Lecture 1

Weather, Climate and the Atmosphere

1.1 Overview of the Earth's Atmosphere

Meteorology is the study of the atmosphere and its phenomena. The earth's atmosphere is a thin, gaseous envelope comprised mostly of nitrogen N_2 (78%) and oxygen O_2 (21%), with small amounts of other gases, such as water vapor H_2O (0 - 4 %) and carbon dioxide CO_2 (0.037 %). Although our atmosphere extends upward for many hundreds of kilometers, almost 99 percent of the atmosphere lies within a mere 30 km of the earth's surface. This thin blanket of air constantly shields the surface and its inhabitants from the sun's dangerous ultraviolet radiant energy, as well as from the attack of material from the outer space. There is no definite upper limit to the atmosphere; rather, it becomes thinner and thinner, eventually merging with empty space, which surrounds all the planets.

The concentration of the invisible gas water vapor, however, varies greatly from place to place, and from time to time. Close to the surface in warm, steamy, tropical locations, water vapor may account for up to 4 percent of the atmospheric gases, whereas in colder arctic areas, its concentration may be reduced to less than (1%).

Water vapor molecules are, of course, invisible. They become visible only when they transform into larger liquid or solid particles, such as cloud droplets and ice crystals.

Carbon dioxide (CO_2), is a natural component of the atmosphere, occupies a small (but important) percent of a volume of air, about 0.037 percent. Carbon dioxide enters the atmosphere mainly from the decay of vegetation, but it also comes from volcanic eruptions, the exhalations of animal life, from the burning of fossil fuels (such as coal, oil, and natural gas), and from deforestation. The removal of CO_2 from the atmosphere takes place during photosynthesis, as plants consume CO_2 to produce green matter. The CO_2 is then stored in roots, branches, and leaves. The oceans act as a huge reservoir for CO_2, as phytoplankton (tiny drifting plants) in surface water fixes CO_2 into organic tissues. Estimates are that the oceans hold more than 50 times the total atmospheric CO_2 content.

Figure 1.1 reveals that the atmospheric concentration of CO_2 has risen more than 15 percent since 1958.

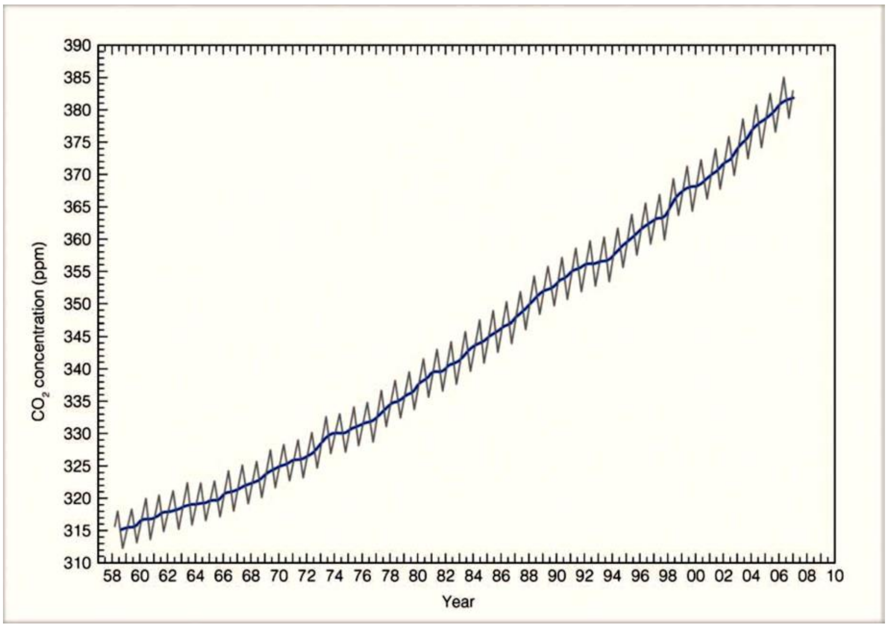

Fig. 1.1 Measurements of CO_2 in parts per million (ppm) at Mauna Loa Observatory, Hawaii, USA. Notice that the concentration of CO_2 has increased by more than 20 percent since 1958.

