Intermediate Wildland Fire Behavior S-290

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Student Workbook

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Intermediate Wildland Fire Behavior S-290

Student Workbook

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PREFACE

Intermediate Wildland Fire Behavior, S-290 is a suggested training course in the National Wildfire Coordinating Group (NWCG) wildland and prescribed fire curriculum. It was developed by an interagency group of experts with guidance from NWCG Training under authority of the NWCG. The primary participants in this development effort were:

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The NWCG appreciates the efforts of these personnel, and all those who have contributed to the development of this training product.

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Intermediate Wildland Fire Behavior, S-290

Unit 0 – Introduction

OBJECTIVES:

During this unit the cadre will:

1. Introduce instructors and students.
2. Discuss administrative concerns.
3. Explain the purpose of the course.
4. Review the course objectives.
5. Discuss course expectations.
6. Explain course evaluation methods.
7. Explain where the course fits in the wildland fire behavior curriculum.
8. Review pre-course work.

I. INTRODUCTION

II. PURPOSE OF COURSE

To provide the student with wildland fire behavior knowledge applicable for safe and effective wildland fire management activities (wildfires, fire use, and prescribed fire).

This course introduces students to characteristics and interactions of the wildland fire environment (fuels, weather, and topography) that affect wildland fire behavior for safety purposes. Students will also be shown how such information can be applied.

This course builds upon Introduction to Wildland Fire Behavior, S-190. The materials in this course, as well as in S-190, are elements of the wildland fire behavior curriculum.

This may be the last formal wildland fire behavior training that students receive for the next few years. However, they will be expected to know and apply this training throughout their careers.

III. COURSE OBJECTIVES

- Identify and describe the characteristics of fuels, weather, and topography that influence wildland fire behavior.

- Describe the interaction of fuels, weather, and topography on wildland fire behavior, fireline tactics, and safety.

- Describe the causes of extreme wildland fire behavior (long-range spotting, crowning, and firewhirls) developing due to fuels, weather, and/or topography.

- Interpret, apply, and document wildland fire behavior and weather information.

IV. EXPECTATIONS

A. Class Expectations

1. Attendance at all sessions.
2. Be prepared to start on time.
3. Participate and share ideas.

B. Student Expectations

V. EVALUATIONS

A. Student Evaluations

Students must obtain 70% or higher on the final exam to receive a certificate of completion for this course.

B. Course Evaluations

This is an opportunity for students to comment on the course and instructors for the purpose of improving future courses.

VI. WHERE DOES THIS COURSE FIT IN THE WILDLAND FIRE BEHAVIOR CURRICULUM?

A. Introduction to Wildland Fire Behavior, S-190

Entry-level course designed around the basics of fuel, weather, and topography and how they affect wildland fire behavior in terms of safety and fire suppression actions.

The course is presented to all individuals who will or could be involved with fire management activities.

B. Intermediate Wildland Fire Behavior, S-290

Builds upon the basics in S-190, but with more detailed information of fuels, weather, and topography.

Provides a better basis for analyzing variables and understanding how they interact and affect wildland fire behavior for firefighter safety.

In addition, the use of the Fireline Assessment Method (FLAME) provides a fireline practical tool predicting significant changes in wildland fire behavior such as rate of spread (ROS).

C. Introduction to Wildland Fire Behavior Calculations, S-390

Introduces wildland fire behavior calculations by manual methods such as tables and nomograms.

Gives an in depth understanding of the determinants of wildland fire behavior by discussing input to the prediction process:

- Wind
- Slope
- Fuels
- Fuel moisture

Interpretations of the wildland fire behavior outputs are taught to enhance the student's ability to understand why fire behaves as it does, and to provide "tools" to help in fire management decisions.

D. Advanced Wildland Fire Behavior Calculations, S-490

Designed to give state of the art capability to determine inputs for wildland fire behavior determination and in depth knowledge of interpretations of model outputs.

The course teaches students to project fire perimeter growth based on weather predictions and knowledge of fuels and topography.

