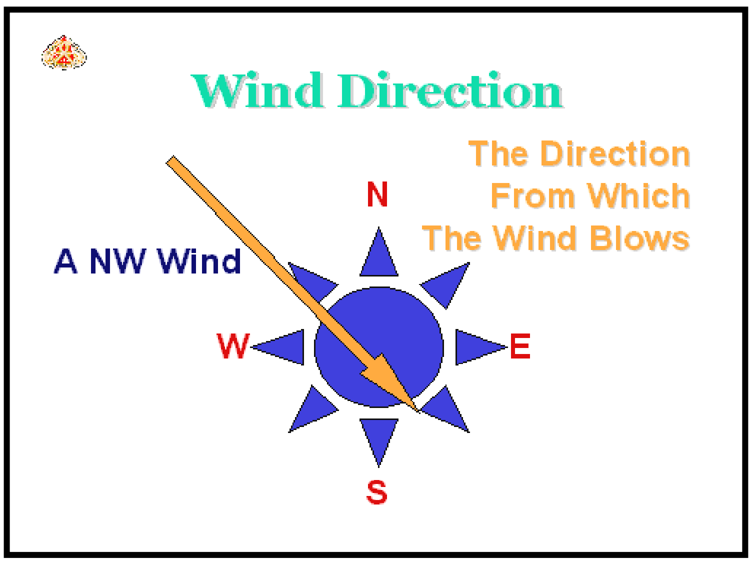
Weather is the most critical element of fire behavior. Weather is also the most unpredictable element. Firefighting personnel should be knowledgeable in local weather conditions. When operating in unfamiliar areas, attempt to gain local information from incident action plans, newspapers, and local personnel.

WIND

Controls spread of fire. Supplies fresh air which speeds combustion. Some larger fires create their own wind. Local winds are part of the diurnal cycle, or the daily heating and cooling of the earth.

What is Wind?

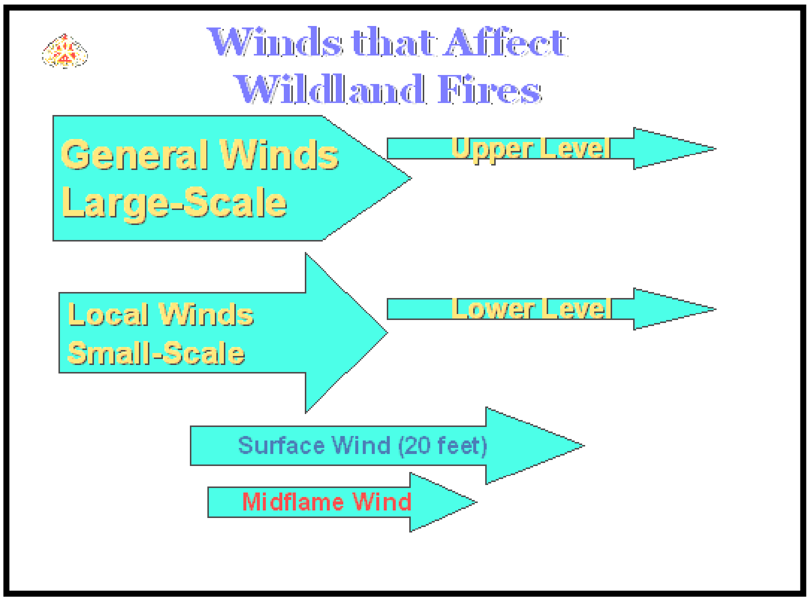
By simple definition, wind is the horizontal movement of air relative to the earth's surface. This movement of air is similar to water flowing in a stream. We are concerned with winds of two major scales in the atmosphere -- the larger scale general wind and the smaller scale local wind. Portions of either of these can contribute to the actual 20-foot surface wind.



Wind Direction

The direction from which the wind is blowing. For example, an easterly wind is blowing from the east, not toward the east. It is reported with reference to true north, or 360 degrees on the compass, and expressed to the nearest 10 degrees, or to one of the 16 points of the compass (N, NE, WNW, etc.).

