

## UNIT VII--ATMOSPHERIC STABILITY AND INSTABILITY

The stability or instability of the atmosphere is a concern to firefighters. This unit discusses how changes in the atmosphere affect fire behavior, and how firefighters can recognize existing and changing atmospheric conditions. Before starting the unit, read the instructions to students on page 1 and then the unit objectives on page 2 of your workbook. When you have finished, return to this script.

In earlier weather units of this course, we discussed the facts that the earth's gaseous mantle, called "the atmosphere," is very fluid, with air constantly moving and mixing, and that air changes in temperature, moisture, pressure, and other properties. By now you know that air moves horizontally or vertically in response to the earth's rotation, to large and small scale pressure gradients, to various lifting mechanisms, and to gravity.

Unit 6 concentrated on the horizontal movement of air or wind. In this unit, we will discuss vertical air movement, what causes it, and what it means to firefighters. This vertical movement, either upward or downward, is generally influenced by the degree of stability or instability of the atmosphere at any particular time.

What is atmospheric stability? On page 3, we give a simple definition of stability as the resistance of the atmosphere to vertical motion. Air may be stable, neutral, or unstable, depending on its temperature distribution at various levels in the atmosphere.

Temperature distribution and lapse rates were discussed in Unit 4, where you learned that temperatures normally increase as we get closer to the earth's surface. This is due in part to the greater molecular activity of denser, more compressed air at lower altitudes. These conditions change throughout a 24-hour period, as the daytime solar heating and nighttime heat loss to and through the atmosphere tend to modify the temperature distributions.

The term "adiabatic process" was used in Unit 4, which simply means warming by compression, or cooling by expansion, without a transfer of heat or mass into a system. As air moves up or down within the atmosphere, it is affected by this process. See figure 1. This temperature difference will be 5-1120 decrease per 1,000 feet increase in altitude. This is also termed the dry adiabatic lapse rate. The atmosphere may or may not have a temperature distribution that fits the dry adiabatic lapse rate. Usually it does not.

The actual lapse rate may be greater or less than the dry adiabatic lapse rate and may change by levels in the atmosphere. This variation from the dry adiabatic lapse rate is what determines whether the air is stable or unstable. If the air is unstable, the vertical movement of air is encouraged, and this tends to increase fire activity. If the air is stable, vertical movement of air is discouraged, and this usually decreases or holds down fire activity. The importance of this atmospheric property will become evident by the time you have completed this unit.

The actual temperature lapse rate in a given portion of the atmosphere could range from a plus 15° per 1,000 feet to a minus 15° per 1,000 feet. These would represent the extremes of very stable air to very unstable air. Rather than be concerned with all of these degrees of stability or

instability, we usually describe the atmosphere as falling into one of five conditions. See item A on page 4, and complete the blanks. The atmosphere is highly variable in air temperature distribution. For dry air it ranges as follows:

1. Very stable. Here temperature increases with increase in altitude. This is a "plus" temperature lapse rate, or an inversion.
2. Stable. The temperature lapse rate is less than the dry adiabatic rate, but temperature decreases with altitude increase.
3. Neutral. The temperature lapse rate is the same as the dry adiabatic rate of  $5.5^\circ$  decrease per 1000-foot increase.
4. Unstable. The temperature lapse rate is greater than the dry adiabatic rate. It may be 6 degrees or more.
- 5: Very unstable. The temperature lapse rate is much greater than the dry adiabatic rate and is called super-adiabatic.

You will want to refer back to these five general conditions later in the unit.

Now try question 1. Mark your choice or choices, then return to the text.

Under question 1, you should have marked statements 2 and 4. Unstable air conditions tend to increase or promote fire activity, while stable air conditions tend to decrease or hold down fire activity.

Next we'll look at the effects of stability or instability on vertical air movement. On page 5, figure 2 illustrates three general atmospheric conditions--stable, neutral, and unstable air. We said that stable air tends to resist vertical air movement. If a horizontally moving parcel of air is lifted or forced to rise, as over a mountain, that parcel will tend to settle back to its original level. It is heavier than the air around it; therefore, it will sink back, if possible, to the level from which it originated.

If the atmosphere is neutral; that is, the actual temperature lapse rate equals the dry adiabatic lapse rate, a parcel of air that is lifted will be neither heavier nor lighter at a different altitude. As this parcel is forced up, it decreases in temperature at a rate of  $5\text{-}1/2^\circ$  per 1,000 feet. The surrounding air at the new altitude will have the same temperature, and it will remain neutral.

