UNIT IV--TEMPERATURE-MOISTURE RELATIONSHIP

Weather is the most variable and often the most critical determinant of fire behavior. This is the first of several units that will deal with weather and its relationship to fire behavior. This unit will discuss atmospheric temperatures, moisture, and the relationship between these two elements.

Before starting the unit, read the instructions to students on page 1 of your workbook. On page 2, you will find the unit objectives on which you will be tested at the end of this unit. Please study these objectives. When you have finished, return to this text.

You should be familiar with the atmosphere that surrounds the earth and its life-supporting elements of oxygen, moisture, and other gases that affect our activities and well-being. This atmosphere is very dynamic, with conditions changing from moment to moment, that can impact on our activities on very short notice.

These short term atmospheric variations are what we call weather. To most people, weather is thought of in terms of temperature, humidity, precipitation, cloudiness, sunshine, visibility, and wind. The fire manager is concerned with all of these factors, since his successes and failures are often dependent on his keeping current with the weather. An understanding of weather processes and the ability to observe and interpret atmospheric conditions are of great advantage to the fire manager.

This unit will concentrate on several weather factors, especially those related to temperature and moisture in the atmosphere. On page 3, we begin our discussion with temperature and heat. The two are not synonymous, although often used in the same sense. Temperature is defined as the degree of hotness or coldness of a substance; a measurement of its molecular activity. It is measured by a thermometer on a designated scale such as Fahrenheit or Celsius. In this course, all temperatures will be given in degrees Fahrenheit.

Where does heat come from? For the most part, all of the heating of the earth's surface and its atmosphere comes from the sun through solar radiation. On a very small scale, heat may be generated by a large, active forest fire or some other energy-releasing activity, but the sphere of influence by these heat sources, worldwide, are relatively small. This discussion will concentrate on solar radiation.

Fortunately, our planet basks in the radiant heat of "O1' Sol" each day and provides a climate favorable to all living things. It's also fortunate that our day-night cycle is only 24 hours in length; if longer, we might have much greater temperature differences between day and night. Much of the heat incoming during the day is lost at night. The atmosphere and the earth retain a certain amount of heat from day to day which reduces the wide temperature variations that might otherwise exist.

The distribution of incoming solar radiation varies from day to day, depending on atmospheric conditions. See figure 1 on page 3. Perhaps 43 percent of the sun's energy reaches the earth's surface. Some of, the rays are reflected back into space, and some are absorbed by the atmosphere.

Turn to page 4. The primary concern relating to this daytime solar heating is the temperature it will create on the earth's surface and in the surrounding air. These temperatures vary on a daily basis and are mostly dependent on three factors. Under item A list the following:

1. The amount of moisture and pollutants in the air. . . These can reflect and/or absorb incoming radiation. The presence and thickness of clouds, water vapor, haze and smoke are factors.

2. The angle and duration of solar rays striking the surface. These are affected by time of day and year, and by topography. Latitude, slope, aspect, elevation, and shape of the country are factors.

3. The surface properties of terrain and vegetation. . . These reflect and absorb incoming radiation. Color, texture, transparency, thermal conductivity, and specific heat are factors.

These terms describing surface properties should be explained. Heat gain and heat loss at the earth's surface are dependent on:

1. Color and texture--both affect the ability of substances to absorb or reflect radiation. For example, black mostly absorbs while white mostly reflects. A rough textured surface absorbs more energy than a smooth surface, for example, a rough-barked tree versus a smooth-barked tree.

2. Transparency--this property affects the distribution of incoming heat throughout a substance. As examples, water is transparent, while soil is not.

3. Conductivity--the ability to transfer heat through a substance. For example, rock has much better conductivity than wood.

4. Specific heat--the capacity of various materials for containing, holding, or absorbing heat, compared to that of water. For comparison, the specific heat of water is five times that of rock.

5. Surface moisture is also a factor, because heat is gained or lost during changes of moisture state. For example, evaporation cools, while condensation releases heat. We will go into this aspect more later.