Before we get very far, let's discuss a concept that has caused much confusion in the past -- that is wind direction. Wind direction is defined as the direction from which the wind is blowing. When you hear the wind described as "northerly," this means the wind is from the north. If you are facing into the wind, name the wind from that direction. It is important that every firefighter understand this, because someday it could save your life.



How Wind Affects Wildland Fires

Wind affects wildland fires in several important ways.

- It carries away moisture-laden air and hastens the drying of wildland fuels.
- Once a fire is ignited, winds aid combustion by increasing the supply of oxygen.
- Wind increases fire spread by carrying heat and burning embers to new fuels. The common name is spotting.
- It bends the flames closer to unburned fuels ahead of the fire.
- The direction of fire spread is determined mostly by the wind direction.

SEA AND LAND BREEZES

Local Winds

We define local winds as smaller-scale winds caused by local temperature differences. Terrain has a very strong influence on local winds, and the more varied the terrain, the greater the influence.

Importance of Local Winds

Winds of local origin can be as important in fire behavior as the winds produced by the large-scale pressure patterns. In many areas, the general winds are blocked by high terrain, and local winds are the predominant daily winds. If their interactions are understood and their patterns known, local winds can be predicted with reasonable accuracy.

We're going to discuss some common local winds -- sea and land breezes, slope winds and valley winds.

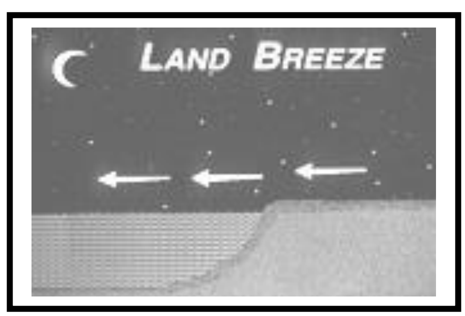
The Sea Breeze and How It Develops

The surface properties of land and water cause the land surfaces to become warmer than water surfaces during the daytime. As a result of this local-scale temperature and pressure difference, a sea breeze begins to flow inland from over the water, forcing the warm air over the land to rise and to cool. In the absence of strong general winds, this air flows seaward aloft to replace air that has settled and moved toward shore, and thus completes a circulation cell.

The sea breeze begins between midmorning and early afternoon, depending on time of year and location. It strengthens during the afternoon and then ends shortly after sunset. The sea breeze first begins at the coast, then gradually pushes farther inland during the day, reaching its maximum penetration about the time of maximum heating. Cooler temperatures and higher relative humidity accompany the sea breeze as it moves inland. Typical speed of the sea breeze is 10 to 20 mi/h. However, it can locally attain 20 to 30 mi/h along the California, Oregon, and Washington coasts.

Along the Pacific coast, fog or low clouds, very cool temperatures, and high humidity accompany the sea breeze as it moves inland. This usually results in diminished fire activity.

The Land Breeze and How It Develops



The land breeze at night is the reverse of the daytime sea breeze circulation. At night, land surfaces cool more quickly than water surfaces. Air in contact with the land then becomes cooler than air over adjacent water. Again, a difference in air pressure develops between air over the land and over the water. The air must be replaced, but return flow aloft is likely to be weak and diffuse and is diminished in the prevailing general winds. The land breeze begins 2 to 3 hours after sunset and usually ends shortly after sunrise. Wind speeds with the land breeze are lighter than with the sea breeze, typically between 3 and 10 mi/h.

SLOPE WINDS

Another type of local wind is the slope wind. Slope winds are diurnal winds present on all sloping surfaces. They flow upslope during the day as the result of surface heating, and downslope at night due to surface cooling. Slope winds are produced by the local pressure gradient caused by the difference in temperature between the air near the slope and air at the same elevation away from the slope.

Upslope winds

During the day, the warm air sheath next to the slope serves as a natural chimney and provides a path of least resistance for the upward flow of warm air. The layer of warm air is turbulent and buoyant, increasing in depth as it progresses up the slope. This process continues during the daytime as long as the slope is receiving solar radiation. When the slope becomes shaded or night comes, the process is reversed.

