2. The Structure and Physical Characteristics of the Atmosphere

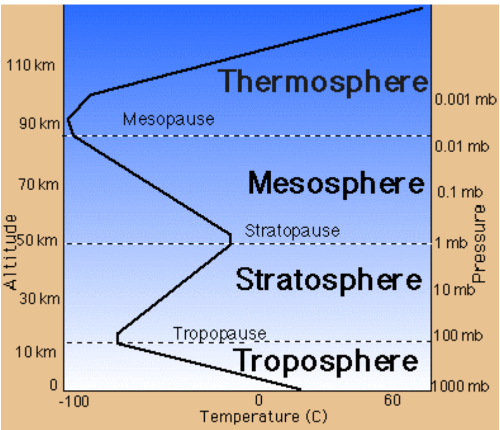
What is the atmosphere?

Earth is surrounded by an atmosphere which is continually in motion. The atmosphere is a layer of gases about 800 km (500 miles) thick which protects the earth from harmful solar radiation and supports all living things.

Composition

The earth's atmosphere (air) is a mixture of gases, mainly nitrogen (N_2) and oxygen (O_2), that are held to the earth by gravity. Near the earth's surface, air is composed of about 78% nitrogen and about 21% oxygen. Small amounts of other gases, such as carbon dioxide (CO_2), argon (Ar), methane (CH_4) and oxides of nitrogen (NO_x), are also present. The atmosphere also contains water (H_2O), as a vapour. The concentration of water vapour varies from place to place and from time to time. In warm tropical areas, the concentration of water vapour may reach 4%, while near the poles its concentrations may be much less than 0.1%. This amount of water vapour may seem small and insignificant, but it plays an important role in the world's weather.

Structure



By studying the atmosphere, meteorologists have discovered that it can be divided into a series of layers. Based on a vertical profile of temperature, the layers consist of the troposphere, stratosphere, mesosphere, and thermosphere. 99% of the mass of the atmosphere occurs below about 32 km.

The lowest layer, the troposphere, is warmed by the earth. Sunlight warms the earth's surface, and the surface warms the air. Therefore, the warmest air is next to the ground and air temperature normally decreases with height. This pattern of decreasing air temperature with altitude occurs usually up to an altitude of between about 8000 m (about 26,000 ft) at the poles and 16,000 m (about 52,000 ft) at the equator. The rate of change of air temperature with height is called the "lapse rate". In the troposphere, the lapse rate is generally about 6.5 degrees C per kilometre increase in altitude. The temperature can increase with height in the lower troposphere. When this happens, it is called an "inversion". If the temperature remains the same with height, it is called isothermal". The actual lapse rate varies with location, time of day, weather conditions, season, etc. The troposphere is described by meteorologists as being "well-mixed". If pollutants are released into the troposphere, they are mixed throughout its depth in a few days and, usually within a week or so, will fall back to the ground with the rain (e.g., acid rain). It is in this layer that the earth's weather occurs.

The layer of atmosphere above the troposphere is called the stratosphere. The stratosphere is marked by a temperature inversion from about 11-12 km to 50 km above sea level. Because warmer air lies above cooler air in this region, there are few air currents and, thus, the stratosphere is a region of little mixing. Particles that travel from the troposphere into the stratosphere can stay aloft for many years without returning to the ground. For example, large volcanic eruptions force ash to be projected into the stratosphere, where it may remain for years and causing slight global cooling in the process. It is relatively easy to see where the stratosphere begins when there are large thunderstorms around. The tops of these storms reach only into the lowest level of the stratosphere. Because of the temperature inversion, air rising in the thunderstorm eventually becomes cooler than its environment in the stratosphere and stops rising. Air temperature begins to increase with height, mainly because ozone (a type of gas similar to oxygen) in the stratosphere absorbs energy from the sun, principally ultraviolet radiation. Although the amount of ozone in the stratosphere is quite small, it is important because it protects living things on the earth by absorbing the sun's harmful ultraviolet radiation. However, chemicals emitted near the earth, such as chlorofluorocarbons (CFCs), can be injected into the stratosphere by the updrafts in thunderstorms. In the stratosphere these chemicals can help to destroy ozone. Occasionally, concentrations of CFCs in the stratosphere are high enough to destroy nearly all of the ozone over large regions, producing a hole in the ozone layer. In recent years, such holes have occurred over Antarctica. Concorde flies in the lower reaches of the stratosphere.

Above the ozone-rich stratosphere lies the mesosphere, where air temperature, again, decreases with height. The mesosphere is the coldest layer of the atmosphere and extends from an altitude of about 50 km to about 85 km (about 30 to 50 miles). There is not a layer of ozone to cause heating, so temperatures are colder as height increases. The air pressure and density in the mesosphere are extremely low (about 1/1000th of that at the surface) and there is not enough oxygen to breathe here.

