level winds spread ice crystals in the top of the cloud horizontally. At its base, the thunderstorm is several kilometers in diameter. The mature air mass thunderstorm contains heavy rain, thunder, lightning, and produces wind gusts at the surface.

Figure 30: Mature thunderstorm cloud with typical anvil shaped cloud.

Figure 31: Downdrafts from this mature thunderstorm are moving air and rain from the cloud to the ground.

The mature thunderstorm begins to decrease in intensity and enters the dissipating stage after about half an hour. Air currents within the convective storm are now mainly downdrafts as the supply of warm moist air from the lower atmosphere is depleted. Within about 1 hour, the storm is finished and precipitation has stopped.

Thunderstorms form from the equator to as far north as Alaska. They occur most commonly in the tropics were convectional heating of moist surface air occurs year round. Many tropical land based locations experience over 100 thunderstorm days per year. Thunderstorm formation over tropical oceans is less frequent because these surfaces do not warm rapidly. Outside the tropics, thunderstorm formation is more seasonal occurring in those months where heating is most intense.

Tornadoes: A tornado is a vortex of rapidly moving air associated with some severe thunderstorms (see Figure 32). Tornadoes that travel across lakes or oceans are called waterspouts. Winds within the tornado funnel may exceed 500 kilometers per hour. High velocity winds cause most of the damage associated with these weather events. Tornadoes also cause damage through air pressure reductions. The air pressure at the tornado center is approximately 800 millibars (average sea-level pressure is 1013 millibars) and many human made structures collapse outward when subject to pressure drops of this magnitude. The destructive path of a tornado is usually about half a kilometer wide, and usually no more than 25 kilometers long.

Figure 32: Tornado photographed on June 2, 1995 in Texas,U.S.A.

About 74% of all tornadoes have wind speeds between 65 and 181 kilometers per hour. These events are classified according to the Fujita tornado intensity scale as being weak (Table 6). Damage from these tornadoes varies from broken windows and tree branches to shingles blowing off roofs and moving cars pushed from roads. Weak tornadoes have a path that is about 1.5 kilometers long and 100 meters wide, and they generally last for only 1 to 3 minutes. According to the Fujita scale, strong tornadoes can have wind speeds between 182 and 332 kilometers per hour. These phenomena cause considerable damage and occur about 25% of the time. Strong tornadoes can have a course up to 100 kilometers long and half a kilometer wide, and they can last for more than 2 hours. The rarest tornadoes are those with either a F4 or F5 rating. These events have wind speeds between 333 to 513 kilometers per hour and are very destructive and violent. F4 tornadoes occur only about 1% of the time, while F5 are even more rare with a chance of about 1 in 1000 of happening.

Table 6: Fujita tornado intensity scale.

F-Scale	Category	Kilometers per Hour (Miles per Hour)	Comments
0	Weak	65-118 (40-73)	Damage is light. Chimneys on houses may be damaged; trees have broken branches; shallow-rooted trees pushed over; some windows broken; damage to sign boards.
1	Weak	119-181 (74-112)	Shingles on roofs blown off; mobile homes pushed off foundations or overturned; moving cars pushed off roads.
2	Strong	182-253 (113-157)	Considerable damage. Roofs torn off houses; mobile homes destroyed; train boxcars pushed over; large trees snapped or uprooted; light-objects thrown like missiles.
3	Strong	254-332 (158-206)	Damage is severe. Roofs and walls torn off better constructed homes, businesses, and schools; trains overturned; most trees uprooted; heavy cars lifted off ground and thrown some distance.
4	Violent	333-419 (207-260)	Better constructed homes completely leveled; structures with weak foundation blown off some distance.
5	Violent	420-513 (261-318)	Better constructed homes lifted off foundations and carried considerable distance where they disintegrate; trees debarked; cars thrown in excess of 100 meters.

Tornadoes occur in many parts of the world. Some notable hots spots include South Africa, Australia, Europe, New Zealand, northern India, Canada, Argentina, Uruguay, and the United States. Of these locations, the United States has some specific regions within its boundaries that have an extremely high number of events per year.

Hurricanes: Hurricanes are intense cyclonic storms that develop over the warm oceans of the tropics (Figure 33). These tropical storms go by other names in the various parts of the world: India/Australia -

cyclones; western North Pacific - typhoons; and the Philippines - baguio. By international agreement, the term tropical cyclone is used by most nations to describe hurricane-like storms that originated over tropical oceans. Surface atmospheric pressure in the center of a hurricane tends to be extremely low. The lowest pressure reading ever recorded for a hurricane (typhoon Tip, 1979) is 870 millibars (mb). However, most storms have an average pressure of 950 millibars. To be classified as a hurricane, sustained wind speeds must be greater than 118 kilometers per hour at the storm's center. Wind speed in a hurricane is directly related to the surface pressure of the storm. The following graph (Figure 33) shows the relationship between surface pressure and sustained wind speed for a number of tropical low pressure systems.

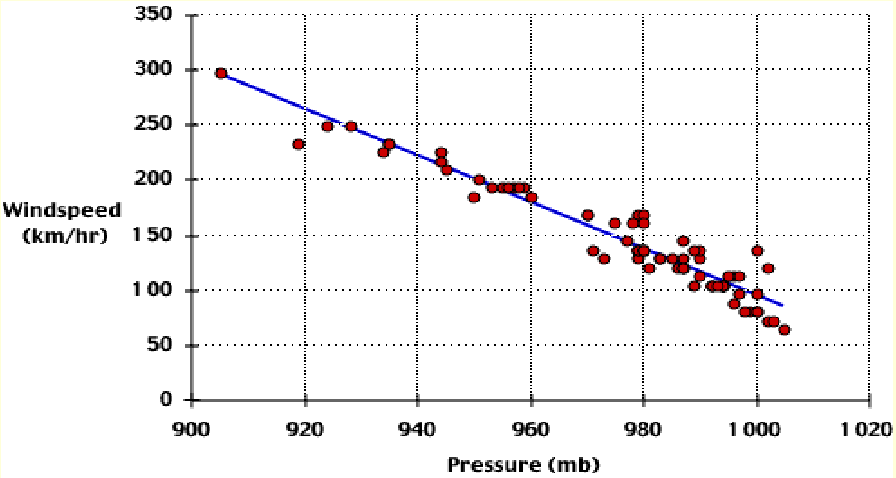

Figure 33: Relationship between surface pressure and wind speed for a number of tropical lowpressure systems. Tropical low pressure systems are classified as hurricanes when their pressure is 980 millibars or lower, and sustained wind speeds are greater than 118 kilometers per hour.

Hurricanes have no fronts associated with them like the mid-latitude cyclones of the polar front. They are also smaller than the mid-latitude cyclone, measuring on average 550 kilometers in diameter. One of the largest hurricanes ever measured was Typhoon Tip (October 12, 1979) which had a diameer of about 2100 kilometers. Mature hurricanes usually develop a cloud-free eye at their center (Figure 34). In the eye, air is descending creating clear skies. The eye of the hurricane may be 20 to 50 kilometers in diameter. Surrounding the eye are bands of organized thunderstorm clouds formed as warm air move in and up into the storm (Figure 35) . The strongest winds and heaviest precipitation are found in the area next to the eye where a vertical wall of thunderstorm clouds develops from the Earth's surface to the top of the troposphere.

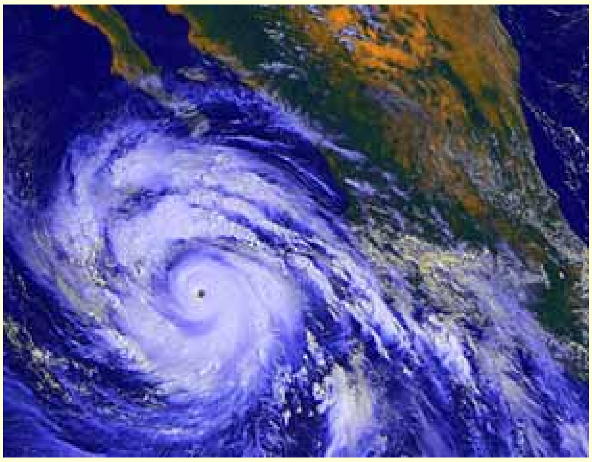

Figure 34: Hurricane as seen from the space shuttle

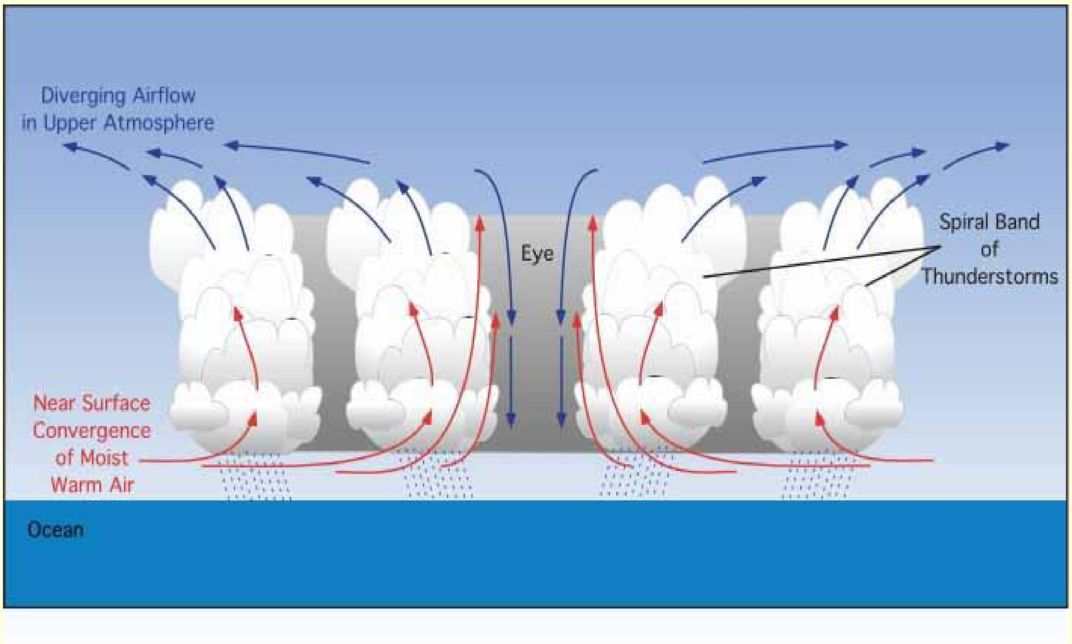

Figure 35: Graphical model showing a vertical cross-section of the air circulation, clouds, and precipitation associated with a hurricane.

9. Climate Classification & climatic regions of the world:

Climate Classification: The Köppen Climate Classification System is the most widely used system for classifying the world's climates. Its categories are based on the annual and monthly averages of temperature and precipitation. The Köppen system recognizes five major climatic types; each type is designated by a capital letter.

A - Tropical Moist Climates: all months have average temperatures above 18° Celsius.
B - Dry Climates: with deficient precipitation during most of the year.
C - Moist Mid-latitude Climates with Mild Winters.
D - Moist Mid-Latitude Climates with Cold Winters.
E - Polar Climates: with extremely cold winters and summers.

Moist Climates (A): Tropical moist climates extend northward and southward from the equator to about 15 to 25° of latitude. In these climates all months have average temperatures greater than 18° Celsius. Annual precipitation is greater than 1500 mm. Three minor Köppen climate types exist in the A group, and their designation is based on seasonal distribution of rainfall. Af or tropical wet is a tropical climate where precipitation occurs all year long. Monthly temperature variations in this climate are less than 3° Celsius. Because of intense surface heating and high humidity, cumulus and cumulonimbus clouds form early in the afternoons almost every day. Daily highs are about 32° Celsius, while night time temperatures average 22° Celsius. Am is a tropical monsoon climate. Annual rainfall is equal to or greater than Af, but most of the precipitation falls in the 7 to 9 hottest months. During the dry season very little rainfall occurs. The tropical wet and dry or savanna (Aw) has an extended dry season during winter. Precipitation during the wet season is usually less than 1000 millimeters, and only during the summer season.

Dry Climates (B): The most obvious climatic feature of this climate is that potential evaporation and transpiration exceed precipitation. These climates extend from 20 - 35° North and South of the equator and in large continental regions of the mid-latitudes often surrounded by mountains. Minor types of this climate include:

- BW - dry arid (desert) is a true desert climate. It covers 12% of the Earth's land surface and is dominated by xerophytic vegetation. The additional letters h and k are used generally to distinguish whether the dry arid climate is found in the subtropics or in the mid-latitudes, respectively.
- BS - dry semiarid (steppe). Is a grassland climate that covers 14% of the Earth's land surface. It receives more precipitation than the BW either from the intertropical convergence zone or from mid-latitude cyclones. Once again, the additional letters h and k are used generally to distinguish whether the dry semiarid climate is found in the subtropics or in the mid-latitudes, respectively.

Moist Subtropical Mid-Latitude Climates (C): This climate generally has warm and humid summers with mild winters. Its extent is from 30 to 50° of latitude mainly on the eastern and western borders of most continents. During the winter, the main weather feature is the mid-latitude cyclone. Convective thunderstorms dominate summer months. Three minor types exist: Cfa - humid subtropical; Cs - Mediterranean; and Cfb - marine. The humid subtropical climate (Cfa) has hot muggy summers and frequent thunderstorms. Winters are mild and precipitation during this season comes from mid-latitude cyclones. A good example of a Cfa climate is the southeastern USA. Cfb marine climates are found on the western coasts of continents. They have a humid climate with short dry summer. Heavy precipitation occurs during the mild winters because of the continuous presence of mid-latitude cyclones. Mediterranean climates (Cs) receive rain primarily during winter season from the mid-latitude cyclone. Extreme summer aridity is caused by the sinking air of the subtropical highs and may exist for up to 5 months. Locations in North America are from Portland, Oregon to all of California.

Moist Continental Mid-latitude Climates (D): Moist continental mid-latitude climates have warm to cool summers and cold winters. The location of these climates is pole ward of the C climates. The average temperature of the warmest month is greater than 10° Celsius, while the coldest month is less than -3° Celsius. Winters are severe with snowstorms, strong winds, and bitter cold from Continental Polar or Arctic air masses. Like the C climates there are three minor types: Dw - dry winters; Ds - dry summers; and Df - wet all seasons.

Polar Climates (E): Polar climates have year-round cold temperatures with the warmest month less than 10° Celsius. Polar climates are found on the northern coastal areas of North America, Europe, Asia, and on the landmasses of Greenland and Antarctica. Two minor climate types exist. ET or polar tundra is a climate where the soil is permanently frozen to depths of hundreds of meters, a condition known as permafrost. Vegetation is dominated by mosses, lichens, dwarf trees and scattered woody shrubs. EF or polar ice caps has a surface that is permanently covered with snow and ice.

Factors Influencing the World Climatic Regions: The climate of a particular place is the function of a number of factors. These factors include:

1) Latitude and its influence on solar radiation received.

2) Air mass influences.

3) Location of global high and low pressure zones.

4) Heat exchange from ocean currents.

5) Distribution of mountain barriers.

6) Pattern of prevailing winds.

7) Distribution of land and sea.

8) Altitude.

At a macro-level, the first three factors are most important in influencing a region's climate.

Climatic Region Descriptions: The following discussion organizes the climatic regions of the world into eight different groups. Categorization of these climates is based on their Köppen classification and seasonal dominance of air masses.

Tropical Wet

- Köppen Classification - Af.
- Dominated by Maritime Tropical air masses all year long.

The tropical wet climate is characterized by somewhat consistent daily high temperatures ranging between 20 to 30° Celsius. The monthly temperature averages vary from 24 to 30° Celsius. Annual range of monthly temperatures is about 3° Celsius. It has reasonably uniform precipitation all year round, and total rainfall over 2000 millimeters or greater.

Tropical Wet and Dry

- Köppen Classification - Aw and Am.
- Maritime Tropical air masses high Sun season and Continental Tropical air masses low Sun season.

This climate has distinct wet/dry periods. During the rainy season, the climate of this location is similar to the tropical wet climate: warm, humid, and has frequent thunderstorms. During the dry season more or less semi-desert conditions prevail.

Subtropical Desert and Steppe

- Köppen Classification - BWh and BSh.
- Dominated by Continental Tropical air masses all year.

This climate type covers 12 percent of all land area on the continents. The heart of the tropical desert climate is found near the tropics of Cancer and Capricorn, usually toward the western side of the continents. Regions with this climate have the following common climatic characteristics:

- low relative humidity and cloud cover.
- low frequency and amount of precipitation.
- high mean annual temperature.
- high monthly temperatures.
- high diurnal temperature ranges.
- high wind velocities.

Precipitation is very low in quantity and very infrequent in distribution, both temporally and spatially.Temperature varies greatly both diurnally and annually. The highest average monthly temperatures on the Earth are found in the tropical desert. They range between 29 to 35° Celsius. Winter monthly temperatures can be 15 to 25° cooler than summer temperatures. This climate also has extreme diurnal ranges of temperature. The average diurnal range is from 14 to 25° Celsius.

Mid-Latitude Desert and Steppe

- Köppen Classification - BWk and BSk.
- Dominated by Continental Tropical air masses during summer and Continental Polar in winter.

This climate type covers 14 percent of all land area on the continents. Regions with this climate have the following similar climatic characteristics:

- low relative humidity and cloud cover.
- low frequency and amount of precipitation.
- moderate to high annual temperature.
- moderate to high monthly temperatures.

These climates are dry because of extreme continentality and the effect of high elevations. Being located at the center of a continent limits the amount of moisture supplied from ocean sources. Without this moisture precipitation can not occur. The presence of mountains upwind of these climates can further reduce moisture availability because of the rainshadow effect. Major expanses of mid-latitude deserts can be found east of the Caspian Sea, north of the Himalayas, in western United States, and east of the Andes in a narrow region in southern South America. Mid-latitude deserts have a greater range of both daily and annual temperatures than their subtropical counterparts. In most cases, summer temperatures are not as high in mid-latitude deserts when compared to subtropical deserts. There are, however, exceptions like Death Valley, California which is one of the hottest places on our planet. Winter temperatures tend to be quite cool.

Mid-latitude steppe climates cover considerable parts of western North America and central Asia. This climate generally has similar temperature characteristics as mid-latitude deserts. However, mid-latitude steppe climates do receive slightly more precipitation than mid-latitude deserts.

Mid-Latitude Wet

- Köppen Classification - Cf and Df.
- Maritime Tropical in summer and Maritime Polar in winter.

The Mid-Latitude Wet climate is found in the Northern Hemisphere in the region from 60° North to 25 to 30° North mainly along the eastern margins of the continents. In North America, this climate extends from the Pacific coast of Canada at latitudes above 55° eastward to the Atlantic coast where it dominates the eastern half of the continent. In the Southern Hemisphere, this climate exists on the Southeastern tip of South America, New Zealand and the Southeast coast of Australia.

Summer weather is dominated by Maritime Tropical air masses which produce many thunderstorms from daytime heating. Monthly average temperature ranges from 21 to 26° Celsius with the tropical areas going as high as 29° Celsius. This is slightly warmer than the humid tropics. Frontal weather associated with the mid-latitude cyclone dominates the climate of more polar areas and is more frequent in all regions in the winter.

Precipitation in this climate is fairly evenly distributed throughout the year. Annual totals of precipitation are quite variable and depend on the latitude and continental position of the regions. During the summer and on the equatorial margins, convectional rainfall is the primary mechanism of precipitation. The southeast of the United Sates averages 40 to 60 days of thunderstorms per year. The frequency of thunderstorms decreases rapidly from south to north. Hurricanes also provide a mechanism for producing precipitation in more tropical regions of this climate.

Mid-Latitude Winter-Dry

- Köppen Classification - Cw and Dw.
- Maritime Tropical air masses in summer and Continental Polar air masses in winter.

This climate is characterized by a strong seasonal pattern of both temperature and precipitation. The normal location of the Mid-Latitude Winter-Dry climate is in the interior of the continents in the mid-latitudes. This continental location causes a large annual temperature range because of continentality.

This climate receives Maritime Tropical air masses in the summer with occasional Continental Tropical air masses from the adjacent deserts. Summers are hot and humid with intense summer convectional storms. Continental Polar air masses are dominant in the winter with an occasional outbreak of Maritime Polar air. Continental Polar air masses are associated with cold, dry weather conditions. Precipitation mainly occurs in the summer from thunderstorm activity. The mid-latitude cyclone produces a smaller quantity of precipitation in the winter.

Mid-Latitude Summer-Dry

- Köppen Classification - Cs.
- Summer weather is dominated by Continental Tropical air, while in the winter, Maritime Polar air masses are frequent.

The Mid-Latitude Summer-Dry climate is found on the western margins of the continents between 30 to 40° of latitude. Usually, this climate does not spread into the continents very far. This climate is often called a Mediterranean climate.Precipitation falls mainly in the winter in this climate via the mid-latitude cyclone. During the summer these areas are influenced by stable subtropical highs, that give them dry, warm weather.

Polar Tundra

- Köppen Classification - ET.
- Maritime Polar in summer and Continental Polar or Arctic in winter.

The polar tundra climate is characterized by cold winters, cool summers, and a summer rainfall regime. Areas experiencing this climate are the North American Arctic coast, Iceland, coastal Greenland, the Arctic coast of Europe and Asia, and the Southern Hemisphere islands of McQuarie, Kerguelen, and South Georgia. Annual precipitation averages less than 250 mm for most locations and most of this precipitation falls during the summer.

Polar Ice Cap

- Köppen Classification - EF.
- Continental Arctic and Continental Polar air masses dominate.

Polar ice cap climates are located in the high latitudes over continental areas, like Greenland and the Antarctica. This climate type covers a vast area of the planet. For half of the year no solar radiation is received. During the summer months, available insolation is fairly high because of long days and a relatively transparent atmosphere. Average monthly temperatures are all generally below zero° Celsius. Winds are consistent and velocity is high enough to produce blizzard conditions most of the time.

Causes of Climate Change: Figure 36 illustrates the basic components that influence the state of the Earth's climatic system. Changes in the state of this system can occur externally (from extraterrestrial systems) or internally (from ocean, atmosphere and land systems) through any one of the described components. For example, an external change may involve a variation in the Sun's output which would externally vary the amount of solar radiation received by the Earth's atmosphere and surface. Internal variations in the Earth's climatic system may be caused by changes in the concentrations of atmospheric gases, mountain building, volcanic activity, and changes in surface or atmospheric albedo.

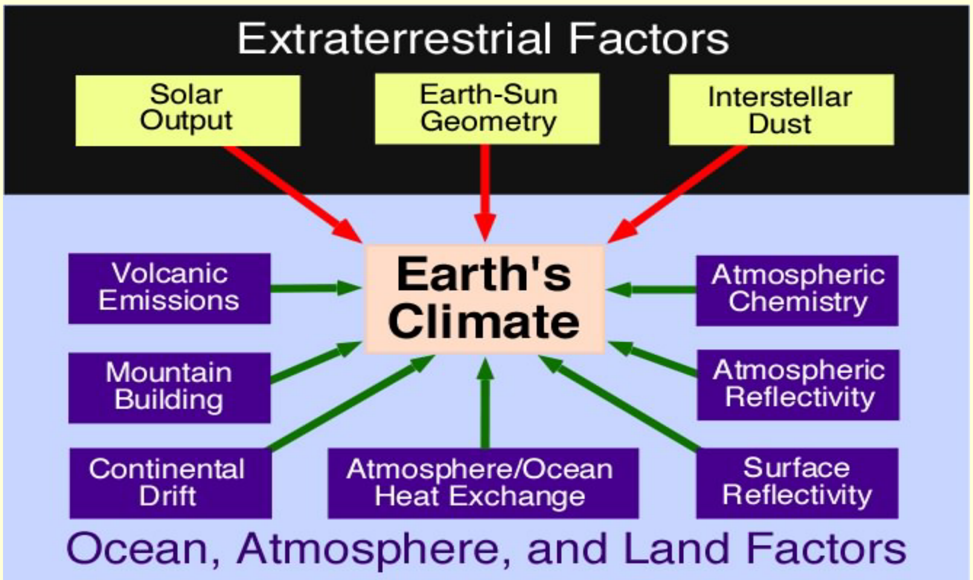

Figure 36: Factors that influence the Earth's climate.

The work of climatologists has found evidence to suggest that only a limited number of factors are primarily responsible for most of the past episodes of climate change on the Earth. These factors include:

- Variations in the Earth's orbital characteristics.
- Atmospheric carbon dioxide variations.
- Volcanic eruptions
- Variations in solar output.

III. Hydrosphere:

Hydrosphere is the name given to all the water of the Earth in solid, liquid and gaseous forms. It thus includes the water of the atmosphere, water on the Earth's surface (e.g. oceans, rivers, ice-sheets and ground water). Oceans, which are interconnected, cover about 70.8 percent of the surface of the Earth. Pacific Ocean, which is the largest among 'the oceans, sprawls over an area of about 165,760,000 sq km, an area which is more than the total combined area of all the continents.

The oceans have an average depth of 3.5 km but their depth varies from place to place. The deepest known point is the Challenger Deep, a part of the Mariana Trench in the Pacific Ocean, which is 11.776 km deep.

The water in the oceans totals over 1,300 million cubic km, which is more than 97 percent of world's total water. The balance of water resources are contributed by glaciers, ice and snow, fresh water lakes, rivers and the underground water.

The ocean floor consists of three main zones, 97%., the continental shelf, the continental slope and the abyss. The continental shelves are, in fact, the submerged parts of the continents that gently slope into the oceans bordering these continents. They extend onwards to a depth of about 180 metres (600 feet) and considerably vary in width. For example, the continental shelf off north western Europe extends to about 300 kilometres, but off the west coast of North America, there is practically no continental shelf.

The true edge of the continents is, however, the continental slope which begins from the point where the continental shelf ends. The continental slope descends steeply having a depth extending to over 3.6 kilometres.

The abyss contains large sediment covered plains below the oceans. These plains are often interspersed by lofty volcanic mountains some of which surface as islands and long broad ridges which are in some places 2 to 4 kilometres high and up to 4,000 kilometres wide. The abyss also contains yawning chasms called deep sea trenches.

Continental Shelf (Littoral) is the sea bed bordering die continents, which is covered by shallow water up to about 100 fathoms (600 feet) beyond which is the continental slope.

Continental Slope is die region of die sea extending next to the continental shelf and having a depth up to 2,000 fathoms.

Continental Drift is a theory or hypothesis that continents have moved relative to each other across the surface of the Earth. The idea was originally put forth by Antonio Snider-Pellegrini in 1858 and developed by the German geologist Alfred Wegener from 1910. He stated that there was just one supercontinent, Pangaea which began to break up about 200 million years ago, since then the continents have drifted to their present positions.

Salinity of the Water is effected by the extent of evaporation of surface water and the volume of fresh water added by rainfall, rivers and meeting of icebergs. Enclosed seas in tropical areas which are subjected to rapid evaporation and denied fresh water are highly saline (e.g., Sambar Lake of Rajasthan in India and Dead Sea).

Isohaline is the line which joins, on a map, points of die sea/oceans having equal salinity.

Ocean Current is the movement of a sizeable body of water as a current for fairly long distances along a specific padi. It is known as 'drift current' when caused by the winds and as 'convection current' when brought about by variations in temperature. A 'warm current' is the one which flows from a warm to a cold region. The current flowing from a cold to a warm region is called a 'cold current'.

Stream refers to any body of running water that flows on or under the surface of the water.

Swamp is a portion of wet, waterlogged or flooded land.

Tide is die periodic rise and fall of sea water. The rise and fall occur alternately twice a day. The rising of water is called the Flood Tide and the falling of water is termed as die Ebb Tide.Spring Tides are caused as a result of the Moon and the Sun pulling the Earth gravitationally in the same direction. They occur twice a month around full moon and new moon.Neap Tides are caused when the Moon and the Sun pull the Earth gravitationally in opposite directions. They occur twice a month during first and last quarters of the Moon, when the Sun, the Earth and the Moon are at right angles.

Lagoon is a shallow stretch of water which is pardy or completely separated from sea by a narrow strip of land.

Reef is a ridge of submerged rock or other hard substance in sea water. It becomes visible at low tides.

Coral Reef is a ridge of coral and other organic material consolidated into limestone lying near die sea level.

Bay is a wide curving indentation in a coasdine lying between two head lands.

Atoll is a circular or horseshoe-shaped coral enclosing within it a lagoon.

Fjord is a shallow stretch of river that may be crossed on foot or in a vehicle, commonly found in Norway or Sweden.

Strait is a narrow sea passage that links two large areas of sea, for example the Strait of Gibraltar.

Isthmus is a narrow strip of land connecting two large areas of land {e.g., Isthmus of Panama joining the North and Soudi American continents).

Hinterland is the land which lies behind a seaport or seaboard and supplies the bulk of the exports and in which are distributed the bulk of the "imports of that seaport or seaboard.

River is a large stream of fresh water flowing down hill within a channel to enter another river, lake or sea.

World's Largest River is South America's Amazon which flows into the South Atlantic Ocean. It is so regarded in view of die size and the volume of water it discharges into die sea.
World's Longest River is Nile of Egypt which flows into the Mediterranean Sea. It extends to 6,690 km.

Levee refers to the river bank formed by die accumulation of silt during flood or the embankment built by man.

Estuary is the tidal mouth of a river where die salt water of die tide meets die fresh water of the river current.

Delta is a triangular tract of land formed by die accumulation of silt at the river's mouth near the sea. It is so called because of its resemblance to the letter A (delta) of the Greek alphabet.

World's Largest Delta is the Sunderbans Delta which is created in the Bay of Bengal by die Ganges and die Brahmaputra in West Bengal in India and Bangladesh. It covers an area of 75,000 sq km.

Meander is a curve in the course of a river which continuously swings from side to side in wide loops, as it progresses across the flat country. The term 'meander' is on the name of river Meander of Asia Minor.

1. **Atmospheric Humidity:** The term humidity describes the fact that the atmosphere can contain water vapor. The amount of humidity found in air varies because of a number of factors. Two important factors are evaporation and condensation. At the water/atmosphere interface over our planet's oceans large amounts of liquid water are evaporated into atmospheric water vapor. This process is mainly caused by absorption of solar radiation and the subsequent generation of heat at the ocean's surface. In our atmosphere, water vapor is converted back into liquid form when air masses lose heat energy and cool. This process is responsible for the development of most clouds and also produces the rain that falls to the Earth's surface.