Down slope winds

A short transition period occurs as a slope goes into shadow; the upslope winds die, there is a period of relative calm, and then a gentle, smooth down slope flow begins. Down slope winds are very shallow and may not be represented by a 20-foot surface wind speed. The cooled dense air is stable, and the down slope flow tends to be quite smooth and slower than upslope winds. The principle force here is gravity. Down slope winds usually continue throughout the night until morning, when slopes are again warmed by solar radiation.

The times during which winds change from down slope to upslope and vice versa can depend on aspect, time of year, slope percent, current weather conditions, and other lesser factors.

VALLEY WINDS

Up valley winds

During the day, air in mountain valleys and canyons tends to become warmer than air at the same elevation over adjacent plains or larger valleys, thus creating a pressure gradient that results in up valley winds. The main difference between upslope winds and up valley winds is that the up valley winds do not start until most of the air in the valley has warmed.

Usually, this is late morning or early afternoon, depending largely on the size of the valley. These winds reach their maximum speeds by mid or late afternoon and continue into the evening.

Down valley winds

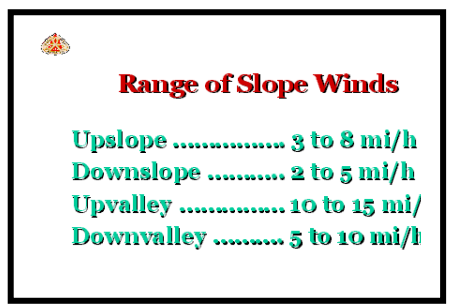
The transition from up valley to down valley flow takes place in the early night. The transition is gradual; first the downslope winds, then a pooling of cool, heavy air in the valley bottoms. The cools air in the higher valley bottoms will flow to lower elevations and increase in velocity as the pool of cool air deepens. This continues through the night and diminishes after sunrise.

The velocities of the slope and valley winds vary considerably with the terrain and current weather conditions. For example, slope and valley winds develop better under clear skies when the heating and cooling processes are more pronounced. Slope and valley winds are less pronounced and may not even develop under cloudy skies. Other factors to consider would be the length of, and steepness of, the slope. Aspect is also important; north slopes typically have the lightest upslope winds due to their reduced isolation.

Determine Typical Slope and Valley Winds During a 24-hour Period

Range of Slope and Valley Wind Speeds

We can give you some broad ranges to indicate typical wind speeds in mountain topography. Upslope winds usually range from 3 to 8 mi/h, while down slope winds are somewhat less, typically 2 to 5 mi/h. Up valley winds are normally stronger, with a range of 10 to 15 mi/h common, while down valley winds can be 5 to 10 mi/h.



Time of Day Influences Strength of Slope and Valley Winds

The discussion of slope and valley winds to this point might suggest that upslope and up valley winds occur on all slopes at the same time. This is not usually the case. For one example, let's suppose we have a ridgeline and canyon parallel to each other running north and south. In the morning, the sun will heat the east aspects, but steeper west aspects remain shaded.

Upslope winds can occur on the east slopes, while down slope winds occur on the west slopes. As the sun passes overhead and into the afternoon position, the west slopes become heated and the east slopes become shaded. The east slopes can have down slope winds while the west slopes have upslope winds. This is the reverse of the morning situation.

Winds of Most Concern to Firefighters

The wind conditions that we have covered so far may, or may not, be considered problem winds to the firefighter. These are normal, everyday winds with which the firefighter must deal. Moderate to strong winds present a particular concern because fire behavior is so reactive to wind. Firelines are most often lost, large acreage burned, and property and lives lost when strong winds fan a fire out of control. We will talk about four kinds of winds that produce severe fire weather conditions -- cold front winds, foehn winds, thunderstorm downdrafts, and whirlwinds. Whirlwinds can be either dust devils or fire whirls.

How surface winds shift with time

Wind direction is always the direction from which the wind is blowing. As fronts move through a region, the winds at a given location will experience a marked shift in direction.

Ahead of a warm front, winds will be out of the northeast and east. Winds ahead of an approaching cold front usually shift gradually from southeast to south, and on to southwest. As the cold front passes, winds shift rapidly to west, then northwest.