E. Advanced Wildland Fire Behavior Interpretation, S-590.

This is the last course of the wildland fire behavior series and the most demanding.

It is designed to train future Fire Behavior Analyst (FBAN) and Long Term Fire Analyst (LTAN) used in wildland fire suppression and fire use organizations.

Intermediate Wildland Fire Behavior, S-290

Unit 1 – The Fire Environment

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Describe the three components of the wildland fire environment.

2. List and give examples of the three methods of heat transfer.

3. List three methods of mass transport of firebrands on wildland fire.

4. Explain the relationship between flame height/length and its relationship to the fireline intensity.

5. Describe primary environmental factors affecting ignition, fire intensity, and rate of spread of wildland fires.

6. Discuss the relationship of wildland fires of different intensities to their environments.

7. Describe the behavior of wildland fires using standard fire behavior terminology.

I. THE WILDLAND FIRE ENVIRONMENT

A. Wildland Fire Behavior

S-190, Introduction to Wildland Fire Behavior explained the fire triangle (heat, oxygen and fuel) and introduced the fire behavior triangle (fuels, weather and topography).

Through this course you will learn how the fire behavior triangle components vary over space and time to produce changes in the behavior of wildland fire.

Wildland fire behavior can be defined as the manner in which fuels ignite, flames develop, and fire spreads and exhibits other phenomena.

Analysis of fire behavior recognizes the complexity of the many variable factors that influence it.

Wildland fire behavior is shaped by its physical environment. Fire spread rates, fire intensity, and other characteristics of fire behavior respond to the unique and ever-changing combination of the fire environmental components.

Not only does the environment affect a fire's behavior, but the fire itself can influence the environment in which it is burning.

B. The Three Components of the Wildland Fire Environment

- Weather
- Topography
- Fuels

The changing states of each of the environmental components—weather, topography, and fuels—and their interactions with each other and with the fire itself, determine the characteristics and behavior of a fire at any given moment.

Changes in fire behavior in space and time occur in relation to changes in the environmental components.

C. Weather Factors Relating to Wildland Fire

There are five factors relating to the weather:

- Temperature
- Relative humidity
- Atmospheric stability
- Wind speed and direction
- Precipitation

Weather is the most variable component of the fire environment. It is dependent on the current air mass and the time of day.

These weather factors can vary with time and space over both short and long time periods.

There are five topographic factors important to wildland fire behavior:

- Elevation
- Position on slope
- Aspect
- Shape of the country
- Steepness of slope

Topography is the most constant of the three fire environment components.

The most important factor under topography is steepness of slope, since changes in slope have very direct and profound effects on fire behavior.

Fuel factors important to wildland fire behavior:

- Fuel loading
- Size and shape
- Compactness
- Horizontal continuity
- Vertical continuity
- Chemical content

These six factors are characteristics of the type of vegetative state of the fuel complex.

These fuel factors can vary with both time and space but generally over a long time period.

Other important fuel factors that affect fire behavior are fuel moisture and temperature.

Fuel moisture and temperature are directly affected by all three major components of the fire environment and can vary with both time and space over very short time periods.

II. THREE METHODS OF HEAT TRANSFER

Heat transfer refers to the physical processes by which heat energy moves to and through unburned fuel, thus preheating the fuel prior to ignition and adding to the fire spread.

A. Conduction

Conduction is the transfer of heat from one molecule of matter to another. An example of conduction would be a cast iron pan handle too hot to touch.

Since wood is generally a poor conductor of heat, conduction is the least important method of the three in wildland fires.

B. Convection

Convection is the transfer of heat resulting from the motion of air (or fluid).

It is the natural buoyant rise of warm air over a heat source that induces the circulation within an air mass.

Examples of convection:

- A fire spreading from surface fuels to aerial fuels.

- Columns of smoke rising high into the atmosphere.

Convection also includes direct flame contact, a powerful heat transfer process, especially in a head fire.

C. Radiation

Radiation is the transmission of heat energy by electromagnetic waves passing from a heat source to an absorbing material.

1. Examples of radiation:

   - The heat received from the sun.