Earlier we mentioned the heat gained at the earth's surface during the daytime is lost at night. To maintain a favorable climate, the daily outgoing thermal radiation must equal the incoming solar radiation on the average. How does this occur? Turn to page 5, figure 2, and see the reverse of figure 1.

If the sky is clear, much of the heat absorbed by the surface will radiate back into space. Some heat is absorbed by clouds and other elements in the atmosphere. Clouds may reflect the rays back into the lower atmosphere and onto the surface. Thus, cloudy skies reduce the amount of heat loss at night. This is sometimes called the "greenhouse effect."

Some surface heat is transferred to the surrounding air by conduction and convection. As the surface cools, the air in contact with it also cools. Condensation of moisture in this surface air can occur with the cooling. The condensation of dew releases heat when it changes state, but that heat is soon lost by one of three heat transfer methods. In summation, air near the earth's surface is heated and cooled by conduction, radiation, and convection.

Question 1 relates to diurnal heat gains and losses. Mark your choice or choices, then return to the text.

For question 1 you should have marked statements 1, 2 and 4. These are all reasons for greater heat gains and heat losses and therefore a greater spread in temperatures. In statement 3, there is less condensation of surface air moisture at night. This is not a big factor, however, as the condensation of dew would raise the surface temperature only about one or two degrees.

In figure 3 on page 6, you see again how surface properties affect surface temperatures. Here is an average summer day situation. The four surface areas and the air immediately in contact with these surfaces will have different temperatures resulting from their surface properties.

The lake has a transparent surface, thus distributing heat deeper into its mass. Its color and surface texture may reflect and/or absorb heat at the same time. The specific heat of water is much greater than that of soil; thus considerably more heat is required to raise its temperature. Water's conductivity is good. The evaporation of water will have a cooling effect.

The forested area has a canopy of vegetation with low conductivity. Its color and texture will both absorb and reflect heat rays. Much of the forest floor will be shaded, thus keeping surface temperatures lower. The transpiration or moisture loss from trees and air mixing through the canopy will have a cooling effect. Over all, temperatures will be warmer than on the lake.

Moving to the grass and brush area, temperatures will be considerably warmer because of less vegetation and less shading of the ground. The soil will receive more direct radiation and absorb considerable heat due to color, lack of transparency, lower specific heat, and lower surface moisture.

Finally, the plowed field will have the highest surface temperatures due primarily to color and texture, lack of shading, and no transparency. Soil moisture will probably be higher than in the grass and brush area due to the lack of vegetation. Soil moisture can raise the specific heat and conductivity.

What about heat losses at night? Well, you can reverse the order of these areas. The greatest heat losses and lowest nighttime temperatures will occur in the plowed field, while the lowest heat losses and higher nighttime temperature can occur on the lake. Most of the surface properties responsible for daytime heat gains will affect heat losses as well. Vegetative cover will have some insulating effect and serve to retain surface heat.

Now please answer question 2; mark your choice or choices.

In question 2, you should have marked all of the statements. These are all reasons why forested areas have lower daytime temperatures than grasslands.

We have discussed reasons for diurnal temperature variations in various geo-graphical areas. Figure 4 on page 7 illustrates a typical temperature trace from a low-level station. Note the similarity in temperatures by time of day' for the three days shown. Temperatures range from a nighttime minimum of about 55 degrees to a daytime maximum of about 78 degrees. Also, notice the times in which these minimums and maximums occur.

The difference between these daily high and low temperatures is about 23 degrees. This difference will vary by parts of the country due to local topography and climatic conditions. In the western United States, the daily diurnal temperature difference during the summer is usually about 35 degrees.

Up to this point, we have been discussing air temperatures near the earth's surface. The temperature of the air at different levels in the atmosphere is a much different story. Those temperatures may not seem important to us on the ground, but you will see a little later just how much influence they have on fire behavior.