   Scientists have developed a number of different measures of atmospheric humidity. We are primarily interested in three of these measures: mixing ratio, saturation mixing ratio, and relative humidity. Mixing ratio is a measure that refers to the mass of a specific gas component relative to the mass of the remaining gaseous components for a sample of air. When used to measure humidity mixing ratio would measure the mass of water vapor relative to the mass of all of the other gases. In meteorological measurements, mixing ratio is usually expressed in grams of water vapor per kilogram of dry air.

Saturation mixing ratio refers to the mass of water vapor that can be held in a kilogram of dry air at saturation. Saturation can be generally defined as the condition where any addition of water vapor to a mass of air leads to the condensation of liquid water or the deposition of ice at a given temperature and pressure. The data in Table 7 indicates that warmer air has a higher saturation mixing ratio than cooler air at a constant atmospheric pressure. It is important to note that this relationship between temperature and water vapor content in the air is not linear but exponential. In other words, for each 10° increase in temperature, saturation mixing ratio increases by a larger quantity.

Table 7: Saturation mixing ratio (at 1000 mb).

Temperature Degrees Celsius	Vapor (g) per Kilogram of Dry Air
50	88.12
40	49.81
30	27.69
20	14.85
10	7.76
0	3.84

The most commonly used measure of humidity is relative humidity. Relative humidity can be simply defined as the amount of water in the air relative to the saturation amount the air can hold at a given temperature multiplied by 100. Air with a relative humidity of 50% contains a half of the water vapor it could hold at a particular temperature. Figure37 illustrates the concept of relative humidity.

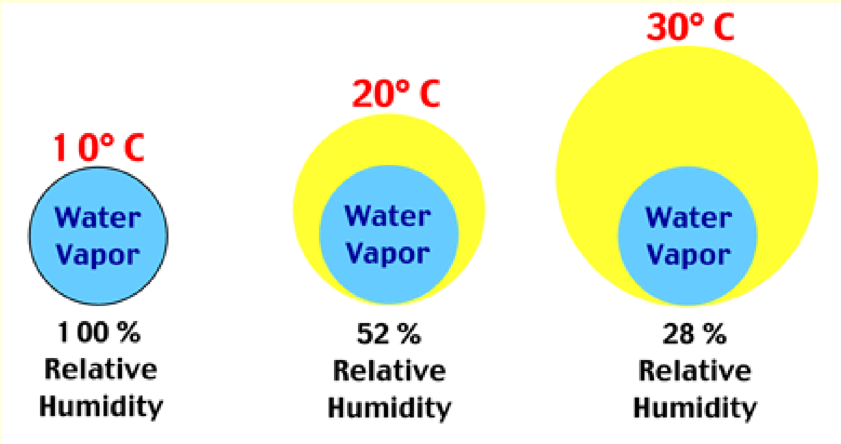

Figure 37: The following illustration describes how relative humidity changes in a parcel of air with an increase in air temperature. At 10° Celsius, a parcel of dry air weighing one kilogram can hold a maximum of 7.76 grams of water vapor (see Table 7). In this state, the parcel of air would be at saturation and its relative humidity would be 100%. Increasing the temperature of this parcel, without adding or removing any water, would increase its ability to hold water vapor. According to Table 7, a 10 degree Celsius rise in temperature would increase the saturation mixing ratio of this parcel of air to 14.85 grams. Since no water has been added or removed, the actual amount of water in the parcel would remain 7.76 grams. This quantity is known as the mixing ratio. Dividing the mixing ratio by the saturation mixing ratio and then multiplying this number by 100 determines the relative humidity of the parcel of air (7.76/14.85 x 100 = 52%). At a temperature of 20° Celsius, relative humidity would be 52%. Raising the temperature of the parcel of air by another 10° Celsius would again lower its relative humidity. In this state, the actual

mixing ratio would still be 7.76 grams, while the saturation mixing ratio would increase to 27.69 grams. Relative humidity would drop to 28% at a temperature of 30° Celsius (7.76/27.69 x 100 = 28%).

Measuring Humidity: Humidity can be measured using a variety of instruments. Relative humidity is often determined using a sling psychrometer or a hair hygrometer. A sling psychrometer is a device that consists of two thermometers joined to a piece of plastic or metal (Figure 38). One of the thermometers, called the wet-bulb thermometer, has small cloth hood (wick) that is pulled over the reservoir bulb. The other thermometer has no hood and is called the dry-bulb thermometer. At one end of instrument is a rotating handle. To use the sling psychrometer, the wick is moistened with clean water and the device is twirled in the air using the handle. As the device is spun in the air, evaporation of the water from the wet-bulb thermometer occurs cooling it. The amount of evaporation and cooling taking place is controlled by the dryness of the air. If the air is saturated, the wet-bulb and dry-bulb thermometers would have the same temperature because no evaporation can occur. After a few minutes of twirling, the temperatures of the wet-bulb and dry-bulb thermometers are determined, a value called the wet-bulb depression is calculated (dry-bulb minus wet-bulb temperature), and a psychrometric table is used to find the corresponding relative humidity from the dry-bulb temperature and wet-bulb depression.

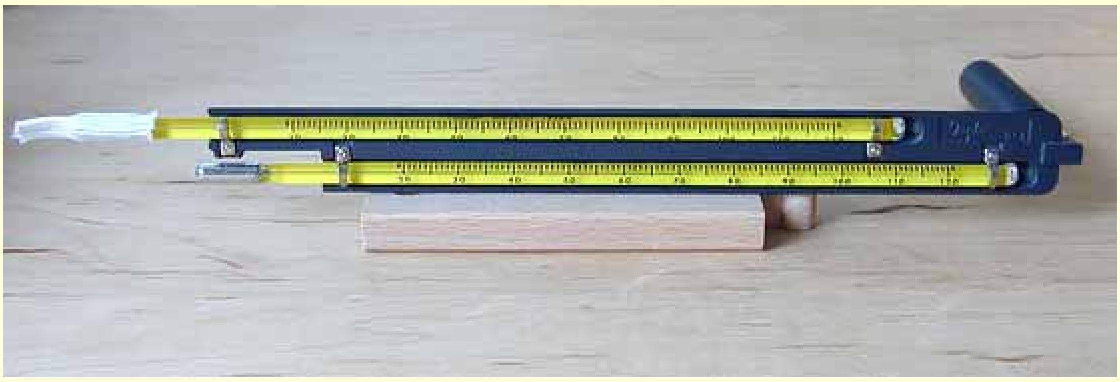

Figure 38: Sling psychrometer. Note the wet-bulb thermometer is located on top.

Hair hygrometers work on the fact that hair changes its length when humidity varies. This device usually consists of a number of human or horse hairs connected to a mechanical lever system. When humidity increases the length of the hairs becomes longer. This change in length is then transmitted and magnified by the lever system into a measurement of relative humidity.

Humidity is also measured on a global scale using remotely placed satellites. These satellites are able to detect the concentration of water in the troposphere at altitudes between 4 and 12 kilometers. Satellites that can measure water vapor have sensors that are sensitive to infrared radiation. Water vapor specifically absorbs and re-radiates radiation in this spectral band. Satellite water vapor imagery plays an important role in monitoring climate conditions (like the formation of thunderstorms) and in the development of future weather forecasts.

Dew Point and Frost Point

Associated with relative humidity is dew point (if the dew point is below freezing, it is referred to as the frost point). Dew point is the temperature at which water vapor saturates from an air mass into liquid or solid usually forming rain, snow, frost, or dew. Dew point normally occurs when a mass of air has a relative humidity of 100%. This happens in the atmosphere as a result of cooling through a number of different processes.

2. Precipitation and Fog:

Precipitation: We can define precipitation as any liquid or solid aqueous deposit that forms in a saturated atmosphere (relative humidity equals 100%) and falls from clouds to the ground surface. It is important to recognize that most clouds do not produce precipitation. In many clouds, water droplets and ice crystals are just too small to overcome the natural updrafts found in the lower atmosphere. As a result, the tiny water droplets and ice crystals remain suspended in the atmosphere until they are converted back into vapor.

Water droplets and ice crystals can only fall to the Earth's surface if they grow to a size that can overcome updrafts. Conditions for growth can develop in clouds via two different processes. In clouds with temperatures above freezing, turbulent atmospheric mixing can cause droplets to grow through the processes of collision and coalescence. One initial condition, however, must be met for this process to begin: droplet size in the cloud must be variable. This initial condition allows larger and heavier droplets to collide and coalesce with lighter smaller droplets during downdraft periods. If enough atmospheric mixing occurs the larger droplets can expand by up to 250 times and can become heavy enough to fall to the Earth's surface.

The other mechanism of precipitation development involves clouds whose temperature is below freezing. In these clouds, large ice crystals grow due to the differences in vapor pressure between ice crystals and supercooled water droplets. Vapor pressure differences between ice and supercooled water causes a net migration of water vapor from water droplets to ice crystals. The ice crystal then absorbs the water vapor, depositing it on their surface. At the same time, the loss of vapor from the water droplets causes them to shrink in size. A necessary initial requirement for this process is the presence of both condensation nuclei and deposition nuclei. While deposition nuclei form ice crystals at temperatures just below zero degrees Celsius, condensation nuclei can remain liquid (supercooled) to temperatures as low as -40° Celsius depending on size. Because of this phenomenon, cold clouds can contain both ice crystals and supercooled water droplets. The relative proportion of these two types of particles determines whether snow crystals grow to a size to overcome atmospheric updrafts.

The following list describes the various types of precipitation that can form in the atmosphere:

Rain is any liquid deposit that falls from the atmosphere to the surface and has a diameter greater than 0.5 millimeters. The maximum size of a rain drop is about 5 millimeters. Beyond this size inter-molecular cohesive forces become too weak to hold the mass of water together as a single drop.

Freezing rain takes place when falling liquid water droplets encounter a surface with a temperature below 0° Celsius. Upon contact with this surface, the rain quickly turns into ice. Another inportant condition required for freezing rain is that the atmosphere where rain develops must be above freezing. A situation where warm air is found on top of cold air is called a temperature inversion. Temperature inversions are not the common state of the lower atmosphere. Usually, air temperature descreases with an increase in altitude in the troposphere. In the mid-latitudes, we often find temperature inversions developing along the moving front edge of a cold air mass that is overtaking warmer air. This condition causes the less dense warm air to be pushed up and over the more dense cold air.

Ice pellets or sleet are transparent or translucent spheres of frozen water. They have a diameter smaller than 5 millimeters. This form of precipitation develops first as raindrops in a relatively warm atmosphere where the temperature is above freezing. These raindrops then descend into a colder lower layer of the atmopshere where freezing temperatures occur. In this layer, the cold temperatures cause the raindrops to freeze into ice pellets during their transit to the ground surface. Similar to freezing rain, an air temperature inversion is required for the formation of ice pellets.

Snow is a type of precipitation common to the mid and high latitudes. Snow develops when water vapor deposits itself (skipping the liquid phase) directly on a six-sided (hexagon) deposition nuclei as a solid crystals, at temperatures below freezing. The unique form of snowflakes occurs because ice crystal growth is most rapid at the six points associated with geometric shape of the deposition nuclei. These points are more directly exposed to the atmosphere and consequently convert more water vapor into ice. Snow is usually generated by frontal lifting associated with mid-latitude cyclones. Snowfall can occur in the fall, winter, and spring months when atmospheric temperatures can drop below freezing.

Snow pellets or graupel are spherical white bits of ice that have a diameter less than 5 millimeters. Snow pellets develop when supercooled droplets freeze onto the surface of falling snowflakes. Snow pellets usually fall for only a brief period of time when a precipitation event changes from ice pellets to snow.

Hail is a type of frozen precipitation that is more than 5 millimeters in diameter. Hailstones often have concentric shells of ice alternating between those with a white cloudy appearance and those that are clear. The cloudy white shells contain partially melted snowflakes that freeze onto the surface of the growing hailstone. The clear shells develop when liquid water freezes to the hailstone surface. Strong updrafts in mature thunderstorm clouds provide the mechanism for hail formation. These updrafts move hailstone embryos (often large frozen raindrops) upward through the storm cloud where they encounter layers of ice crystals, snow, and supercooled rain. Each encounter causes the hailstone to grow larger in size as ice, snow, and rain accretes to the surface. Hailstones can grow very large in size when they are carried upward by more than one updraft. When the hailstone becomes too heavy to be supported by updrafts, it begins falling under the influence of gravity. Descending hailstones can lose a significant amount of their mass because of melting as they encounter the warm air found in between the cloud base and the Earth's surface. Small hailstones often melt completely before they reach the ground.

Fog: Fog is simply a cloud of minute water droplets that exists at gound level. Fog develops when the air at ground level is cooled enough to cause saturation (relative humidity equals 100%). Meteorologist have a very specific definition to determine if fog exists. This definition suggests that fog is occurring when the visibility of the atmosphere, near the Earth's surface, becomes less than 1 kilometer. Fog can be created by a variety of processes:

Radiation fog or ground fog, is produced by near surface cooling of the atmosphere due to longwave radiation emission. This particular type of fog is normally quite shallow and develops during the evening hours. Shortly after sunrise the radiation fog disappears because of surface heating due to the absorption of solar radiation.

Upslope fog is created when air flows over higher topography. When the air is forced to rise in altitude because of the topographic barrier, it is cooled by adiabatic expansion. This type of fog is often found forming on the windward slopes of hills or mountains.
Advection fog is generated when air flows over a surface with a different temperature. Warm air advection can produce fog if it flows over a cold surface. The contact cooling associated with this process causes satuation to occur in a relatively thin layer of air immediately above the ground surface.

Evaporation fog is a specific type of advection fog. It occurs when you get cold air advancing over warm water or warm, moist land surfaces. In this situation, fog forms as water from the surface evaporates into the cold air and then saturates. This type of fog can also be called steam fog or sea smoke.

Frontal fog is a type of fog that is associated with weather fronts, particularly warm fronts. In this situaton, rain descending into the colder air ahead of the warm front can increase the quantity of water vapor in this atmosphere through evaporation. Fog then forms when the quanity of water in the atmosphere ahead of the front reaches saturation (relative humidity equals 100%).

3. **Oceans:** Seen from space, our planet's surface appears to be dominated by the color blue. The Earth appears blue because large bodies of saline water known as the oceans dominate the surface. Oceans cover approximately 70.8% or 361 million square kilometers (139 million square miles) of Earth's surface (Table 8) with a volume of about 1370 million cubic kilometers (329 million cubic miles). The average depth of these extensive bodies of sea water is about 3.8 kilometers (2.4 miles). Maximum depths can exceed 10 kilometers (6.2 miles) in a number of areas known as ocean trenches. The oceans contain 97% of our planet's available water. The other 3% is found in atmosphere, on the Earth's terrestrial surface, or in the Earth's lithosphere in various forms and stores (see the Hydrologic Cycle).

Table 8: Surface area of our planet covered by oceans and continents.

Surface	Percent of Earth's Total Surface Area	Area Square Kilometers	Area Square Miles
Earth's Surface Area Covered by Land	29.2%	148,940,000	57,491,000
Earth's Surface Area Covered by Water	70.8%	361,132,000	139,397,000
Pacific Ocean	30.5%	155,557,000	60,045,000
Atlantic Ocean	20.8%	76,762,000	29,630,000
Indian Ocean	14.4%	68,556,000	26,463,000
Southern Ocean	4.0%	20,327,000	7,846,000
Arctic Ocean	2.8%	14,056,000	5,426,000

The spatial distribution of ocean regions and continents is unevenly arranged across the Earth's surface. In the Northern Hemisphere, the ratio of land to ocean is about 1 to 1.5. The ratio of land to ocean in the Southern Hemisphere is 1 to 4. This greater abundance of ocean surface has some fascinating effects on the environment of the southern half of our planet. For example, climate of Southern Hemisphere locations is often more moderate when compared to similar places in the Northern Hemisphere. This fact is primarily due to the presence of large amounts of heat energy stored in the oceans.

The International Hydrographic Organization has divided and named the interconnected oceans of the world into five main regions: Atlantic Ocean, Arctic Ocean, Indian Ocean, Pacific Ocean, and the Southern Ocean. Each one of these regions is different from the others in some specific ways.
Atlantic Ocean

The Atlantic Ocean is a relatively narrow body of water that snakes between nearly parallel continental masses covering about 21% of the Earth's total surface area (Figure 39). This ocean body contains most of our planet's shallow seas, but it has relatively few islands. Some of the shallow seas found in the Atlantic Ocean include the Caribbean, Mediterranean, Baltic, Black, North, Baltic, and the Gulf of Mexico. The average depth of the Atlantic Ocean (including its adjacent seas) is about 3300 meters (10,800 feet). The deepest point, 8605 meters (28,232 feet), occurs in the Puerto Rico Trench. The Mid-Atlantic Ridge, running roughly down the center of this ocean region, separates the Atlantic Ocean into two large basins.

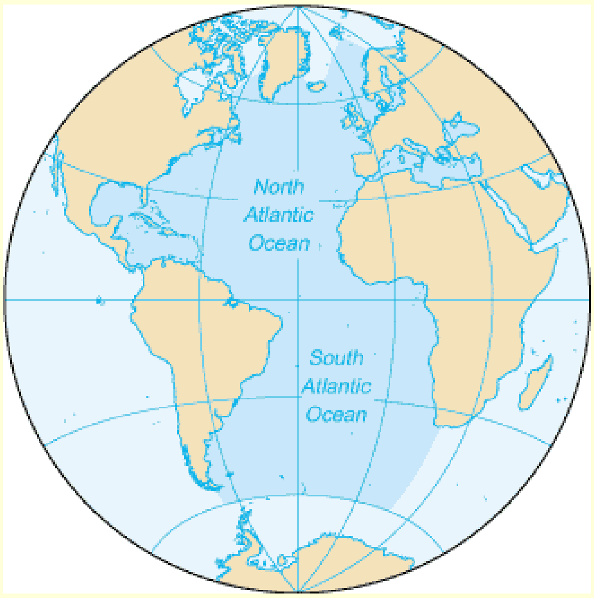

Figure 39: Atlantic Ocean region

Many streams empty their fresh water discharge into the Atlantic Ocean. In fact, the Atlantic Ocean receives more freshwater from terrestrial runoff than any other ocean region. This ocean region also drains some of the Earth's largest rivers including the Amazon, Mississippi, St. Lawrence, and Congo. The surface area of the Atlantic Ocean is about 1.6 times greater than the terrestrial area providing runoff.

Arctic Ocean: The Arctic Ocean is the smallest of the world's five ocean regions, covering about 3% of the Earth's total surface area. Most of this nearly landlocked ocean region is located north of the Arctic Circle (Figure 40). The Arctic Ocean is connected to the Atlantic Ocean by the Greenland Sea, and the Pacific Ocean via the Bering Strait. The Arctic Ocean is also the shallowest ocean region with an average depth of 1050 meters (3450 feet). The center of the Arctic Ocean is covered by a drifting persistent icepack that has an average thickness of about 3 meters (10 feet). During the winter months, this sea ice covers much of the Arctic Ocean surface. Higher temperatures in the summer months cause the icepack to seasonally shrink in extent by about 50%.

Figure 40: Artic Ocean region

Indian Ocean: The Indian Ocean covers about 14% of the Earth's surface area. This ocean region is enclosed on three sides by the landmasses of Africa, Asia, and Australia. The Indian Ocean's southern border is open to water exchange with the much colder Southern Ocean. Average depth of the Indian Ocean is 3900 meters (12,800 feet). The deepest point in this ocean region occurs in the Java Trench with a depth of 7258 meters (23,812 feet) below sea level. The Indian Ocean region has relatively few islands. Continental shelf areas tend to be quite narrow and not many shallow seas exist. Relative to the Atlantic Ocean, only a small number of streams drain into the Indian Ocean. Consequently, the surface area of the Indian Ocean is approximately 400% larger than the land area supply runoff into it. Some of the major rivers flowing into the Indian Ocean include the Zambezi, Arvandrud/Shatt-al-Arab, Indus, Ganges, Brahmaputra, and the Irrawaddy. Sea water salinity ranges between 32 and 37 parts per 1000. Because much of the Indian Ocean lies within the tropics, this basin has the warmest surface ocean temperatures.

Pacific Ocean: The Pacific Ocean is the largest ocean region (Figure 41) covering about 30% of the Earth's surface area (about 15 times the size of the United States). The ocean floor of the Pacific is quite uniform in depth having an average elevation of 4300 meters (14,100 feet) below sea level. This fact makes it the deepest ocean region on average. The Pacific Ocean is also home to the lowest elevation on our planet. The deepest point in the Mariana Trench lies some 10,911 meters (35,840 feet) below sea level as recorded by the Japanese probe, Kaiko, on March 24, 1995. About 25,000 islands can be found in the Pacific Ocean region. This is more than the number for the other four ocean regions combined. Many of these islands are actually the tops of volcanic mountains created by the release of molten rock from beneath the ocean floor.

Figure 41: Pacific Ocean region

Relative to the Atlantic Ocean, only a small number of rivers add terrestrial freshwater runoff to the Pacific Ocean. In fact, the surface area of the Pacific is about 1000% greater than the land area that drains into it. Some of the major rivers flowing into this ocean region include the Colorado, Columbia, Fraser, Mekong, Río Grande de Santiago, San Joaquin, Shinano, Skeena, Stikine, Xi Jiang, and Yukon. Some of larger adjacent seas connected to the Pacific are Celebes, Tasman, Coral, East China, Sulu, South China, Yellow, and the Sea of Japan.

Southern Ocean: The Southern Ocean surrounds Antarctica extending to the latitude 60° South (Figure 42). This ocean region occupies about 4% of the Earth's surface or about 20,327,000 square kilometers (7,846,000 square miles). Relative to the other ocean regions, the floor of the Southern Ocean is quite deep ranging from 4000 to 5000 meters (13,100 to 16,400 feet) below sea level over most of the area it occupies. Continental shelf areas are very limited and are mainly found around Antarctica. But even these areas are quite deep with an elevation between 400 to 800 meters (1300 to 2600 feet) below sea level. For comparison, the average depth of the continental shelf for the entire planet is about 130 meters (425 feet). The Southern Ocean's deepest point is in the South Sandwich Trench at 7235 meters (23,737 feet) sea level. Seas adjacent to this ocean region include the Amundsen Sea, Bellingshausen Sea, Ross Sea, Scotia Sea, and the Weddell Sea. By about September of each year, a mobile icepack situated around Antarctic reaches its greatest seasonal extent covering about 19 million square kilometers (7 million square miles). This icepack shrinks by around 85% six months later in March.

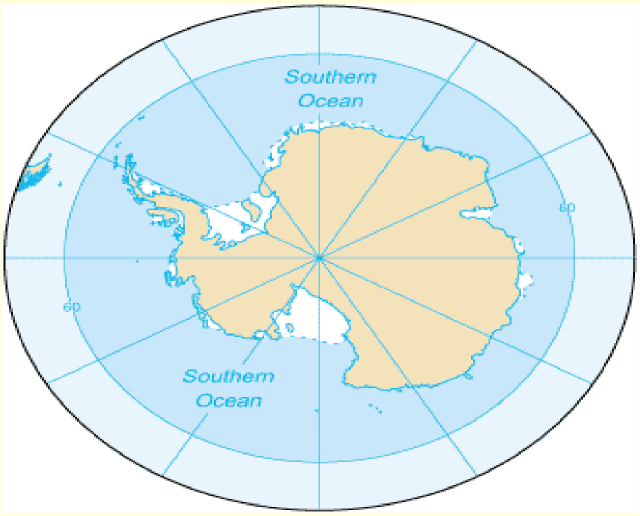

Figure 42: Southern Ocean region

4. Ocean Currents

Surface Ocean Currents: An ocean current can be defined as a horizontal movement of seawater at the ocean's surface. Ocean currents are driven by the circulation of wind above surface waters. Frictional stress at the interface between the ocean and the wind causes the water to move in the direction of the wind. Large ocean currents are a response of the atmosphere and ocean to the flow of energy from the tropics to polar regions. In some cases, currents are transient features and affect only a small area. Other ocean currents are essentially permanent and extend over large horizontal distances.

On a global scale, large ocean currents are constrained by the continental masses found bordering the three oceanic basins. Continental borders cause these currents to develop an almost closed circular pattern called a gyre. Each ocean basin has a large gyre located at approximately 30° North and South latitude in the subtropical regions. The currents in these gyres are driven by the atmospheric flow produced by the subtropical high pressure systems. Smaller gyres occur in the North Atlantic and Pacific Oceans centered at 50° North. Currents in these systems are propelled by the circulation produced by polar low pressure centers. In the Southern Hemisphere, these gyre systems do not develop because of the lack of constraining land masses.

A typical gyre displays four types of joined currents: two east-west aligned currents found respectively at the top and bottom ends of the gyre; and two boundary currents oriented north-south and flowing parallel to the continental margins. Direction of flow within these currents is determined by the direction of the macro-scale wind circulation. Boundary currents play a role in redistributing global heat latitudinally.

Subsurface Currents: The world's oceans also have significant currents that flow beneath the surface (Figure 43). Subsurface currents generally travel at a much slower speed when compared to surface flows. The subsurface currents are driven by differences in the density of sea water. The density of sea water deviates in the oceans because of variations in temperature and salinity. Near surface sea water begins its travel deep into the ocean in the North Atlantic. The downwelling of this water is caused by high levels of evaporation which cools and increases the salinity of the sea water located here. The high levels of evaporation take place in between Northern Europe and Greenland and just north of of Labrador, Canada. This sea water then moves south along the coast of North and South America until it reaches Antarctica. At Antarctica, the cold and dense sea water then travels eastward joining another deep current that is created by evaporation occuring between Antarctica and the southern tip of South America. Slightly into its eastward voyage the deep cold flow splits off into two currents, one of which moves northward. In the middle of the North Pacific and in the Indian Ocean (off the east coast of Africa), these two currents move from the ocean floor to its surface creating upwellings. The current then becomes near surface moving eventually back to the starting point in the North Atlantic or creating a shallow warm flow that circles around Antarctica. One complete circuit of this flow of sea water is estimated to take about 1,000 years.

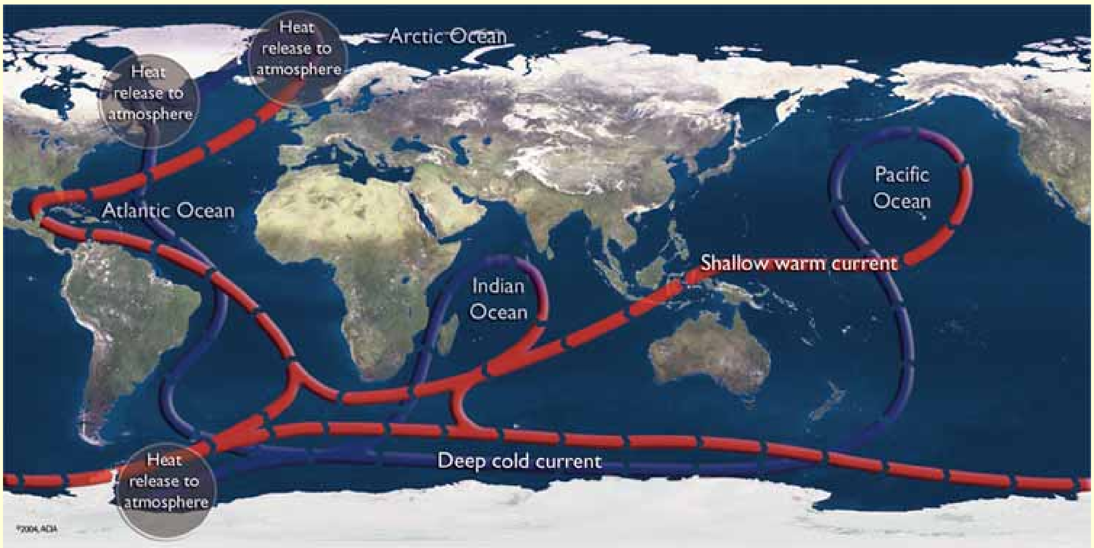

Figure 43: The following illustration describes the flow pattern of the major subsurface ocean currents. Near surface warm currents are drawn in red. Blue depicts the deep cold currents. This system is continuously moving water from the surface to deep within the oceans and back to the top of the ocean.

5. **Ocean Tides:** An ocean tide refers to the cyclic rise and fall of seawater. Tides are caused by slight variations in gravitational attraction between the Earth and the moon and the Sun in geometric relationship with locations on the Earth's surface. Tides are periodic primarily because of the cyclical influence of the Earth's rotation.

The moon is the primary factor controlling the temporal rhythm and height of tides. The moon produces two tidal bulges somewhere on the Earth through the effects of gravitational attraction. The height of these tidal bulges is controlled by the moon's gravitational force and the Earth's gravity pulling the water back toward the Earth. At the location on the Earth closest to the moon, seawater is drawn toward the moon because of the greater strength of gravitational attraction. On the opposite side of the Earth, another tidal bulge is produced away from the moon. However, this bulge is due to the fact that at this point on the Earth the force of the moon's gravity is at its weakest. Considering this information, any given point on the Earth's surface should experience two tidal crests and two tidal troughs during each tidal period.

The timing of tidal events is related to the Earth's rotation and the revolution of the moon around the Earth. If the moon was stationary in space, the tidal cycle would be 24 hours long. However, the moon is in motion revolving around the Earth. One revolution takes about 27 days and adds about 50 minutes to the tidal cycle. As a result, the tidal period is 24 hours and 50 minutes in length.

The second factor controlling tides on the Earth's surface is the Sun's gravity. The height of the average solar tide is about 50% the average lunar tide. At certain times during the moon's revolution around the Earth, the direction of its gravitational attraction is aligned with the Sun's. During these times the two tide producing bodies act together to create the highest and lowest tides of the year. These spring tides occur every 14-15 days during full and new moons.
When the gravitational pull of the moon and Sun are at right angles to each other, the daily tidal variations on the Earth are at their least. These events are called neap tides and they occur during the first and last quarter of the moon.

Types of Tides: The geometric relationship of moon and Sun to locations on the Earth's surface results in creation of three different types of tides. In parts of the northern Gulf of Mexico and Southeast Asia, tides have one high and one low water per tidal day (Figure 44). These tides are called diurnal tides.