   - The preheating of fuels ahead of a flaming front.

   Radiation from glowing char or flames is very strong. This is why firefighters often must shield exposed skin.

   The amount of heat received by fuels ahead of the fire depends on the fire intensity and the distance from the fire.

2. Factors that increase radiant heat transfer:

   a. Fire below preheats fuels upslope.

   b. Fire travels faster when there is wind. Increasing winds will increase the intensity of the fire by adding oxygen.

   c. A pile of wood burns hotter than scattered wood because the fuels are concentrated.

   Why? Part of the answer is the increased radiant heat from the fire to the adjacent fuels.

   Fuels upslope or downwind from the flames are preheated at a faster rate; thus fire spread is increased.

D. Combining of Heat Transfer Methods

Branches above the fire receive heat by convection and radiation.

Tree trunks and shrubs receive heat by radiation and convection from the fire.

Fuels on the ground are preheated by conduction and radiation.

Preheating of fuels may be occurring by all of these methods at the same time, depending on the arrangement or loading of the fuels.

All three heat transfer methods are important factors in determining the spread of a wildland fire.

III. METHODS OF MASS TRANSPORT OF FIREBRANDS ON WILDLAND FIRE

Watch Out Situation #16 – "Getting frequent spot fires across line."

The primary cause of spot fires is firebrands. Spot fires present some of the most serious control problems in wildland fire. This mass transport of firebrands is called spotting. In each of these cases, we are dealing with new ignitions outside the main fire perimeter.

The three methods of mass transport of firebrands are:

A. Convection

Small pieces of burning material can be lifted in a convection column and be carried some distance ahead of a fire.

Examples of fire brands affected by convection:

- Pine cones
- Bark flakes
- Pine needles

B. Wind

Wind by itself can cause short-range spotting of firebrands.

The combination of wind and strong convective currents can carry firebrands considerable distances downwind from the fire causing long-range spotting.

Examples of fire brands affected by wind:

- Bark flakes
- Pine needles

C. Gravity

Gravity can also be responsible for spotting of firebrands down slope. Usually, the steeper the slope, the greater the spotting problems caused by hot material rolling down slope.

Examples of fire brands affected by gravity:

- Pine cones
- Logs

IV. FLAME HEIGHT/LENGTH AND ITS RELATIONSHIP TO FIRELINE INTENSITY

A. Flame Height

- Flame height is the average height of flames as measured on a vertical axis.
- May be less than flame length if flames are angled.
- Used in estimating size of safety zone.
- "The distance separation between the firefighter and the flames must be at least four times the maximum flame height."

B. Flame Length

- The distance measured from the tip of the flame to the middle of the flaming zone at base of the fire.
- Measured on a slant when the flames are tilted due to effects of wind and slope.

- Used to estimate fireline intensity.

  – Fireline intensity is the rate of heat released per foot of fire front per second.

  – While you can’t see a British thermal unit (Btu) you can measure flame length visually.

  – It is expressed as Btu/feet (ft)/second.

V. PRIMARY ENVIRONMENTAL FACTORS AFFECTING THE IGNITION, FIRE INTENSITY, AND RATE OF SPREAD OF WILDLAND FIRES

The firefighter is concerned with how the fire environment affects the ignition, fire intensity, and rate of spread of wildland fires.

A. Ignition

1. Ignition of wildland fuels requires a heat source.

   This may be either natural (lightning) or artificial (matches, campfires, sparks from chain saws).

   - There must be enough energy to heat the fuels to their ignition temperature, or the temperature to which the material must be heated to produce self-sustaining combustion.

   - For wildland fuels this is 600°F.

2. The primary factors which affect the ignition of wildland fuels are:

   - Size and shape of fuels.
   - Compactness or arrangement of fuels.
   - Fuel moisture content.
   - Fuel temperature.

   All of these factors interact to determine whether ignition will occur in a natural fuel complex.

B. Fireline Intensity

The rate of heat released per foot of fire front per second (Btu).

1. This represents the heat that a firefighter would feel at the fire's flaming front.

   This is the rate of heat energy released during combustion.