This increase means that CO_2 is entering the atmosphere at a greater rate than it is being removed. The increase appears to be due mainly to the burning of fossil fuels; however, deforestation also plays a role as cut timber, burned or left to rot, releases CO_2 directly into the air, perhaps accounting for about 20 percent of the observed increase.

Carbon dioxide and water vapor are not the only greenhouse gases. There are other gases include methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs).

1.2 The Vertical Structure of the Atmosphere

A vertical profile of the atmosphere reveals that it can be divided into a series of layers. Each layer may be defined in a number of ways: by the manner in which the air temperature varies through it, by the gases that comprise it, or even by its electrical properties. Before we talk about these layers, we will study two important variables: air pressure and air density.

Air Pressure: Air molecules are held near the earth by gravity. The more air above a level, the greater the squeezing effect or compression. Since air density is the number of air molecules in a given space (volume), it follows that air density is greatest at the surface and decreases as we move up into the atmosphere. Notice in Fig. 1.2 that, owing to the fact that the air near the surface is compressed, air density normally decreases rapidly at first, then more slowly as we move farther away from the surface. The weight of the air molecules acts as a force upon the earth. The amount of force exerted over an area of surface is called atmospheric pressure or, simply, air pressure (pressure=force/area). As we climb in elevation, fewer air molecules are above us; hence, atmospheric pressure always decreases with increasing height. Like air density, air pressure decreases rapidly at first, then more slowly at higher levels (see Fig. 1.2).

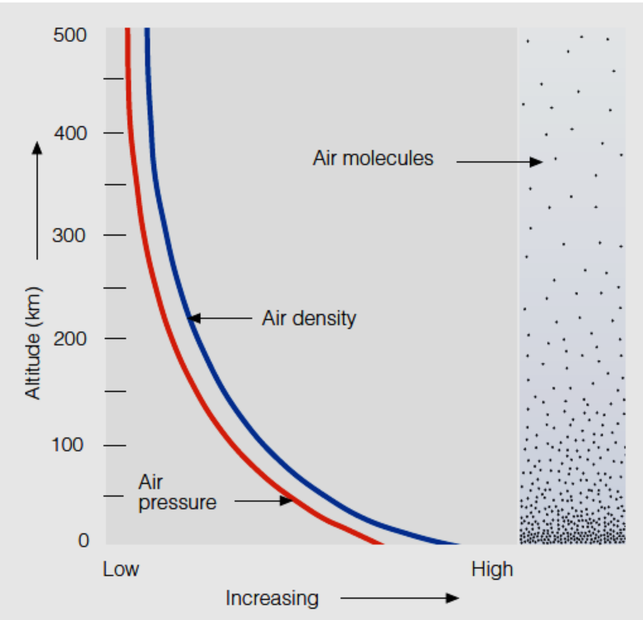

Fig. 1.2

Both air pressure and air density decrease with increasing altitude.

The most common unit for air pressure is the millibar (mb), although the hectopascal (hPa) is gradually replacing the millibar as the preferred unit of pressure on surface maps. At sea level, the average or standard value for atmospheric pressure is: (1013.25 mb = 1013.25 hPa)

Air temperature, however, has a more complicated vertical profile (see Fig. 1.3) and notice that air temperature normally decreases from the earth's surface up to an altitude of about 11 km. This decrease in air temperature with increasing height is due primarily to the fact that sunlight warms the earth's surface, and the surface, in turn, warms the air above it. The rate at which the air temperature decreases with height is called the temperature lapse rate.