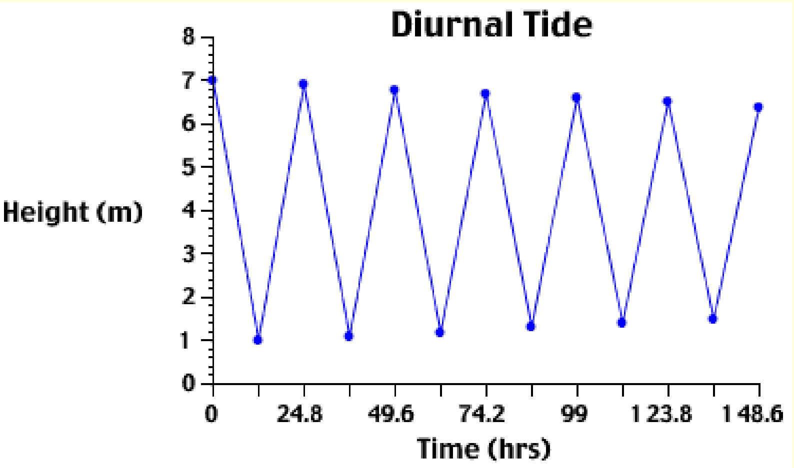

Figure 44: Cyclical tidal cycles associated with a diurnal tide.

Semi-diurnal tides have two high and two low waters per tidal day (Figure 45). They are common on the Atlantic coasts of the United States and Europe.

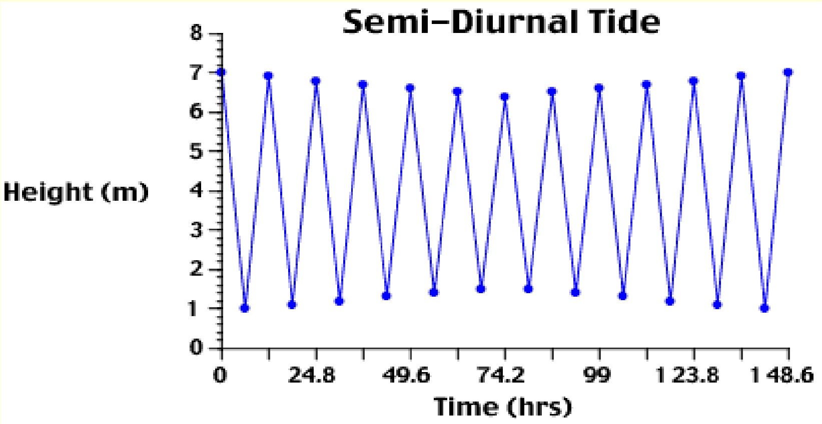

Figure 45: Cyclical tidal cycles associated with a semi-diurnal tide.

Many parts of the world experience mixed tides where successive high-water and low-water stands differ appreciably (Figure 46). In these tides, we have a higher high water and lower high water as well as higher low water and lower low water. The tides around west coast of Canada and the United States are of this type.

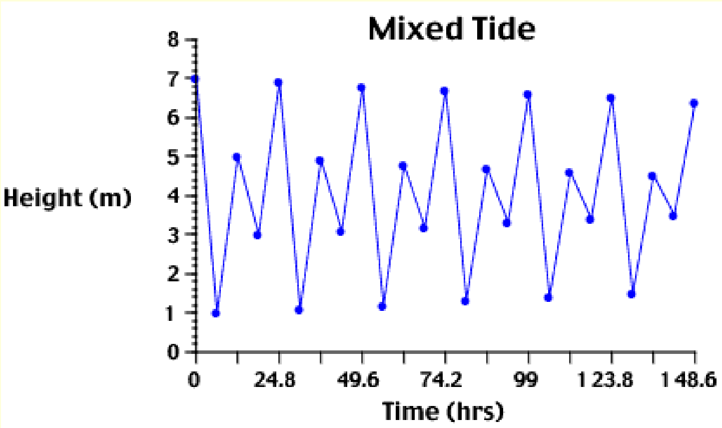

Figure 46: Cyclical tidal cycles associated with a mixed tide.

The map in Figure 47 shows the geographic distribution of these three tide types on the Earth.

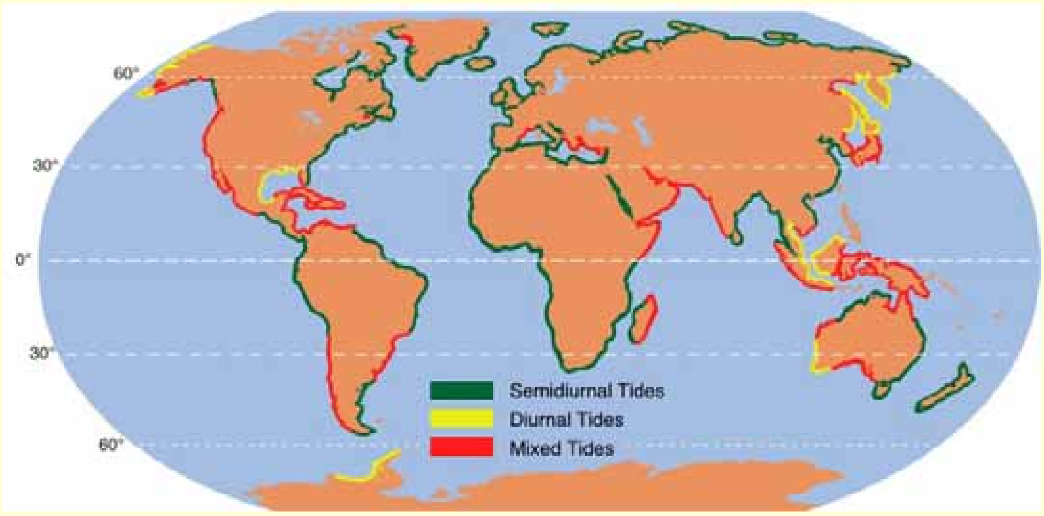

Figure 47: Global distribution of the three tidal types. Most of the world's coastlines have semidiurnal tides.

IV. Biosphere:

1. Organization of Life: Scientists have recognized that life can be organized into several different levels of function and complexity. These functional levels are: species, populations, communities, and ecosystems.

Species: Species are the different kinds of organisms found on the Earth. A more exact definition of species is a group of interbreeding organisms that do not ordinarily breed with members of other groups. If a species interbreeds freely with other species, it would no longer be a distinctive kind of organism. This definition works well with animals. However, in some plant species fertile crossings can take place among morphologically and physiologically different kinds of vegetation. In this situation, the definition of species given here is not appropriate.

Populations: A population comprises all the individuals of a given species in a specific area or region at a certain time. Its significance is more than that of a number of individuals because not all individuals are identical. Populations contain genetic variation within themselves and between other populations. Even fundamental genetic characteristics such as hair color or size may differ slightly from individual to individual. More importantly, not all members of the population are equal in their ability to survive and reproduce.

Communities: Community refers to all the populations in a specific area or region at a certain time. Its structure involves many types of interactions among species. Some of these involve the acquisition and use of food, space, or other environmental resources. Others involve nutrient cycling through all members of the community and mutual regulation of population sizes. In all of these cases, the structured interactions of populations lead to situations in which individuals are thrown into life or death struggles.

In general, ecologists believe that a community that has a high diversity is more complex and stable than a community that has a low diversity. This theory is founded on the observation that the food webs of communities of high diversity are more interconnected. Greater interconnectivity causes these systems to be more resilient to disturbance. If a species is removed, those species that relied on it for food have the option to switch to many other species that occupy a similar role in that ecosystem. In a low diversity ecosystem, possible substitutes for food may be non-existent or limited in abundance.

Ecosystems: Ecosystems are dynamic entities composed of the biological community and the abiotic environment. An ecosystem's abiotic and biotic composition and structure is determined by the state of a number of interrelated environmental factors. Changes in any of these factors (for example: nutrient availability, temperature, light intensity, grazing intensity, and species population density) will result in dynamic changes to the nature of these systems. For example, a fire in the temperate deciduous forest completely changes the structure of that system. There are no longer any large trees, most of the mosses, herbs, and shrubs that occupy the forest floor are gone, and the nutrients that were stored in the biomass are quickly released into the soil, atmosphere and hydrologic system. After a short time of recovery, the community that was once large mature trees now becomes a community of grasses, herbaceous species, and tree seedlings.

2. **Major components of an Ecosystem:** Ecosystems are composed of a variety of abiotic and biotic components that function in an interrelated fashion. Some of the more important components are: soil, atmosphere, radiation from the Sun, water, and living organisms.

Soils are much more complex than simple sediments. They contain a mixture of weathered rock fragments, highly altered soil mineral particles, organic matter, and living organisms. Soils provide nutrients, water, a home, and a structural growing medium for organisms. The vegetation found growing on top of a soil is closely linked to this component of an ecosystem through nutrient cycling.

The atmosphere provides organisms found within ecosystems with carbon dioxide for photosynthesis and oxygen for respiration. The processes of evaporation, transpiration, and precipitation cycle water between the atmosphere and the Earth's surface.

Solar radiation is used in ecosystems to heat the atmosphere and to evaporate and transpire water into the atmosphere. Sunlight is also necessary for photosynthesis. Photosynthesis provides the energy for plant growth and metabolism, and the organic food for other forms of life.

Most living tissue is composed of a very high percentage of water, up to and even exceeding 90%. The protoplasm of a very few cells can survive if their water content drops below 10%, and most are killed if it is less than 30-50%. Water is the medium by which mineral nutrients enter and are translocated in plants. It is also necessary for the maintenance of leaf turgidity and is required for photosynthetic chemical reactions. Plants and animals receive their water from the Earth's surface and soil. The original source of this water is precipitation from the atmosphere.

Ecosystems are composed of a variety of living organisms that can be classified as producers, consumers, or decomposers. Producers or autotrophs, are organisms that can manufacture the organic compounds they use as sources of energy and nutrients. Most producers are green plants that can manufacture their food through the process of photosynthesis. Consumers or heterotrophs get their energy and nutrients by feeding directly or indirectly on producers. We can distinguish two main types of consumers. Herbivores are consumers that eat plants for their energy and nutrients. Organisms that feed on herbivores are called carnivores. Carnivores can also consume other carnivores. Plants and animals supply organic matter to the soil system through shed tissues and death. Consumer organisms that feed on this organic matter, or detritus, are known as detritivores or decomposers. The organic matter that is consumed by the detritivores is eventually converted back into inorganic nutrients in the soil. These nutrients can then be used by plants for the production of organic compounds.

The following graphical model describes the major ecosystem components and their interrelationships (Figure 1).

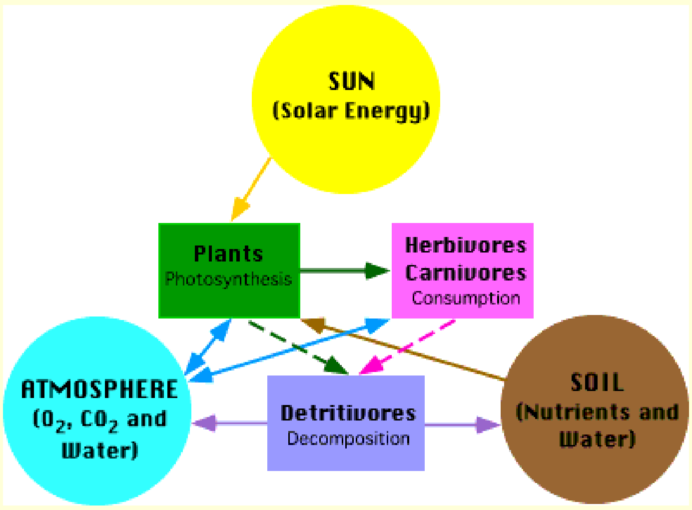

Figure 1: Relationships within an ecosystem.

The following diagram models the various inputs and outputs of energy and matter in a typical ecosystem (Figure 2).

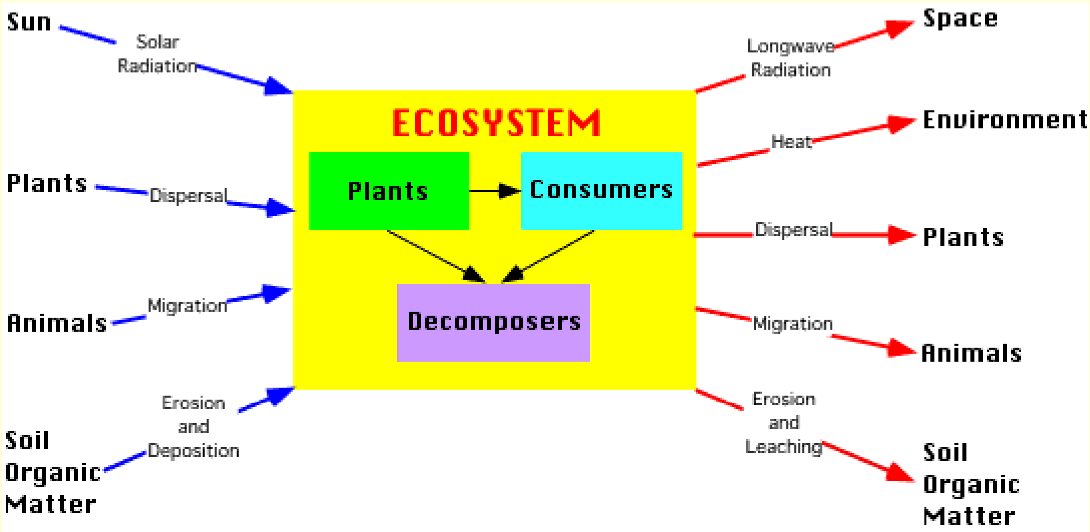

Figure 2: Inputs and outputs of energy and matter in a typical ecosystem.

Nutrient Inputs to Ecosystems: Important nutrients for life generally enter ecosystems by way of four processes:

Weathering: Rock weathering is one of the most important long-term sources for nutrients. However, this process adds nutrients to ecosystems in relatively small quantities over long periods of time. Important nutrients released by weathering include:

- Calcium, magnesium, potassium, sodium, silicon, iron, aluminum, and phosphorus.
- All of the micro nutrients.

Carbon, oxygen and nitrogen are not transferred into ecosystems by weathering. The main source for these important elements is the atmosphere and the decomposition of organic matter.

Atmospheric Input: Large quantities of nutrients are added to ecosystems from the atmosphere. This addition is done either through precipitation or by a number of biological processes.

- Carbon - absorbed by way of photosynthesis.
- Nitrogen - produced by lightning and precipitation.
- Sulfur, chloride, calcium, and sodium - deposited by way of precipitation.

The quantity of nitrogen added to ecosystems by lightning and rain annually ranges from 1 to 20 kilograms per hectare depending on geographical location. A value of 5 to 8 kilograms per hectare is typical for temperate ecosystems like deciduous forest or grasslands.

Biological Nitrogen Fixation: Biological nitrogen fixation is a biochemical process where nitrogen gas (N2) from the atmosphere is chemically combined into more complex solid forms by metabolic reactions in an organism. This ability to fix nitrogen is restricted to a small number of species. This special group of life includes a few species of bacteria (that have symbiotic associations with legumes and some other types of higher plants), several species of actinomycetes (filamentous form of bacteria), and blue-green algae (cyanobacteria). The amount of nitrogen fixed biologically has been estimated to be around 170 million metric tons per year. This is approximately twice as much as the total nitrogen added to ecosystems from non-biological sources.

Immigration: The immigration of motile animals into an ecosystem can sometimes add significant additions of nutrients to an ecosystem that are locked up in the biomass of the organisms. These nutrients are released when the organism dies or sheds its tissues.

Nutrient Outputs to Ecosystems: Important nutrients required for life leave ecosystems by way of four processes:

Erosion: Soil erosion is probably the most import means of nutrient loss to ecosystems. Erosion is very active in agricultural and forestry systems, where cultivation, grazing, and clearcutting leaves the soil bare and unprotected. When unprotected, the surface of the soil is easily transported by wind and moving water. The top most layers of a soil, which have an abundance of nutrient rich organic matter, are the major storehouse for soil nutrients like phosphorus, potassium, and nitrogen.

Leaching: Another important process of nutrient loss is leaching. Leaching occurs when water flowing vertically through the soil transports nutrients in solution downward in the soil profile. Many of these nutrients can be completely lost from the soil profile if carried into groundwater and then horizontally transported into rivers, lakes, or oceans. Leaching losses are, generally, highest in disturbed ecosystems. In undisturbed ecosystems, efficient nutrient cycling limits the amount of nutrients available for this process.

Gaseous Losses: High losses of nutrients can also occur when specific environmental conditions promote the export of nutrients in a gaseous form. When the soil is wet and anaerobic, many compounds are chemically reduced to a gas from solid forms in the soil. This is especially true of soil nitrogen. Scientific studies in Netherlands have shown that about 80% of the nitrogen fertilizer applied to the soil for crop consumption may be lost through the process of denitrification.

Emigration and Harvesting: Just as material may be introduced to ecosystems by migration, so too may it be lost. The emigration of animals, and the removal of vegetation by humans are both processes by which outputs can occur from an ecosystem.

3. **The Carbon Cycle:** All life is based on the element carbon. Carbon is the major chemical constituent of most organic matter, from fossil fuels to the complex molecules (DNA and RNA) that control genetic reproduction in organisms. Yet by weight, carbon is not one of the most abundant elements within the Earth's crust. In fact, the lithosphere is only 0.032% carbon by weight. In comparison, oxygen and silicon respectively make up 45.2% and 29.4% of the Earth's surface rocks.

Carbon is stored on our planet in the following major sinks (Figure 3 and Table 1): (1) as organic molecules in living and dead organisms found in the biosphere; (2) as the gas carbon dioxide in the atmosphere; (3) as organic matter in soils; (4) in the lithosphere as fossil fuels and sedimentary rock deposits such as limestone, dolomite and chalk; and (5) in the oceans as dissolved atmospheric carbon dioxide and as calcium carbonate shells in marine organisms.

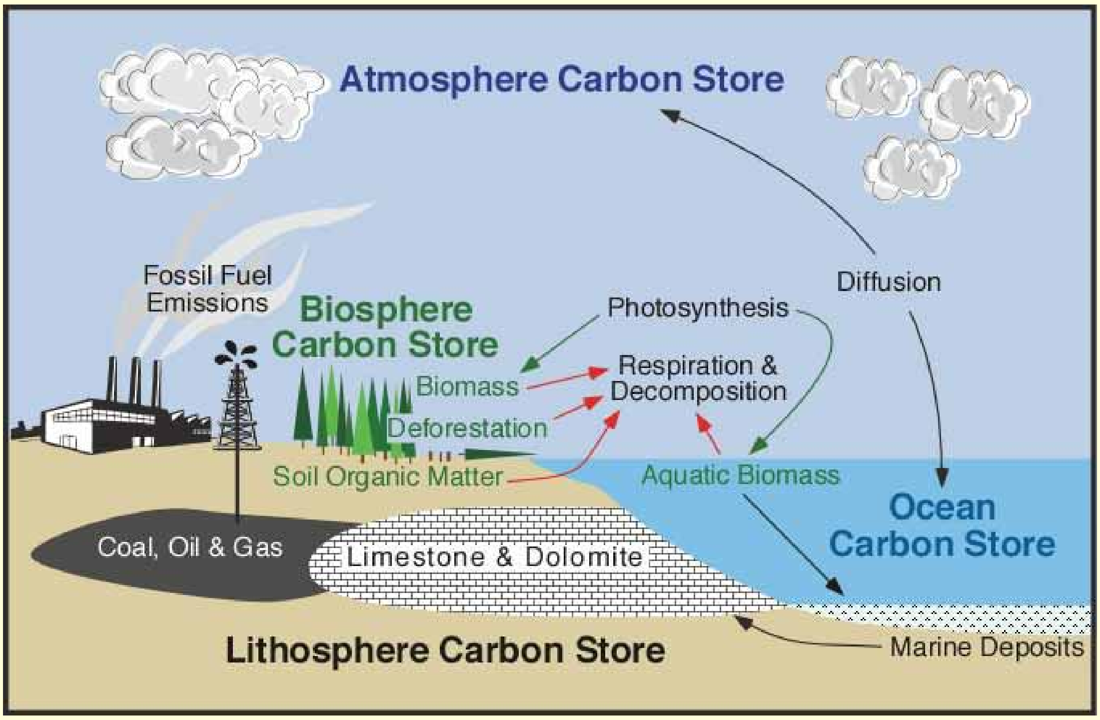

Figure 3: Carbon cycle.

Table 1: Estimated major stores of carbon on the Earth.

Sink	Amount in Billions of Metric Tons
Atmosphere	578 (as of 1700) - 766 (as of 1999)
Soil Organic Matter	1500 to 1600
Ocean	38,000 to 40,000
Marine Sediments and Sedimentary Rocks	66,000,000 to 100,000,000
Terrestrial Plants	540 to 610
Fossil Fuel Deposits	4000

Ecosystems gain most of their carbon dioxide from the atmosphere. A number of autotrophic organisms have specialized mechanisms that allow for absorption of this gas into their cells. With the addition of water and energy from solar radiation, these organisms use photosynthesis to chemically convert the carbon dioxide to carbon-based sugar molecules. These molecules can then be chemically modified by these organisms through the metabolic addition of other elements to produce more complex compounds like proteins, cellulose, and amino acids. Some of the organic matter produced in plants is passed down to heterotrophic animals through consumption.

Carbon dioxide enters the waters of the ocean by simple diffusion. Once dissolved in seawater, the carbon dioxide can remain as is or can be converted into carbonate (CO_3^{-2}) or bicarbonate (HCO_3^-). Certain forms of sea life biologically fix bicarbonate with calcium (Ca^{+2}) to produce calcium carbonate ($CaCO_3$). This substance is used to produce shells and other body parts by organisms such as coral, clams, oysters, some protozoa, and some algae. When these organisms die, their shells and body parts sink to the ocean floor where they accumulate as carbonate-rich deposits. After long periods of time, these deposits are physically and chemically altered into sedimentary rocks. Ocean deposits are by far the biggest sink of carbon on the planet (Table 1).

Carbon is released from ecosystems as carbon dioxide gas by the process of respiration. Respiration takes place in both plants and animals and involves the breakdown of carbon-based organic molecules into carbon dioxide gas and some other compound by products. The detritus food chain contains a number of organisms whose primary ecological role is the decomposition of organic matter into its abiotic components.

Over the several billion years of geologic history, the quantity of carbon dioxide found in the atmosphere has been steadily decreasing. Researchers theorized that this change is in response to an increase in the Sun's output over the same time period. Higher levels of carbon dioxide helped regulate the Earth's temperature to levels slightly higher than what is perceived today. These moderate temperatures allowed for the flourishing of plant life despite the lower output of solar radiation. An enhanced greenhouse effect, due to the greater concentration of carbon dioxide gas in the atmosphere, supplemented the production of heat energy through higher levels of longwave counter-radiation. As the Sun grew more intense, several biological mechanisms gradually locked some of the atmospheric carbon dioxide into fossil fuels and sedimentary rock. In summary, this regulating process has kept the Earth's global average temperature essentially constant over time.

Carbon is stored in the lithosphere in both inorganic and organic forms. Inorganic deposits of carbon in the lithosphere include fossil fuels like coal, oil, and natural gas, oil shale, and carbonate based sedimentary deposits like limestone. Organic forms of carbon in the lithosphere include litter, organic matter, and humic substances found in soils. Some carbon dioxide is released from the interior of the lithosphere by volcanoes. Carbon dioxide released by volcanoes enters the lower lithosphere when carbon-rich sediments and sedimentary rocks are subducted and partially melted beneath tectonic boundary zones.

Since the Industrial Revolution, humans have greatly increased the quantity of carbon dioxide found in the Earth's atmosphere and oceans. Atmospheric levels have increased by over 30%, from about 275 parts per million (ppm) in the early 1700s to just over 365 PPM today. Scientists estimate that future atmospheric levels of carbon dioxide could reach an amount between 450 to 600 PPM by the year 2100. The major sources of this gas due to human activities include fossil fuel combustion and the modification of natural plant cover found in grassland, woodland, and forested ecosystems. Emissions from fossil fuel combustion account for about 65% of the additional carbon dioxide currently found in the Earth's atmosphere. The other 35% is derived from deforestation and the conversion of natural ecosystems into agricultural systems. Researchers have shown that natural ecosystems can store between 20 to 100 times more carbon dioxide than agricultural land-use types.

4. **The Nitrogen Cycle:** The nitrogen cycle represents one of the most important nutrient cycles found in terrestrial ecosystems (Figure 4). Nitrogen is used by living organisms to produce a number of complex organic molecules like amino acids, proteins, and nucleic acids. The store of nitrogen found in the atmosphere, where it exists as a gas (mainly N2), plays an important role for life. This store is about one million times larger than the total nitrogen contained in living organisms. Other major stores of nitrogen include organic matter in soil and the oceans. Despite its abundance in the atmosphere, nitrogen is often the most limiting nutrient for plant growth. This problem occurs because most plants can only take up nitrogen in two solid forms: ammonium ion (NH4+) and the ion nitrate (NO3-). Most plants obtain the nitrogen they need as inorganic nitrate from the soil solution. Ammonium is used less by plants for uptake because in large concentrations it is extremely toxic. Animals receive the required nitrogen they need for metabolism, growth, and reproduction by the consumption of living or dead organic matter containing molecules composed partially of nitrogen.

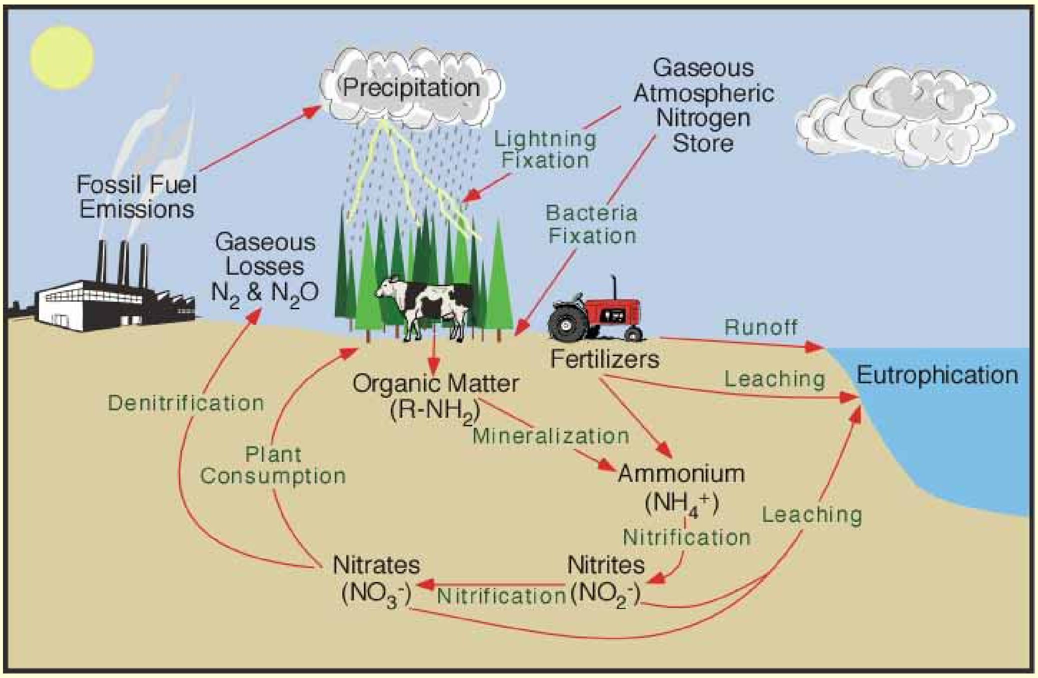

Figure 4: Nitrogen cycle.

In most ecosystems nitrogen is primarily stored in living and dead organic matter. This organic nitrogen is converted into inorganic forms when it re-enters the biogeochemical cycle via decomposition. Decomposers, found in the upper soil layer, chemically modify the nitrogen found in organic matter from ammonia (NH3) to ammonium salts (NH4+). This process is known as mineralization and it is carried out by a variety of bacteria, actinomycetes, and fungi.

Nitrogen in the form of ammonium can be absorbed onto the surfaces of clay particles in the soil. The ion of ammonium has a positive molecular charge is normally held by soil colloids. This process is sometimes called micelle fixation. Ammonium is released from the colloids by way of cation exchange. When released, most of the ammonium is often chemically altered by a specific type of autotrophic bacteria (bacteria that belong to the genus Nitrosomonas) into nitrite (NO2-). Further modification by another type of bacteria (belonging to the genus Nitrobacter) converts the nitrite to nitrate (NO3-). Both of these processes involve chemical oxidation and are known as nitrification. However, nitrate is very soluble and it is easily lost from the soil system by leaching. Some of this leached nitrate flows through the hydrologic system until it reaches the oceans where it can be returned to the atmosphere by denitrification. Denitrification is also common in anaerobic soils and is carried out by heterotrophic bacteria. The process of denitrification involves the metabolic reduction of nitrate (NO_3^-) into nitrogen (N_2) or nitrous oxide (N_2O) gas. Both of these gases then diffuse into the atmosphere.

Almost all of the nitrogen found in any terrestrial ecosystem originally came from the atmosphere. Significant amounts enter the soil in rainfall or through the effects of lightning. The majority, however, is biochemically fixed within the soil by specialized micro-organisms like bacteria, actinomycetes, and cyanobacteria. Members of the bean family (legumes) and some other kinds of plants form mutualistic symbiotic relationships with nitrogen fixing bacteria. In exchange for some nitrogen, the bacteria receive from the plants carbohydrates and special structures (nodules) in roots where they can exist in a moist environment. Scientists estimate that biological fixation globally adds approximately 140 million metric tons of nitrogen to ecosystems every year.

The activities of humans have severely altered the nitrogen cycle. Some of the major processes involved in this alteration include:

- The application of nitrogen fertilizers to crops has caused increased rates of denitrification and leaching of nitrate into groundwater. The additional nitrogen entering the groundwater system eventually flows into streams, rivers, lakes, and estuaries. In these systems, the added nitrogen can lead to eutrophication.
- Increased deposition of nitrogen from atmospheric sources because of fossil fuel combustion and forest burning. Both of these processes release a variety of solid forms of nitrogen through combustion.
- Livestock ranching. Livestock release a large amounts of ammonia into the environment from their wastes. This nitrogen enters the soil system and then the hydrologic system through leaching, groundwater flow, and runoff.
- Sewage waste and septic tank leaching.