2. Fire intensity is primarily affected by:

   - Fuel loading.
   - Compactness or arrangement of fuels.
   - Fuel moisture content.
   - The rate of spread.

   Fire intensity can be measured in several ways. The most useful measurement for fire suppression operations is fireline intensity. Fireline intensity itself is difficult to measure and impossible to see.

C. Rate of Spread (ROS)

Rate of spread is the relative activity of a fire in extending its horizontal dimensions.

1. Rate of spread is expressed as:

   - Rate of increase of the total perimeter of the fire.

   - Rate of forward spread of the fire front.

   - Rate of increase in area, depending on the intended use of the information.

   Usually its (forward) rate of spread is expressed in chains per hour (ch/hr) or acres per hour (acre/hr).

2. The primary factors that will affect rate of spread are:

   - Wind speed

   - Steepness of slope

   - Changes in fuel type

     – Grass to timber litter
     – Surface fuels to aerial fuels

   The occurrence of long-range spotting can affect the rate of spread in some situations.

3. Fire spread and area growth

That portion of the fire edge spreading most actively is called the head of the fire.

We are most concerned with the forward rate of spread, or spread at the fire's head, as this is generally the most dangerous and difficult type of spread to control.

Unlike forward spread, area growth rates are not linear. A rough prediction of area growth is given by multiplying the acreage burned in the first hour times the number of hours squared, if allowed to burn unobstructed.

4. Elliptical spread pattern

Wildland fires spread in near-elliptical patterns, depending partly on wind speed. As wind speed increases, the ellipse elongates.

These shapes may not fit your fire situation exactly as conditions in the field will cause variations in the elliptical shape of the fire.

These field conditions can include:

a. Heterogeneous fuel complexes that cause fingering.

b. Barriers that stop or partially stop the spread.

c. The effect of slope reducing or increasing fire spread at the head or flanks.

d. Spotting ahead of or down slope from a fire.

All of these complicate the task of estimating where the fire perimeter will be in the future.

VI. RELATIONSHIP OF WILDLAND FIRES OF DIFFERING INTENSITIES TO THEIR ENVIRONMENTS

Why do some fires remain small while others get large very rapidly? What happens when a fire gets large and intense? How does fire interact with its environment?

A. Vertical Dimension of a Wildland Fire

1. Consider the extent of a fire's environment.

   For a very small fire, the fire environment is limited to a few feet horizontally and vertically.

2. As a fire grows in size, so does the extent of the environment affected.

   For a large fire the fire environment may extend many miles horizontally and thousands of feet vertically.

3. High intensity wildland fires, whether large or small in size, usually have a considerable effect on the atmosphere vertically. Their convection columns evidence this.

B. Vertical Development of a Fire's Convection or Smoke Column

There are generally three factors that determine the extent of vertical development of a fire's convection or smoke column.

1. Fire intensity or heat energy generated from the fire.

   a. Low intensity fires

      Low intensity fires create weak indrafts at the fire's edge that feed a low, weak smoke or convection column over the fire.

With low intensity fires, the environment mostly controls the fire. The fire's influence is very small, and causes only slight modification of weather elements in the proximity of the fire.

b. High intensity fires

In contrast, a high intensity fire creates much stronger indrafts at the fire’s edge.

This can help feed a convection column which may build too many thousands of feet into the atmosphere.

With high intensity fires, the fire can control the environment to a marked extent and its influence can significantly modify weather elements near and adjacent to the fire.

2. Stability of the lower atmosphere

Stability is defined as a state of the atmosphere in which the vertical distribution of temperature is such that an air particle will resist vertical displacement from its level.

If the lower atmosphere is very unstable it allows for more vertical movement of particles, which contributes to potentially dangerous thunderstorms.

3. Winds aloft

Strong winds tend to discourage vertical development of convection columns.

C. Open and Closed Fire Environments

1. Open fire environment

In an open fire environment, the fuels and the fire are "open" to the weather elements (winds, solar radiation). Fire behavior can respond readily to these weather changes.

