Basic Atmospheric Properties

The Earth's atmosphere is the gaseous envelope that surrounds our planet. While there is no exact upper limit for the extent of the atmosphere, we think of the **exosphere** as the region where our atmosphere merges into space, occurring at an altitude of approximately 500 km.

Our atmosphere is composed of different gases, the two most abundant of which are N_2 and O_2. N_2 accounts for 79% of the atmosphere and O_2 for 20%. The subscript "2"s indicate that the form of oxygen and nitrogen found commonly in the atmosphere are molecules of oxygen and nitrogen in which two atoms of N (and O) are bound together. We will study later that oxygen can exist in a triatomic form (O_3)called **ozone** which has the significant property of absorbing ultraviolet solar radiation.

While oxygen and nitrogen are by far the most abundant molecues in our atmosphere, they are not the only important atmospheric constituents. Water vapor, whose abundance can vary from almost nothing in the driest of locales to about 4% of the atmosphere, is responsible for the formation of all clouds (when water vapor condenses into liquid droplets or freezes into ice crystals) and all the precipitation we receive on Earth. Additionally, water vapor is a **greenhouse gas**, and plays a key role in the heat budget of the Earth.

Another significant greenhouse gas is carbon dioxide CO_2. As you have likely read, CO_2 is emitted as a byproduct of many industrial processes, and its increasing abundance in the atmosphere is the source of much concern regarding future climate change via global warming.

To understand weather and climate on the Earth, we must first understand the nature and properties of gases. To do that, we will focus and illustrate some of the most important concepts relating to the study of weather. **Temperature**

TemperatureEveryone knows this word and could easily provide a definition for it. Most people would argue that temperature is 'how hot or cold we feel on a given day.' However, the definition of temperature is much more specific than this, and requires us to think about processes occuring on the molecular level. Temperature measures the random speed at which molecules move; a higher temperature means that molecules are moving more rapidly in their random motion, a lower temperature means they are moving more slowly.

Temperature Profile of the Earth

The temperature of the Earth varies as one moves upward from the surface of the Earth. Imagine you were a meteorologist rising in the Earth's atmosphere, taking temperature measurements as high as you could go (actually, you could not go as high as indicated here, but we can imagine doing so). If you plotted your results, you would get a graph like the one below:

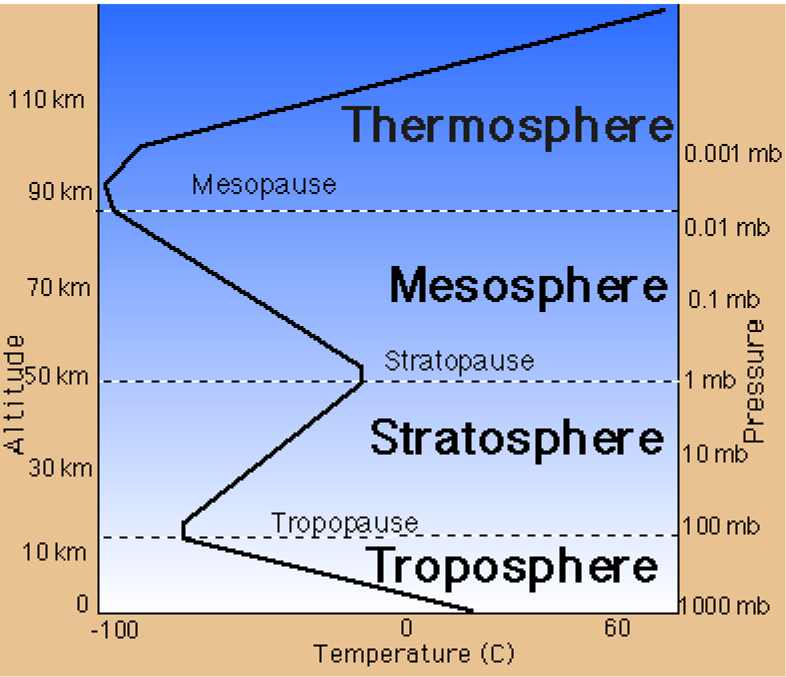

image courtsey shodor.org

This graph shows a great deal of interesting information. First, notice the axes. Altitude is shown on the left (in km), temperature is shown on the bottom (in degrees Centigrade), and the pressure of the atmosphere is shown on the right vertical axis, in a unit called **millibars**, abbreviated as mb.This shows that the pressure of the atmosphere decreases as you rise higher; meteorologists would say the pressure decreases with (increasing) height.

This graph shows that the vertical variation of the Earth's temperature is not quite so simple to describe. There are regions where the temperature increases with height, and regions where the temperature decreases with height. Notice also that the Earth's atmosphere into different layers based upon whether the temperature is increasing or decreasing with height.

The lowest of these, the **troposphere** is where we live, and where essentially all of our weather occurs. If you took a full semester weather course, you would spend almost all of your time studying processes and events occuring in the troposphere. Notice that on average, temperature decreases with height in the troposphere at the rate of approximately 6.5^{o}/km>, although this rate can vary from day to day and place to place, sometimes quite dramatically.