V. Lithosphere: Lithosphere is the topmost crust of the Earth on which stand our continents and ocean basins. The lithosphere has a thickness between 35 to 50 km in the continental regions, but becomes thin between 6 to 12 km under the ocean beds. In the high mountain regions, its thickness is estimated at about 60 km.Though, strictly speaking, lithosphere includes both the land mass and the ocean floors, generally it is used to denote only the land surface, which occupies a little less than 30 per cent of total area of the Earth. Our knowledge about the interior of the Earth is based on the seismic waves, as they travel through the Earth.

1. Structure of the Earth: The Earth is an oblate spheroid. It is composed of a number of different layers as determined by deep drilling and seismic evidence (Figure 1). These layers are:

- The core which is approximately 7000 kilometers in diameter (3500 kilometers in radius) and is located at the Earth's center.
- The mantle which surrounds the core and has a thickness of 2900 kilometers.
- The crust floats on top of the mantle. It is composed of basalt rich oceanic crust and granitic rich continental crust.

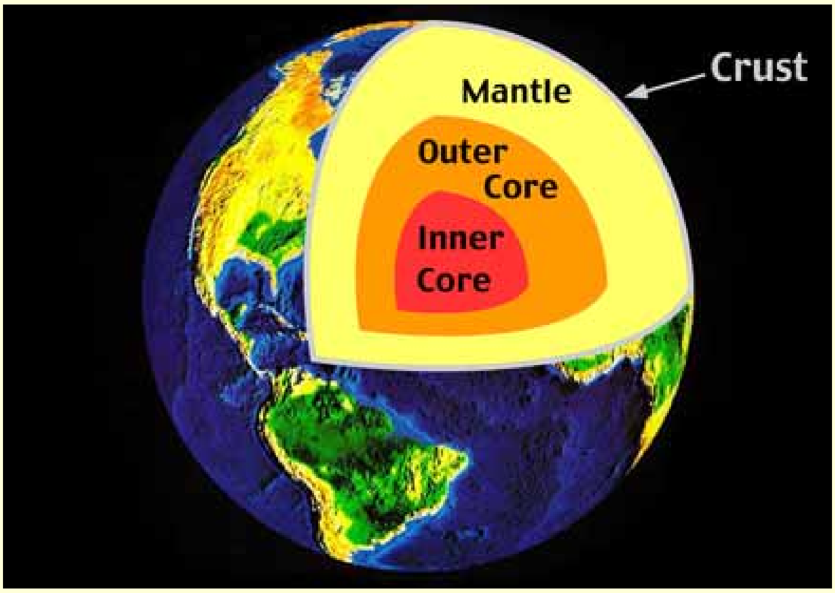

Figure 1: Layers beneath the Earth's surface.

The core is a layer rich in iron and nickel that is composed of two layers: the inner and outer cores. The inner core is theorized to be solid with a density of about 13 grams per cubic centimeter and a radius of about 1220 kilometers. The outer core is liquid and has a density of about 11 grams per cubic centimeter. It surrounds the inner core and has an average thickness of about 2250 kilometers.

The mantle is almost 2900 kilometers thick and comprises about 83% of the Earth's volume. It is composed of several different layers. The upper mantle exists from the base of the crust downward to a depth of about 670 kilometers. This region of the Earth's interior is thought to be composed of peridotite, an ultramafic rock made up of the minerals olivine and pyroxene. The top layer of the upper mantle, 100 to 200 kilometers below surface, is called the asthenosphere. Scientific studies suggest that this layer has physical properties that are different from the rest of the upper mantle. The rocks in this upper portion of the mantle are more rigid and brittle because of cooler temperatures and lower pressures. Below the upper mantle is the lower mantle that extends from 670 to 2900 kilometers below the Earth's surface. This layer is hot and plastic. The higher pressure in this layer causes the formation of minerals that are different from those of the upper mantle.

The lithosphere is a layer that includes the crust and the upper most portion of the asthenosphere. This layer is about 100 kilometers thick and has the ability to glide over the rest of the upper mantle. Because of increasing temperature and pressure, deeper portions of the lithosphere are capable of plastic flow over geologic time. The lithosphere is also the zone of earthquakes, mountain building, volcanoes, and continental drift.

The topmost part of the lithosphere consists of crust. This material is cool, rigid, and brittle. Two types of crust can be identified: oceanic crust and continental crust (Figure 2). Both of these types of crust are less dense than the rock found in the underlying upper mantle layer. Ocean crust is thin and measures between 5 to 10 kilometers thick. It is also composed of basalt and has a density of about 3.0 grams per cubic centimeter.

The continental crust is 20 to 70 kilometers thick and composed mainly of lighter granite (Figure 2). The density of continental crust is about 2.7 grams per cubic centimeter. It is thinnest in areas like the Rift Valleys of East Africa and in an area known as the Basin and Range Province in the western United States (centered in Nevada this area is about 1500 kilometers wide and runs about 4000 kilometers North/South). Continental crust is thickest beneath mountain ranges and extends into the mantle. Both of these crust types are composed of numerous tectonic plates that float on top of the mantle. Convection currents within the mantle cause these plates to move slowly across the asthenosphere.

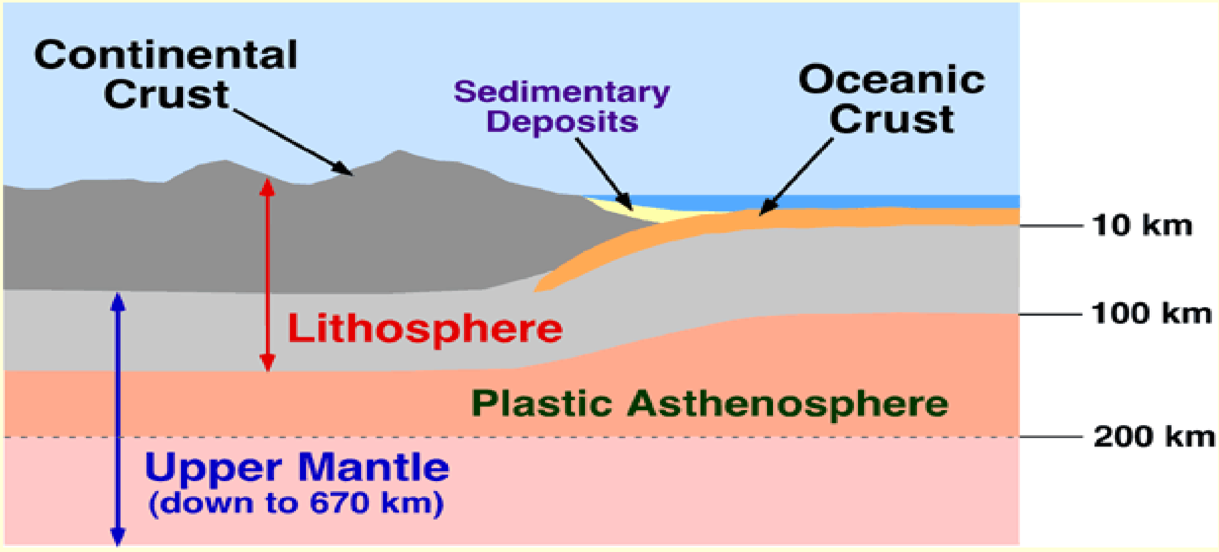

Figure 2: Structure of the Earth's crust and top most layer of the upper mantle. The lithosphere consists of the oceanic crust, continental crust, and uppermost mantle. Beneath the lithosphere is the asthenosphere. This layer, which is also part of the upper mantle, extends to a depth of about 200 kilometers. Sedimentary deposits are commonly found at the boundaries between the continental and oceanic crust.

2. **Rocks:** A rock can be defined as a solid substance that occurs naturally because of the effects of three basic geological processes: magma solidification; sedimentation of weathered rock debris; and metamorphism. As a result of these processes, three main types of rock occur:

Igneous Rocks - produced by solidification of molten magma from the mantle. Magma that solidifies at the Earth's surface conceives extrusive or volcanic igneous rocks. When magma cools and solidifies beneath the surface of the Earth intrusive or plutonic igneous rocks are formed.

Sedimentary Rocks - formed by burial, compression, and chemical modification of deposited weathered rock debris or sediments at the Earth's surface.

Metamorphic Rocks - created when existing rock is chemically or physically modified by intense heat or pressure.

Most rocks are composed of minerals. Minerals are defined by geologists as naturally occurring inorganic solids that have a crystalline structure and a distinct chemical composition. Of course, the minerals found in the Earth's rocks are produced by a variety of different arrangements of chemical elements. A list of the eight most common elements making up the minerals found in the Earth's rocks is described in Table 1.

Table 1: Common elements found in the Earth's rocks.

Element	Chemical Symbol	Percent Weight in Earth's Crust
Oxygen	O	46.60
Silicon	Si	27.72
Aluminum	Al	8.13
Iron	Fe	5.00
Calcium	Ca	3.63
Sodium	Na	2.83
Potassium	K	2.59
Magnesium	Mg	2.09

Over 2000 minerals have been identified by earth scientists.

3. **Earthquakes:** An earthquake is a sudden vibration or trembling in the Earth. More than 150,000 tremors strong enough to be felt by humans occur each year worldwide. Earthquake motion is caused by the quick release of stored potential energy into the kinetic energy of motion. Most earthquakes are produced along faults, tectonic plate boundary zones, or along the mid-oceanic ridges . At these areas, large masses of rock that are moving past each other can become locked due to friction. Friction is overcome when the accumulating stress has enough force to cause a sudden slippage of the rock masses. The magnitude of the shock wave released into the surrounding rocks is controlled by the quantity of stress built up because of friction, the distance the rock moved when the slippage occurred, and ability of the rock to transmit the energy contained in the seismic waves. The San Francisco earthquake of 1906 involved a 6 meter horizontal displacement of bedrock. Sometime after the main shock wave, aftershocks can occur because of the continued release of frictional stress. Most aftershocks are smaller than the main earthquake, but they can still cause considerable damage to already weakened natural and human constructed features.

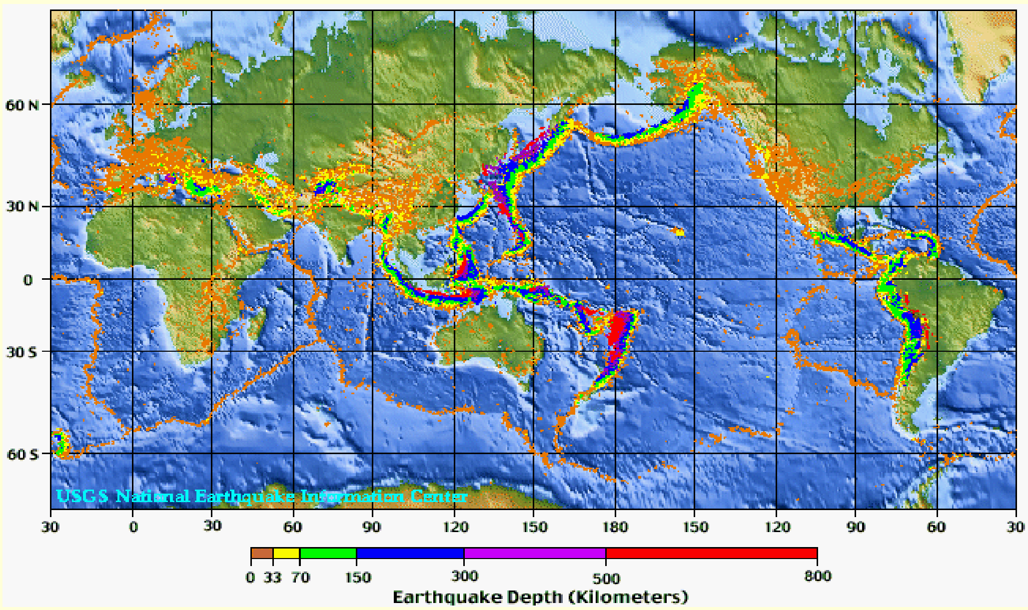

Figure 3: Distribution of earthquake epicenters from 1975 to 1995. Depth of the earthquake focus is indicated by color. Deep earthquakes occur in areas where oceanic crust is being actively subducted. About 90% of all earthquakes occur at a depth between 0 and 100 kilometers.

Earthquake Waves: Earthquakes are a form of wave energy that is transferred through bedrock. Motion is transmitted from the point of sudden energy release, the earthquake focus, as spherical seismic waves that travel in all directions outward (Figure 4). The point on the Earth's surface directly above the focus is termed the epicenter.

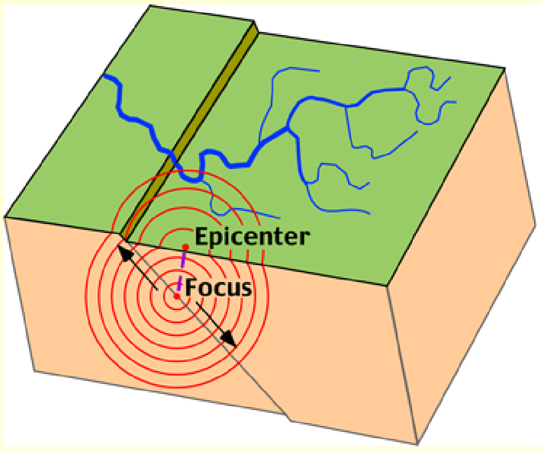

Figure 4: Movement of body waves away from the focus of the earthquake. The epicenter is the location on the surface directly above the earthquake's focus.

Two different types of seismic waves have been described by geologists: body waves and surface waves. Body waves are seismic waves that travel through the lithosphere. Two kinds of body waves exist: P-waves and S-waves. Both of these waves produce a sharp jolt or shaking. P-waves or primary waves are formed by the alternate expansion and contraction of bedrock and cause the volume of the material they travel through to change .They travel at a speed of about 5 to 7 kilometers per second through the lithosphere and about 8 kilometers per second in the asthenosphere. The speed of sound is about 0.30 kilometers per second. P-waves also have the ability to travel through solid, liquid, and gaseous materials. When some P-waves move from the ground to the lower atmosphere, the sound wave that is produced can sometimes be heard by humans and animals.

S-waves or secondary waves are a second type of body wave. These waves are slower than P-waves and can only move through solid materials. S-waves are produced by shear stresses and move the materials they pass through in a perpendicular (up and down or side to side) direction.

Surface waves travel at or near the Earth's surface. These waves produce a rolling or swaying motion causing the Earth's surface to behave like waves on the ocean. The velocity of these waves is slower than body waves. Despite their slow speed, these waves are particularly destructive to human construction because they cause considerable ground movement.

Earthquake Measurement: The strength of an earthquake can be measured by a device called a seismograph. When an earthquake occurs this device converts the wave energy into a standard unit of measurement like the Richter scale. In the Richter scale, units of measurement are referred to as magnitudes. The Richter scale is logarithmic. Thus, each unit increase in magnitude represents 10 times more energy released. Table 2 describes the relationship between Richter scale magnitude and energy released. The following equation can be used to approximate the amount of energy released from an earthquake in joules when Richter magnitude (M) is known:

Energy in joules = 1.74 x 10(5 + 1.44*M)

Table 2: Relationship between Richter Scale magnitude and energy released.

Magnitude in Richter Scale	Energy Released in Joules	Comment
2.0	1.3×10^{8}	Smallest earthquake detectable by people.
5.0	2.8×10^{12}	Energy released by the Hiroshima atomic bomb.
6.0 - 6.9	7.6×10^{13} to 1.5×10^{15}	About 120 shallow earthquakes of this magnitude occur each year on the Earth.
6.7	7.7×10^{14}	Northridge, California earthquake January 17, 1994.
7.0	2.1×10^{15}	Major earthquake threshold.
7.4	7.9×10^{15}	Turkey earthquake August 17, 1999. More than 12,000 people killed.
7.6	1.5×10^{16}	Deadliest earthquake in the last 100 years. Tangshan, China, July 28, 1976. Approximately 255,000 people perished.
8.3	1.6×10^{17}	San Francisco earthquake of April 18, 1906.
9.3	4.3×10^{18}	December 26, 2004 Sumatra earthquake.
9.5	8.3×10^{18}	Most powerful earthquake recorded in the last 100 years. Southern Chile on May 22, 1960. Claimed 3,000 lives.

Figures 5 and 6 describe the spatial distribution of small and large earthquakes respectively. These maps indicate that large earthquakes have distributions that are quite different from small events. Many large earthquakes occur some distance away from a plate boundary. Some geologists believe that these powerful earthquakes may be occurring along ancient faults that are buried deep in the continental crust. Recent seismic studies in the central United States have discovered one such fault located thousands of meters below the lower Mississippi Valley. Some large earthquakes occur at particular locations along the plate boundaries. Scientists believe that these areas represent zones along adjacent plates that have greater frictional resistance and stress.

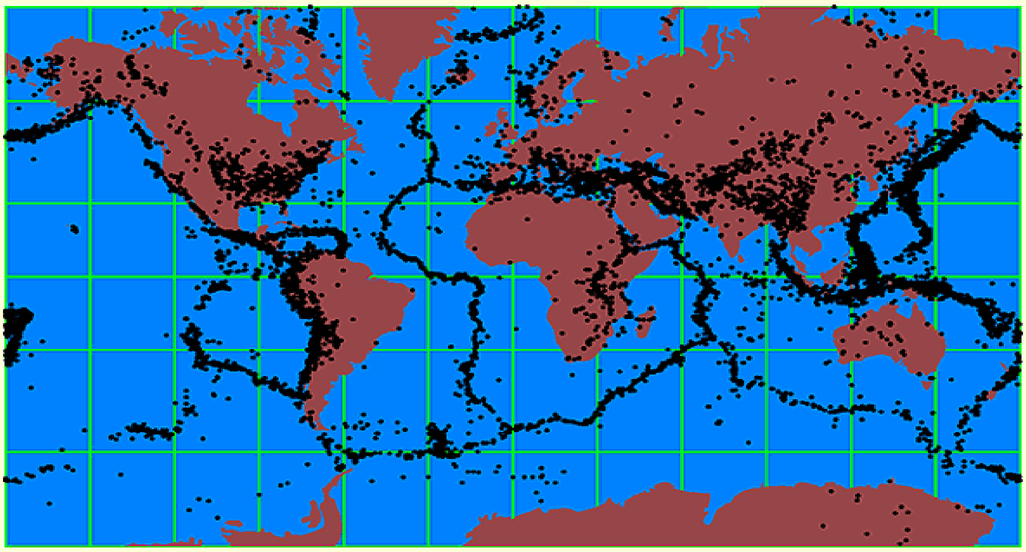

Figure 5: Distribution of earthquakes with a magnitude less than 5 on the Richter Scale.

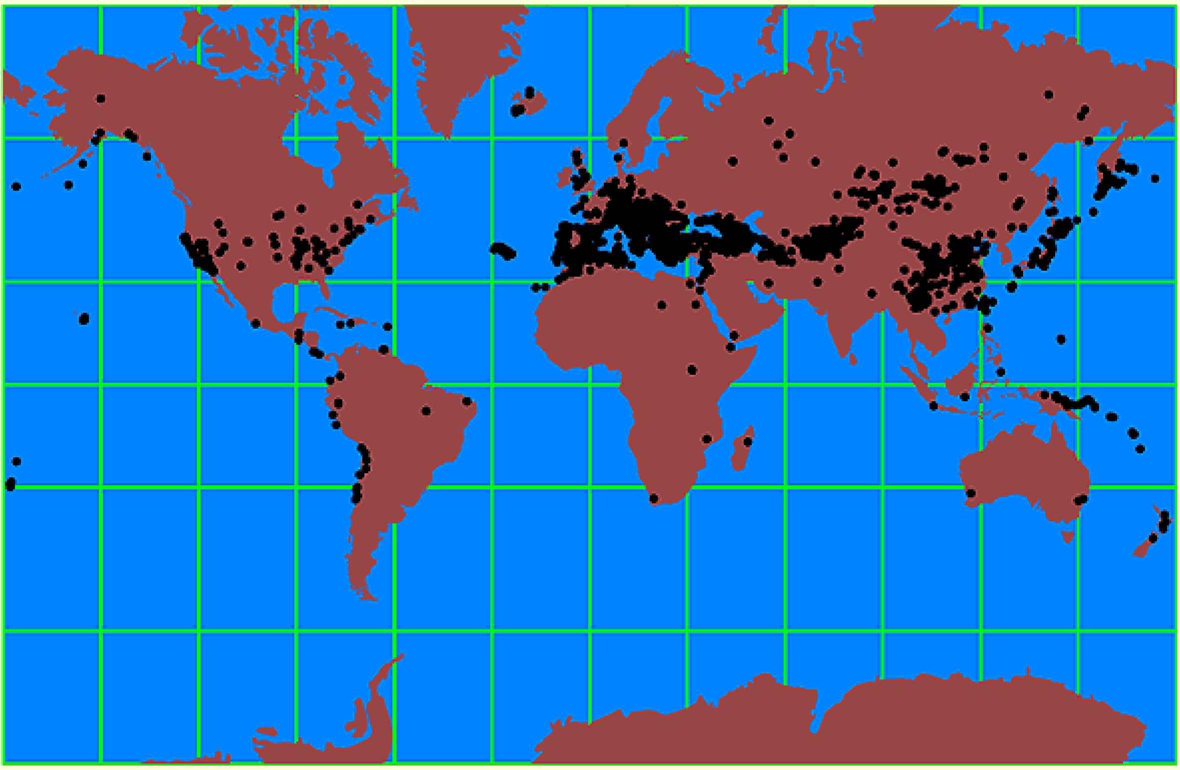

Figure 6: Distribution of earthquakes with a magnitude greater than 7 on the Richter Scale.

Earthquake Damage and Destruction: Earthquakes are a considerable hazard to humans. Earthquakes can cause destruction by structurally damaging buildings and dwellings, fires, tsunamis, and mass wasting. Earthquakes can also take human lives. The amount of damage and loss of life depends on a number of factors. Some of the more important factors are:

- Time of day. Higher losses of life tend to occur on weekdays between the hours of 9:00 AM to 4:00 PM. During this time interval many people are in large buildings because of work or school. Large structures are often less safe than smaller homes in an earthquake.
- Magnitude of the earthquake and duration of the event.
- Distance form the earthquake's focus. The strength of the shock waves diminish with distance from the focus.
- Geology of the area effected and soil type. Some rock types transmit seismic wave energy more readily. Buildings on solid bedrock tend to receive less damage. Unconsolidated rock and sediments have a tendency to increase the amplitude and duration of the seismic waves increasing the potential for damage. Some soil types when saturated become liquefied.
- Type of building construction. Some building materials and designs are more susceptible to earthquake damage.
- Population density. More people often means greater chance of injury and death.

Another consequence of earthquakes is the generation of tsunamis. Tsunamis, or tidal waves, form when an earthquake causes a sudden movement of the seafloor. This movement creates a wave in the water body which radiates outward in concentric shells. On the open ocean, these waves are usually no higher than one to three meters in height and travel at speed of about 750 kilometers per hour. Tsunamis become dangerous when they approach land. Frictional interaction of the waves with the ocean floor, as they near shore, causes the waves to slow down and collide into each other. This amalgamation of waves then produces a super wave that can be as tall as 65 meters in height.

4. **Volcanoes:** A volcano is generally a conical shaped hill or mountain built by accumulations of lava flows, tephra, and volcanic ash. About 95% of active volcanoes occur at the plate subduction zones and at the mid-oceanic ridges (Figure 7). The other 5% occur in areas associated with lithospheric hot spots. These hot spots have no direct relationships with areas of crustal creation or subduction zones. It is believed that hot spots are caused by plumes of rising magma that have their origin within the asthenosphere.

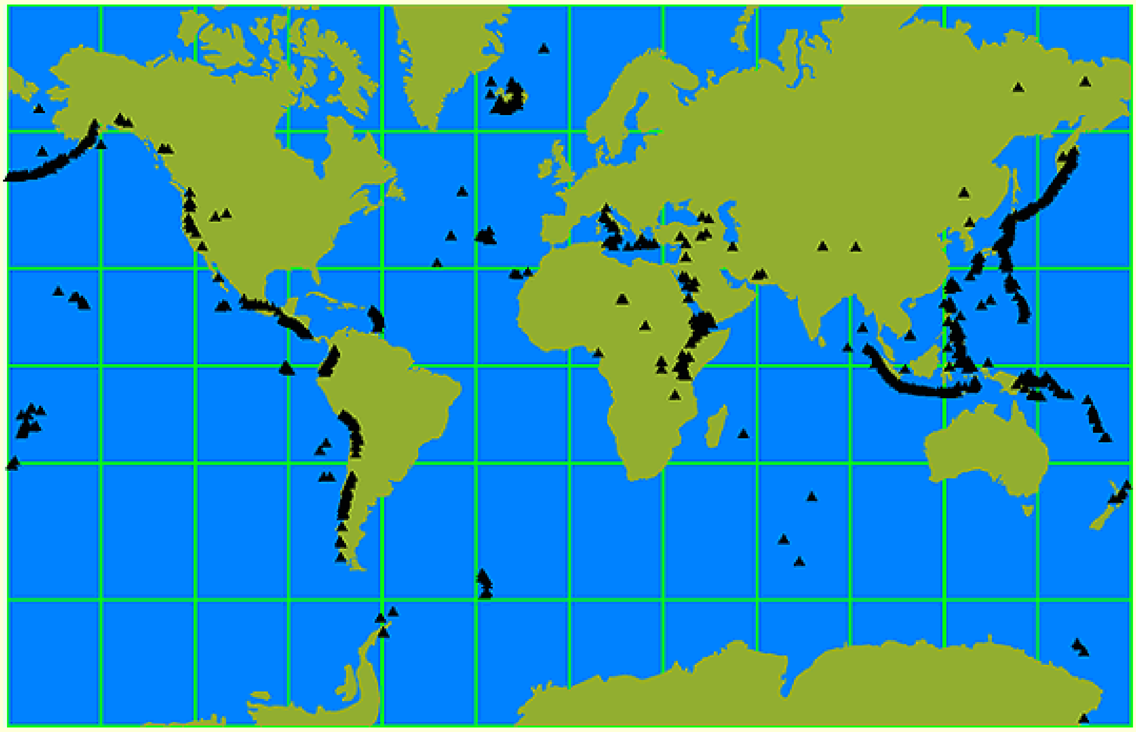

Figure 7: Location of the Earth's major volcanoes. Most occur along tectonic plate.

Not all volcanoes are the same. Geologists have classified five different types of volcanoes. This classification is based on the geomorphic form, magma chemistry, and the explosiveness of the eruption.
The least explosive type of volcano is called a basalt plateau. These volcanoes produce a very fluid basaltic magma with horizontal flows. The form of these volcanoes is flat to gently sloping and they can occupy an area from 100,000 to 1,000,000 square kilometers. Deposits of these volcanoes can be as thick as 1800 meters. Large basalt plateaus are found in the Columbia River Plateau, western India, northern Australia, Iceland, Brazil, Argentina, and Antarctica.

Some basaltic magmas can produce very large slightly sloping volcanoes, 6 to 12°, that have gently flowing magmas called shield volcanoes. Shield volcanoes can be up to 9000 meters tall. The volcanoes of the Hawaiian Islands are typical of this type. Extruded materials from this type of volcano mainly consist of low viscosity basaltic lava flows.

A cinder cone is a small volcano, between 100 and 400 meters tall, made up of exploded rock blasted out of a central vent at a high velocity. These volcanoes develop from magma of basaltic to intermediate composition (andesite). They form when large amounts of gas accumulate within rising magma. Examples of cider cones include Little Lake Volcano in California and Paricutin Volcano in Mexico.

Composite volcanoes are made from alternate layers of lava flows and exploded rock . Their height ranges from 100 to 3500 meters tall. The chemistry of the magma of these volcanoes is quite variable ranging from basalt to granite. Magmas that are more granitic tend to be very explosive because of their relatively higher water content. Water at high temperatures and pressures is extremely volatile. Examples of composite volcanoes include Italy's Vesuvius, Japan's Mount Fuji, and Washington State's Mount Rainier and Mount St. Helens.

5. **Weathering:** Weathering is the breakdown and alteration of rocks and minerals at or near the Earth's surface into products that are more in equilibrium with the conditions found in this environment. Most rocks and minerals are formed deep within the Earth's crust where temperatures and pressures differ greatly from the surface. Because the physical and chemical nature of materials formed in the Earth's interior are characteristically in disequilibrium with conditions occurring on the surface. Because of this disequilbrium, these materials are easily attacked, decomposed, and eroded by various chemical and physical surface processes.

Weathering is the first step for a number of other geomorphic and biogeochemical processes. The products of weathering are a major source of sediments for erosion and deposition. Many types of sedimentary rocks are composed of particles that have been weathered, eroded, transported, and terminally deposited in basins. Weathering also contributes to the formation of soil by providing mineral particles like sand, silt, and clay. Elements and compounds extracted from the rocks and minerals by weathering processes supply nutrients for plant uptake. The fact that the oceans are saline in the result of the release of ion salts from rock and minerals on the continents. Leaching and runoff transport these ions from land to the ocean basins where they accumulate in seawater. In conclusion, weathering is a process that is fundamental to many other aspects of the hydrosphere, lithosphere, and biosphere.
There are three broad categories of mechanisms for weathering: chemical, physical and biological.

Products of Weathering: The process of weathering can result in the following three outcomes on rocks and minerals:

(1) The complete loss of particular atoms or compounds from the weathered surface.
(2) The addition of specific atoms or compounds to the weathered surface.
(3) A breakdown of one mass into two or more masses, with no chemical change in the mineral or rock.

The residue of weathering consists of chemically altered and unaltered materials. The most common unaltered residue is quartz. Many of the chemically altered products of weathering become very simple small compounds or nutrient ions. These residues can then be dissolved or transported by water, released to the atmosphere as a gas, or taken up by plants for nutrition. Some of the products of weathering, less resistant alumino-silicate minerals, become clay particles. Other altered materials are reconstituted by sedimentary or metamorphic processes to become new rocks and minerals.

Chemical Weathering: Chemical weathering involves the alteration of the chemical and mineralogical composition of the weathered material. A number of different processes can result in chemical weathering. The most common chemical weathering processes are hydrolysis, oxidation, reduction, hydration, carbonation, and solution.

Hydrolysis is the weathering reaction that occurs when the two surfaces of water and compound meet. It involves the reaction between mineral ions and the ions of water (OH- and H+), and results in the decomposition of the rock surface by forming new compounds, and by increasing the pH of the solution involved through the release of the hydroxide ions. Hydrolysis is especially effective in the weathering of common silicate and alumino-silicate minerals because of their electrically charged crystal surfaces.