If the atmosphere is unstable, any parcel of air that is lifted will tend to rise like a hot air balloon. As this parcel rises, it decreases in temperature at a rate of  $5\text{-}1/2^\circ$  per 1,000 feet, and will continue to rise until it reaches a level in which its new temperature equals that of the surrounding air.

In Unit 4, we learned that as a parcel of air cools, its relative humidity increases. If the parcel cools enough, 100-percent relative humidity, or its dew point, will be reached. At that point

clouds form. Saturated air that continues to rise gives up more and more of its bound moisture as it cools. This saturated air now cools at a lesser rate, about  $3^{\circ}$  per 1,000 feet, due to the released latent heat of condensation. Air rises and cools at the dry adiabatic lapse rate until it reaches its saturation point and then continues to rise and cool at the wet adiabatic lapse rate.

What causes these differences in temperature lapse rates in the atmosphere? Well, there are several factors that contribute to varying temperature distributions, but the most important is heating and cooling at the earth's surface. See figure 3. As the earth loses its heat at night through radiation, the air in contact with the ground also cools. Conduction becomes an important process here, as air at lower levels cools faster than the air above. This creates a condition of cool, heavier air below warmer air. The layer of cool air above the surface deepens as the night progresses. In mountainous terrain, this condition is even more pronounced in the valleys, as cool air drainage from the slopes above helps to deepen the layer of cold air. The deepening of the cool air layer is also affected by the amount of cloud cover at night. Clear nights cool faster than cloudy nights. Warmer air just above a cool air layer creates a very stable air condition. Smoke or any other parcel of air that is forced to rise will stop when the warmer air is reached. This inversion layer discourages vertical air movement.

Conditions usually begin to reverse after sunrise. As the earth's surface is heated by solar radiation, it warms the air in contact with it and above it by conduction and convection. The stable air at lower levels warms until it is no longer colder than the air above, and the temperature lapse rate approaches the dry adiabatic rate. Inversions usually disappear sometime before noon as unstable conditions continue to develop. Air near the surface is not much warmer than the air above, thus making it buoyant and able to rise. Any lifted parcel of air will continue to rise until it reaches a level of equal temperature. A smoke column could rise many thousands of feet.

The lower atmosphere at night is usually always stable; whereas, during the daytime it is usually unstable. This is especially true if the weather is fair with mostly clear skies. Stable or unstable air conditions can develop under cloudy skies, but their degree of development is usually less.

See page 6. From the two illustrations in figure 3, we can conclude that diurnal changes of temperature in the lower atmosphere occur due to heating and cooling at the earth's surface. We can also conclude that cooling from below promotes stability, while heating from below promotes instability. These diurnal changes in the lower atmosphere have a pronounced effect on fire behavior.

Now do question 2; mark your choice or choices.

In question 2, statement 2 is true.

In the next portion of this unit, we will discuss how atmospheric stability affects fire behavior. What do you remember about stable air? On page 7, see question 3; mark your choice or choices.

Statements 2 and 4 are true. In stable air, a parcel of air that is lifted will settle back to its original level. This is because the actual lapse rate is less than the adiabatic lapse rate of  $5\text{-}1/2^{\circ}$

decrease per 1,000 feet increase. Thus, the parcel will become heavier in its new surrounding air and will sink to its original level.

There are several aspects of stable air conditions that should be understood by the firefighter. One is the relationship of surface inversions to thermal belts. In figure 4, we again illustrate the nighttime drainage of cool air into a valley. Air in contact with the upper slopes cools and flows downslope like water, always seeking the lowest elevation. This drainage is most prominent in side canyons and draws.

Depending on the size of the valley, the pooling of cool air may be several hundred feet deep. An inversion develops above the pool of cool air. Turn to page 8. Remember, an inversion is a layer of air in which the temperature increases with increase in altitude.

Where the inversion layer contacts the mountain slopes, we have a relatively warm area called the thermal belt. See figure 5 on page 8. At night, the temperature in this region is actually warmer than on the slopes above or below. The elevation of the thermal belt varies by locality and depends on the time of night and the size of the valley below. Its depth also varies.

Thermal belts can, and often do, have a significant effect on fire control efforts. To the firefighter, the thermal belt is an area on a mountainous slope that typically experiences the least variation in diurnal temperature, has the highest average temperature, and has the lowest average relative humidity. Overall, this area can have the highest average fire danger. Most important is the continued active burning during the night, while areas above and below the thermal belt are relatively quiet.

On page 9, please answer question 4.

Statements 3 and 4 are true. Stable air conditions always exist in a thermal belt. However, firefighters are often surprised by active burning in this area throughout the night. This is because of higher temperatures and lower humidities in the thermal belt. Because the air is stable, winds will tend to be relatively light and steady.