The region above the troposphere is the **stratosphere**, and in this region, temperatures actually increase with increasing height. What explains this behavior which is so different from our common experience in the troposphere? In the troposphere, sunlight is not absorbed by any gases to any appreciable degree, so the gases in the troposphere are not significantly warmed by the Sun. Rather, sunlight reaches the surface of the Earth, warms the Earth, and the Earth emits energy back into the atmosphere. The troposphere is thus not heated by the Sun directly, but by the Earth. So the farther one gets from the source of direct heating, in the case of the troposphere this is the Earth, the cooler it gets.

The stratosphere, though, is directly warmed by the Sun. The stratosphere has a higher concentration of ozone than the troposphere (and even though this concentration is one part of ozone per million), the stratosphere is sometimes called the ozone layer. Ozone, as noted above, is a very effective absorber of solar ultraviolet radiation. When stratospheric ozone absorbs this energy, the stratosphere warms, and of course, the ultraviolet energy does not reach the surface of the Earth since it has been absorbed in the stratosphere.

Many atmospheric scientists are concerned that the amount of ozone is being decreased because of the release in past decades of certain molecules called **chlorofluorocarbons**, molecules contained in aerosol sprays and refrigeration units. These molecues have been observed to rise into the stratosphere, where they react with ozone and convert it to O_2, a much less efficient absorber of ultraviolet radiation.

The next layer up is the mesosphere. Air is very thin at this height, and almost no attention is given this region of the atmosphere, causing some scientists to dub it the "ignorosphere."

The thermosphere is the region of the atmosphere where the most energetic solar energy is absorbed. Air is even thinner here than in the mesosphere, still, there are sufficient numbers of O and N atoms to absorb solar X-rays and gamma rays. If you look at the temperature scale, you might think it would feel very hot in the thermosphere. Actually, if you stuck your bare hand out in this region (and it managed not to explode because of the low external pressure), you would feel severe cold. Understanding this requires we use our definition of temperature: a measurement of the random speed of molecules and atoms. In the thermosphere, atoms move very rapidly as they absorb high energy solar radiation, however, the atmosphere is very thin at this altitude. So, while each atom has a lot of individual energy, there are so few atoms that the total energy, and hence temperature, of the region is low. Another way to think of this is to imagine sticking your hand out in the thermosphere; because there are so few atoms, your hand would radiate its energy to space before receiving any energy via collision with a fast moving molecule. This thought experiment nicely shows the difference between temperature and total energy content.

Pressure

One of the most important of all concepts needed to understand the nature of weather is that of **pressure**. Pressure is another word that is used commonly in everyday language ('I can't take all this *pressure*); in science, pressure has a very specific meaning. We should think of pressure at a location as the weight of the column of air above that location. The diagram below shows how the pressure of the atmosphere decreases with height.

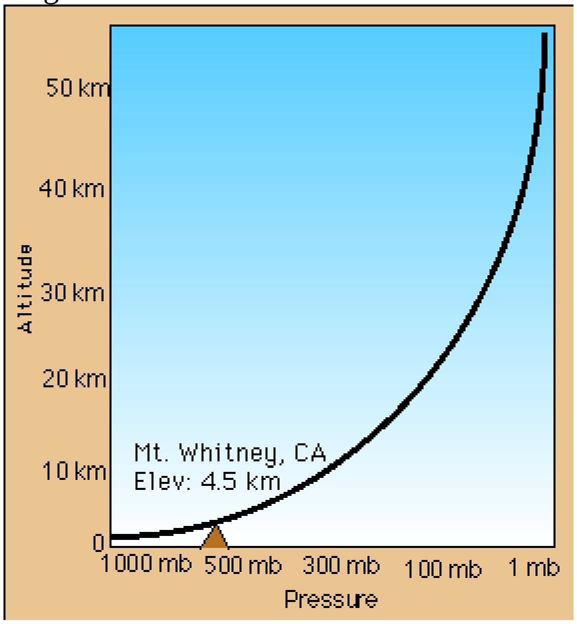

image courtesy shodor.org

Be careful to observe that the horizontal axis on this graph shows pressures decreasing to the right.

The vertical profile of pressure is not surprising; if pressure is the weight of the column of air above you, there is simply less air above you as you go higher into the atmosphere.

Thus, when we hear on the news that there is a high pressure system somewhere, that means that the column of air above that city is greater than the weight of columns of air in neighboring cities. The importance of this becomes more evident when we learn about one of the most important properties of fluids (both gases and liquids are fluids): whenever a force is exerted on a fluid, that force is transmitted equally in all directions in the fluid. A simple and everyday example of this is a toothpaste tube. We know that if we squeeze in the middle of a tooth paste tube, we can cause toothpaste to squirt out the end, even if the direction of our force was perpendicular to the long axis of the toothpaste. (Try moving a desk like this; if you push straight down on the desk, do you think you can make it move in a direction perpendicular to the force? Of course not, but this is exactly what happens with fluids--a force in any direction is transmitted equally in all other directions.) If you use a needle and puncture holes all over your tube and then squeeze, you will see toothpaste ooze out of every hole you have made (as long as the holes are large enough).