Oxidation is the reaction that occurs between compounds and oxygen. The net result of this reaction is the removal of one or more electrons from a compound, which causes the structure to be less rigid and increasingly unstable. The most common oxides are those of iron and aluminum, and their respective red and yellow staining of soils is quite common in tropical regions which have high temperatures and precipitation. Reduction is simply the reverse of oxidation, and is thus caused by the addition of one or more electrons producing a more stable compound.

Hydration involves the rigid attachment of H+ and OH- ions to a reacted compound. In many situations the H and OH ions become a structural part of the crystal lattice of the mineral. Hydration also allows for the acceleration of other decompositional reactions by expanding the crystal lattice offering more surface area for reaction.

Carbonation is the reaction of carbonate and bicarbonate ions with minerals. The formation of carbonates usually takes place as a result of other chemical processes. Carbonation is especially active when the reaction environment is abundant with carbon dioxide. The formation of carbonic acid, a product of carbon dioxide and water, is important in the solution of carbonates and the decomposition of mineral surfaces because of its acidic nature.

Water and the ions it carries as it moves through and around rocks and minerals can further the weathering process. Geomorphologists call this phenomena solution. The effects of dissolved carbon dioxide and hydrogen ions in water have already been mentioned, but solution also entails the effects of a number of other dissolved compounds on a mineral or rock surface. Molecules can mix in solution to form a great variety of basic and acidic decompositional compounds. The extent, however, of rock being subjected to solution is determined primarily by climatic conditions. Solution tends to be most effective in areas that have humid and hot climates.

The most important factor affecting all of the above mentioned chemical weathering processes is climate. Climatic conditions control the rate of weathering that takes place by regulating the catalysts of moisture and temperature. Experimentation has discovered that tropical weathering rates, where temperature and moisture are at their maximum, are three and a half times higher than rates in temperate environments.

Physical Weathering: Physical weathering is the breakdown of mineral or rock material by entirely mechanical methods brought about by a variety of causes. Some of the forces originate within the rock or mineral, while others are applied externally. Both of these stresses lead to strain and the rupture of the rock. The processes that may cause mechanical rupture are abrasion, crystallization, thermal insolation, wetting and drying, and pressure release.

Abrasion occurs when some force causes two rock surfaces to come together causing mechanical wearing or grinding of their surfaces. Collision between rock surfaces normally occurs through the erosional transport of material by wind, water, or ice.

Crystallization can cause the necessary stresses needed for the mechanical rupturing of rocks and minerals. Crystal growth causes stress as a result of a compound's or an element's change of physical state with change in temperature. The transformation from liquid to solid crystalline form produces a volumetric change which in turn causes the necessary mechanical action for rupture. There are primarily two types of crystal growth that occur; they are ice and salt. Upon freezing the volumetric change of water from liquid to solid is 9%. This relatively large volumetric change upon freezing has potentially a great rupturing effect. Several researchers have discovered in the laboratory and the field that frost action plays a major role in weathering in temperate and polar regions of the Earth. The threshold temperature for frost action is at least - 5° Celsius, and it is at this temperature that the most effective rupturing occurs.

The crystallization of salt exhibits volumetric changes from 1 to 5 percent depending on the temperature of the rock or mineral surface. Most salt weathering occurs in hot arid regions, but it may also occur in cold climates. For example, cavernous salt weathering of granite is widespread in the dry valley regions of South Victoria Land, Antarctica. At this location outcrops and large boulders are pitted by holes up to 2 meters in diameter. Researchers have also found that frost weathering is greatly enhanced by the presence of salt.

The physical breakdown of rock by their expansion and contraction due to diurnal temperature changes is one of the most keenly debated topics in rock weathering research. Known as insolation weathering, it is the result of the physical inability of rocks to conduct heat well. This inability to conduct heat results in differential rates of expansion and contraction. Thus, the surface of the rock expands more than its interior, and this stress will eventually cause the rock to rupture. Differential expansion and contraction may also be due to the variance in the colors of mineral grains in rock. Dark colored grains, because of their absorptive properties, will expand much more than light colored grains. Therefore, in a rock peppered with many different colored grains, rupturing can occur at different rates at the various mineral boundaries.

Alternate wetting and drying of rocks, sometimes known as slaking, can be a very important factor in weathering. Slaking occurs by the mechanism of "ordered water", which is the accumulation of successive layers of water molecules in between the mineral grains of a rock. The increasing thickness of the water pulls the rock grains apart with great tensional stress. Recent research has shown that slaking in combination with dissolved sodium sulfate can disintegrate samples of rock in only twenty cycles of wetting and drying.

Pressure release of rock can cause physical weathering due to unloading. The majority of igneous rocks were created deep under the Earth's surface at much higher pressures and temperatures. As erosion brings these rock formations to the surface, they become subjected to less and less pressure. This unloading of pressure causes the rocks to fracture horizontally with an increasing number of fractures as the rock approaches the Earth's surface. Spalling, the vertical development of fractures, occurs because of the bending stresses of unloaded sheets across a three dimensional plane.

Biological Weathering: Biological weathering involves the disintegration of rock and mineral due to the chemical and/or physical agents of an organism. The types of organisms that can cause weathering range from bacteria to plants to animals.

Biological weathering involves processes that can be either chemical or physical in character. Some of the more important processes are:

1. Simple breaking of particles, by the consumption of soils particles by animals. Particles can also fracture because of animal burrowing or by the pressure put forth by growing roots.

2. Movement and mixing of materials. Many large soil organisms cause the movement of soil particles. This movement can introduce the materials to different weathering processes found at distinct locations in the soil profile.

3. Simple chemical processes like solution can be enhanced by the carbon dioxide produced by respiration. Carbon dioxide mixing with water forms carbonic acid.

4. The complex chemical effects that occur as a result of chelation. Chelation is a biological process where organisms produce organic substances, known as chelates, that have the ability to decompose minerals and rocks by the removal of metallic cations.

5. Organisms can influence the moisture regime in soils and therefore enhance weathering. Shade from aerial leaves and stems, the presence of roots masses, and humus all act to increase the availability of water in the soil profile. Water is a necessary component in several physical and chemical weathering processes.

6. Organisms can influence the pH of the soil solution. Respiration from plant roots releases carbon dioxide. If the carbon dioxide mixes with water carbonic acid is formed which lowers soil pH. Cation exchange reactions by which plants absorb nutrients from the soil can also cause pH changes. The absorption processes often involves the exchange of basic cations for hydrogen ions. Generally, the higher the concentration of hydrogen ions the more acidic a soil becomes.

6. **Soils:** An important factor influencing the productivity of our planet's various ecosystems is the nature of their soils. Soils are vital for the existence of many forms of life that have evolved on our planet. For example, soils provide vascular plants with a medium for growth and supply these organisms with most of their nutritional requirements. Further, the nutrient status of ecosystem's soils not only limits both plant growth, but also the productivity of consumer type organisms further down the food chain.

Soil itself is very complex. It would be very wrong to think of soils as just a collection of fine mineral particles. Soil also contains air, water, dead organic matter, and various types of living organisms (Figure 8). The formation of a soil is influenced by organisms, climate, topography, parent material, and time. The following items describe some important features of a soil that help to distinguish it from mineral sediments.

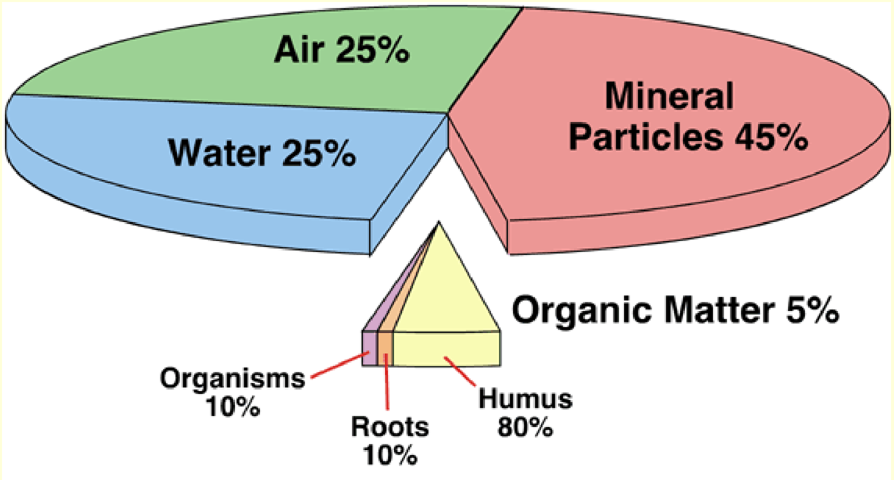

Figure 8: Most soils contain four basic components: mineral particles, water, air, and organic matter. ` Organic matter can be further sub-divided into humus, roots, and living organisms. The values given above are for an average soil.

Organic Activity: A mass of mineral particles alone do not constitute a true soil. True soils are influenced, modified, and supplemented by living organisms. Plants and animals aid in the development of a soil through the addition of organic matter. Fungi and bacteria decompose this organic matter into a semi-soluble chemical substance known as humus. Larger soil organisms, like earthworms, beetles, and termites, vertically redistribute this humus within the mineral matter found beneath the surface of a soil.

Humus is the biochemical substance that makes the upper layers of the soil become dark. It is colored dark brown to black. Humus is difficult to see in isolation because it binds with larger mineral and organic particles. Humus provides soil with a number of very important benefits:

- It enhances a soil's ability to hold and store moisture.
- It reduces the eluviation of soluble nutrients from the soil profile.
- It improves soil structure which is necessary for plant growth.

Organic activity is usually profuse in the near surface layers of a soil. For instance, one cubic centimeter of soil can be the home to more than 1,000,000 bacteria. A hectare of pasture land in a humid mid-latitude climate can contain more than a million earthworms and several million insects. Earthworms and insects are extremely important because of their ability to mix and aerate soil. Higher porosity, because of mixing and aeration, increases the movement of air and water from the soil surface to deeper layers where roots reside. Increasing air and water availablity to roots has a significant positive effect on plant productivity. Earthworms and insects also produce most of the humus found in a soil through the incomplete digestion of organic matter.

Translocation: When water moves downward into the soil, it causes both mechanical and chemical translocations of material. The complete chemical removal of substances from the soil profile is known as leaching. Leached substances often end up in the groundwater zone and then travel by groundwater flow into water bodies like rivers, lakes, and oceans. Eluviation refers to the movement of fine mineral particles (like clay) or dissolved substances out of an upper layer in a soil profile. The deposition of fine mineral particles or dissolved substances in a lower soil layer is called illuviation.

Soil Texture: The texture of a soil refers to the size distribution of the mineral particles found in a representative sample of soil. Particles are normally grouped into three main classes: sand, silt, and clay. Table 3 describes the classification of soil particles according to size.

Table 3: Particle size ranges for sand, silt, and clay.

Type of Mineral Particle	Size Range
Sand	2.0 - 0.06 millimeters
Silt	0.06 - 0.002 millimeters
Clay	less than 0.002 millimeters

Clay is probably the most important type of mineral particle found in a soil. Despite their small size, clay particles have a very large surface area relative to their volume. This large surface is highly reactive and has the ability to attract and hold positively charged nutrient ions. These nutrients are available to plant roots for nutrition. Clay particles are also somewhat flexible and plastic because of their lattice-like design. This feature allows clay particles to absorb water and other substances into their structure.

Soil pH: Soils support a number of inorganic and organic chemical reactions. Many of these reactions are dependent on some particular soil chemical properties. One of the most important chemical properties influencing reactions in a soil is pH . Soil pH is primarily controlled by the concentration of free hydrogen ions in the soil matrix. Soils with a relatively large concentration of hydrogen ions tend to be acidic. Alkaline soils have a relatively low concentration of hydrogen ions. Hydrogen ions are made available to the soil matrix by the dissociation of water, by the activity of plant roots, and by many chemical weathering reactions.

Soil fertility is directly influenced by pH through the solubility of many nutrients. At a pH lower than 5.5, many nutrients become very soluble and are readily leached from the soil profile. At high pH, nutrients become insoluble and plants cannot readily extract them. Maximum soil fertility occurs in the range 6.0 to 7.2.

Soil Color: Soils tend to have distinct variations in color both horizontally and vertically. The coloring of soils occurs because of a variety of factors. Soils of the humid tropics are generally red or yellow because of the oxidation of iron or aluminum, respectively. In the temperate grasslands, large additions of humus cause soils to be black. The heavy leaching of iron causes coniferous forest soils to be gray. High water tables in soils cause the reduction of iron, and these soils tend to have greenish and gray-blue hues. Organic matter colors the soil black. The combination of iron oxides and organic content gives many soil types a brown color. Other coloring materials sometimes present include white calcium carbonate, black manganese oxides, and black carbon compounds.

7. **Glaciation:** Various types of paleoclimatic evidence suggest that the climate of the Earth has varied over time. The data suggests that during most of the Earth's history, global temperatures were probably 8 to 15° Celsius warmer than they are today. However, there were periods of times when the Earth's average global temperature became cold. Cold enough for the formation of alpine glaciers and continental glaciers that extended in to the higher, middle and sometimes lower latitudes. In the last billion years of Earth history, glacial periods have started at roughly 925, 800, 680, 450, 330, and 2 million years before present (B.P.). Of these ice ages, the most severe occurred at 800 million years ago when glaciers came within 5 degrees of the equator

Today, glacial ice covers about 10% of the Earth's land surface. During the height of the Pleistocene, ice sheets probably covered about 30%. Currently, the most extensive continental glaciers are found in Antarctica and Greenland. We can also find smaller glaciers at higher elevations in various mountain ranges in the lower, middle, and higher latitudes.

Glaciers can be classified according to size. Continental glaciers are the largest, with surface coverage in the order of 5 million square kilometers. Antarctica is a good example of a continental glacier (Figure 9).

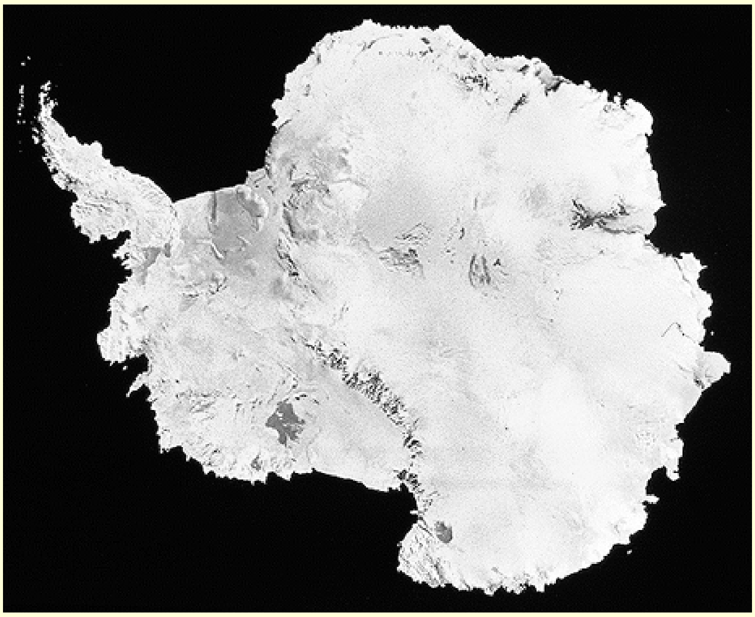

Figure 9: Antarctica glacier

Mountain or alpine glaciers are the smallest type of glacier. These glaciers can range in size from a small mass of ice occupying a cirque to a much larger system filling a mountain valley (Figure 10). Some mountain glaciers are even found in the tropics. The merger of many alpine glaciers creates the third type of glacier, piedmont glaciers. Piedmont glaciers are between several thousand to several tens of thousands of square kilometers in size.

Figure 10: Alpine valley glacier

VI. Important Geographical Data

PRINCIPAL MOUNTAIN PEAKS OF THE WORLD

Mountain	Height in metres	Range	Date of First ascent
1. Mount Everest	8,848	Himalayas	29-May-53
2. K-2 (Godwin Austen)	8,611	Karakoram	31-Jul-54
3. Kanchenjunga	8,598	Himalayas	25-May-55
4. Lhotse	8,511	Himalayas	18-May-56
5. Makalu I	8,481	Himalayas	15-May-55
6. Dhaulagiri I	8,172	Himalayas	13-May-60
7. Manaslu I	8,156	Himalayas	9-May-56
8. Cho Uyo	8,153	Himalayas	Oct. 19, 1954
9. Nanga Parbat	8,126	Himalayas	3-Jul-53
10. Annapuma I	8,078	Himalayas	3-Jun-50
11. Gasherbrum I	8,068	Karakoram	5-Jul-58
12. Broad Peak I	8,047	Karakoram	9-Jun-57
13. Gasherbrum II	8,034	Karakoram	7-Jul-56
14. Shisha Pangma (Gosainthan)	8,013	Himalayas	2-May-64
15. Gasherbrum III	7,952	Karakoram	Aug. 11,1975
16. Annapuma II	7,937	Himalayas	17-May-60
17. Gasherbrum IV	7,924	Karakoram	Aug. 6, 1958
18. Gyachung Kang	7,921	Himalayas	Apr. 10, 1964
19. Kangbachen	7,902	Himalayas	26-May-74
20. Disteghil Sar I	7,884	Karakoram	9-Jun-60
21. Himal Chuli	7,841	Himalayas	24-May-60
22. Khinyang Chhish	7,852	Karakoram	Aug. 26, 1971
23. Nuptse	7,821	Himalayas	16-May-61
24. Manaslu II (Peak 29)	7,835	Himalayas	Oct. 1970
25. Masherbrum (Peak 29)	7821	Karakoram	6-Jul-60
26. Nanda Devi	7817	Himalayas	Aug. 29, 1936
27. Chomo Lonzo	7815	Himalayas	Oct. 30, 1954
28. Ngojumba Ri I	7805	Himalayas	5-May-65
29. Kakaposhi	7788	Karakoram	25-Jun-58
30. Batura Muztagh I	7785	Karakoram	30-Jun-76
31. Zemu Gap Peak	7780	Himalayas	Unclimbed
32. Kanjut Sar	7761	Karakoram	19-Jul-59
33. Kamet	7,756	Himalayas	21-Jun-31
34. Namcha Barwa	7,755	Himalayas	Unclimbed
35. Dhaulagiri II	7,751	Himalayas	18-May-71
36. Saltoro Kangri I	7,741	Karakoram	24-Jul-62
37. Batura Muztagh II	7,730	Karakoram	1978
38. Gurla Mandhata	7,728	Himalayas	Unclimbed

39. Ulugh Muztagh	7,725	Kunlun Shan	Unclimbed
40. Qungur II (Kongur)	7,719	Pamir	12-Jul-81
41. Dhaulagiri III	7,715	Himalayas	Oct. 23, 1973
42. Jannu	7,709	Himalayas	Apr. 27, 1962
43. Tirich Mir	7,706	Hindu Kush	21-Jul-50
44. Saltoro Kangri II	7,691	Karakoram	Unclimbed
45. Disteghil Sar E	7,700	Karakoram	Unclimbed
46. Saser Kangri I	7,672	Karakoram	5-Jun-73
47. Chogolisa South West	7,665	Karakoram	Aug. 2, 1975
48. Phola Gangchhen	7,661	Himalayas	Unclimbed
49. Dhaulagiri IV	7,661	Himalayas	9-May-75
50. Shahkang Sham	7,660		Unclimbed

VOLCANOES of the World

Name	Height		Range or	Country	Date of Last
	(ft)	(metres)	Location		Notified eruption
Ojos del Salado	22588	6885	Andes	Argentina - Chile	1981-Stearms
Guallatiri	19882	6060	Andes	Chile	1960
Cotopaxi	19347	5897	Andes	Ecuador	1975
Lascar	18507	5641	Andes	Chile	1968
Tupungatito	18504	5640	Andes	Chile	1964
Popocatepetl	17887	5451	Altiplano De Mexico	Mexico	1920 - Stearms
Nevado del Ruiz	17690	5400	Andes	Colombia	1985
Sangay	17159	5230	Andes	Ecuador	1976
Klyuchevskaya Soplea	15913	4850	Sredinnyy Khrebet (Kamchatka Peninsula)	CIS *(formerly USSR)	1974
Purace	15059	4590	Andes	Colombia	1977
Tajumulco	13881	4220		Guatemala	Rumbles
Muna Loa	13680	4170	Hawaii	USA	1978
Tacana	13379	4078	Sierra Madre	Guatemala	Rumbles
Cameroon Mt	13350	4070	(monarch)	Cameroon	1959
Erebus	12450	3795	Ross I	Antarctica	1975
Rindjani	12224	3726	Lombok	Indonesia	1966
Pico de Teide	12198	3718	Tenerife, Canary Is	Spain	1909
Semeru	12060	3676	Java	Indonesia	1976
Nyiragongo	11385	3470	Virunga	Zaire	1977
Koryakshkaya	11339	3456	Kamchatka Peninsula	CIS *	1957
Irazu	11325	3452	Cordillera	Costa Central	1967
Slamat	11247	3428	Java	Indonesia	1967
Mt. Spurr	11070	3474	Alaska Range	USA	1953
Mt. Etna	10853	3308	Sicily	Italy	2002

** Commonwealth of Independent States*

WORLD'S DEEPEST CAVES

Cave	Country	Depth in metres
Reseau du foillis, Haute Savoie	France	1455
Reseau de la Pierre St. Martin, Haute Savoie	France	1321
Snezhanaya, Caucasus	CIS	1280
Sistema Huautla	Mexico	1220
Gouffre Berger	France	1198
Sima de Ukendi	Spain	1185
Avence B 15, Pyrenees	Spain	1150
Schneeloch, Salzburg	Austria	1111
Sima G.E.S. Malaga	Spain	1098
Lamprechtosfen	Austria	1024
Reseau Felix Trombe	France	1018
Ogof Ffynnon Ddu, Powys	Wales	308
Giant;s Hole-Oxlow Caverns, Derbyshire	England	214
Reyfad Pot, Fermanagh	North Ireland	179
Carrowmore Cavern	Ireland, Republic	140

WORLD'S PRINCIPAL DESERTS

Name	Approximate area in sq km	Territories
The Sahara	9065000	Africa. Spreads across Algeria, Chad, Libya, Mali, Mauritania, Niger, Sudan, Tunisia, Egypt, Morocco. Embraces the Libyan Desert (1,550,000 sq km) and die Nubian Desert (260,000 sq km)
Australian Desert	1550000	Australia. Embraces the Great Sandy (or Warburton) (420,000 sq km), Great Victoria (325,000 sq km), Simpson (Arunta) (310,000 sq km), Gibson (220,000 sq km) and Sturt Deserts
Arabian Desert	1300000	Asia. Spreads across Southern Arabia, Saudi Arabia, Yemen, includes the Ar Rab'al Khali or Empty Quarter (647,500 sq km), Syrian (325,000 sq km) and An Nafud (129,500 sq km)
The Gobi	1295000	Asia. Embraces Mongolia and China (Inner Mongolia)
Libyan	1165500	Africa. Embraces Libya, SW Egypt and Sudan
Rub-al-Khali (Empty Quarter)	647500	Southern Saudi Arabia (Asia)
Lalahari Desert	582000	Botswana (Africa)
Chihuahuan	363600	Texas, New Mexico (USA)
Takla Makan	362600	Sinkiang, China
Great Sandy	338500	North West Australia
Great Victoria	338500	South West Australia

Name	Approximate area in sq km	Territories
Gibson	310800	Western Australia
Namib Desert	310000	South West Africa (Namibia)
Kara Kum	310000	Turkmenistan, CIS
Somali Desert	260000	Somalia (Africa)
Nubian	259000	North East Sudan (Africa)
Syrian	259000	North Saudi Arabia, Eastern Jordan, Southern Syria, Western Iraq (Asia)
Thar Desert	259000	North Western India and Pakistan (Asia)
Kyzyl Kum	259000	Uzbekistan-Kazakhstan, CIS (Asia)
Sonoran Desert	181300	Arizona and California, USA and Mexico (North America)
Atacama Desert	181300	Northern Chile (South America)
An Nafud	103600	North South Arabia (Asia)
Simpson	103600	Central Australia
Dasht-e-Kaveir	77600	Central Iran (Asia)
Dasht-e-Lut	51800	Eastern Iran (sometimes called Iranian Desert)
Mojave Desert	38900	Southern California (USA)
Desierto De Sechura	26000	North West Peru (South America)
Negev	12200	Southern Israel (Asia)
Death Valley	7800	Eastern California, South West Nevada (USA)
Black Rock	2600	North West Nevada (USA)
Painted Desert	320	North Arizona (USA)

LARGEST PENINSULAS OF THE WORLD

Name	Area in sq km	Name	Area in sq km
Arabia	3250000	Labrador	1300000
Southern India	2072000	Scandinavia	800300
Alaska	1500000	Iberian Penisula	584000

LARGEST ISLANDS OF THE WORLD

Island	Location	Area in sq km
Greenland	North Atlantic (Denmark)	2175597
New Gunea	Southwest Pacific (Irian Jaya, Indonesia, west part; Papua New Guinea, east part)	820033
Borneo	West mid-Pacific (Indonesia, south art; British protectorate and Malaysia, north part),	743107
Madagascar	Indian Ocean (Malagasy Republic)	587042
Baffin	North Atlantic (Canada)	476068
Sumatra	Northeast Indian Ocean (Indonesia)	473605
Honshu	Sea of Japan—Pacific Qapan)	230316
Great Britain	Off coast North-west Europe (England, Scodand and Wales)	229883
Ellesmere	Arctic Ocean (Canada)	212688
Victoria	Arctic Ocean (Canada)	212199
Celebes	West mid-Pacific (Indonesia)	189034
South Island	South Pacific (New Zealand)	150461
Java	Indian Ocean (Indonesia)	126884
North Island	South Pacific (New Zealand)	114688
Cuba	Caribbean Sea (Republic)	114525
Newfoundland	North Adantic (Canada)	110681
Luzon	West mid-Pacific (Philippines)	104688
Eceland	North Atlantic (Republic)	102999
Mindanao	West mid-Pacific (Philippines)	94631
Novaya Zemlya	Arctic Ocean (Russia)	90650
Ireland	West of Great Britain (Republic, south part; United Kingdom, north part)	84426
Hokkaido	Sea of Japan - Pacific 0apan)	78663
Hispaniola	Caribbean Sea (Dominican Republic, east part; Haiti, west part)	76029
Tasmania	South of Australia (Australia)	67897
Sri Lanka	Indian Ocean (Republic)	65610
Sakhalin (Karafuto	North of Japan (CIS)	63610
Banks	Arctic Ocean (Canada)	60166
Devon	Arctic Ocean (Canada)	54030
Tierr del Fuego	Southern tip of South America (Argentina, east part; Chile, west part)	48187
Kyushu	Sea of Japan—Pacific (Japan)	42018
Melville	Arctic Ocean (Canada)	41805
Axel Heiberg	Arctic Ocean (Canada)	40868
Southampton	Hudson Bay (Canada)	40663

SEAS

Sr. No.	Principal Sea	Area in sq km	Average depth in metres
1	South China Sea	2974600	1200
2	Caribbean Sea	2753000	2400
3	Mediterranean Sea	2503000	1485
4	Bering Sea	2265180	1400
5	Gulf of Mexico	1542985	1500
6	Sea of Okhotsk	1527570	840
7	East China Sea	1249150	180
8	Hudson Bay	1232300	120
9	Sea of Japan	1007500	1370
10	Andaman Sea	797700	865
11	North Sea	575300	90
12	Black Sea	461980	1100
13	Red Sea	437700	490
14	Baltic Sea	422160	55
15	Persian Gulf (Arabian Gulf)	238790	24
16	Gulf of St. Lawrence	237760	120
17	Gulf of California	162000	810
18	English Channel	89900	54
19	Irish Sea	88500	60
20	Bass Strait	7500	70

DEEP SEA TRENCHES

Name	Length in km	Deepest point	Depth in metres
Mariana Trench (West Pacific)	2250	Challenger Deep	11776
Tonga - Kermadec Trench (South Pacific	2575	Vityaz 11 (Tonga)	10850
Kuril – Kamchatka Trench (West Pacific)	2250		10542
Philippine Trench (West Pacific)	1325	Galathea Deep	10539
Idzu-Bonin Trench (sometimes included in the Japan Trench)			9810
New Hebrides Trench (South Pacific)	320+	North Trench	9165

Name	Length in km	Deepest point	Depth in metres
Solomon or New Britain Trench (South Pacific)	640		9140
Puerto Rico Trench (West Atlantic)	800	Milwaukee Deep	8648
Yap Trench (West Pacific)	560		8527
Japan Trench (West Pacific)	1600		8412
South Sandwich Trench (South Atlantic)	965	Meteor Deep	8263
Aleutian Trench (North Pacific)	3200		8100
Peru-Chile (Atacama) Trench (East Pacific)	3540	Bartholomew Deep	8064
Palau Trench (sometimes included in the Yap Trench)			8050

PRINCIPAL RIVERS OF THE WORLD

River	Source	Outflow	Length (km)
Nile	Tributaries of Lake Victoria, Africa	Mediterranean Sea	6,690
Amazon	Glacier-fed lakes, Peru	Atlantic Ocean	6,296
Mississippi-Missouri-Red Rock	Source of Red Rock, Montana	Gulf of Mexico	6,240
Yangtze Kiang	Tibetan Plateau, China	China Sea	5,797
Amur-Argun	Khingan Mts., China	Tatar Strait	5,780
Ob	Altai Mts., CIS	Gulf of Ob	5,567
Yellow (Huang Ho)	Eastern part of Kunlan Mts., west China	Gulf of Chihli	4,667
Yenisei	Tannu-Ola Mts., western Tuva, CIS	Arctic Ocean	4,506
Parana	Confluence of Paranaiba and Grande rivers	Rio de la Plata	4,498
Irtish	Altai Mts., CIS	Ob River	4,438
Congo	Confluence of Lualaba and Luapula rivers, Zaire	Atlantic Ocean	4,371
Amur	Confluence of Shilka (CIS) and Argun (Manchuria) rivers	Tatar Strait	4,352
Lena	Baikal Mts., CIS	Arctic Ocean	4,268
Mackenzie	Head of Finlay river, British Columbia, Canada	Beaufort Sea (Arctic Ocean)	4,241
Niger	Guinea	Gulf of Guinea	4,184
Mekong	Tibetan highlands	South China Sea	4,023
Mississippi	Lake Itasca, Minnesota	Gulf of Mexico	3,779
Missouri	Confluence of Jefferson, Gallatin and Madison rivers, Montana	Mississippi River	3,726
Volga	Valdai plateau, CIS	Caspian Sea	3,687
Madeira	Confluence of Beni and Maumore rivers, Bolivia-Brazil boundary	Amazon River	3,238