People who live in mountainous regions know that the high elevations are generally cooler than the low elevations. If you gain altitude in an air-plane or hot air balloon, you experience lower temperatures. On the average, this is true throughout the atmosphere.

There are natural processes responsible for the decrease in temperature at higher altitudes. In meteorology, we describe the temperature differences in terms of temperature lapse rates. There are three lapse rates which are of significance to us. Under item B, list the following:

1. Dry; the lapse rate is 5-1/2°/1,000 feet. This occurs when dry air is moving vertically upward or downward. This temperature change is a function of atmospheric pressure, air density, and the molecular activity of a parcel of air. In other words, the air at lower altitudes is more compressed, more dense, and therefore warmer because of increased molecular activity.

2. Wet; its lapse rate is 3°/1,000 feet. This decrease occurs when moist air is rising. If the same air were dry, it would be decreasing at 5-1/2°/1,000 feet of rise. The difference in lapse rate between 3° and 5-1/2° is due to the latent heat released by condensation. Clouds and perhaps precipitation may result.
3. Normal; its lapse rate averages about 3-1/2°/1,000 feet. This is an average throughout the lower atmosphere over time and space. It changes by time of day depending on air stability and the winds mixing the air at various levels. This will be explained in more detail in Unit 7, Atmospheric Stability and Instability. You should be aware that lapse

rates near the surface can be more than 5-1/2°, which would make that air layer unstable, or it can be less than 3° at various levels, which would be stable air.

Figure 5 on page 8 illustrates moist air moving up one side of a mountain range and descending on the lee side. Notice how condensation in the form of clouds and precipitation can occur as the moist air is cooled by lifting. As the same air descends on the lee side, it begins to warm and condensation stops. This air below the cloud will descend and warm at the dry lapse rate. The cooling and warming processes discussed here are known to meteorologists as adiabatic processes. Unit 7 will discuss how the adiabatic processes can affect fire behavior.

Now do question 3; fill in the blanks.

The first statement in question 3 should be 3°; the second, 5-1/2°; the third, 3-1/2°; and the fourth, 5-1/2°. It's important that you remember these figures, as you will be expected to know them later.

Moisture has entered into our discussion of temperature several times. It's difficult to separate the two when we discuss general weather and its effect on fire behavior. The next portion of this unit, starting on page 9, further discusses atmospheric moisture and its importance to fire control.

You should realize that moisture in the atmosphere can appear in three states--solid, liquid, and a gaseous vapor. It is very rare when the air does not contain some water vapor. When the air is cooled to its saturation point, condensation occurs in the form of clouds and perhaps precipitation. At very high altitudes where the air is very cold, clouds consist of tiny ice crystals. And, of course, precipitation can occur in the form of snow and hail.

An important point to remember is that each time water changes state it either gives off or takes on heat energy. When ice melts it requires about 144 BTUs of heat to change 1 pound of ice to water with a temperature of 32°. This is called the heat of fusion. It takes additional heat to raise the temperature of the water to reach its boiling point. This is about 180 BTUs for 1 pound of water. To change the liquid state into water vapor, it requires an additional 972 BTUs per pound of water. By changing state twice; that is, ice to water to vapor, approximately 1,300 BTUs of heat energy per pound of water has been stored in the moisture which is bound to the air. Any time condensation and freezing occurs, that amount of heat energy will be released, thus raising the temperature of the air.

It is possible in the atmosphere for ice crystals to go directly into water vapor, or water vapor directly to ice crystals. This process is called sublimation. The amount of heat involved in sublimation equals the sum of the heat of fusion plus the latent heat of vaporization.

Now, let's see how well you understand moisture changing states. Do question 4; mark your choice or choices.

In question 4 you should have marked statements 1, 3, and 4.

When discussing moisture in the atmosphere, it's desirable to have some points of reference or means of qualifying the amounts present at any one time or place. The two most common points of reference used are dew point and relative humidity.