Wind Speed Changes with Passage of Fronts

Wind speeds increase in strength as a front approaches, and usually become quite strong and gusty when the front passes an area. This is because pressure gradients are tight, and strong upper winds are more easily mixed down to the surface in very unstable air. Typical cold front wind speeds range between 15 and 30 mi/h, but can be much higher with strong cold fronts. Warm fronts are relatively weak compared to cold fronts, and have little significance during fire season.

Cold fronts may bring thunderstorm activity, with possible precipitation. However, during the summer months in the west, cold fronts are often dry. They will have the moderate to strong winds (up to 50 mi/h) and cooler air, but not enough moisture for precipitation.

Foehn Winds

Another kind of wind that causes firefighters great concern is the foehn wind. Foehn winds are a special case of general winds, associated with mountain range systems. They occur as heavy, stable air pushes across a mountain range and then descends the slopes on the leeward side, becoming warmer and drier due to compression. Foehn winds tend to be stronger at night because they can then combine with local down-canyon winds.

Chinook winds

The Chinook occurs on the east slopes of several large mountain ranges in the Western United States. Chinook winds are most prevalent on the east side of the Rocky Mountains during fall and winter. In the case of the Chinook winds, air pushed up on the windward side is cooled to the point that clouds and precipitation may occur. As the air passes over the mountains and descends on the lee side, it is warmed at 5.5 degrees per 1,000 feet of fall. It also gains velocity as it passes through the constricted topography and accelerates as it flows downslope. In descending to the lowlands on the leeward side of the range, the air arrives as a strong, gusty, drying wind.

Santa Ana Winds

The Santa Ana creates the most critical fire weather situation in areas of Southern California during the fall and winter. Foehn winds are produced when the large-scale circulation is sufficiently strong and deep to force air completely across a major mountain range in a short period of time. The slide shows how strong high pressure at the surface in the Great Basin leads to Santa Ana winds. Subsidence or heavy air lowering within the pressure cell may push up against a mountain range. This heavy or stable air speeds up as it flows through passes and saddles, then down the lee slopes by gravity and pressure gradients. Foehn winds originate from areas of high pressure, but their winds are flowing out toward lower pressure. A strong foehn wind can scour the previously existing air mass clear out of an area.

Other Well-Known Foehn Winds

Among the other well-known foehn winds in the Western United States are East winds, North winds, and Mono winds. All foehn winds can cause serious fire control problems. Speeds often reach 40 to 60 mi/h, and some have been measured in excess of 90 mi/h.

Recognizing and Anticipating the Effects of Foehn Winds

The common denominator for all foehn wind types is that they lead to increased and sometimes extreme, fire behavior in the lower lee side locations. If you know of foehn wind conditions existing in your locale, you should develop a local knowledge about them. There are likely to be peculiarities for each area, and knowing these can help you in recognizing or anticipating the effects of foehn winds.

THUNDERSTORM DOWNDRAFTS

Necessary Ingredients for Thunderstorm Formation

Cumulonimbus clouds can build over an area when there is adequate atmospheric moisture and instability, along with a lifting mechanism to force air to rise. The most common lifting mechanism for thunderstorms is convection, which is caused by heating from below and/or cooling aloft

Visual description

Thunderstorms begin as small, puffy cumulus clouds. A fully developed thunderstorm (cumulonimbus cloud) can reach 30,000 to 40,000 feet in the West, and 40,000 to

60,0000 in the East. Such clouds have vast amounts of stored energy. Not only are there strong in drafts into the base of the cloud, but also strong downdrafts occur with the release of its energy. Violent local storms are produced, accompanied by thunder and lightning, perhaps rain and/or hail, and strong winds.

Downdrafts

The bases of mature thunderstorms are from downdrafts and virga. Air moving down out of the thunderstorm base is cooled by evaporation, becoming heavier than surrounding air. It also accelerates due to gravity. Downdrafts that reach the ground usually spread in all directions. This results in cool, gusty surface winds that can be experienced within about 5 to 10 miles of the thunderstorm. In mountainous terrain, this distance can be considerably farther due to channeling by ridges and/or canyons.