Above the mesosphere lies the hot thermosphere, where air temperatures can exceed 1000° C, primarily due to oxygen absorbing the sun's energetic rays. Unlike in the troposphere and stratosphere, temperatures in the thermosphere can change by hundreds of degrees depending on the amount of solar activity.

Air Temperature

Molecules of air are in constant motion and the speed of air molecules corresponds to the amount of heat energy in the air. Air temperature is a measure of the average speed at which air molecules are moving; high speeds correspond to higher temperatures. The temperature of the air is usually measured using a dry-bulb thermometer.

Air Pressure

Air is held to the earth by gravity. This strong force pulls the air downward, giving air molecules weight. The weight of the air molecules exerts a force upon the earth and everything on it. The amount of force exerted is called atmospheric pressure or air pressure. Higher in the atmosphere, there are fewer air molecules pressing down from above so air pressure always decreases with increasing height above the ground. Because air can be compressed, the density of the air (the mass of the air molecules in a given volume) normally is greatest at the ground and decreases at higher altitudes.

The most common unit of pressure found on weather maps is the millibar (1 millibar equals 100 Newton/sq. m, where Newtons are the metric unit of force). Inches of mercury is a pressure unit commonly used in television and radio weather broadcasts. On average, at sea level, the standard value of the atmospheric pressure is 1013.25 millibars, 29.92 inches of mercury, and 14.7 lbs/sq. in. Air pressure is measured using a barometer.

Wind

Wind is air in motion. It is caused by horizontal variations in air pressure. The greater the difference in air pressure between any two places at the same altitude, the stronger the wind will be. The wind direction is the direction from which the wind is blowing. A north wind blows from the north and a south wind blows from the south. The prevailing wind is the wind direction most often observed during a given time period. Wind speed is the rate at which the air moves past a stationary object. A variety of instruments measure wind. A wind vane measures wind direction. At airfields a windsock is used instead of a vane. Most wind vanes consist of a long arrow with a tail that moves freely on a vertical shaft. The arrow points into the wind and gives the wind direction. Wind speed is measured using an anemometer. Most anemometers consist of three or more cups that spin horizontally on a vertical post. The rate at which the cups rotate is related to the speed of the wind.

A commonly used scale to express the speed and strength of wind is the Beaufort Scale. This scale is based on the reaction of common, easily recognizable objects to wind forces rather than on complicated scientific notation. British Admiral Sir Francis Beaufort, the scale's inventor, assigned a Force Number (related to specific wind speed range) to each reaction.

Beaufort Scale				
Beaufort No.	Wind Speed (Knots)	Description	Land Signs	Sea State
0	Below 1	Calm	Smoke rises vertically. Leaves still.	Mirror smooth.
1	1 - 3	Light Air	Smoke drifts.	Scaly ripples.
2	4 - 6	Light Breeze	Leaves rustle. Wind felt on face	Small wavelets. Crests do not break.
3	7 – 10	Gentle Breeze	Light flags, leaves and twigs move.	Large wavelets. Crests may occasionally break.
4	11 – 16	Moderate Breeze	Small tree branches move.	Small waves with white caps.
5	17 – 21	Fresh Breeze	Small trees in motion.	Moderate waves with many white caps.
6	22 - 27	Strong Breeze	Large branches in motion. Umbrellas difficult to use.	Large waves with foam crests and spray.
7	28 – 33	Moderate Gale	Whole trees move. Pressure walking into wind.	White foam. Breaking waves.
8	34 – 40	Fresh Gale	Branches break. Walking difficult.	Moderately high waves.
9	41 - 47	Strong Gale	Slight structural damage. Slates blown from roof.	Higher waves. Dense foam. Crests topple with spray.
10	48 - 55	Whole Gale	Trees uprooted. Structural damage occurs.	Sea almost white. Violent waves.
11	56 – 63	Storm	Widespread damage.	Very high violent waves. Poor visibility
12	64+	Hurricane	Massive violence and destruction.	Sea almost totally white. Enormous waves. Visibility seriously impaired.

Precipitation

Precipitation is any form of water (either liquid or solid) that falls from the atmosphere and reaches the ground, such as rain, snow, or hail but not dew or frost. Rainfall is measured using a rain gauge and the amount of rainfall is expressed in millimetres.

Humidity

Humidity refers to the amount of water vapour in the air. The maximum amount of water vapour that the air can hold depends on the air temperature; warm air is capable of holding more water vapour than cold air. Relative humidity is the ratio of the amount of water vapour in the air compared to the maximum amount of water vapour that the air could hold at that temperature and is expressed as a percentage. When the air is holding all of the moisture possible at a particular temperature, the air is said to be saturated. Tropical countries usually have high relative humidities and polar regions have generally low relative humidities. In high humidity conditions people sweat more.

Relative humidity and dew-point temperature (the temperature to which air would have to be cooled for saturation to occur) are often measured using wet and dry-bulb thermometers and reference to a set of tables. Professional meteorologists use a device called a psychrometer.

A wet-bulb thermometer