The definition of dew point is the temperature to which a parcel of air must be cooled to reach its saturation point. This is a useful reference because it tells at which temperature clouds and precipitation will occur. Does dew point change with changes in temperature or relative humidity? First, you should understand that the temperature of the air influences the amount of water vapor that can be bound to the molecules of air. Water vapor capacity increases with temperature increase. See figure 7 on page 10. There are three parcels of air, each in separate containers. Only relative values of moisture and temperature are shown. At low temperatures, the air will hold only two parts of water vapor. As the temperature increases, it will hold 6, then 12 parts of water vapor. If the very warm air on the right is cooled, it must lose some of its bound water vapor. This will occur through condensation.

In any one stationary parcel of air, the dew point of that air will remain the same as will the amount of moisture in that parcel, regardless of air temperature. But as air temperature increases, so will the capacity of that air to hold more water vapor. The higher the air temperature, the stronger the bond between water and air molecules, and the drier the air seems to be.

To determine how dry or wet the air is at any given temperature, we use a unit of measure called relative humidity. This is defined as the ratio of the actual amount of water vapor in a given volume of air to the amount which could be present if the air were saturated at the same temperature. IVs commonly expressed as a percentage.

Since warm air will hold more moisture than cold air, the percentage of relative humidity must change with changes in air temperature. Figure 8 illustrates this relationship. Again we have three parcels or containers of air. The number of water vapor molecules is the same in each container. At 40° air temperature, the parcel is saturated and will hold no more molecules of water vapor. The relative humidity is 100 percent. If the temperature of that air parcel is raised by 20°, it will hold about twice as many water molecules to reach saturation. Thus, the new relative humidity is now 48 percent. If the temperature is raised another 20°, it will again double its capacity to hold water vapor molecules. The relative humidity is only 24 percent.

The importance of air temperature to moisture is obvious. At 80°, the air has a relatively low humidity and is relatively dry. As it cools, the humidity increases, reaching its saturation point at 40°. Now the air is very moist, and clouds will form. The dew point of the air is 40° in all three containers in the illustration.

Figure 8 illustrates an interesting re relationship between temperature and relative humidity. That is, with each 20° rise in temperature, the relative humidity drops to approximately one-half.

See page 11. We can use this relationship as a rule of thumb. Remembers relative humidity doubles with each 20° decrease, or halves with each 20° increase in temperature within a stationary airmass.

Let's use the rule of thumb in question 5; mark your choice.

In question 5, you should have marked answer number 3. Relative humidity would double from 40 percent to 80 percent with a 20° decrease in temperature.

Generally, as temperature goes up, relative humidity goes down and vice versa. This relationship is illustrated in figure 9. Here typical temperature and relative humidity traces, as recorded for three days with a hygrothermograph, show the inverse relationship. Remember that the top scale is in degrees Fahrenheit, while the bottom scale is in percent. Take a moment to study the figure; then move on to question 6 on page 12.

In question 6, you should have marked statements 2 and 3. If you have any problems with these statements, go back and review page 11.

On page 13, exercise 1 requires that you match some meteorology terms with their definitions. You may have to look up some of them in the glossary. When you've finished, return to the text.

Now please turn to page 14. Why are we devoting an entire unit to temperature and moisture relationships? Well, part of the reasons is in question 7; mark your choice or choices.

In question 7, you should have marked all the statements. These are some good reasons for keeping current with relative humidity.

Our next objective is to teach you how to determine the relative humidity of the air. You will need an instrument called a psychrometer. The instrument in the lower right of figure 10 is one kind of psychrometer. It has two thermometers, one with a cotton wick that is wetted. The thermometer with the wet cotton wick will give wet bulb readings; the other will give dry bulb readings. The wet bulb must be ventilated with a small fan or other means to cause rapid evaporation of the water in the wick. Heat is required to change water to vapor. Thus the wet bulb will be cooled as it is ventilated and evaporation occurs. When the lowest reading is obtained on the wet bulb thermometer, read and record temperatures from both thermometers. These readings will be entered into a special table to obtain relative humidity.