River	Source	Outflow	Length (km)
Purus	Peruvian Andes	Amazon River	3,207
San Francisco	Southwest Minas Gerais, Brazil	Adantic Ocean	3,198
Yukon	Junction of Lewes and Pelly rivers, Yukon Territory, Canada	Bering Sea	3,185
St. Lawrence	Lake Ontario	Gulf of St. Lawrence	3,058
Rio Grande	San Juan Mts., Colorado	Gulf of Mexico	3,034
Tunguska (Lower)	North of Lake Baikal, Russia	Yenesei River	2,995
Brahmaputra	Himalayas	Ganges River	2,897
Indus	Himalayas	Arabian Sea	2,897
Danube	Black Forest, Germany	Black Sea	2,842
Euphrates	Confluence of Murat Nehri and Kara Sun rivers, Turkey	Shatt-al-Arab	2,799
Darling	Central part of Eastern Highlands, Australia	Murray River	2,739
Zambezi	11° 21'S, 24° 22'E, Zambia	Mozambique Channel	2,736
Tocantins	Goias, Brazil	Para River	2,699
Murray	Australian Alps, New South Wales	Indian Ocean	2,589
Nelson	Head of Bow River, western Alberta, Canada	Hudson Bay	2,575
Paraguay	Mato Grosso Plateau, Brazil	Parana River	2,549
Ural	Southern Ural Mts., CIS	Caspian Sea	2,533
Ganges	Himalayas	Bay of Bengal	2,506
Amu Darya (Oxus)	Nicolas Range, Pamir Mts., CIS	Aral Sea	2,414
Japura	Andes, Colombia	Amazon River	2,414
Sahveen	' Tibet, south of Kunlun Mts.	Gulf of Martaban	2,414
Arkansas	Central Colorado	Mississippi River	2,348
Colorado	Grand Country, Colorado	Gulf of California	2,333
Dnieper	Valdai Hills, CIS	Black Sea	2,284
Syr Darya	Tien Shan, China/Kyrgyzstan	Aral Sea	2,206
Ohio-Allegheny	Potter County, Pennsylvania	Mississippi River	2,102
Irrawaddy	Confluence of Nmai and Mali rivers, northeast Myanmar	Bay of Bengal	2,092
Orange	Lesotho	Adantic Ocean	2,092
Orinoco	Serra Parima Mts., Venezuela	Atlantic Ocean	2,062
Pilcomayo	Andes Mts., Bolivia	Paraguay River	1,999
Xi Jiang (Si Kiang)	Eastern Yunnan Province, China	China Sea	1,989
Columbia	Columbia Lake, British Columbia, Canada	Pacific Ocean	1,983
Don	Tula, RSFSR, CIS	Sea of Azov	1,968
Sungari	China-North Korea boundary	Amur River	1,955
Saskatchewan	Canadian Rockey Mts.	Lake Winnipeg	1,939
Peace	Stikine Mts., British Columbia, Canada	Great Slave River	1,923
Tigris	Taurus Mts., Turkey	Shatt-al-Arab	1,899
Rhine	Confluence of Hinterrhein and Vorderrhein rivers, Switzerland	North Sea	1,320

PRINCIPAL LAKES OF THE WORLD

Name and location	Area in sq km	Length in sq km	Max. depth in metres
Caspian Sea, CIS – Iran	394299	1199	946
Superior, USA – Canada	82414	616	406
Victoria, Tanzania – Uganda	69485	322	82
Aratl, CIS	66457	428	68
Huron, USA – Canada	59596	397	229
Michigan, USA	58016	517	281
Tanganyika, Tanzania – Zaire	32893	676	1435
Baikal, CIS	31500	636	1741
Great Bear, Canada	31080	373	82
Nyasa, Malawi – Mozambizue – Tanzania	30044	579	706
Great Slave, Canada	28930	480	614
Chad, Chad – Niger – Nigeria	25760		7
Erie, USA – Canada	25719	388	64
Winnipeg, Canada	23553	425	62
Ontario, USA - Canada	19477	311	237
Balkash, CIS	18428	605	27
Ladoga, CIS	18130	200	225
Onega, CIS	9891	248	110
Titicaca, Bolivia – Peru	8135	177	370
Nicaragua, Nicaragua	8001	177	70
Athabaska, Canada	7920	335	124
Rudolf, Kenya	6405	248	-
Reindeer, Canada	6330	245	-
Eyre, South Australia	6216	209	Vries
Issyk – Kul, CIS	6200	182	700
Urmia, Iran	6001	130	15
Torrens, South Australia	5698	209	
Vanern, Sweden	5545	140	98
Winnipegosis, Canada	5403	245	18
Mobuto Sese Seko, Uganda	5299	161	55
Nettilling, Baffin Island, Canada	5051	113	-
Nipigon, Canada	4843	116	-
Manitoba, Canada	4706	225	7
Great Salt, USA	4662	121	5/8
Kioga, Uganda	4403	80	9
Koko – Nor, China	4222	106	

WORLD'S GREATEST MAN-MADE LAKES

Name of dam	Location	Million cubic metres	Year completed
Owen Falls	Uganda	204800	1954
Kariba	Zimbabwe	181592	1959
Bratsk	CIS	169270	1964
High Aswan (Sadd-el-Aali)	Egypt	168000	1970
Akosombo	Ghana	148000	1965
Daniel Johnson	Canada	141852	1968
Gur (Raul Leoni)	Venezuela	136000	1986
Krasnoyarsk	CIS	73300	1967
Bennet W.A.C.	Canada	70309	1967
Zeya	CIS	68400	1978
Cabora Bassa	Mozambique	63000	1974
La Grande 2	Canada	61720	1982
La Grande 3	Canada	60020	1982
Ust – Iiimsk	CIS	59300	1980
Volga – V.I. Lenin	CIS	58000	1955
Caniapiscau	Canada	53790	1981
Pati (Chapeton)	Argentina	53700	-
Upper Wainganga	India	50700	-
Sao Felix	Brazil	50600	-
Bukhtarma	CIS	49740	1960
Ataturk (Karababa)	Turkey	48000	-
Cerros Coloradors	Argentina	48000	1973
Irkutsk	CIS	46000	1956
Tucurui	Brazil	36375	1984
Vilyuy	CIS	35900	1967
Sanmenxia	China	35400	1960
Hoover	USA	35154	1936
Sobridinho	Brazil	34200	1981
Glen Canyon	USA	33304	1964
Jenpeg	Canada	31790	1975

HIGHEST WATERFALLS OF THE WORLD

Waterfall	Location	River	Height in metres
Angel	Venezuela	Tributary of Caroni	1000
Tugela	Natal, South Africa	Tugela	914
Cuquenan	Venezuela	Cuquenan	610
Southerland	South Island, N.Z.	Arthur	580
Takkakaw	British Columbia	Tributary of Yoho	503
Ribbon(Yosemite)	Califormia USA	Creek Flowing into Yosemite	491
Upper Yosemite	Califormnia, USA	Yosemite Creek, tributary of Merced	436
Gavarnie	Southwest France	Gave de Pau	422
Vettisfoss	Norway	Morkedola	366
Widows' Tears (Yosemite)	California, USA	Tributary of Merced	357
Staubbach	Switzerland	Staubbach (Lauter – brunnen Valley)	300
Middle Cascade (Yosemite)	California, USA	Yosemite Creek, tributary of Merced	227
King Edward VIII	Guyana	Courantyne	259
Jog Falls (Gersoppa)	Karnataka, Inda	Sharvati	253
Kaieteur	Guyana	Potaro	251
Skykje	Norway	In shkykjedal (valley of Inner – Hardinger Fjord	250
Kalambo	Tanzania – Zambia		219
Fariy (Mt. Rainier Park)	Washington, USA	Stevens Creek	213
Trummedlbach	Switzerland		213
Aniene (Teverone)	Italy	Tiber	207
Cascata delle Marmore	Italy	Velino, tributary of Nera	198
Maradalsfos	Norway	Stream flowing into Ejkisdalsvand (lake)	196
Feather	California, USA	Fall river	195
Maletsunyane	Lesotho	Malesunyane	192
Bridalveil (Yosemite)	California, USA	Yosemite Creek	189
Multnomah	Oregon, USA	Multnomah Creek tributary of Colombia	189
Voringsfos	Norway	Bjoreia	182
Nevada (Yosemite)	California, USA	Merced	181
Skjeggedal	Norway	Tysso	160
Marina	Guyana	Tributary of Kuribrong, tributary of Potaro	152
Tequendama	Colombia	Funza, tributary of Magdalena	130
Trummelbach	Switzerland		213
King george's	Cape of Good Hope, South Africa	Orange	122
Illilouette	California, USA	Illilouette Creek, tributary of Merced	113
Victoria	Zimbabew– Zambia boundary	Zambezi	108

Waterfall	Location	River	Height in metres
Handol	Sweden	Handol Creek	105
Lower Yosemite	California, USA	Yosemite	98
Comet (Mt. Rainier Park)	Washington USA	Van Trump Creek	98
Vernal (Yosemite)	California	Merced	97
Virginia	Northwest Territories, Canada	South Nahanni, tributary of Mackenzie	96
Lower Yellowstone	Wyoming, USA	Yellowstone	94

MAJOR RIVERSIDE CITIES

WORLD			INDIA		
Alexandria	Nle	Egypt	Agra	Yamuna	Uttar Pradesh
Amsterdam	Amsel	The Netherlands	Ahmedabad	Sabarmati	Gujarat
Antwerp	Scheldt	Belgium	Allahabad	Ganga and Yamuna	Uttar Pradesh
Ankara	Kizil	Turkey	Ayodhya	Saryu	Uttar Pradesh
Baghdad	Tigris	Iraz	Badrinath	Alaknanda	Uttarakhand
Bangkok	Menam	Thailand	Kolkata	Hooghly	West Bengal
Belgrade	Danube	Serbia	Cuttack	Mahanadi	Odisha
Berline	Spree	Germany	Delhi	Yamuna	Delhi
Bon	Rhine	Germany	Dibrugarh	Brahmaputra	Assam
Bristol	Avon	England	Ferozepur	Sutlej	Punjab
Budapest	Danube	Hungary	Guwahati	Brahmaputra	Assam
Cairo	Nile	Egypt	Hardwar	Ganga	Uttarakhand
Canton	Canton	China	Hyderabad	Musi	Andhra Pradesh
Chittagong	Karnaphuli	Banlgadesh	Jabalpur	Narmada	Madhya Pradesh
Chungking	Yang-tse-Kiang	China	Jamshedpur	Suvarnarekha	Jharkhand
Cologne	Rhine	Germany	Kanpur	Ganga	Uttar Pradesh
Glasgow	Clyde	Scotland	Kota	Chambal	Rajasthan
Hull	Humber	England	Lucknow	Gomti	Uttar Pradesh
Hamburg	Elbe	Germany	Ludhiana	Sutlej	Punjab
Karachi	Indus	Pakistan	Mathura	Yamuna	Uttar Pradesh
Khartoum	Blu & white Nile	Sudan	Nashik	Godvari	Maharashtra
Lahor	Ravi	Pakistan	Pandharpur	Bhima	Maharashtra
Lisbon	Tagus	Portugal	Patna	Ganga	Bihar
Liverpool	Mersey	England	Ropar	Sutlej	Punjba
London	Thames	England	Sambalpur	Mahanadi	Odisha
Montreal	Ottawa	Canada	Srinagar	Jhelum	Jammu and Kashmir
Moscow	Moskva	Russia	Surat	Tapti	Gujarat
Nanking	Yang-tse-Kiang	China	Tiruchirappalli	Cauvery	Tamil Nadu

WORLD			INDIA		
New	Mississippi	USA	Ujjain	Shipra	Madhya Pradesh
Orleans			Varanasi	Ganga	Uttar Pradesh
New York	Hudson	USA	Vijayawada	Krishna	Andhra Pradesh
Paris	Seine	France	***RIVERS FLOWING INTO LAKES***		
Philadelphia	Delaware	USA	River	Lake	Country
Qeubec	St. Lawrence	Canada	Volga	Caspian Sea	CIS
Yangon	Irawadi	Myanmar	Ural	Caspian Sea	CIS
Rome	Tiber	Italy	Jordan	Dead Sea	West Asia
Shanghai	Yang-tse-Kiange	China			
Tokyo	Sumida	Japan			
Vienna	Danube	Austria			
Warsaw	Vistula	Poland			
Washington	Potomac	USA			

MAJOR LOCAL WINDS	
Temporates:	Central America; monsoon winds
Virazon:	Peru and Chile; sea winds
Shamal:	Iran, Iraq, Arab; dry
Southern Burster:	North SouthWales - Australia; dry wind
Samoon:	Iran
Bise:	France; cold
Purga:	Tundra region and Russia;cold
Ponente:	Mediterranean (France);cold
Papagayo:	Mexico; hot
Baguis:	Philippines; warm tropical
Berg:	South Africa
Gregale:	Southern Europe; cold
Jorran:	Geneva Lake; cold dry
Leste:	hot
Levanter:	Southern Spain; strongeasterly cold wind
Karaburan:	Tarim Basin (Central Asia); hot
Maestro:	Mediterranean
Norte:	Central America; cold
North Western Wind:	New Zealand
Loo:	North India; dry
Haboob:	Sudan
Yamo:	A warm and dry wind in Japan
Zonda:	A warm wind in Argentina
Tramontane:	A warm wind in central Europe
Bora:	Southern Europe; cold
Mistral :	Southern Europe; cold
Blizzard :	North America; cold

MAJOR LOCAL WINDS	
Buran :	Siberia (Russia); cold
Pampero :	Argentina
Norther :	Texas (USA)

MAJOR GRASSLANDS

Grasslands	Continents/Countries
Prairies	North America
Pampas	South America
Veld	South Africa
Steppes	Eurasia
Downs	Australia
Pustaz	Hungary
Cantanburry	New Zealand
Manchurian	China

MAJOR TYPES OF CLOUDS

Name	Main Constituent	Height (Km)	Temp (^{0}C)	Appearance / Precipitation
Cirrus	Ice	5-3	-20^0 to - 60^0	Detached, delicate white filaments, oftern fibrous; no large ice crystals in trails; wispy, no layers
Cirrocumulus	Ice	5-3	-20^0 to - 60^0	White patch layer with smaller granular or rippled; no elements; wispy and puffendup
Cirrostratus	Ice	5-3	-20^0 to - 60^0	Translucent cloud veil; Halo; no phenomenon, wispy and layered
Altocumulus	Water	2-7	-10^0 to - 30^0	White grey layer with shading or broken sharp outlines and not detached; small, fleecy, globular and relatively thin patches; usually with shaded portions; abandoned layers of ice
Altostratus	Water	2-7	+10^0 to - 30^0	Grey bluish sheet; uniform appearance; occasionally, may have layers of ice
Nimbostratus	Water	1-3	+10^0 to - 15^0	Dark grey layer, rendered diffuse; persistent and iced y falling rain or snow
Stratocumulus	Water	1/2-2	+15^0 to - 5^0	Grey white patchy sheet; many occur in long rows
Stratus (Lowest)	Water	0-1/2	+20^0 to - 5^0	Grey uniform layer; drizzle
Cumulus	Water			Detached clouds; dense with sharp outlines; many grow small vertical showers
Cumulonimbus	Water			Huge towering clouds over dense, and ice dark mountains; flattened; heavy downpour and thunderbolt

IMPORTANT BOUNDARY LINES:

Durand Line: The boundary between India and Afghanistan demarcated by Sir Mortimer Durand in 1896. At present, the line separates Afghanistan and Pakistan.

Hindenburg line : The line to which the Germans retreated in 1917 during the World War I, defines the boundary between Germany and France.

Line of Control: The line of Control divides Kashmir between India and Pak-occupied Kashmir (PoK).

Line of Actual Control : This line divides north-eastern part of India and China.

International Date Line: The line roughly corresponds to 180° E or W meridian of longitude which falls on the opposite side of the Greenwich meridian and the date changes by one day (i.e., 24 hours), as this line is crossed. On crossing this line from east to west a day is added, and a day is subtracted on crossing it from west to east.

McMahon Line : The boundary between China and India as demarcated by Sir Henry McMahon. China does not recognise this line.

Maginot Line : The boundary between France and Germany.

Oder Neisse Line : The boundary between Germany and Poland.

Radcliffe Line : Drawn by Sir Cyril Radcliffe in 1947, it demarcates the boundary of India and Pakistan.

Siegfried Line : It is the line of fortification drawn up by Germany on her borders with France.

17th Parallel: The line which defined the boundary between North Vietnam and South Vietnam before the two were united.

38th Parallel : The boundary line between North Korea and South Korea.

49th Parallel : The boundary line between the USA and Canada.

B. Geography Of India

I. Introduction: The Indian subcontinent occupies a strategic position in Southern Asia. It is favourably situated on the world's highways of trade and commerce both to the east and the west. The Arabian peninsula and African continent lie in its west and Myanmar, Malaysia and Indonesia in the east. Its distance from Europe is only 7000km through the Suez Canal. It also has links with North America and South America both through the Suez Canal and the Cape of Good Hope. The third biggest ocean in the world known as Indian Ocean is named after it. It is a distinct geographic entity, separated from the rest of Asia by the lofty mountain barriers of the Himalayas, the Kirthar, the Sulaiman, the Hindukush and the Poorvanchal mountain ranges. The countries that the Indian subcontinent comprises are India, Pakistan, Nepal, Bhutan and Bangladesh, India being the largest among them. Infact, it is the second largest country in the world in terms of population and seventh largest in the world in terms of area.

Seventh largest country (areawise)

Area	: 32,87,263 sq. km
North to South	: 3214 km
West to East	: 2933 km
Latitudinal extent	: $8^0$4' N to $37^0$6' N
Longitudinal extent	: 68^0 7' E to 97^0 25' E (for mainland)

Southernmost point - Indira Point or Pygmalion Point (Andaman and Nicobar islands) 64^0 5' N

Coastline is 6100 km (along main landmass) and 7516 km (if Andaman and Nicobar Islands and Lakshadweep are considered)

Total land frontier is 15200 km

India is situated in the Northern Hemisphere. The southern tip of India lies at $8^0$4' N. The Tropic of Cancer ($23^0$30' N) almost divides India into two haves. The line passes through eight States - Gujarat, Rajasthan, Madhya Pradesh, Chhattisgarh, Jharkhand, West Bengal, Tripura and Mizoram. The latitudinal and longitudinal extent of India are 3214 km and 2933 km respectively.

II. Physical Features: India has three distinct physical divisions. The northern boundaries of India are provided by the lofty ranges of the Himalayas, which run almost in a wall-like shape from north-west to north-east. Then we have the Great Plains of northern India formed by the basins of three mighty river systems, the Indus, the Ganga and the Brahmaputra. Down below, we have the Deccan Plateau of the Peninsular India, which is geologically the oldest structure of the Indian subcontinent. It consists of huge rock blocks of very ancient times.

The Great Mountain Wall of the north: India's northern frontiers are distinctly marked out by an are-shaped huge mountain wall stretching for about 3600 km comprising the snow-capped mountain ranges of the Karakoram and the Himalayas. The width of this mountain belt varies between 150 km and 400 km The Karakoram mountain ranges rise from the Pamir Knot in the north-west and stretch towards southeast up to the Indus gorge in Jammu and Kashmir. The world's second highest mountain peak K2 (Godwin Austen), which has a height of 8611 meters, belongs to this chain of mountains famous Baltoro and Siachen Glacier also lie in the high valleys of Karakoram ranges. To the south of the Karakoram Mountains is the Ladakh range and further below southwards is the Zaskar range of mountains, both of which lie in Jammu and Kashmir.

The Himalayas (meaning the abode of snow), which form almost a 2500 km long continuous mountain wall on India's North, extending from Indus in the west to Brahmaputra in the east, can be divided into Western, Central and eastern Himalayas. The Western Himalayas encompass Jammu and Kashmir and Himachal Pradesh. The Central Himalayas are spread over Uttrakhand and Nepal. The Eastern Himalayas cover northern parts of the West Bengal and extend into Sikkim, Bhutan and Arunanchal Pradesh.

The Himalayas broadly consist of three parallel ranges of mountains, the Himadri, the Himachal and the Shivaliks. The Himadri range, also known as the Greater Himalayas, comprises the northernmost range and lies on the edge of the Tibetan Plateau. It is the highest mountain range with an average height of about 6000 metres above the sea level. The world's highest mountain peak, Mount Everest (8848 metres) in Nepal, belongs to the Greater Himalayas. Kanchenjunga (8598 metres), Nanga Parbat (8126 metres) and Nanda Devi (7817 metres) are the highest peaks of the Greater Himalayas in India.

Western Himalayas	**Eastern Himalayas**
1. Lie to the west of 80 degree East longitude between the Indus and Kali river	1. Lie to the east of 88 degree east longitude between the Tista and the Brahmaputra river
2. Rise gradually in a series of ranges	2. Rise abruptly from the plains of Bihar and West Bengal
3. Average annual rainfall is less than 100 cms	3. Average annual rainfall is more than 200 cms
4. Vegetation consists mainly of alpine and coniferous forests	4. Large tracks are covered with dense evergreen forests

South of the Himadri lies the Himachal range, which is also known as the Middle or the Lesser Himalayas, which has a height varying between 3700 and 4500 metres above sea level This range of alternating ridges and valleys and highly dissected uplands contains many of India's important hill stations. The beautiful Kashmir, Kulu and Kangra valleys of India and Kathmandu valley in Nepal, lie in this mountain range. The popular hill stations of Shimla (Himachal Pradesh), Mussoorie, Nainital (both in Uttrakhand) and Darjeeling (West Bengal) are also located on the Himachal ranges of the Himalayas.

The Shivalik range is the southernmost range of Himalayas which is the lowest among the Himalayan ranges with a height of between 900 metres to 1200 metres above the sea level. Made up of mud and soft rocks, it is a discontinuous range which lies on the northern border of the Ganga plain and extends towards east to merge with the main mountains.

Though the Himalayas, with their loftiest mountain ranges, form the impeccable barrier on India's northern frontiers, they do contain some gaps in their ranger which provide natural routes across these high mountains. These gaps, called 'passes', have not only been traditional trade routes over the past many centuries, but have also provided easy access to the foreign invaders and greatly influenced the course of India's history. The important passes in the Himalayas are the Jelep La, Shipki La, Nathu La, Bomdi La, etc.

On India's north-eastern side are located the Poorvanchal mountains, which consist of the Patkai Bum and the Naga Hills in the north; Mizo and Lushai Hills in the south, and the Garo, Khasi and Jaintia Hills in the centre. These mountain ranges are neither as tall nor as spectacular as the mighty Himalays.

Peak	Height (in metres above Mean Sea Level)	
1. K2 (Godwin Austen)	8611	In Pak occupied territory
2. Kanchenjunga	8598	
3. Nanga Parbat	8126	
4. Gasher Brum	8068	In Pal occupied territory
5. Broad Peak	8047	-do-
6. Disteghil Sar	7885	-do-
7. Masher Brunm E	7821	
8. Nanda Devi	7817	
9. Masher Brum W	7806	In Pal occupied territory
10 Rakaposhi	7788	-do-
11. Kamet	7756	
12. Saser Kangri	7672	
13. Skyang Kangri.	7544	In Pal occupied territory
14. Sia Kangri	7422	-do-
15. Chaukhamba (Badrinath Peak)	7138	
16. Trisul West	7138	
17. Nunkun	7135	
18. Pauhunri	7128	
19. Kangto	7090	
20. Dunagiri	7066	

The Great Plains of Northern India: India, which has the world's highest and the most spectacular mountas, is also fortunate in possessing one of the world's most extensive and fertile plains, approximately 2500 km from the Sutlej in the west to the Brahmaputra in the east made up of alluvial soil brought down in the form of fine silt by the mighty rivers. These Great Northern Plains consist of the Indus basin, the Ganga-Brahmaputra basin and the tributaries of these mighty river systems. The bulk of the Indus basin falls within Pakistan but a part of it is shared by Punjab and Haryana. The Ganga Brahmaputra basin is larger of the two and covers a large number of states in northern India

The most salient characteristic feature of the Great Plains of northern India is the extreme horizontality or levelness. There is practically no difference in geomorphologic features of the two parts, the Indus basin and the Ganga-Brahmaputra basin – except the water divide which separates these two basins. This divide is made by a low narrow ridge of Aravalli range passing through Delhi and Ambala. The average height of the water divide is not more than 300 metres above the sea level, and this gives the plain a touch of continuity between these two drainage basins of the Indus and Ganga. However, according to the terrain characteristics, this plain can be divided into two parts:

(i) The upland plain which lies above the flood level and is made up of old alluvium. This plain is called the Bangar Land; and

(ii) The lowland plain, whichis liable to inundation during floods and thus acquires fresh doses of new alluvium. This is called the Khadar Land.

The Drainage of the Great Plains: The Indus and the Ganga-Brahmaputra river systems together form the Great Plains of northern India. River Indus is a trans-Himalayan river. It originates beyond Himalayan river. It originates beyond Himalayas in Tibet and flows throughout in Pakistan. Among its tributaries, Jhelum and Chenab, which originate in India, also flow though Pakistan, while Ravi makes a small run through India before entering Pakistan. Only Sutlej, another trans-Himalayan river and a tributary of Indus flows for its major cause through India,while Beas, a tributary of Sutlej, remains in India throughout its journey in the plains. Thus, only a small portion of the Indus river basin, comprising Punjab and Haryana, lies in the northern plains of India.

The Ganga-Brahmaputra river system forms the largest part of the Great Plains of north India. It covers almost one – fourth of the total land area of the county. The Ganga rises from the Gangotri glacier in the Himalayas and is joined by the Yamuna and Sone rivers on its right bank. Rivers joining the Ganga on its left side are the Gomti, the Ghaghra, the Gandak and the Kosi.The Yamuna rises from the Yamunotri glacier in the Himalayas, but its important tributaries, the Chambal, the Betwa and the Ken rise from the Malwa Plateau.

Beyond Farakka, the main stream of the Ganga flows into Bangladesh and it known as the river Padma. Some 80 km above, before falling into the Bay of Bengal, Padma is joined by the mighty Brahmaputra, a trans-Himalayan river which rises from the Manasarovar Lake in Tibet. And together they from the world's largest and perhaps the most fertile delta in Indo - Bangladesh region. The other stream of Ganga, bifurcated at Farakka, runs southwards into West Bengal and is called river Hooghly. It splits up into a number of channels.

Before falling into the Bay of Benagal beyond Kolkata. The Great Plains of the north, being extremely fertile and most suited to agriculture, makes them the granary of India. Apart from the food scrops of rice, wheat and millets, this region also provides cash crops like sugarcane, oilseeds, jute, etc. This region has a dense population in its large number of towns and villages and also accounts for a number of industries.

West Coastal Plain

- Located between the Western Ghats and the Arbian Sea coast
- Narrow plain (average width 64 km)
- Drained by several short and swift streams which are unable to form deltas
- There are several lagoons especially in the southern part of this plain
- The western plain has indentated coast which supports many ports
- It is a submerged coast and hence tilting has left no scope for depositional action of the rivers

East Coastal Plain

- Located between the Eastern Ghats and the Bay of Bengal coast
- Comparatively broad (average width 80-100 km)
- Big rivers like the Mahanadi, the Godavari, the Krishna and the Cauvery have formed large deltas
- Lagoons are comparatively little in this plain
- The eastern plain has more or less a straight coast where god ports are lacking
- Mostly of emergent type, characterized by offshore bars, fine sea beaches, sand ridges and lagoons

The Great Plateau of Peninsular India: To the south of the Great Plains of northern India lies the old landmass of the Peninsular India which is made up of hard metamorphic rocks. This part of land adjoining northern plains, is known as the Great Plateau of Peninsular India. This Great Plateau has two distinct parts, the Malwa Plateau and the Deccan Plateau.

The Malwa Plateau, which comprises the northern region of the Great Plateau of Peninsular India, is bounded by the Aravalli hills in the north-west and the Vindhyas in the south, both these low old mountains forming the sharp edges of this plateau. The third side of this triangular Malwa Plateau, which extends from west to east, slopes gradually towards the plain of Ganga and merges into it. The valley of the river Narmada forms the southern boundary of the Malwa Plateau, while its extensions to the east form the Bundelkhand and Baghelkhand in southern Uttar Pradesh and Chotangpur in Jharkhand. Most of the rivers of this plateau flow northward into the river Yamuna. The Malwa Plateau, particularly its north-eastern part called Chotanagpur plateau, is the richest mineral producing region of India.

The Deccan Plateau, which is roughly of a triangular shape, extends from the Satpura hills in the north to Kanyakumari, the southernmost tip of India ending in the Indian Ocean. On the western edge of the Plateau lie the Sahyadri, the Nilgiri, the Annamalai and the Cardamom Hills, the Annamalai and the Cadamom Hills, commonly known as the Western Ghats. Which run along the Arabian Sea, goes on increasing towards the south. Anaimudi peak in Kerala, with a height of 2695 metres above the sea level, is the highest peak of the Peninsular India. In the Nilgiris lies the Udagamandalam (Formerly Ooty), the best-known hill station of southern India.

From the Western Ghats, the Decan Plateau gradually slopes away towards east to the Bay of Bengal. The eastern edge of the Decan Plateau is less marked as the Eastern Ghats have discontinuous low hills called Mahendra Giri. All the major rivers of the Decan Plateau, Mahanadi, Godavari, Krishna and Cauvery, flow from west to east and piercing throught these low discontinuous ranges of the Eastern Ghat hill merge into the Bay of Bengal. Only Narmada and Tapti are the two major rivers which flow from east to west and fall in the Arabian Sea.

The north-western part of the Great Plateau is made up of lava flows or the igneous rocks called Basalt, also known as Decan Trap. These several hundred metres thick rocks are spread over the whole of Maharashtra and parts of Gujrat and Madhya Pradesh giving a thick dark sil in these regions, This soil, called Regur or Black soil, is especially suited to cotton cultivation and makes this region the most important cotton growing belt in India. Many parts of the Great Plateau are rich in minerals and the famous gold fields of Kolar, the uranium deposits of Tamil Nadu and Jharkhand, the manganese, iron ore and copper deposits of the north-east lie in the regions comprising this Great Plateau.