2. Closed fire environment (sheltered)

A fire burning under a forest canopy can be compared to a fire burning inside a closed building. Conditions outside the building or over the canopy have relatively little effect on the fire inside.

Closed environment fires may remain low in intensity and have a low rate of spread. However, once a fire breaks through the forest canopy, it can create an open fire environment. The change from closed to open in a short period of time can drastically increase the fire intensity and fire spread.

Remember that any wildfire is a heat source that can and will interact with its natural environment. The size of that sphere of influence will depend on the size and intensity, or heat energy output, of the fire.

The physical location of the fire and the sheltering effect from surrounding terrain and vegetation is often a contributing factor to the potential behavior of that fire.

VII. DESCRIBING THE BEHAVIOR OF WILDLAND FIRES USING STANDARD FIRE BEHAVIOR TERMINOLOGY

This course uses wildland fire terminology that students must learn in order to understand the basic concepts of wildland fire behavior. Being able to describe exactly what a fire is doing is the first step toward understanding fire behavior.

INTERACTIVE EXERCISE: Fire Behavior Terminology.

The purpose of this exercise is to increase student's knowledge of fire behavior terminology. For each wildland fire behavior shown, choose the correct fire behavior term:

a. Ground fire (smoldering and creeping)
b. Surface fire (creeping)
c. Convection column
d. Spotting (wind and convection)
e. Fire whirls
f. Crown fire
g. Torching
h. Surface fire (running)
i. Convection column (bent)
j. Spotting (gravity)
k. Flaming front

Photo 1 fire behavior:
Heat transfer: conduction/radiation
Fuels: compact
Fire intensity: low
Fire behavior term:

Photo 2 fire behavior:
Heat transfer: radiation
Fuels: horizontal continuity, compactness
Fire intensity: low
Fire behavior term:

Photo 3 fire behavior:
Heat transfer: radiation/convection
Fuels: horizontal continuity, fuel loading, fuel size, slope
Fire intensity: moderate to high
Fire behavior term:

Photo 4 fire behavior:
Heat transfer: convection/radiation
Fuels: loadings, vertical continuity
Fire intensity: high
Fire behavior term:

Photo 5 fire behavior:
Heat transfer: convection/radiation
Fuels loading: vertical continuity
Fire intensity: extreme
Fire behavior term:

Photo 6 fire behavior:
Environment: open and unstable
Fire behavior term:

Photo 7 fire behavior:
Environment: open, unstable with high winds due to weather
Fire behavior term:

Photo 8 fire behavior:
Method of transporting firebrands: wind and convection cause spotting ahead of fire front.
Fire behavior term:

Photo 9 fire behavior:
Method of transporting firebrands: rolling down hill
Fire behavior term:

Photo 10 fire behavior:
Weather: unstable
Spotting: high potential
Fire intensity: high to extreme
Fire behavior term:

Photo 11 fire behavior:
Heat transfer: conduction/radiation (the zone of a moving fire where the front is primarily flaming)
Fire intensity: moderate to high
Fire behavior term:

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Unit 2 – Topographic Influences on Wildland Fire Behavior

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Identify standard features on a topographic map.

2. Describe how topography affects fuels and their availability for combustion.

3. Describe how topography can affect the direction and rate of spread of wildland fires.

4. Describe how changes in fuels and topography can provide full and partial barriers to the spread of wildland fires.

5. Describe how slope percent can be determined or estimated in the field.

I. TOPOGRAPHIC MAPS

Predicting fire behavior is a difficult job because of the many variables in nature.

- Burning conditions, relating to weather and fuels, are constantly changing as a fire spreads over time.
- Although the terrain usually does not change over time, it can change considerably over distance.
- Topographic features are important in predicting the behavior of fire.