Another aspect of stable air conditions which can create problems for firefighters is "subsidence." Subsidence is a slow sinking motion of high level air over a broad area occurring in high-pressure systems. The sub-siding air is warmed by compression and becomes more stable. See figure 6. Subsidence is a slow process that occurs over a period of several days. During summer and autumn, somewhat stationary, deep high-pressure cells often develop over relatively large areas of the land.

If the high-pressure system persists for a period of days, a subsidence inversion aloft slowly lowers toward the surface. The cold, dry air at very high altitudes, which is lowering, becomes warmer and drier as it reaches lower altitudes. The tops of mountain ranges will experience the warm, very dry air first. If this condition persists, fuels are dried out and burning conditions become severe.

Another important-effect of subsidence can be foehn winds. See figure 7 on page 10. Foehn winds often occur on the lee slopes of prominent mountain ranges when the windward sides of the mountains are exposed to areas of subsidence. Heavy, stable air within the high-pressure cell pushes out in all directions from the center of the high but is restricted in its horizontal movement by the presence of the mountains. Eventually, this heavy air pours over the ridges and through canyons, creating strong, warm, dry winds at lower elevations on the lee side of the mountains. The character and effects of foehn winds were discussed in Unit 6.

Now do question 5; mark your choices.

In question 5 on page 10, you should have marked choices 2, 3, and 4. All of these were discussed in this portion of the unit.

The next portion, starting on page 11, concentrates on atmospheric instability and its effects on fire behavior. Erratic or severe fire behavior is frequently associated with unstable air conditions. Let's see what you remember about instability. Do question 6.

Statements 1 and 4 are true. In an unstable atmosphere a parcel of air that is lifted will continue to rise. This is because the actual lapse rate is greater than the dry adiabatic lapse rate; thus any parcel of rising air will continue to be warmer than surrounding air and will be buoyant.

Figure 8 illustrates some forms of instability. Strong surface heating produces several kinds of convective systems. Upslope winds develop along heated slopes and convection currents continue to rise. Superheated air in flat terrain escapes upward in bubbles or in the form of whirlwinds or dust devils. The height to which convective currents and bubbles of air rise will be dependent on the stability or instability of the atmosphere at various levels.

How does this affect fire behavior? See item B page 12. Atmospheric instability can contribute to increased fire behavior by increasing the following:

1. The chances of dust devils and firewhirls,
2. Other convective wind activity at the surface,
3. The heights and strengths of convection columns, and
4. The chance of firebrands being lifted by the column.

We'll look at each of these problem areas. Dust devils are rather common, sometimes erratic in their movement, and have been known to scatter fire and cause spotting across fire control lines. Firewhirls are much less common but present serious safety and security problems on the fireline. Firewhirl development will be discussed in detail in Unit 9 of this course.

Any convective lifting at the surface causes indrafts from adjacent areas to replace the rising air. These indrafts can be gusty and erratic.

Smoke convection columns rise much higher in unstable air. Chimneys, of a sort, develop with indrafts feeding the fire at the base of the column and strong convective currents rising through the column. The greater the instability and fire intensity, the stronger the indrafts and convection column updrafts. Of primary concern is the spotting potential of high, well developed convection columns due to the rise of firebrands in the column. Convection column development and spotting by aerial firebrands will be further discussed in Unit 9.

We'll give you some more examples of instability which occur on a daily basis. Figure 9 illustrates rising bubbles of air from the surface which are called updrafts or thermals. Sailplane pilots seek out rising air currents or thermals which can give their aircraft lift and prolong flight. Large soaring birds also take advantage of thermals to sustain flight. Uneven heating at the surface produces thermals at some locations more readily than others. Cumulus clouds are often good indicators of thermals produced from below. These clouds may develop at specific locations and then drift with the prevailing winds.

We have described one of the common lifting processes which produce clouds in an unstable atmosphere. There are other lifting processes that also aid cumulus cloud buildups. See page 13. The cloud most likely to cause problems for the firefighter is the cumulonimbus or thunderhead. There are four lifting processes which can cause thunderstorm development. Under item C, list the following: Convection or thermal, orographic, frontal, and convergence. You should understand each of these processes.

Figure 10 illustrates three of the lifting processes. We have already discussed thermal lifting. Orographic lifting occurs in mountainous terrain when a mass of moving air is forced to rise because of the presence of slope. Air that is forced upward cools adiabatically. If this air reaches its saturation point, clouds develop. Orographic lifting and thermal lifting often work together to produce cumulus clouds in mountainous areas.