Wind Speeds of Thunderstorm Downdrafts

Surface wind velocities will often be 25 to 35 mi/h and can reach as high as 60 mi/h. Thunderstorm downdrafts will be cooler and will be somewhat moister than surrounding air. This is not to say that the relative humidity will be high, but merely higher than otherwise.

Indications that downdrafts have begun

There are several things to watch for that will indicate when downdrafts from a thunderstorm have begun. First, you may see a small roll cloud developing on the downwind side of the cloud base. You might see virga hanging from a ragged, dark base. (Virga is rain that falls part way to the ground.) Then, you might observe a dust cloud, as the first gusts spread out over the countryside.

Depending on your proximity to a thunderstorm, you may experience varying weather conditions. The important thing is that you be prepared for the worst, should it occur. Remember, winds from large or high-based thunderstorms can easily reach 40 to 60 mi/h. *Extreme caution must be exercised when you have a fire between you and a thunderstorm.*

WHIRLWINDS

Dust devils

Dust devils occur on hot days over dry terrain when skies are clear and general winds are light. Whirlwinds are an indicator of intense local heating. Strong convection currents or updrafts develop in the areas of intense heating. The whirl becomes visible if the updraft becomes strong enough to pick up dust and other surface materials. Whirlwinds vary in size from just a few feet to over 100 feet in diameter, and to heights of nearly 4,000 feet. On fires, dust devils are common in an area that has just burned over, since the blackened ash and charred materials are good absorbers of solar radiation and thus encourage local heating. This can lead to a "smoke filled" dust

Fire whirls

The fire whirl carries flames and burning materials up into its column. It is usually caused by very high fire intensities in local areas. Fire whirls are usually considered more dangerous than dust devils, but both can scatter fire, cause spotting across control lines, and generally increase fire intensity in local areas.

In order for fire whirls to develop, certain environmental conditions are usually present. These include:

- Mostly clear skies.
- Light surface winds.
- Strong heating (very unstable air near the surface).
- Location on the backside of a shallow ridge or on the lee slopes from the prevailing wind. These are both areas where eddying would be likely.

General and Local Winds

General and local winds combine to produce the winds that we experience at the surface. The measurement of surface winds has been standardized at 20 feet above the ground in a clearing, or 20 feet above the average vegetative cover.

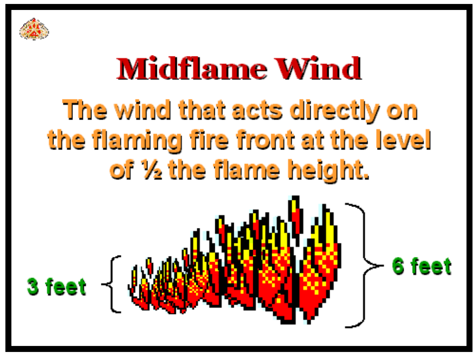
Let us take a moment to review the different types of winds:

- General winds- the general winds are large scale winds caused by high and low pressure systems.

- Local winds- local winds are smaller scale winds that develop as a result of local temperature differences.

— 20-foot surface wind- the 20-foot surface wind is the wind measured 20 feet above the ground in a clearing, or 20 feet above the average vegetative cover.

— Mid flame Winds- the wind speed that will directly affect the movement of the flaming front. This is the wind speed at the mid-height of the flames. The difference between 20-foot wind speed and mid flame wind speed is due to friction with the surface vegetative cover and topography. Generally, mid flame wind speed will be less than the 20-foot wind speed.



All of these wind levels can affect, either directly or indirectly, the behavior of wildfires, although we are generally not concerned with higher-level winds unless fire intensities and convection columns are very high and long-range spotting become a problem. Most weather forecasts that are available to firefighters address the general and surface winds because these are more appropriate to fire danger predictions.

AIR STABILITY

Stable air is defined as air that resists any upward movement. Unstable air, on the other hand, promotes upward air movement. Atmospheric stability is simply the resistance of the atmosphere to vertical motion. Air moves horizontally or vertically in response to the earth's rotation and to large and small changes in temperature and pressure. Wind is the horizontal movement of air. The vertical movement of air is related to stability. Depending on the temperature distribution in the atmosphere, air can rise, sink or remain at the same level. Stable air resists vertical motion. Unstable air encourages vertical motion.