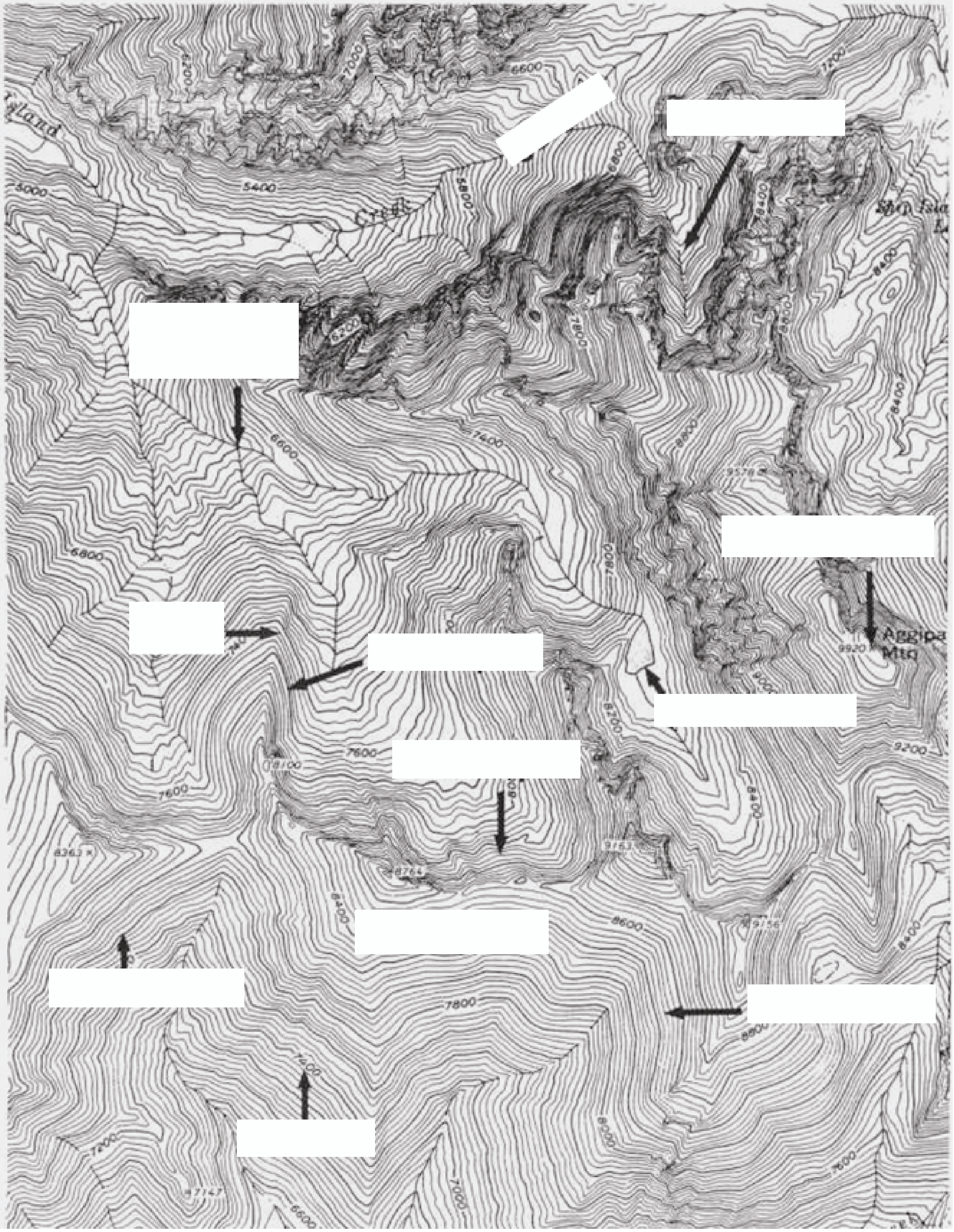
A common method used to depict these various land features is the topographic map.

EXERCISE 1. Topographic Features.

Fill in the feature each arrow is pointing to on the topographic map.

- Contour line
- Elevation
- East aspect
- North aspect
- South aspect
- West aspect
- Canyon
- Barrier
- Box canyon
- Mountain peak
- Intersecting drainage
- Ridge

Topographic Map Features



II. HOW TOPOGRAPHY AFFECTS FUELS AND THEIR AVAILABILITY FOR COMBUSTION

Topography alters the normal heat transfer processes and modifies the general weather patterns, thus producing localized weather conditions that influence the types of vegetation or fuels.