The psychrometer shown is battery powered but requires some manual operation. There also are automatic ways of determining and recording temperatures and relative humidity. The instrument in the upper right is called a hygrothermograph. It measures and records both temperature and relative humidity on a continuous recording graph. This instrument is utilized by placing it in a specially designed field instrument shelter like the one shown on the left. Certain standards have been established to insure uniformity of measurements, for example, the shelter will be positioned 4 feet above the ground in a nonshaded, open area that has good air ventilation. Such shelters and weather instruments are found at every weather station.

On page 15, see question 8; mark your choice or choices.

For question 8 you should have marked choices 1, 2, and 3. If you marked number 4, remember that the thermometers must be shaded, as inside the shelter. However, the shelter should be in the open.

Now we will proceed to the next steps in determining relative humidity. On page 16 is a psychrometric table. On page 15, we have listed six steps illustrating how to use these tables. Read through the six steps, then return to the text.

Let's take a closer look at figure 11. First, the table is for use at elevations between 501 and 1,900 feet above sea level. Note that the wet bulb temperatures across the top range from 39° to 90°. On the left side, the dry bulb temperatures range from 61° to 90°. Wet bulb readings will always be' lower than dry bulb readings unless the air is saturated. Then the two will be the same, and the relative humidity will be 100 percent

Let's enter two temperature values into this table. Find a wet bulb reading of 65° at the top. Now locate a dry bulb reading of 80° on the left side Follow the line from 80°, horizontally, until you intersect with the 65° column. The two values in the block are 56 and 45. The top value of 56 is the dew point temperature, while the bottom value is relative humidity.

Question 9 on page 15 requires that you use this table. Mark your choice.

The answer to question 9 should be number 2, 16 percent. If you did not get 16 percent, go back to the table and try to locate the proper block.

Now do question 10 on page 17; mark your choice or choices.

In question 10, you should have marked statements 2 and 3. The amount of cooling due to evaporation affects wet bulb temperatures. Cooling occurs because heat is required to evaporate water on the wet bulb wick.

Another use for dew point temperature is to determine relative humidity at various temperatures within a fixed or stationary airmass. The steps to accomplish this task are on page 17. Read through those steps, then return to the text.

Since this is an important and useful procedure, let's do a few more problems. Do exercise 2 on page 18, then return to the text.

One of the questions in exercise 2 asked about the airmass being wet or dry. Wet and dry are used in a relative sense, but the dew point of an airmass gives the best indication of its moisture content. The example on the bottom of page 18 shows a relatively moist airmass with a dew point of 60°. A relatively dry airmass has a dew point of 38°. This illustration shows that a cool, dry airmass may actually have a higher relative humidity than a warm, moist airmass. Relative humidity alone can be misleading when com-paring atmospheric moisture conditions.

The last part of this unit addresses clouds and their effect on fire weather. See page 19. Clouds, consisting of many minute water and/or ice particles in the atmosphere, are the result of condensation of water vapor in air. Clouds are classified according to levels or heights of their bases in the atmosphere. Under item C list these levels as the following:

1. High or cirro, which are clouds that develop bases above 20,000 feet, including cirrus, cirrocumulus, and cirrostratus.

2. Middle or alto, which are clouds that develop bases between 6,500 and 20,000 feet, including altocumulus, altostratus, and nimbostratus:

3. Low or strato, which are clouds that develop bases from near the ground to 6,500 feet, including stratus and stratocumulus.

4. Vertical development, which are clouds with bases that range from 1,500 to 10,000 feet, and tops to 50,000 feet, including cumulus and cumulonimbus.

5. Fog, which is cloud-like in nature, but forming at, and touching the surface of the ground.

Several of these clouds are illustrated in figure 12 on page 20. We will not go into the identification of all of these clouds. Only clouds of special significance to firefighters will be discussed.