Stable Air Resists Vertical Motion

We said that stable air tends to resist vertical air movement. If a layer of stable air is lifted or forced to rise, as over a mountain, that layer 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 started.

Unstable Air

Rises until it reaches a level in which its new temperature equals that of the surrounding air.

If the atmosphere is unstable, any layer of air that is lifted will tend to rise like a hot air balloon. As this bubble rises, it decreases in temperature at a rate of 5.5 degrees F 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.

There are methods other than strong heating or cooling of the surface that can change the stability of the atmosphere. Cooling the upper portions of the atmosphere will also cause the atmosphere to become unstable, while warming aloft will create more stable conditions.

Atmospheric Instability May Contribute to Increased Fire Behavior

Extreme fire behavior is frequently associated with unstable air conditions. In an unstable atmosphere, a bubble of air that is lifted will continue to rise. This is because the actual lapse rate is greater than the dry lapse rate; thus, any bubble of rising air will continue to be warmer and lighter than surrounding air.

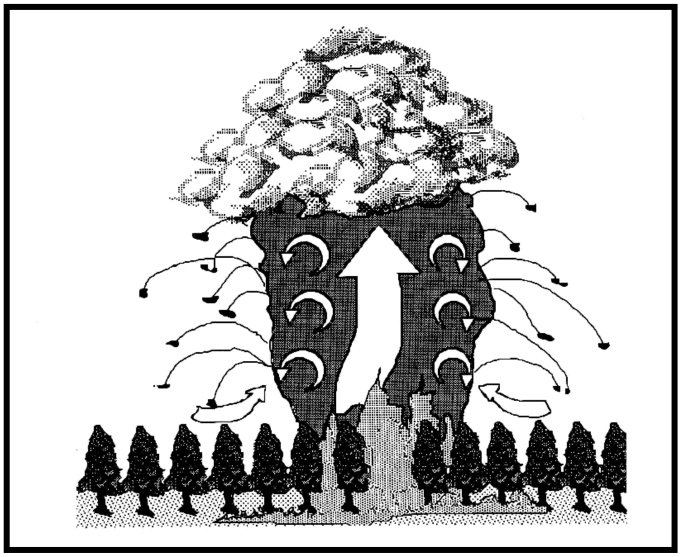
How does this affect fire behavior? Unstable air can contribute to increased fire behavior by increasing the following:

- The chances of Dust Devils and Fire Whirls
- Potential for Gusty Surface Winds
- The heights and strengths of Convection Columns
- The chance of Firebrands being lifted by Convection Columns (spotting)

Dust devils are rather common, sometimes erratic in their movement, and have been known to scatter fire and cause spotting across fire control lines. Fire whirls are much less common, but present serious safety and security problems on the fire line.

With unstable air, stronger winds aloft can be brought down towards the lower portions of the atmosphere that can produce much stronger and gusty winds.

Smoke convection columns rise much higher in unstable air. The greater the instability and fire intensity, the stronger the in drafts and convection column updrafts.



Of primary concern is the spotting potential of tall, well-developed convection columns due to the rise of firebrands in the column.

INVERSIONS

Layer of Air in which the Temperature Increases with Increase in Altitude.

Temperatures in an inversion may increase as much as 15 degrees F per 1000 feet in altitude.

An inversion is a layer of very stable air where the temperature increases with increase in altitude. Temperatures in an inversion may increase as much as 15 degrees F per 1,000 feet in altitude. Inversions act as a lid and severely limit the amount of vertical motion in the atmosphere. Under an inversion, smoke generated by a fire will rise to the inversion, then flatten out and spread horizontally because it has lost its lift.

Inversion Types

There are three different types of inversions. They are categorized by how they are formed and whether they are located at the earth's surface or aloft.

- Radiation or Nighttime
- Marine
- Subsidence

Radiation or Nighttime Inversion

Air in contact with the ground is cooled and is trapped beneath warmer air above.