These, in turn, result in micro-climates with localized moisture conditions. All in all, topography directly or indirectly affects fuels and their availability for combustion.

A. Elevation Above Sea Level

Elevation above sea level influences general climate and thereby affects fuel availability by:

- Amount of precipitation received.
- Snow melt dates.
- Fuel types and loadings.
- Dates of curing of vegetation.
- Length of the fire season.
- General fire danger.

B. Position on Slope

1. Variations in temperature and relative humidity.

   Variations in slope contribute to variations in temperature and relative humidity. This allows for fuel types, fuel loadings, and fuel moistures to vary.

2. Greater amounts of fuels available

   Statistically, fires that start at the base of a slope become the largest fires. Because fire spreads best uphill, once the fire at the base of a slope gains momentum, the availability of a greater fuel area enables the fire to reach a greater size.

C. Aspect

1. Definition

Aspect is the direction a slope is facing, and most commonly expressed as one of the eight cardinal directions:

- North
- South
- East
- West
- Northeast
- Northwest
- Southeast
- Southwest

Aspect affects fire occurrence and burning conditions of fires through variations in the amounts of sunshine, precipitation, and wind.

2. South and southwest aspects

In general, south and southwest aspects are most favorable for fire start and spread.

- These aspects receive more direct sunshine, therefore, have lower humidity.

- They are influenced by summer winds and higher fuel temperatures.

- Over much of the United States, summer winds from the southwest are hot and dry.

- Snow melt dates are earlier on the southern aspects.

These events result in fuels that are more available and sparse, due to lack of soil moisture and lower relative humidity.

3. Northern aspects

North facing aspects have more shade which results in:

- Heavier fuels
- Lower temperatures
- Higher humidity
- Higher fuel moistures

A north facing aspect will have less fire activity than a south facing slope; however, the heavier fuels will contribute to increased fire behavior when burning conditions are favorable.

4. East and West aspects

East facing aspects experience heating and cooling earlier.

West facing aspects experience heating and cooling later.

5. Daily variations

During the day, sunlight moves across different aspects, and changes:

- Air temperature
- Relative humidity
- Fuel moisture
- Fuel temperature

An inactive surface fire on a southwest aspect in the early morning may become an active crown fire that afternoon.

After the sun sets, the same fire may again become a surface fire with approachable fire intensities.

D. Micro-climate Conditions or Site Specific Conditions

Fire danger can change due to the micro-climate conditions at all elevations.

The type and availability of fuels can be affected by micro-climate conditions due to:

- Localized weather patterns
- Local soil and terrain factors

General shape of the country and various aspects contribute greatly to the resulting climates of small areas and resulting fuel situations.

A combination of topographic factors is usually present to influence fuel availability and the manner in which fire spreads.

Slope percent, aspect, and position on the slope are all important factors; however, there are more factors involved than just topographic factors.

III. HOW TOPOGRAPHY CAN AFFECT THE DIRECTION AND RATE OF SPREAD OF WILDLAND FIRES

A. Slope

- Important in the study of fire behavior.
- A primary factor that affects fire ignition and spread by preheating the fuels upslope.
- Enables spotting to occur from rolling and aerial firebrands.

1. Fire behavior

   Slope has a direct effect on flame length and rate of spread.

   - If fuels and wind are constant, the flame length and rate of spread will increase as the slope becomes steeper.
   - The steeper the slope, the more likely a fire will run in a wedge shape with a narrower head.
   - Spotting ahead of the front is more likely.

2. Slope reversals

   Slope reversals occur when the fire crosses onto a slope of opposite direction.

   Two common examples:

   - A fire running to the top of a ridge begins to back down on the opposite slope.
   - A fire backing down a slope crosses a drainage and begins to run up the next ridge.

   The direction and rate of fire spread can respond quickly to slope reversals.