The Great Desert of Rajasthan: To the north-west of the Malwa Plateau lies the Thar Desert or the Great Desert of Rajashtan. The desert, which it made up sand, interrupted by rocky hills and waterless valley, begins from the west of the Aravalli ranges and extends deep into Pakistan. The desert is the region of inland drainage system, as the few rivers that flow in this area either drain into the salt lakes or disappear into the sands. Only the river Luni drains off into the Rann of Kutch. The desert climate, being arid and unfavourable for human settlement, makes the area sparsely populated.

The Coastal Strips: The Deccan Plateau is flanked, on its west and east, by narrow coastal plains along the Arabian Sea and the Bay of Bengal. The western Coastal Plain lies between the Western Ghats and the Arabian Sea. The southern part of the Western coastal Plain, called the Malabar Coast, is narrow, uneven and gradually dissected by a number of fast flowing streams and rivers. It has a number of lagoons, backwaters and raised beaches. The northern part of the Western Coastal Plains, called the Konkan Coast, getswider as it movers further northwards and encompasses plains of Gujarat.

The eastern coastal plain, lying between the Eastern Ghats and the Bay of Bengal, is wider and more leveled. It contains some of the most fertile and well-watered deltas formed by Krishna, Cauvery, Godavari and Mahanadi rivers. The southern part of the eastern Coastal Plains is known as Coromandel Coast and its northern part as the Northern Sircars. The soils of eastern coast are deep and fertile.

Himalayan Rivers	Peninsular Rivers
1. Perennial in nature	1. Non – perennial
2. Uncertain nature and caprician in behavior	2. More stable, flow predictable
3. Some are meandering in their flow and subject to drastic change of course	3. No such drastic change in course
4. Rivers are in youthful stage	4. Rivers are in old stage
5. Rivers are eroding, transporting and depositing agenst.	5. Rivers are only depositing agents

Indian Islands: Besides the manland, India has two groups of islands, the Andaman and Nicobar islands in the Bay of Bengal and the Lakshadweep islands in the Arabian Sea. The Andaman and Nicobar islands are a group of islands many of which are too small and uninhabited. The northern cluster of islands is called the Andamans, a group of 204 small islands, while the southern cluster is known as the Nicobar islands, a group of 19 islands. Together they form the Union Territory of the Andaman and Nicobar Islands, with Port Blair as the capital.

The Lakshadweep comprises a group of 27 coral islands scattered in the Arabian Sea, about 300 kilometres to the west of Kerala coast. None of these horse-shoe or ring shaped islands is more than a couple of kilometers in length and breadth and about 17 of these islands are uninhabited. The Kavaratti island is the capital of the union Territory of Lakshadweep.

III. Climatic features: India, with its vast size and marked variations in terrain, is a land of climatic contrasts. On an extremely hot summer afternoon, the temperature may occasionally shoot up to 55^0C in certain parts of Rajasthan and south-west Punjab. And on a severe winter night, the mercury may dip to as low as minus 45^0 C in a cold arid region such as Kargil. Similarly, Cherapunji, with its annual rainfall of 1080 cm and Mawsynram (Both in Meghalaya) are known to be the wettest places in the world while the dry regions of western Rajasthan receive no more than 13 cm of annual rainfall. In between these two extremes, there are regions of equable, moderate and uniform climate. These variations in temperature and rainfall make India a land of diverse climate and weather conditions.

The Tropic of Cancer divides India into two halves - Southern India lies in the tropical zone and Northern India in the sub-tropical zone, keeping the temperature high all over the country, except in the areas of high altitudes. Besides, some of the phenomena influencing India's weather and climatic conditions lie much beyond its geographical limits. The western disturbances affecting winter weather in northern India originate from the low pressure systems developing in the eastern Mediterranean region. Temperature and pressure conditions in East Africa, Iran, Central Asia and Tibet affect the behaviour of monsoons. The weather conditions in the rest of the Indian subcontinent, the Indian Ocean and the China Sea also affect the weather conditions in various parts of India. The upper air currents or jet streams too, have their influence on the country's climatic and weather conditions.

The most important factor in shaping India's climatic conditions is monsoons that affect almost all parts of the country with varying intensity and duration and account for seasonal rhythm. An important characteristic feature of the monsoons is the complete reversal of winds which leads to the alternation of season. On the basis of monsoon variations, the year is divided into four seasons. These are:

(i)	The cold weather season	December to February
(ii)	The hot weather season	March to May
(iii)	The south – west monsoon season or the rainy season	June to September or
(iv)	The season of retreating south – west monsoon	October to November

The Winter Season: Starting in December, the cold weather season becomes fully established in January and the temperature distribution over India shows a marked decline as one moves from south to north. Generally, the days are bright and sunny but the nights are cold. The generally fine weather of this period, is, however, occasionally disturbed by the western disturbances, which bring light rainfall and severe cold waves.

The Summer Season: The period between March and May is that of rising temperatures and decreasing air pressures as the belt of intense heat shifts from south to north. In March, the day's temperature reaches 35°C in the regions south of the Vindhayas. In April, the heat belt moves further north to Gujarat and Madhya Pradesh and the temperature exceeds 37°C in the northern India. In May, it goes up to 41 °C or above and dry hot winds blow over most of the northern region and dust storms of great velocity strike Punjab, Haryana and Uttar Pradesh which are afterwards followed by light showers and cool breeze.

By the end of May, low pressure trough is developed which occasionally attracts the moisture-laden winds. After coming into contact with the hot dryland winds, it causes pre-monsoon rains. Kerala and coastal plains of the west receive a fair share of pre-monsoon showers, commonly known as 'mango showers'. Assam and West Bengal also receive rain during this season, but north-west India remains comparatively dry.

The South-West Monsoon Season: By early June, the low pressure area over north-western plains becomes highly intense to attract the south-west rain-bearing winds, which approach suddenly with thunder and lightning. Within almost one month's time, these winds overrun almost the entire country.

The south-west monsoons originate from the Indian Ocean and blow over the land mass of India from June to September. Due to the intense summer heat, a low pressure area is formed over the northern plains of India. But the oceanic region has a low temperature and high pressure centre. Consequently, air starts moving from the high pressure area of the Indian Ocean towards the low pressure area over the land mass of India in the form of rain bearing monsoon winds. The south-east trade winds, which originate south of Equator, are also sucked into the wind system of the northern Indian Ocean and are deflected towards India. The landmass of peninsular India divides these southwest monsoons into two branches, *vi%.,* the Arabian Sea branch and the Bay of Bengal branch.

The monsoon winds arising from the Arabian Sea, strike the Western Ghats and cause heavy rains. Having crossed the Ghats, they advance over the Deccan Plateau and Madhya Pradesh and are joined by a current of winds arising from the Bay of Bengal. Another part of the Arabian Sea monsoon winds cross the coast of Saurashtra and Kutch and passing over Aravalli hills, reach Punjab and Haryana. These winds also join the winds from the Bay of Bengal and cause widespread heavy rains in western Himalayas. The monsoon winds from the southern Bay of Bengal mainly move towards Burma, but a part of these winds is deflected by the Arakan Hills and moves westward, over the Ganga-Brahmaputra valley. It strikes the northeastern hills and causes heavy rainfall in West Bengal, its adjoining States, sub-Himalayan region and the northern plains.

In all parts of the country, with the exception of the east coast of Tamil Nadu, bulk of annual rainfall is received during the monsoon season. But the distribution of rainfall is highly unequal as the monsoon winds become weaker as they traverse over longer distances. Thus, Kolkata receives 120 cm rainfall, Patna 102 cm, Allahabad 91 cm and New Delhi 56 cm. The windward side of the Western Ghats receives heavy rainfall while the leeward side gets much smaller amount. The intensity and frequency of the cyclonic depressions originating in the Bay of Bengal and their crossing over to the mainland as well as the passage followed by them account for the variations in geographical distribution of rainfall.

Monsoon is a seasonal wind that blows over the northern part of the Indian Ocean, especially the Arabian Sea, and over most of the surrounding land areas. The monsoon blows continually from the southwest from April to October. It blows from the northeast from November to March.

Monsoons are generated by the difference in the heating and cooling of air over land and sea. During the summer, radiant energy from the sun heats land surfaces far more than it does sea surfaces. The strongly heated air over the land rises and is replaced by a southwesterly wind carrying warm, moist air from the Indian Ocean. Water vapour in the rising air condenses and forms clouds and rain. This process releases large amounts of heat, which helps drive monsoons.

In winter, the land is cooled much more than the sea. The cool air over the land sinks and spreads out to the sea as a dry northeasterly wind.

The southwesterly monsoon brings heavy rains to southern and southeastern Asia, including Bangladesh, Burma, India and Thailand. The strength of the southwesterly monsoon—and the time in April that it begins - affects agriculture in southern Asia. Abnormal monsoons can destroy a region's crops and livestock and disrupt its economy. Monsoons also blow over the coast of northern Australia, eastern Asia, parts of Africa and the southwestern United States.

The Retreating South-West Monsoon Season: The monsoon winds start retreating from Punjab and Haryana by mid-September, reach Ganga delta by late October and the Peninsular India by early November, leaving the land moist and the atmosphere, humid. However, from the middle of October, temperature begins to decline in northern parts of India. The weather during this season is characterised by high day temperature, clear sky and pleasant nights. The fall in temperature continues and the winter season becomes firmly established by December.

During this transition period of October-November, the low pressure conditions disappear from the north-western India and are transferred to the centre of the Bay of Bengal. These cyclonic depressions in the Bay of Bengal often cross the Southern Peninsula and cause widespread heavy rains along the coastal regions of Tamil Nadu, making October-November as the rainiest months in this part of the country.

North - East Monsoons: The north - east monsoons are the winds blowing out from the landmass of north-western India toward the Indian Ocean during the period of December and February. The low pressure area formed in the Ocean region attracts these winds from the high pressure areas formed during chilly winters over the north-western parts of India. These cold and dry winds move down the Ganga valley towards the Indian Ocean. The winds that move through the Bay of Bengal become moisture laden and strike the Tamil Nadu coast to bring winter rains in that region.

IV. Vegetation and Forests: Forests are a renewable source and contribute substantially to economic development. They play a major role in enhancing the quality of environment. The forest cover in the country is 69.09 mha and constitutes 21.02 percent of its geographical area. Of this, very dense forest constitutes 8.35 mha (1.56 percent), moderately dense forest constitutes 31.90 mha (10.32 percent) and open forest 2, 87,669 sq. km (8.76 per cent).

According to State of Forest Report, the mangrove cover in the country occupies an area of 4,639 sq. km (0.14 percent) of geographic area of which the very dense mangrove comprises 1,162 sq. km (26.05 percent of mangrove cover), moderately dense mangrove is 1,657 sq. km (37.14 percent) while open mangrove covers an area of 1,642 sq. km (36.81 percent). The total tree cover for the country (national area with 70 percent canopy density) has been estimated as 92,769 sq. km or about 2.82 percent.

Types of Forests: India possesses a variety of forests and natural vegetation which varies from region to region due to variations in climatic conditions, soil types and relief features. The country can be divided into five major vegetation regions which are: (i) the tropical evergreen and semi-evergreen forests, (ii) the tropical deciduous forests, (iii) the dry thorn forests, (iv) the tidal forests and (v) the hill forests of the Himalayan region.

Tropical Evergreen Forests: These forests thrive in regions of very high rainfall, usually over 200 centimeters per year, in a climate of high humidity and even temperatures. The vegetation is very thick and the trees are lofty, reaching a height of 60 metres or even more. Most of such forests are found on the windward side of the Western Ghats on altitudes ranging from 500 to 1,500 metres, and in the hill regions of the north-eastern part of India.

Semi-evergreen Forests: These lie on the relatively dry sides of the evergreen forests in Western Ghats, West Bengal, Odisha and other north-eastern region of India. These forests are generally confined to areas receiving about 200 centimetres of rainfall per year. The trees in these forests are lofty and hard-wooded, vegetation is dense and undergrowth is very thick. Bamboo, ebony and rubber trees are the economically important vegetations of this region, but difficulties of exploitation make them of little commercial use.

Tropical Deciduous Forests: These forests, also known as monsoon forests, are found in the regions that get about 100 to 200 centimeters of rainfall per annum. They extend from the Shiwalik ranges in the north to the eastern flanks of the Western Ghats in the peninsular India. The trees in these forests shed leaves for about 6 to 8 weeks in summer, but since each specie has its own shedding time, the forests, on the whole, never look absolutely bare of greenery in any part of the year. Teak, sal, sandalwood, shisham and mahua trees that grow in abundance in these forests are economically very valuable.

Thorn Forests: The thorn forests are the vegetation of the comparatively dry and arid regions which have annual rainfall of less than 80 centimeters. This type of vegetation is common in western Punjab, south-west Haryana, Rajasthan, parts of Gujarat and Madhya Pradesh and the drier parts of the Deccan. The relatively wet areas of these forests have widely scattered growth of wild dates and kikar and babul trees which have long roots and sharp thorns. Bushes, scrubs and cacti grow in the very dry areas and the desert regions.

Tidal Forests: These forests have grown along the deltas of rivers which are subjected to tides, important among them being the forests of the Mahanadi and Ganga deltas. The mangrove forests of Sundarbans in the Ganga delta are the haunts of the famous Bengal Tiger and the forest region itself has been named after the Sundari trees that grow there. These forests yield firewood and tanning material.

Forests of the Himalayan Region: In the Himalayan region, the forests and the type of vegetation differ with the difference in altitude. The outermost Himalayas or the Shiwaliks are covered with the tropical moist deciduous forests vegetation of teak, sal and rose wood trees. At the higher elevations are found the evergreen forests of oak, chestnut, beech, ash and elm. At still higher altitudes ranging from 1,600 to 3,300 metres, are found the coniferous forests of pine, cedar, silver fir and spruce. And at altitudes beyond 3,500 metres are found grasses and shrubs called the Alpine vegetation, which, farther onward give place to the naked snowcapped mountain ranges.

Social Forestry: The concept of social forestry, which has now been recognised and accepted by the Government and is being implemented on a massive scale, aims at not only providing adequate quantities of fuelwood, fodder and other forest produce, but also meeting the requirements of ecological balance through large-scale afforestation on community lands and waste lands in the country. The farm forestry, which has been largely practised in the country so far, aims at growing of trees on private lands, on the farm boundaries and private plantations. The social forestry programme, on the other hand, mainly comprises three schemes, *viz.,* (i) mixed plantation on waste lands, (ii) re - afforestation of degraded forests, and (iii) raising of shelter belts. Thus, social forestry involves creating potentials of forest raw material resources on degraded forest areas, waste lands, panchayat lands and on the sides of roads, canals and railway lines. Under the social forestry schemes, fuel wood plantations are grown for quickly raising the supply of fuel wood and fodder.

V. Land Resources: India has a geographical area of about 329 million hectares but statistical information is available only for about 93 percent of the area (viz, for 305 million hectares). More than half of the area (51 percent) is under cultivation compared to 11 percent of world's average. Our farmer is very hard-working and raises two crops in a year instead of one being the normal practice in the other countries.

According to state of forest Report, 2003, Forests cover about 20.6 percent of land area for which data is available. Another 30.3 percent of area is not available for cultivation because it either comprises fallow lands, residential or commercial areas or is otherwise not fit for cultivation. Consequently, cultivation is done only on about 50 percent of the total reporting area in the country.

Soil Types: Soil quality is an important factor in crop-yield. The soil provides nourishment and water to the plant life. It consists of minerals, organic matter, water, air, etc., all of which determine its characteristics, fertility, depth, texture and structure and, thus, govern the type and quality of plants and crops that can be grown in any region of the country. India, with its vast land surface and diverse relief features, possesses a large variety of soils, which, according to the National Council of Agricultural Research, are classified into the following eight categories.

(i) Alluvial Soil: Alluvial soil covers almost a quarter of India's land surface and provides the base for the largest share of country's agricultural production. This type of soil is composed of sediments deposited by the mighty rivers in the interior parts of India and by the sea wave in the coastal areas of the country. The Great Plains of India running from Punjab to Assam possess rich alluvial soil which is also found in Narmada and Tapti valleys in Madhya Pradesh and Gujarat, Mahanadi Valley in Chhattisgarh and Odisha, Godavari Valley in Andhra Pradesh and Cauvery Valley in Tamil Nadu. It also occurs in the deltas of Mahanadi, Godavari, Krishna and Cauvery rivers. Alluvial soils are generally deficient in nitrogen and humus and thus necessitate repeated fertilisation. Such soils are suitable for growing all types of cereals, pulses, sugarcane, vegetables, oilseeds, etc.

(ii) Black Soil: Black soil is found largely in the Deccan Plateau. It is eminently suitable for cotton cultivation and is, therefore, also called black cotton soil. In some areas, it is known as 'regur'. The black colour of the soil is attributed to the presence of compound of iron and aluminium. This soil is generally deficient in nitrogen, phosphates, and organic matter, but is quite rich in potash, lime, aluminium, calcium and magnesium. The black soil exists in many areas of Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Andhra Pradesh and Tamil Nadu. Cotton, cereals, some oilseeds and a variety of vegetables are grown in areas of black soil.

(iii) Red Soil: The red soil occurs mostly in the southern peninsula and extends up to Jhansi (Uttar Pradesh) in the north, Kutch (Gujarat) in the west and Rajmahal Hills in the east. This soil is made up of crystalline and metamorphic rocks and is rich in ferro - manganese minerals and soluble salts but is deficient in nitrogen and humus and thus needs fertilisation. It has a light texture and a porous structure. Red soil is most suited to the growth of rice, ragi, tobacco and vegetables.

(iv) Laterite Soil: This type of soil is found in areas of high rainfall and temperature with alternate dry and wet periods. The soil contains high content of iron oxides. It is deficient in nitrogen, phosphorus, potash and magnesium. Such soil is found in the high reaches of Sahyadris, Western Ghats, Rajmahal Hills and the hilly tracts of the eastern region. It is also found in parts of Karnataka, • Andhra Pradesh, Kerala, Odisha and West Bengal. This type of soil is suitable for rice, ragi and sugarcane cultivation.

(v) Forest Soils: Forest soil is rich in organic matter and humus. It is found in the Himalayas and other mountain regions of the north, higher summits of the Sahyadris, Eastern Ghats, Karnataka, Tamil Nadu, Kerala, Manipur, Jammu and Kashmir and Himachal Pradesh. Crops like tea, coffee, spices and tropical fruits are grown on this type of soil.

(vi) Arid and Desert Soils: The arid and semi-arid regions of north-west India have this type of soil which is generally deficient in nitrogen and humus. It is largely found in the areas west of Aravalli Ranges and covers Rajasthan, parts of Haryana and Punjab and extends up to the Rann of Kutch. Generally desert soil is infertile but its fertility improves with proper irrigation and fertilisation.

(vii) Saline and Alkaline Soils: Saline and alkaline soils are found in the arid and semi-arid parts of Rajasthan, Punjab, Haryana, Uttar Pradesh and Bihar. These soils, variously called *'reb', 'usar' or 'kallar'* are largely infertile. However, they can be improved through proper treatment and reclamation measures.

(viii) Peaty and other Organic Soils: Peaty soils contain large accumulations of humus, organic matter and soluble salts. These soils are highly saline and are deficient in phosphorus and potash. Marshy soils occur in regions of Odisha, West Bengal and Tamil Nadu. They are also found in central and north Bihar and in Almora district of Uttarakhand.

Crop Pattern:

Crop Seasons: There are three major crop seasons in India, viz., *Kharif, Rabi* and *Zaid.* The Kharif crops are associated with the monsoons. They are sown in the months of June and July and are harvested in autumn months, in September and October. Important among the Kharif crops are rice, jowar, bajra, ragi, maize, sugarcane, cotton and jute.

The Rabi crops are sown in the period between October and December and harvested in April and May. Important among the Rabi crops are wheat, barley, peas, rabi pulses, linseed, rapeseed and mustard.

The Zaid is the summer season crop. Rice, maize, vegetables, sunflower and groundnut are grown during this season.

Again, areas, which are extensively irrigated, grow three to four crops per year and, thus, fall out of the purview of the distinction between the Kharif and Rabi crops. Similarly, in southern half of the Peninsular India where temperatures are sufficiently high and rainfall is extensive in winter months, rice, jowar, coffee, etc., are sown, thus again blurring this categorisation under Kharif and Rabi crops. However, for most of India, Kharif and Rabi remain the distinct crop seasons with the specific variety of crops grown therein.

Major Crops: Agricultural crops can be broadly divided into two categories, W£, food crops and non-food crops. Foodgrains consist of cereals and pulses. Among the cereals are included rice, wheat, jowar, bajra, maize, etc. Pulses include gram, moong, masur, arhar, etc. The non-food crops comprise a number of cash crops such as sugarcane, cotton, jute, tobacco, etc. Tea, coffee, rubber are included among the plantation crops. Besides these, we have the horticulture crops like fruit, vegetables, coconut, cashew, etc .

India is the largest producer and consumer of **tea** in the world and accounts for around 27 percent of world production and 13 percent of world trade in tea.

In **coffee,** India contributes 4 percent of the global production.

Rubber is primarily produced in the State of Kerala and adjoining Kanyakumari district of Tamil Nadu.

India is the third largest producer of **fish** and second largest producer of inland fish in the world. As per Economic Survey 2010-2011, fish production from marine and inland sources has been at 2.98 million tonnes and 4.87 million tonnes, respectively and marine products worth Rs. 9921 crore were exported in 2009-10.

CROPS AND LEADING PRODUCER STATES	
Bajra :	(1) Gujarat; (2) Rajasthan
Barley:	(1) Uttar Pradesh; (2) Rajasthan
Cardamom :	(1) Karnataka; (2) Kerala
Castor seed :	(1) Gujarat; (2) Andhra Pradesh
Chillies (dry) :	(1) Tamil Nadu; (2) Andhra Pradesh
Coffee :	(1) Karnataka; (2) Kerala
Coriander :	(1) Rajasthan; (2) Andhra Pradesh
Cotton :	(1) Gujarat; (2) Maharashtra; (3)Andhra Pradesh
Ginger (dry) :	(1) Kerala; (2) Himachal Pradesh
Gram:	(1) Rajasthan; (2) Uttar Pradesh
Groundnut :	(1) Gujarat; (2) Andhra Pradesh; (3) Tamil Nadu
Jowar :	(1) Maharashtra; (2) Karnataka
Jute :	(1) West Bengal; (2) Bihar; (3) Assam
Linseed:	(1) Madhya Pradesh; (2) Uttar Pradesh
Maize :	(1) Karnataka; (2) Andhra Pradesh; (3) Uttar Pradesh
Mesta:	(1) Andhra Pradesh; (2) Odisha
Millets (small) :	(1) Madhya Pradesh; (2) Andhra Pradesh
Niger seed:	(1) Odisha; (2) Uttar Pradesh
Paddy:	(1) West Bengal; (2) Tamil Nadu
Potato:	(1) Uttar Pradesh; (2) West Bengal; (3) Bihar
Onion :	(1) Gujarat; (2) Maharashtra; (3) Karnataka
Pulses :	(1) Madhya Pradesh; (2) Uttar Pradesh; (3) Maharashtra
Ragi :	(1) Karnataka; (2) Tamil Nadu
Rape-seed & Mustard :	(1) Rajasthan; (2) UP; (3) Haryana
Rice:	(1) West - Bengal; (2) UP; (3) Punjab
Safflower:	(1) Maharashtra; (2) Karnataka
Sannhemp:	(1) UP; (2) Madhya Pradesh
Soyabean :	(1) Madhya Pradesh; (2) Maharashtra; (3) Rajasthan
Sesamum:	(1) Uttar Pradesh; (2) Rajasthan
Sugarcane :	(1) UP; (2) Tamil Nadu; (3) Maharashtra
Sunflower :	(1) Karnataka; (2) Andhra Pradesh; (3) Maharashtra
Tapioca :	(1) Kerala; (2) Tamil Nadu
Tea :	(1) Assam; (2) West Bengal
Tobacco :	(1) Maharashtra; (2) Tamil Nadu
Tur :	(1) Uttar Pradesh; (2) Madhya Pradesh
Wheat:	(1) Uttar Pradesh; (2) Punjab; (3) Haryana

Irrigation: Water is very important for the survival of all forms of life—plant as well as animal. India, by virtue of its peculiar placement in the foothills of the Himalayas and having the ranges of the Satpura, Aravalli and the Deccan Plateau running through it, has vast water resources which have been very meagrely tapped. Conventional and recognised means of irrigation are tanks, wells and canals.

Wells: Well irrigation is an important type of irrigation in India. Wells are particularly suitable for small farms. The important well-irrigated States are Uttar Pradesh, Punjab, Tamil Nadu and Maharashtra. In these States water-table is high, soil is soft and, therefore, wells are easily sunk.

Tubewells are an important development in India. They are worked by electricity or diesel oil and thus, they relieve our cattle of much of the strain. They are being quickly developed in Uttar Pradesh, Bihar, Haryana and Punjab. This is because these have ample sub-soil water.

Wells and tubewells account for about 48 percent of the total irrigation in India.

Tanks: Tanks are also an important and ancient source of irrigation. They are of considerable importance in central and southern India, specially in Andhra Pradesh and Tamil Nadu. About 8 percent of the total irrigated area is irrigated by tanks.

Canals: Canals are the most important means of irrigation in the country. Some canals were constructed by the early Hindu and Mohammedan kings. Most of the canals, however, are the product of the British rule. At present, canals irrigate about 39 percent of total irrigated area of India. Most of the canals of the country are found in Uttar Pradesh and Punjab. Storage canals have been constructed in Deccan and Madhya Pradesh.

Major, Medium and Minor Irrigation Projects: The methods of irrigation used in India can be broadly classified into major, medium and minor irrigation schemes. Irrigation projects having Culturable Command Area (CCA) of more than 10,000 hectares each are classified as major projects. Those having a CCA between 2,000 hectares and 10,000 hectares fall under the category of medium irrigation projects. And the projects which have a CCA of less than 2,000 hectares are classified as minor irrigation schemes. For the purpose of analysis the major and the medium irrigation projects are generally grouped together. These projects comprise a network of dams, bunds, canals and other such schemes. Such projects require substantial financial outlay and are, therefore, constructed by the government or any other agency which may draw financial assistance from the government and financial institutions.

The minor irrigation projects, on the other hand, comprise all ground water development schemes such as dug wells, private shallow tubewells, deep public tubewells, boring and deepening of dugwells, and small surface water development works such as storage tanks, lift irrigation projects, etc. Minor irrigation projects or the groundwater development schemes are essentially people's programmes implemented primarily through individual and cooperative efforts with finances obtained mainly through institutional sources.

Some Irrigation and Multipurpose Projects

Bargi Project (Madhya Pradesh): It is a multipurpose project consisting of a masonry dam across Bargi river in the Jabalpur district and a left bank canal.

Beas Project (Joint venture of Haryana, Punjab and Rajasthan): It consists of Beas-Sutlej link and Beas Dam at Pong.

Bhadra Project (Karnataka): A multipurpose project across the river Bhadra.

Bhakra Nangal Project (Joint project of Haryana, Punjab and Rajasthan): India's biggest, multipurpose river valley project comprises a straight gravity dam across the Sutlej river at Bhakra, the Nangal dam, the Nangal hydel channel, two power houses at Bhakra dam and two power stations at Ganguwal and Kotla.

Bhima Project (Maharashtra): Comprises two dams, one on the Pawana river near Phagne in Pune district and the other across the Krishna river near Ujjaini in Sholapur district.

Chambal Project (Joint project of Madhya Pradesh and Rajasthan): The project comprises Gandhi Sagar dam, Rana Pratap Sagar dam and Jawahar Sagar dam.

Damodar Valley Project (West Bengal and Bihar): A multipurpose project for the unified development of irrigation, flood control and power generation in West Bengal and Bihar. It comprises multipurpose dams at Konar, Tilaiya, Maithon and Panchet; hydel power stations at Tilaiya, Konar, Maithon and Panchet; barrage at Durgapur; and thermal power houses at Bokaro, Chandrapura and Durgapur. The project is administrated by the Damodar Valley Corporation.

Dulhasti Power Project (Jammu & Kashmir): It is a 390 MW power project in Kishtwar region of Jammu & Kashmir on Chenab River. Work for this project started in 1981. The foundation stone was laid on April 15, 1983 by the then Prime Minister, Indira Gandhi. Work on this project was suspended due to threats of kidnapping and killings by Kashmiri militants resulting in long delay in completion of project.

Farakka Project (West Bengal): The project was taken up for the preservation and maintenance of Calcutta port and for improving the navigability of the Hooghly. It comprises a barrage across the Ganga at Farakka, a barrage at Jangipur across the Bhagirathi and a feeder channel taking off from the Ganga at Farakka and tailing into the Bhagirathi below the Jangipur barrage.

Gandak Project (Joint project of Bihar and Uttar Pradesh): Nepal also derives irrigation and power benefits from this project.

Ghataprabha Project (Karnataka): A project across Ghataprabha in Belgaum and Bijapur districts.

Hirakud (Odisha): World's longest dam, is located on the Mahanadi river.

Jayakwadi Project (Maharashtra): A masonry spillway across the river Godavari.

Kahalgaon Project (Bihar): The 840-MW Kahalgaon Super Thermal Power Project, a joint venture between National Thermal Power Corporation and the Russian State Enterprise Foreign Economic Association, was on August 12, 1996 commissioned and put into commercial operation.

Kakrapara Project (Gujarat) : On the Tapti river near Kakrapara, in Surat district.

Kangsabati Project (West Bengal): The project, put in operation in 1965, is located on the Kangsabati and Kumari rivers.

Karjan Project (Gujarat): A masonry dam across Karjan river near Jitgarh village in Nandoo Taluka of Bharuch district.

Kosi Project (Bihar): A multipurpose project, which serves Bihar and Nepal.

Koyna Project (Maharashtra): It is built on a tributary of river Krishna with a capacity of 880 MW. It feeds power to Mumbai-Pune industrial belt.

Krishna Project (Maharashtra): Dhom dam near Dhom village on Krishna and Kanhar dam near Kanhar village on Varna river in Satna district.