Radiation or nighttime inversions are the most common type of inversion. They are most pronounced over the interior land masses of continents, especially in mountainous terrain. Nighttime inversions are formed when air is cooled at night, primarily by contact with the earth's surface. 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 that the air above. This creates a condition of cool, heavier air below warmer air. The layer of cool air near the surface deepens as the night progresses.

Cool air will pool in drainages 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 cool air is also affected by the amount of cloud cover at night. The air cools faster on clear nights, with little or no wind, than on cloudy and windy nights.

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. When the inversion dissipates and unstable conditions develop, fire activity increases and major problems can occur. Weather changes that occur as the inversion dissipates (breaks) may be gradual or occur rather abruptly; winds may increase suddenly, temperatures increase, and relative humidity decreases. 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.

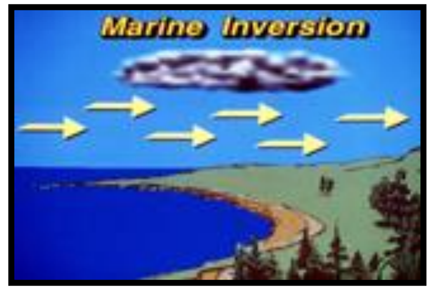
“Remember, When Inversion Breaks”:

- Winds may increase suddenly
- Temperatures increase
- Relative Humidity decreases
- Fire Behavior increases

A good guideline to remember is that cooling from below promotes stable air, while heating from below promotes unstable air.

<u>Marine Inversion</u>

The marine inversion is a common type of inversion found along the coast, particularly in our local area. Cool, moist air spreads over low-lying land. The layer of cool, moist air may vary in depth from a few hundred feet to several thousand feet. If the inversion is several thousand feet thick it will spread over coastal mountains well inland. Marine air frequently penetrates the interior valleys of San Diego County.



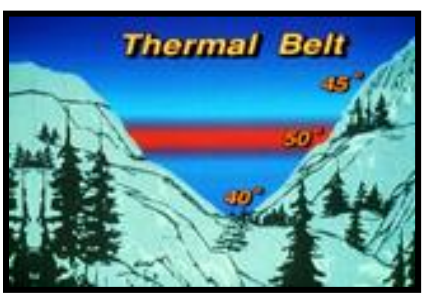
Much warmer, drier, and relatively unstable air tops the marine layer. Marine inversions may persist along the coast during the day, but are strongest and most noticeable at night. Fog often forms in the cool marine air at night and moves inland into coastal basins and valleys

Subsidence Inversion

Subsidence inversions are associated with high-pressure systems in the upper atmosphere. Sinking air in a high-pressure system warms and dries as it descends to lower altitudes. This results in a layer of warm, dry air that becomes progressively warmer and drier as it drops closer to the surface.

Thermal Belts

Where the inversion layer contacts the mountain slopes, we have a relatively warm area called the thermal belt. At night, the temperature in this region is actually warmer than on the slopes above or below. The elevation of 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 daily 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.

Stable air always exists in a thermal belt. However, active burning in this area throughout the night often surprises firefighters. This is because of higher temperatures and lower humidity in the thermal belt. Because the air is stable, winds will tend to be relatively light and steady.

VISUAL INDICATORS OF STABLE OR UNSTABLE AIR

Visual indicators are the easiest way to recognize whether the air is stable or unstable. Alternate methods include consulting the fire weather forecast of a fire weather meteorologist and by taking temperature measurements at different elevations in the field.

Stable Air Visual Indicators

- Clouds are in layers with little vertical motion.
- Smoke column drifts apart after limited rise.
- Poor visibility in lower levels due to accumulation of smoke and haze.
- Fog layers.
- Steady winds.

Unstable Air Visual indicators

- Clouds grow vertically to great heights, cumulus type clouds.
- Upward and downward currents cause gusty surface winds.
- Good Visibility.
- Smoke column rises to great heights.
- Dust devils and fire whirls.

"Watch the Smoke Column"

What Can Smoke Tell Us?

- **Stability** in the lower layers.
- Presence of **Inversion** layers.
- **Direction** of winds aloft.
- **Speed** of winds aloft.

Annual review of fire weather factors is highly recommended in order to remain a safe and competent wildland firefighter.