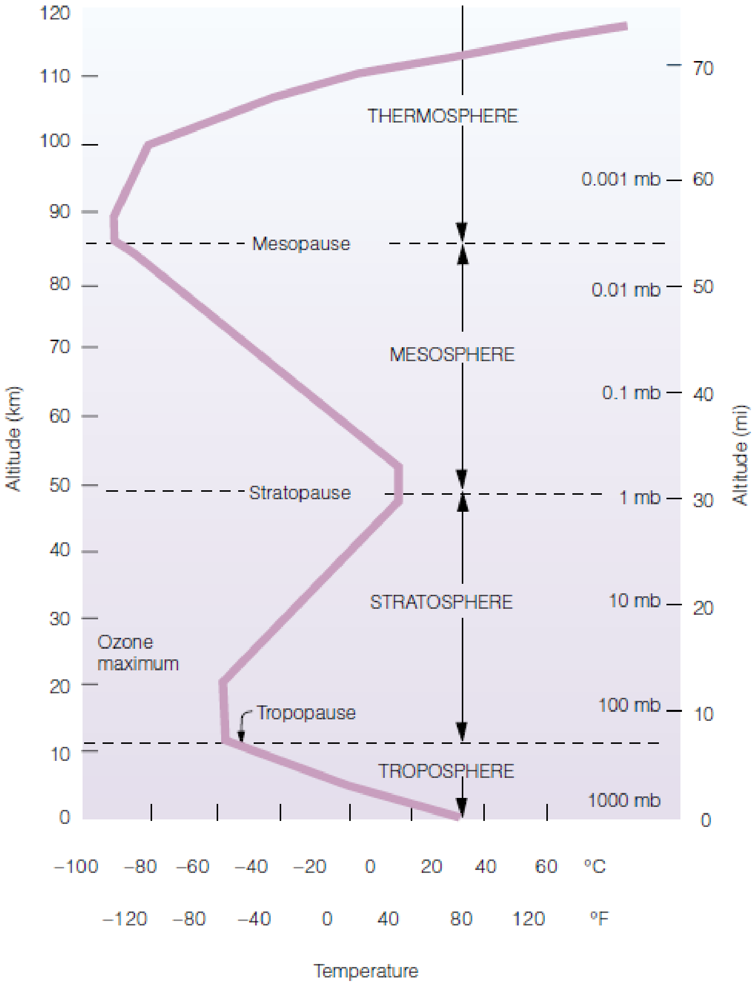

Fig. 1.3
The layers of atmosphere according to the air temperatures above the earth's surface.

The average (or standard) *lapse rate* in this region of the lower atmosphere is about 6.5 degrees Celsius (°C) for every 1000 meters in elevation. Occasionally, the air temperature may actually *increase* with height, producing a condition known as a **temperature inversion.** The instrument that measures the vertical profile of air temperature in the atmosphere is the **radiosonde.**

The **troposphere** is the region of the atmosphere from the surface up to about 11 km contains all of the weather we are familiar with on earth. Notice in Fig. 1.3 that just above 11 km the air temperature normally stops decreasing with height. Here, the lapse rate is zero. This region, where the air temperature remains constant with height, is referred to as the **tropopause**. The top of the troposphere is the beginning of another layer, the **stratosphere.** The height of the tropopause varies (about 18 km at the equator and about 9 km at the poles). From Fig. 1.3 we can see that, in the stratosphere at an altitude near 20 km, the air temperature begins to increase with height, producing a temperature inversion.

The reason for the inversion in the stratosphere is that the gas ozone plays a major part in heating the air at this altitude. Recall that ozone is important because it absorbs energetic ultraviolet (UV) solar energy. Some of this absorbed energy warms the stratosphere, which explains why there is an inversion. Above the stratosphere is the mesosphere. The air here is extremely thin and the atmospheric pressure is quite low. With an average temperature of -90^{o} C, the top of the mesosphere represents the coldest part of our atmosphere.

The "hot layer" above the mesosphere is the thermosphere. Here, oxygen molecules (O_2) absorb energetic solar rays, warming the air. In the thermosphere, there are relatively few atoms and molecules. Consequently, the absorption of a small amount of energetic solar energy can cause a large increase in air temperature that may exceed 500^{o} C. Even though the temperature in the thermosphere is exceedingly high, a person shielded from the sun would not necessarily feel hot. The reason for this fact is that there are too few molecules in this region of the atmosphere to bump against something (exposed skin, for example) and transfer enough heat to it to make it feel warm. The low density of the thermosphere also means that an air molecule will move an average distance of over one kilometer before colliding with another molecule.

The region where atoms and molecules shoot off into space is sometimes referred to as the exosphere, which represents the upper limit of our atmosphere.