Kukadi Project (Maharashtra): Five independent storage dams, *i.e.,* Yodgaon, Manikdohi, Dimbha, Wadaj and Pimpalgaon Jog. The canal system comprises (i) Kukadi left bank canal, (ii) Dimbha left bank canal, (iii) Dimbha right bank canal, (iv) Meena feeder and (v) Meena branch.

Kundoh Project (Tamil Nadu) : It is in Tamil Nadu whose initial capacity of 425 MW has since been expanded to 535 MW.

Left Bank Ghaghra Canal (Uttar Pradesh): A link channel taking off from the left bank of Ghaghra river of Girja barrage and joining with Sarju river. Also a barrage across Sarju.

Madhya Ganga Canal (Uttar Pradesh): A barrage -across Ganga in Bijnore district.

Mahanadi Delta Scheme (Odisha): The irrigation scheme will utilise releases. from the Hirakud reservoir.

Mahanadi Reservoir Project (Madhya Pradesh): It has three phases: (1) Ravishankar Sagar Project and feeder canal system for supply of water to Bhilai Steel Plant and Sandur dam across Sandur village. (2) Extension of Mahanadi feeder canal. (3) Pairi dam.

Mahi Project (Gujarat): A two-phase project, one across die Mahi river near Wanakbori village and the other across Mahi river near Kadana.

Malaprabha Project (Karnataka): A dam across the Malaprabha in Belgaum district.

Mayurakshi Project (West Bengal): An irrigation and hydro-electric project comprises the Canada dam.

Minimato Bango Hasdeo Project (Madhya Pradesh): This project is located at Hasdeo Bango river in Korba district and envisages construction of a masonry dam. A hydel power plant of 120 MW capacity has been commissioned on the Bango dam.

Nagarjunasagar (Andhra Pradesh): On the Krishna river near Nandikona village (about 44 km from Hyderabad).

Panam Project (Gujarat): A gravity masonry dam across Panam river near Keldezar village in Panchmahal district.

Parambikulam Aliyar Joint venture of Tamil Nadu and Kerala): The integrated harnessing of eight rivers, six in the Annamalai Hills and two in the plains.

Pochampad (Andhra Pradesh): Across Godavari river.

Pong Dam (Punjab): It is an important hydro-electric project located on Beas river.

Rajasthan Canal (Indira Gandhi Canal—Rajasthan): The project uses water released from Pong dam and provides irrigation facilities to the northwestern region of Rajasthan, *i.e.,* a part of the Thar desert. It consists of Rajasthan feeder canal (with the first 167 km in Punjab and Haryana and the remaining 37 km in Rajasthan) and 445 km Rajasthan main canal entirely in Rajasthan.

Rajghat Dam Project (Madhya Pradesh): The Rajghat Dam and Rajghat Hydro Electric Projects are Inter-State projects of MP and UP. The Rajghat Dam is almost complete. All the three units of Rajghat Hydro-Electric Project had been synchronised during 1999 and power generation has been continuing ever since.

Ramganga (Uttarakhand): A dam across Ramganga, a tributary of the Ganga river located in Garhwal district. The project has, besides reducing the intensity of floods in central and western Uttar Pradesh, provided water for the Delhi water supply scheme.

Ranjit Sagar Dam (Thein Dam) (Punjab): A multi-purpose highest dam in the country, built on the Ravi river for the benefit of Punjab, Haryana and Jammu and Kashmir.

Rihand Project (Uttar Pradesh and Madhya Pradesh): It is the largest man-made lake in India on the borders of Uttar Pradesh and Madhya Pradesh with a capacity of 300 MW annually.

Sabarmati (Gujarat): A storage dam across Sabarmati river near Dhari village in Mehsana district and Wasna barrage near Ahmedabad.

Salal Project (Jammu & Kashmir): With the successful completion of the 2.5-km long tailrace tunnel, the 690-MW Salal (Stage I and II) project in Jammu and Kashmir became fully operational on August 6, 1996.

Sarda Sahayak (Uttar Pradesh): A barrage across the River Ghaghra, a link channel, a barrage across River Sarda and a feeder channel of two major aqueducts over rivers Gomtd and Sai.

Sharavathi Project (Karnataka): It is located at the Jog Falls with a capacity of 891 MW. It primarily feeds Bengaluru industrial region and also Goa and Tamil Nadu.

Sone High Level Canal (Bihar): An extension on Sone barrage project.

Tawa Project (Madhya Pradesh): A project across the Tawa river, a tributary of the Narmada in Hoshangabad district.

Tehri Dam Project (Uttarakhand): Earth and rock-fill dam on Bhagirathi river in Tehri district.

Tungabhadra Project (Joint Project of Andhra Pradesh and Karnataka): On the Tungabhadra river.

Ukai Project (Gujarat): A multipurpose project across Tapti river near Ukai village.

Upper Krishna Project (Karnataka): A project consisting of Narayanpur dam across the Krishna river and a dam at Almatti.

Upper Penganga Project: (Maharashtra): Two reservoirs on Penganga river at Isapur in Yavatmal district and the other on Rayadhu river at Sapli in Parbhani district.

Uri Power Project (Jammu & Kashmir): It is located on the river jhelum in the Uri Tehsil of Baramulla district in Jammu & Kashmir. It is a 480-MW hydroelectric project which was dedicated to the nation on February 13, 1997.

VI. **Wildlife:** In spite of the high density of population and the consequent onslaughts of human habitation to the remotest corners of India, the country can still boast of a large variety of wildlife comprising over 350 species of animals, 12,000 species of birds and 30,000 species of insects, fishes and reptiles. Much of the wildlife in India is peculiar to this sub-continent and not found anywhere else in the world. The swamp deer is only found in India. The four-horned antelope *(chausingha),* die Kashmir stag and the nilgai exist only in India and Pakistan. The spotted chital, perhaps the most beautiful of all deer, has also its home only in India. The black buck is found nowhere else except in India and Pakistan. The great Indian one-horned rhinoceros is unique to India and Nepal. The Indian lion, which is the only lion to be found outside Africa, is a native of India and not imported from Africa. The Indian bison is not a bison at all; it is gaur which is a specie of wild ox peculiar to India.

National Parks and Wildlife Sanctuaries: The concept of wildlife as a 'thing of beauty' and a 'gift of nature' which need to be preserved, rather than a 'game' to be hunted, grew largely with the birth of independent India in 1947, when many of die former game reserves were redesignated as 'Wildlife Sanctuaries', where all the wild animals and birds were sought to be fully protected so that they will not become extinct. Project Tiger was also launched with the object of preserving and increasing tiger population by safeguarding the tiger, animals of its prey and its habitat in selected areas of the country. The Wildlife (Protection) Act, 1972 governs the conservation and protection of endangered species both inside and outside the forest areas. Under this Act, trade in rare and endangered species has been banned.

Endangered species of animals are those whose numbers are at a critically low level and whose habitats so drastically reduced or damaged that they are in an imminent danger of extinction. Schedule I of the Wildlife (Protection) Act, 1972 lists the rare and endangered species.

Biosphere Reserves are areas of terrestrial and coastal ecosystem which are internationally recognised within the framework of UNESCO's Man and Biosphere Programme.So far, 17 Biosphere Reserves have been set up.

Ramsar Convention (held in 1971 in Iran) defines **wetlands** as areas of marsh or fen, peat-land or water, whether artificial or natural, permanent or temporary, with the water that is static or flowing, a fresh brackish or salt including areas of marine water, the depth of which at low tide does not exceed six metres. Mangroves, corals, estuaries, bays, creeks, flood plains, sea grasses, lakes, etc. are covered under this definition. At present, there are 27 identified wetlands covering 15 States.

Mangrove plants are those that survive high salinity, tidal extremes, strong wind velocity, high temperature and muddy anaerobic soil - a combination of conditions hostile for other plants.

The Mangroves in India comprise 69 species under 42 genera and 28 families. Two species are endemic to India— *Khiophora annamalayana* (found in Pichavaram, Tamil Nadu) and *Heritiera kanikensis* (found in Bhitarkanika, Odisha).

Coral reefs are shallow-water tropical marine ecosystems. Characterised by high biomass production and rich floral and faunal diversity. Four coral reefs have been identified for conservation and management. These are:

1. Gulf of Mannar (fringing reef)
2. Andaman and Nicobar Islands(fringing reef)
3. Lakshadweep Islands (atoll reef)
4. Gulf of Kachchh (platform reef)

Currently, protected areas cover 4.5 percent of the total geographical area of the country, where through the efforts of the Central and the State Governments and with the cooperation of the voluntary agencies, wildlife is sought to be carefully protected and preserved. A Wild Life Week is also observed in the first week of October every year. The Indian Board of Wild Life which is responsible for conservation of wild life of the country is headed by the Prime Minister.

Government of India provides technical and financial support to the State/UT governments for wildlife conservation under the various Centrally Sponsored Schemes - Integrated Development of Wildlife Habitats, Project Tiger, and Project Elephant, and also through Central Sector Scheme—Strengthening of Wildlife Division and Consultancies for Special Tasks, and through Grants in Aid to the Central Zoo Authority and Wildlife Institute of India, Dehradun. The Protected Area network in India includes 100 National Parks and 515 Wildlife Sanctuaries, 43 Conservation Reserves and four Community Reserves. The objective of the Scheme is to provide financial and technical assistance to the States/UTs to conserve wildlife resources. The Scheme supports various activities aimed at the conservation of wildlife that *inter-alia* includes habitat improvement practices, infrastructure development, eco-development activities, anti poaching activities, research, training, capacity building, census of wildlife, etc.

STATE/UNION TERRITORY	BIO-SPHERE RESERVES	NATIONAL PARKS	WILDLIFE SANCTUARIES	BIRD SANCTUARIES
Jammuand Kashmir		Dachigam, Kishtwar, Hemis High Altitude		
Himachal Pradesh		Great Himalayan	Renuka	
Haryana				Sultanpur
Uttarakhand	Nandadevi	Valley of Flowers, Rajaji, Corbett, Nandadevi		
Uttar Pradesh		Dudhwa		Chandraprabha
Madhya Pradesh	Panchmarhi, Achanakmar-Amarkantak (Some parts of Chhattisgarh also)	Panna, Satpura, Pench, Bandhavgarh, Kanha, Fossil		
Chhattisgarh		Sanjay Kangar Valley		
Rajasthan		Desert (Thar), Sariska, Nahargarh, Keoladeo, Ghana, Ranthambore	Sariska	Bharatpur
Gujarat		Marine, Velvahar, Gir, Vansada		Nal Sarovar, Khijadiya, Ratan Mahal
Maharashtra		Sanjay Gandhi, Nawegaon, Tadoba, Indrawati, Panch	Kinwat, Bor, Nagzira, Ratnagiri	Kamala, Great Indian Bustard
Goa		Bhagwan Mahavir		
Karnataka	Nilgiri	Bannerghata, Nagorehole, Bandipur	Ranibennur	Ghatparbha, Adichunchagiri, Ranganthitto
Kerala	Agasthyamalai, Nilgiri	Eravikulam, Periyar, Silent Valley		
Tamil Nadu	Gulf of Mannar, Nilgiri, Kalakad	Guindy	Mudumalai, Annamalai, Mandanthruai,	Vettangudi, Point Calimere
Andhra Pradesh			Kanwal, Srisai lam, Pocharam, Eturnagaram, Pakhal	Pulicat, Kolleru, Neelapattu
Jharkhand		Palamu	Hazaribagh	
Odisha	Similipal	Similipal	Nandankanan	Chilika

STATE/UNION TERRITORY	BIO-SPHERE RESERVES	NATIONAL PARKS	WILDLIFE SANCTUARIES	BIRD SANCTUARIES
West Bengal	Sunderbans		Lothian Islands Parmadan, Saznakhali, Bethuadhari, Jaldapara, Mahananda	Pakhiralaya
Sikkim	Kanchenjunga	Kanchenj unga, Neora Valley, Singalila		
Assam	Manas, Dibru Saikhowa	Kaziranga, Manas	Orang, Sonai-Rupai	
Mizoram			Dampa	
Meghalaya	Nokrek	Balphakaran, Nokrek		
Manipur		Sirohi, Keibul Lamjao		
Arunachal Pradesh	Dehong Debang	Namdapha		
Andaman and Nicobar Islands	Great Nicobar	Saddle Peak, Button, Mt. Harriett		

VII. Mineral Wealth of India: India is endowed with significant mineral resources. It produces 86 minerals out of which 4 are fuel minerals, 10 metallic, 46 non-metallic, 3 atomic and 23 minor minerals.

India is rich in mineral resources and has the potential to become an industrial power. It possesses large reserves of iron ore, extensive deposits of coal, sizeable quantity of mineral oil reserves, rich deposits of bauxite and has a virtual monopoly of mica, all of which hold the potentials of making India economically self-reliant modern industrial nation. No doubt, the country is still deficient in some minerals like petroleum, tin, lead, zinc, nickel, etc., but the continued exploration of India's underground mineral wealth is yielding promising results, thus adding to the known and potential deposits of various minerals. The mineral resources of India are, however, very unevenly distributed. The Great Plains of Northern India are almost entirely devoid of any known deposits of economic minerals. On the other hand, Jharkhand and Odisha areas on the north-eastern parts of peninsular India possess large concentration of mineral deposits, accounting for nearly three-fourths of the country's coal deposits and containing highly rich deposits of iron ore, manganese, mica, bauxite and radioactive materials. Mineral posits are also scattered over the rest of the peninsular India and in parts of Assam and Rajasthan.

Names of some important minerals and the States where they are largely found are given below:

Metallic Minerals

Antimony:	(1) Punjab; (2) Karnataka
Bauxite :	(1) Jharkhand; (2) Odisha
Cbromite	(1) Odisha; (2) Karnataka
Copper:	(1) Madhya- Pradesh;(2) Rajasdian
Diaspore:	(1) Uttar Pradesh; (2) Madhya Pradesh
Gold:	(1) Karnataka; (2) Andhra Pradesh
Ironore:	(1)Jharkhand;(2) Chhattisgarh
Lead:	(1) Rajasthan; (2) Andhra Pradesh
Manganese ore:	(1) Maharashtra;(2) Madhya Pradesh
Mica:	(1) Jharkhand; (2) Bihar
Natural gas:	(1) Andhra Pradesh; (2) Maharashtra
Petroleum :	(1) Maharashtra; (2) Gujarat
Silver:	(1) Rajasthan; (2) Bihar
Tungsten:	(1) Rajasthan; (2) West Bengal
Zinc:	(1) Rajasthan; (2) West Bengal

Non-Metallic Minerals

Asbestos:	(1) Rajasthan; (2) Bihar
Ball clay :	(1) Andhra - Pradesh;(2) Rajasthan
China clay (Kaolin):	(1) Rajasthan; (2) West Bengal
Barytes:	(1) Andhra Prdesh (2) Maharashtra
Calcite :	(1) Rajasthan; (2) Gujarat
Corundum:	(1) Karnataka; (2) Maharashtras
Diamond:	(1) Madhya Pradesh; (2) Uttar Pradesh
Dolomite :	(1)Madhya - Pradesh; (2) Odisha
Felspar:	(1) Rajasthan; (2) Tamil Nadu
Fireclay :	(1) Bihar; (2) Gujarat
Fluorite :	(1) Gujarat; (2) Rajasthan
Graphite :	(1) Odisha; (2) Rajasdian
Gypsum:	(1) Rajasthan; (2) Tamil Nadu
Kyanite :	(1) Bihar; (2) Maharashtra
Limestone:	(1) Madhya Pradesh; (2) Tamil
Nadu Magnetite :	(1) Tamil Nadu; (2) Uttar Pradesh
Mica:	(1) Bihar; (2) Andhra Pradesh
Ochre:	(1) Rajasthan; (2) Madhya Pradesh
Pyrites:	(1) Bihar; (2) Karnataka
Sulphur:	(1) Tamil Nadu
Quartz	(1) Andhra - Pradesh; (2) Karnataka
Quartyte :	(1) Odisha (2) Bihar
Silica Sand:	(1) Uttar Pradesh; (2) Gujarat
Sillimanite:	(1) Maharashtra; (2) Meghalaya

VIII. Energy Resources:

Coal: Coal is a non-renewable source of energy. In India 67 percent of commercial needs of energy is met through coal. It amounts to 60 percent of the total electricity generated. Indian coalfields belong to two geological eras - Gondwana and tertiary. Gondwana category accounts for 99.5 percent of the total reserves. Tertiary coalfield is found in the North-east States and Jammu and Kashmir.

Oldest coalfield	Raniganj
Largest coalfield	Jharia
Per capita production of coal	180kg

Important Coalfields:

Jharkhand: Jharia, Bokaro, Giridih, Karanpura, Ramgarh, Auranga, Hutar, Daltonganj, Deogarh and Rajmahal
West Bengal: Raniganj, Barjora and Darjeeling
Andhra Pradesh : Godavari valley (Singareni coalfields)
MadhyaPradesh/Chhattisgarh: Korba, Chirmiri, Pench-Kanhatawa valley, Hasdo-Arand, Mohpani
Maharashtra: Chhanda, Kamte, Umrer and Bander
Odisha : Talcher

Oil and Natural Gas

Petroleum, also called mineral oil, is an essential, viable but non-renewable source of energy. In 1858, the first oil well was drilled in Cambay, Gujarat. In 1867, first oil field was discovered at Makum in Assam, but production started only in 1882 in Digboi, Assam.

Major oilfields:

Assam **:** Digboi, Nahorkatiya
Arunachal Pradesh : Manabhum, Kharsang, Charali
Tripura : Mamunbhang, Baramura, Dentamura-Subhang, Manu,Amphibagar.
Gujarat : Lunej, Ankleshwar, Kolal, Kosamba, Mehsana, Nawgam, Dholka.

Offshore oilfields of India :

1. Mumbai High (Its platform is calledSagar Samrat)
2. Bassein (Maharashtra)
3. Aliabet near Bhavnagar (Gujarat)Mumbai High produces 62 percent of oil in India, Gujarat 20 percent and Tamil Nadu 1 percent.

Non-conventional energy resources:

Solar Energy : In India solar energy was commercialised in 1983. That desert has been declared as one of the biggest solar powerhouses of the world, that has the potential to produce 10,000 MW. The first two solar projects of 100 KW each have been started in Kalyanpur and Saraisadi (Mau, Uttar Pradesh) and Gurgaon (Haryana). The largest solar pond has been set up at Modapur near Bhuj in Gujarat.

Wind Energy: The first wind farms in India were installed in 1986 in coastal areas of Tamil Nadu, Odisha, Gujarat and Maharashtra. Asia's largest wind farm is located in Muppandal in Tamil Nadu.

Geo-thermal Energy : It envisages the use of heat of the earth in generation of electric power. Two geo-thermal energy plants have been set up in India. The first 5 MW project at Manikaran in Kullu (Himachal Pradesh) and the second of 4.5 MW at Puga Valley in Ladakh (Jammu and Kashmir).

Tidal Energy: It employs the use of tidal waves in generation of electric power. The use of tidal waves in power generation is being employed in Gulf of Kutch, Gulf of Khambhat and in Sunderbans delta region.

Atomic Energy: One of the biggest potentials for electric power generation is that through atomic energy. Three to four percent of total electricity generated in India is through atomic energy. The atomic power plants in India are :

1. Tarapur (Maharashtra)
2. Rawatbhatta (Rajasthan)
3. Kalpakkam (Tamil Nadu)
4. Narora (Uttar Pradesh)
5. Kakrapara (Gujarat)
6. Kaiga (Karnataka)
7. Koodankulam (Tamil Nadu)

IX. Important Places of India:

Abu, Mt. (Hill station in Rajasthan)- sacred centre of Jain worshippers.

Adam's Bridge. (17 miles long) very nearly joined to India between two points Mannar peninsula and Dhanuskodi by a line of sand banks and rocks.

Agra(U.P) Taj Mahal, Tomb of Akbar, the great fort and pearl Mosque Sikandara.

Agha Khan Palace. (Pune) Mahatma Gandhi and his wife Kasturba were kept interned here. Kasturba died in this palace

Ajanta Ellora. (near Aurangabad) Buddhist cave temples.

Ajmer, (Rajasthan) Pilgrim centre for muslims, Tomb of Khwaja Moin-ud-din Chisti.

Aliabet. (near Bhavnagar in Gujarat) India's first offshore oil well.

Alahabad (U.P.) situated at the confluence of Ganga, Jamuna, Saraswati. pilgrim centre for Hindus, Kumbh Mela is held here every 12 years.

Alwaye (Kerala) Monazite Factory.

Amarnath. (Kashmir) Famous Hindu pilgrim centre at the height of 4054 metres.

Amber Fort. (Rajasthan) deserted Capital near Jaipur, finest specimen of Rajput Architecture.

Amritsar. (Punjab) Sikh Shrine, Golden-Temple, Jaliawala Bagh tragedy in April 13, 1919.

Anandpur Sahib, (Punjab) Historic birth place of Sikhism, Known for Takhat Sri Keshgarh Sahib.

Anand Bhawan.(Allahabad) Residence of Pt. Moti Lal Nehru dedicated to Indian National Congress.

Ankleshwar. (Gujarat) oil has recently been struck here.

Aurangabad. (Maharashtra) Tomb of Emperor Aurangzeb.

Auroville. (Pondicherry) City of Dawn.

Avadi (Tamil Nadu) Govt. owned Heavy Vehicle Factory.

Ayodhaya. (U.P) Birth place of Sri Rama. These days, very much in news for Ram Janam Bhoomi-Babri Masjid dispute.

Badrinath. Place of pilgrimage for Hindus near Gangotry Glacier.

Bhakra. (HP.) Hydro power plant. Bhakra Dam built across Sutlej river.

Bharatpur. (Rajasthan) Ghana Bird Sanctuary.

Bhillai (M.P) Biggest steel plant set up with the assistance of Russia.

Bhubneshwar (Orissa) Lingaraja Temple

Bijapur (Karnataka) Gol Gumbaj (tomb of Mohammed Adil Shah)

Bokaro (Bihar) famous for steel plant

Boddh Gaya. (Bihar) It is place where Buddha got Enlightenment. There are modern monastries, rest houses and museums.

Bombay High. Offshore area. First self propelled drilling ship 'Sagar Samrat' started exploration of oil.

Buland Darwaja. (U.P.) Highest and greatest Gateway of India (176 ft.) Gateway to Fatehpur Sikri built by Akbar.

Kolkata, (West Bengal) Big port, city of palaces, Dakshineshwar Temple, Diamond Harbour.

Cape Comorin. (Tamil Nadu) also called Kanyakumari gives a beautiful view, Sunset and Sunrise. Meeting point of Arabian ;sea. Bay of Bengal and Indian Ocean

Chandigarh. (U.T.) Joint Capital of the Punjab & Haryana States. Beautiful Modern, planned city situated at the foot of the Himalayas, famous for Rock Garden.

Cherrapunji. (Meghalaya) Highest rainfall area in the World.

Chidambaram. (Tamil Nadu) Famous for its great Hindu Shiva Temple.

Chittaranjan, (West Bengal) famous for Locomotive works.

Chittorgarh. (Rajasthan) Tower of victory built by Rana Kumbha, Mira Bai's Temple.

Corbett Park. (U.P.) National Park named after Jim Corbett, a famous hunter and writer of 'Shikar' stories.

Dandi. (Gujarat) Famous for Salt, Satya Graha (Dandi March) by Gandhi Ji (1930).

Dilwara Temples. (Rajasthan) Five Hindu Temples.

Elephanta. an Island in Bombay Harbour-famous for rock-cut temples.

Ferozabad. (U.P.) famous for glass bangles Industry.

Gazipur. (U.P) Government opium factory.

Golconda, A ruined city of India, formerly there was a diamond mine.

Gomiah. (Bihar) Explosive Factory.

Gomasteswara. (karnataka) famous for 2000 years old statue of Jain Sage carved out of a single stone.

Gwalior. (M.P.) famous for its fort, Tansen's Tomb, Rani Laxmi Bai's Chhatri.

Hyderabad. (Secunderabad, Andhra Pradesh) Twin city is the Capital of Andhra Pradesh, famous for Char Minar, Golconda Fort, Salarganj museum.

India Gate. A memorial in New Delhi, facing the Rashtrapati Bhawan.

Jadhugoda. (Bihar) famous for Uranium ore Mill.

Jaipur (Rajasthan) The Pink city famous for Hawa Mahal, Amber Fort, Maharaja's city Palace, pottery brassware, ivory, sandal wood work and jewellery.

Jama Masjid. (Delhi) India's biggest mosque, built by Shahjahan.

Jantar Mantar. (Delhi) An observatory constructed in 1724.

Junagodh. (Gujarat) The famous Gir Forest. The only place in Asia where lions are found is Junagodh.

Kalpakkam. (Tamilnadu) Madras Atomic Power Project (MAPP).

Kanchipuram. (Tamilnadu) Golden City. It was Capital city of Hindu Rulers.

Khajuraho. (M.P.) Famous for its group of highly ornate medeivial Hindu Temples.

Kolar (Karnataka) Gold Mining Centre.

Konark (Orissa) Famous for its Black Pagoda, Sun Temple.

Korba. (Madhya Pradesh)is the site of a hung public sector aluminium plant.
Koyal (Maharashtra) Petro-Chemical complex.
Kutub Minar. (Delhi) Biggest minaret in the world, completed by Altarnash in 1232 A.D.
Kurukshetra. (Haryana) Ancient town where the great battle, Mahabharata was fought.
Lucknow. (Uttar Pradesh) Capital of U.P. Famous for its gardens and historical places.
Ludhiana. (Punjab) Known for hosiery, cycle and sewing machine industry.
Lumbini. (Nepal Terai) Birth-Place of Mahatma Buddha.
Light House. St. Thomas Mount, integral coach factory.
Madurai. (Tamilnadu) Minakshi Temple dedicated to Lord Shiva.
Madaras (Tamil Nadu) Known for fort St. George.
Mahabaleshwar (Maharashtra) Principal hill station of the State.
Mahabalipuram. (Tamilnadu) famous for temples and monumental architecture.
Mathura. (U.P.) Birth-place of Lord Krishna.
Moradabad. (U.P.) famous for brasware channel and cutlery Industry.
Nagpur. (Maharashtra) famous for textile mills.
Nalanda (Bihar) Seat of ancient Nalanda University.
Nasik. (Maharashtra) Security Printing Press.
Nilgiris. (Tamilnadu) famous for tea plantations.
Nunamati (Assam) first of the three oil Refineries has been set up here in Public Sector.
Pandharpur (Maharashtra) known for the temple of Vithoba.
Panipat (Haryana) Scene of three successive historical battles, 1526, 1556 and 1761.
Panna. (Madhya Pradesh) known for diamond mines.
Pantnagar (U.P.) famous for a big Agricultural University.
Pimpri (Near Pune) known for penicillin factory.
Pokhran (Rajasthan) India successfully exploded her first nuclear device here on May 18,1974.
Pondicherry. (Union Territory) 'Auroville' an international township has been built here:
Port blair. (Andaman and Nicobar) Island in the Bay of Bengal.
Porbunder (Gujarat) Birth/place of Mahatma Gandhi.
Pusa. (Bihar) Agricultural Research Station.
Raj Ghat (Delhi) Sammadhi of Mahatma Gandhi.
Rana Pratap Sagar. (Rajasthan) Atomic power plant has been set up here,
Ranchi (Jharkhand) Well-known for its picturesque scenery and fine roads.
Raniganj (West Bengal) Coal mining centre.
Red Fort (Delhi) Red/stone fort, built by Shahjahan.
Renukot. (U.P.) Hindustan Aluminium Factory.
Rishikesh. (U.P.) Celebrated centre of Hindu Pilgrimage, Antibiotics plant with aid from U.S.S.R, has been set up here.
Rourkela. (Orrisa) Steel plant and fertilizer factory.
Sabarmati. (Gujarat) Harijan Ashram, founded by Mahatma Gandhi.
Shanti Niketan. (West Bengal) Famous University founded by Rabindranath Tagore near Kolkata.
Sindri (Bihar) Fertilizer factory.
Singerini (Andhra Pradesh) famous for Coal mines.
Tarapore (Maharashtra) Atomic power plant.
Thumba (Kerala) known as Rocket Launching Station.
Titagarh. (West Bengal) Known for paper manufacture.

Ujjain (Madhya Pradesh) Known for Mahakaleshwar temple.

Varanasi (U.P.) Famous for Banaras Hindu University, Vishwanath Temple etc.

Visakhapatnam. (On the eastern coast of India) Ship-building yard.

Wardha (Maharashtra) Centre of cotton trade.

Wellington (Tamil Nadu) Known for Defence Service Staff College.

X. Some Indian Industries:

Aluminium Industry. Renukot (U.P.), Alwaye (Kerala), Katni (M.P.), Asansol (W. Bengal)

Chemical Industry. Delhi, Bombay, Calcutta, Kanpur, Bangalore, Baroda& Amritsar

Cement Industry, Churk(U.P.),Sindri (Bihar), Dalmianagar(Bihar),Lakhri (Rajasthan), Surajpur (Haryana), Jarhul (M.P.), Kistna (Andhra Pradesh) and Porbandar (Gujarat).

Paper Industry. Jagadhari, Saharanpur, Poona, Bombay, Calcutta, Lucknow, Nepangar.

Match Factory. Calcutta, Bareilry, Madras, Ambernath.

Fertilizers industry. Sindri, Alwaye, Nangal, Gorakhpur, Kotah, Trombay, Visakhapatnam, Haldia, Namrup, Baroda, Neyveli

Aeronautics. Bangalore, Kanpur, Nasik, Koraput, Lucknow, Hyderabad.

Automobile Industry. Bombay, Calcutta, Madras, Jamshedpur, Burnpore, Gurgaon.

Glass Industry. Bombay, Tamil Nadu, Bihar, M.P., Ferozabad (U.P.), Amritsar, W. Bengal.

Ship-building Industry. Visakhapatnam, Cochin.

Jute Industry. West Bengal, Bihar, Assam, U.P., Orrisa.

Sugar Industry. Kanpur, Lucknow, Bareilly, Gorakhpur, Muzaffarpur, Dalmianagar, Champaron, Coimbatore, Amritsar.

Woolen Industry. Dhariwal, Kanpur, Panipat, Bombay.

Silk Industry. Srinagar, Murshidabad, Mysore

Cotton Textile. Maharashtra, Delhi; Tamil Nadu, U.P., Gujarat, W. Bengal, M.P., Kerala, Karnataka.

Carpets. Kashmir