The third process is frontal lifting. Here a moving, cooler air mass pushes its way under and lifts a warmer air mass. Again, this lifting action can produce cumulus clouds if saturation occurs. Cumulus cloud development is usually associated with cold front passages, while stratus clouds generally accompany a warm front.

The fourth lifting process, convergence, is illustrated in figure 11 on page 14. Here you see the relationship of convergence to subsidence. In a high-pressure cell, air is piled very high, thus exerting more weight and pressure on air within the cell. The result often is "subsidence," and "divergence," or air flowing out of the a cell at the surface. Diverging air from the high-pressure area always flows toward lower pressure, which is a nearby low-pressure area. Air coming into the low converges to a central point and is then forced up in the center of the cell. Air that is lifted within the low-pressure area frequently causes cloudiness and sometimes precipitation.

Now we'll review the four lifting processes by completing an exercise. Please do exercise 1 and check your answers; then return to the text.

Starting on page 15, the next portion of this unit deals with ways of determining atmosphere stability or instability. There are generally two methods that can be used in the field--visual

indicators and temperature measurements at different elevations or altitudes. We will discuss each of these.

First, note the visual indicators for stable air in figure 12 on page 15. These are clouds in layers, with little vertical motion; stratus type clouds; smoke column drifts apart after limited rise; poor visibility in lower levels due to accumulations of haze and smoke; fog layers; and steady winds. These are all factors that are often observable in the field.

The visual indicators for unstable air are given in figure 13 on page 15. Here clouds grow vertically, and smoke rises to great heights; cumulus type clouds are present; upward and downward air currents, gusty winds, good visibility, and dust whirls are also common.

Using visual indicators is the easiest way to recognize air stability and instability, and the firefighter should be observant of these at all times. However, there will be times when limited visibility will not permit observations at various levels, or perhaps a combination of stable and unstable indicators may confuse the field observer. For these reasons we offer an alternative method. Turn to page 14. Measuring temperatures at various altitudes can help you determine temperature distribution and evaluate the degree of stability or instability of the atmosphere.

Figure 14, on page 16, gives two examples of atmospheric temperature distributions. The situation on the left has temperature readings from three elevations--90° at the fire, 78° at a lookout, and 66° from an aircraft. There is a difference of 2,000 feet elevation between each, and 12° difference between each location. The temperature lapse rate is 6° decrease per 1,000 feet increase in elevation. This lapse rate is greater than the dry adiabatic rate; thus the atmosphere is unstable.

The illustration on the right gives four temperature readings taken at different locations on a slope. Elevations are not given, but we can see that there is a plus lapse rate below midslope and a minus lapse rate above midslope. From this we can conclude that an inversion exists at the 50 level. The air in the canyon below that level is very stable.

Determining actual temperature lapse rates from your own temperature readings is not difficult. Simply divide the temperature difference by the elevation difference expressed in 1,000's of feet. Usually you will have a minus lapse rate, i.e., where temperature decreases with altitude increase. However, under inversion conditions, you may have a plus lapse rate where temperature increases with altitude increase. When you have determined a temperature lapse rate for your situation, check the condition of stability or instability as described on page 4 of this unit.

We want you to practice determining atmospheric stability and instability from temperature distribution data. On page 17, exercise 2 is intended for that purpose. Please complete the exercise; then restart the tape. (BEEP)

We have provided several examples of inversion conditions. How do these affect fire control efforts? Please do question 7 on page 18.

In question 7, you should have marked statement 3. All are generally true statements about surface inversions. However, major problems can occur when the inversion breaks and unstable air conditions develop. This is not necessarily a gradual process, with adequate warning, but substantial weather changes can occur in a matter of minutes. To be surprised by an inversion breakup can present serious safety and control problems.

One way to keep advised of inversion breakups and subsequent weather changes is to monitor the weather. Adequate weather monitoring requires constant or frequent observations of weather elements to detect changing conditions that could influence the behavior of a fire. Weather monitoring will be discussed more in Unit 8.

Now move on to question 8 on page 18; mark your choices.

In question 8, you should have marked choices 1, 3, 5, and 6. The other two are indicators of a stable atmosphere.

Smoke columns are one of the better visual indicators of atmospheric stability or instability. Exercise 3 presents several atmospheric situations that you could encounter on a fire. Complete this exercise; then return to the text.

This unit has presented basic information to help you determine atmospheric stability and instability and to understand the effects that various atmospheric conditions can have on fire behavior. We recognize the atmosphere as a very dynamic system with a number of physical processes interacting to produce our weather. The degree of stability or instability is perhaps the least understood. We have included a supplemental summary on pages 20 and 21 which may help your understanding of this complex process. Please read the summary; then prepare for the unit test.