THE IONOSPHERE

The ionosphere is not really a layer, but rather an electrified region within the upper atmosphere where fairly large concentrations of ions and free electrons exist. The lower region of the ionosphere is usually about 60 km above the earth's surface. From here (60 km), the ionosphere extends upward to the top of the atmosphere. Hence, the bulk of the ionosphere is in the thermosphere. The ionosphere plays a major role in radio communications. The lower part (called the D region) reflects standard AM radio waves back to earth, but at the same time it seriously weakens them through absorption. At night, though, the D region gradually disappears and AM radio waves are able to penetrate higher into the ionosphere (into the E and F regions—see Fig. 1.4), where the waves are reflected back to earth.

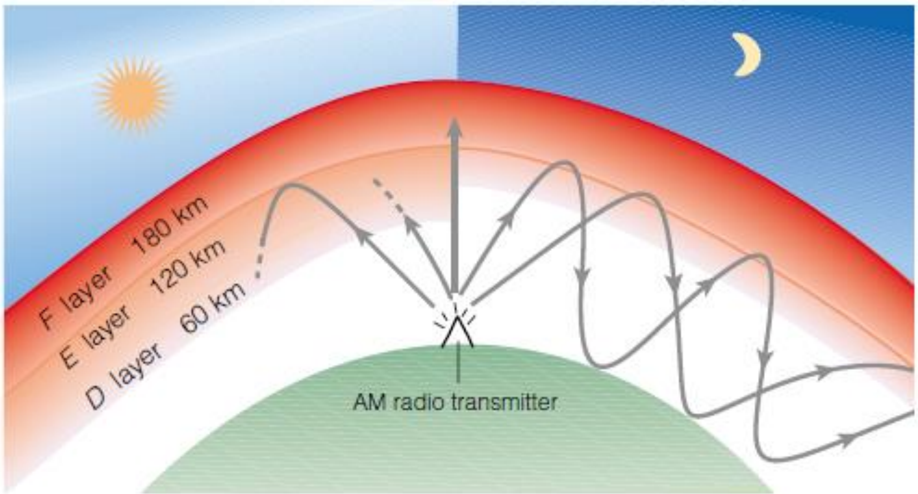

Fig. 1.4
Ionosphere sublayers.

1.3 The Weather and Climate

When we talk about the weather, we are talking about the condition of the atmosphere at any particular time and place. Weather—which is always changing—is comprised of the elements of air temperature, air pressure, humidity, clouds, precipitation, visibility, an wind. If we measure and observe these weather elements over a specified interval of time, say, for many years, we would obtain the "average weather" or the climate of a particular region. Climate, therefore, represents the accumulation of daily and seasonal weather events (the average range of weather) over a long period of time. The concept of climate is much more than this, for it also includes the extremes of weather—the heat waves of summer and the cold spells of winter—that occur in a particular region. The frequency of these extremes is what helps us distinguish among climates that have similar averages. If we were able to watch the earth for many thousands of years, even the climate would change.

Homework:

1. What is the primary source of energy for the earth's atmosphere?
2. List the four most abundant gases in today's atmosphere.
3. Of the four most abundant gases in our atmosphere, which one shows the greatest variation from place to place at the earth's surface?
4. Explain how the atmosphere "protects" inhabitants at the earth's surface.
5. Briefly explain the production and natural destruction of carbon dioxide near the earth's surface. Give a reason for the increase of carbon dioxide over the past 100 years.
7. What are the two most abundant greenhouse gases in the earth's atmosphere?
8. Explain the concept of air pressure in terms of weight of air above some level. Why does air pressure always decrease with increasing height above the surface?
9. What is standard atmospheric pressure at sea level in millibars and hectopascals?
10. On the basis of temperature, list the layers of the atmosphere from the lowest layer to the highest.
11. Briefly describe how the air temperature changes from the earth's surface to the lower thermosphere.
12. (a) What atmospheric layer contains all of our weather? (b) In what atmospheric layer do we find the highest concentration of ozone? The highest average air temperature?
13. Even though the actual concentration of oxygen is close to 21 percent (by volume) in the upper stratosphere, explain why you would not be able to survive there.
14. What is the ionosphere and where is it located?
15. List the common weather elements.
16. How does weather differ from climate?
17. Define meteorology.