How do clouds develop? There are two principal ways in which air can reach its saturation point and cause clouds to form. One is through the addition of moisture to the air, and the other through lowering of air temperature to its dew point. Figure 13 illustrates both of these processes.

Warm, moist air may be cooled by passing over a cold surface. The cooling takes place near the surface, but if winds are strong, they mix the cooled air so clouds form several hundred or more feet above the ground.

Nighttime cooling of the ground surface by radiation, and the subsequent cooling of adjacent moist air, may produce saturation and fog.

Air can become saturated by the addition of moisture. This may occur by evaporation as cold, dry air passes over warm water. Clouds and precipitation can also occur when warm rain falls through cold air; for example, beneath a warm front. Rain falling from the warm clouds above the front causes clouds to develop.

The most important cooling method is by lifting of air (see figure 14). Lifting can be accomplished in these ways--thermal, orographic, or frontal action. These processes produce most clouds. Lifting processes will be discussed more in Unit 7 on atmospheric stability and instability.

Several clouds are especially important to the firefighter. Some of these can have detrimental effects on a fire. Other clouds, called indicator clouds, aid the firefighter. Recognizing them early may help firefighters to anticipate weather to follow.

A real troublemaker, and the most potentially dangerous cloud, is the cumulonimbus or thunderhead (see figure 15 on page 21). By the time you notice this cloud, weather problems may already be occurring. Thunderheads produce strong, gusty winds, sometimes in excess of 60 mph from their bases. These winds can spread out and be experienced on the ground for several miles. They may produce cooler conditions with higher humidity, occasional rain, and lightning.

Thunderheads begin as small, fair-weather cumulus clouds, and grow as atmospheric conditions become more unstable. Towering cumulus clouds, which have not yet developed an anvil-shaped top with an icy appearance, are the clouds to watch carefully. Thunderheads can occur individually as airmass thunder-storms or as a line or wall of thunderstorms associated with a cold front.

Some of the clouds described in this part can produce precipitation, which usually aids the fire manager. Now do question 11 on page 22; mark your choice or choices.

In question 11, you should have marked statement numbers 2, 3, and 4. In statement 1, it's important to have adequate moisture only at middle and lower levels in the atmosphere to produce precipitation. Most rainfall is produced from these levels.

The next indicator cloud is cirrostratus (see figure 16). Cirrostratus clouds are very high, wispy clouds that frequently precede a warm front. The clouds thicken, increase and lower as the front approaches. They indicate rain is possible within the next day or two.

Figure 17 on page 23 illustrates how cirrostratus clouds are formed. The tops of tall cumulonimbus clouds at the weather front are frequently blown off by strong winds aloft and are carried for 500 or more miles. Cirrus clouds can be produced from both warm and cold fronts, but they are more extensive with warm fronts. When you see cirrus clouds with a cold front, you usually are seeing the front itself.

Now do question 12; mark your choice or choices.

In question 12, you should have marked all of the choices. These are all reasons for watching the sky to detect and anticipate pending fire weather conditions.

There are two more important indicator clouds which are in the middle or alto level. The first is altocumulus castellatus. See figure 18 on page 24. 'When seen in the morning, these clouds are strong indicators that thunderheads can develop later in the day.

The other is altocumulus lenticularus (see figure 19). These lens-shaped clouds are usually stationary and develop from wave action of strong winds at middle altitudes. These clouds are usually associated with wave action on the lee side of high, north-south mountain ranges. They are indicators of high wind speeds at those altitudes, but these winds can lower as the day progresses. Your fire could experience strong surface winds, and smoke columns may be sheared by these winds. Spotting is always a concern with strong winds.

Most of these clouds will be discussed again in the units on winds, and/or atmospheric stability and instability. An objective of this unit was to introduce clouds and how they can be used as indicators of pending weather. On page 25, exercise 3 is on clouds as indicators. Please do the exercise. When you have finished, check your answers; then prepare to take the unit test.