How does this apply to our study of weather? Suppose there are two cities at different pressures (one of course will have a higher pressure than the other). This means that the weight of the atmosphere is greater at one place than the other, and we would expect a greater downward force where the pressure is higher. We will experience this, but what is also true is that this greater force will act in all directions, including horizontally (parallel to the surface of the Earth). If we imagine a balloon of air (these are called parcels by meteorologists) situated somewhere between these two cities, this balloon will feel a force pushing it from both sides; however since the force coming from the side of the higher pressure will be greater, the balloon will feel a **net** force acting in the direction from high to low.

This simple thought experiment shows us that winds are caused by pressure differences; the speed of the wind depends on the nature of this pressure difference, the more drastic the pressure change, the faster the winds.

On news casts you are likely to hear pressure measured in the unit of 'inches of mercury'; this unit derives from the days of the first barometers. You can see a diagram of these early barometers and an explanation for how the height of mercury measure air pressure by clicking here.

The unit of pressure that will be used on all weather maps we will study is the milllibar, abbreviated as mb. The average surface pressure on the Earth is 1013.25 mb. Interestingly, surface pressures on the Earth do not vary too much from this value; changes in surface pressure of just a a few percent are enough to generate significant winds and pressure systems. For instance, the highest value of surface pressure ever recorded was 1084 mb (in Siberia), and the lowest surface pressure ever measured was 890 mb in the eye of a massive typhoon (Pacific hurricane). A low pressure system where the pressure is 20 or 30 mb less than surrounding regions would represent a major storm system indeed.

Relative Humidity

Humidity is a general measure for the amount of water vapor in the atmosphere; the more water vapor, the higher the humidity. There are a number of ways of defining humidity, but for purposes of our course we will focus on **relative humidity**. The word 'relative' means that we are making a comparison, or constructing a ratio. In this case, we are comparing how much water vapor is present in the atmosphere to how much water vapor it would take to **saturate** the atmosphere.

To understand the concept of saturation, consider this thought experiment. Suppose you have a large mug of very hot tea or coffee and you stir one teaspoon of sugar into the mug. The sugar will completely dissolve. Now add another teaspoon and if the mug is large enough the sugar will completely dissolve. You can continue this process until you get to the point that no more sugar will dissolve, and any new sugar that is added to the liquid results in an equal amount of sugar falling to the bottom of the mug as solid precipitate. At this point, we say the mug is saturated with sugar.

Suppose we try the experiment again with the same amount of liquid, only this time imagine the liquid has been left out for some time and has cooled down. Your experience should tell you that it will require much less sugar to saturate this cooler liquid.

Similarly, the atmosphere can become saturated with water vapor. At a particular temperature, there is a maximum amount of water vapor that can be dissolved in the atmosphere; attempting to add any more water vapor to the atmosphere will result in some water vapor returning to the liquid state. Just as in our thought example, the amount of water vapor it takes to saturate the atmosphere increases as the temperature of the atmosphere increases. You can review a table of saturation vapor pressures at this site.

Relative humidity can then be expressed as:

Relative Humidity = [(Actual Vapor in Air)/(Saturation Vapor of the Air)]x 100%

This ratio is always expressed as a percentage. A higher value of RH means that the atmosphere is nearing saturation, a lower value means the atmosphere is far from saturation. A RH of 100% means that the amount of vapor in the atmosphere equals the amount of vapor required to saturate the atmosphere. (In almost all cases) when the RH reaches 100%, water droplets begin to condense from the vapor, and this initiates the process of cloud formation. (If the RH reaches 100% on or very near the ground, we will observe the formation of dew. Fogs occur when the air nearest the ground saturates and condenses; fogs are merely clouds on the ground.)

Let's look at the definition of RH again. The numerator--how much vapor is actually in the air at the moment of observation--can change as more or less water vapor is added to the atmosphere. This amount doesn't change too dramatically unless a frontal system moves through the area, changing the nature of the air in your location. The denominator--the amount of vapor required to saturate the atmosphere--does change much more readily. This occurs because the amount of vapor required to saturate the air depends on the temperature of the air, and the temperature of the air is in constant flux.

Given this information about RH, when during the day will we measure the highest values of RH? The lowest values of RH? Can you explain why dew formation occurs in the early morning hours and not in the late afternoon?

One of the important topics in the study of weather is the formation of clouds. As noted above, clouds form when a layer of air above the Earth's surface becomes saturated, in other words, when the RH of the atmosphere at some height reaches 100%. If we look to our equation defining RH again, we see that there are two general ways in which the RH can increase to reach 100%. The first is to increase the amount of water vapor in the atmosphere until the atmosphere becomes saturated, and the second is to lower the temperature of the air until the saturation vapor pressure decreases until the amount of vapor in the air can saturate the now cooler atmosphere. This second mechanism is the one that usually occurs in the atmosphere. You may have heard on weather broadcasts the term **dew point**. The dew point is the temperature to which you would have to cool the atmosphere to saturate the atmosphere without adding or subracting any vapor.