B. Ridges

Commonly, as a fire runs to the ridgetop, it encounters an opposing upslope airflow from the other side of the ridge.

- This effect can slow the fire spread and limit the spotting problem on the opposite slope.

  Often, a ridge provides firefighters with a safe and effective fireline location.

- The effect of erratic winds caused by various winds converging at the ridgetop can contribute to spotting.

  This is especially likely if the windward side of the ridge has stronger winds than the leeward upslope airflow.

- A wildland fire burning near the top of the windward slope can spot across the ridgetop and onto the other slope.

  For this reason, firefighter safety could be easily compromised, and the ridge no longer is an effective fireline location.

C. Narrow Canyons

1. Heat and mass transfer

   Increased fire intensity often produces crowning and spotting, which may cause the fire to cross to the opposite slope that has been preheated by radiation.

   This crossing can happen in a matter of a few minutes, giving little warning to firefighters working in the canyon. Such crossings can occur progressively, at multiple points, creating a hazardous situation for crews. Firefighters need to recognize when these situations can occur.

2. Stable air conditions

Narrow canyons easily allow for stable airmass, such as an inversion to form. This is especially dangerous to firefighters since the smoldering fire continues to slowly consume surface fuels and dry out the aerial fuels present.

- When the inversion breaks, winds will increase into the canyon, and fire activity will increase.

- The dried aerial fuels can easily ignite as well.

3. Air flow

Surface winds will usually be shaped by the canyon, following the canyon's direction, forming eddies and strong upslope currents at its sharp bends.

D. Intersecting Drainages

Where drainages intersect, fire might follow one or both drainages, depending on:

1. The direction of canyon winds as determined by aspect and time of day.

2. The dominant winds in the canyon.

3. Wind eddies at the fork of the canyon.

4. The availability of fuels in the forked area.

At the point of intersecting drainages, the interaction or combination of these variable factors often makes prediction on fire spread very difficult.

E. The Chimney Effect in Canyon Topography

1. The chimney effect

   - A chimney depicts topographic features that form steep narrow chutes with three walls similar to a box canyon.

   - Normal upslope air flow is rapid and funneled to the chimney's shape.

   - Because of upslope preheating and cross-canyon radiation, these chimneys draft a fire, much like a wood stove chimney.

   - Extreme rates of spread can occur, spotting is likely, and difficulty is experienced in establishing and moving to safety zones in chimneys.

2. The chimney effect occurs when:

   - Unstable air conditions at the surface cause a convection current through the canyon.

   - Air is drawn in at the base of the canyon to support the convection currents.

   - Fuels are available to support a rapid burnout in the head of the canyon.

   The unrecognized effect that chimneys have on fire behavior has claimed the lives of numerous firefighters.

IV. HOW CHANGES IN FUEL AND TOPOGRAPHY CAN PROVIDE FULL AND PARTIAL BARRIERS TO THE SPREAD OF WILDLAND FIRES

A. Definition of a Barrier

A barrier is any obstruction to the spread of fire. Typically an area or strip devoid of combustible fuel.

- Another important terrain feature is barriers, whether natural or artificial.
- Areas that lack available fuels, because of higher fuel moisture or sparse fuels are either full or partial barriers to fire spread.
- Barriers can help to limit the direction of fire spread and provide opportunities for easier control.
- Most barriers are effective to limit or slow surface fire spread, but probably ineffective to reducing spotting potential.

B. Types of Barriers

Barriers that either retard or stop the spread of fire:

1. Rocks or bare soil conditions.
2. Lakes, streams, and moist soil situations.
3. Roads, trails, and other improvements.
4. Change in fuel type and fuel moisture conditions.
5. Previous burned areas.

C. Partial Barriers

A change in fuel conditions may offer only a partial barrier by slowing the spread of fire.

Examples:

- In early morning when the cured grasses are still damp with dew, the fire spreading in the dry litter under the canopy will be retarded in its advance across the meadow until the afternoon.
- The green grasses are resistance to fire spread in the spring. Later in the year, the same grass readily carries fire.
- Drainages on north-facing slopes early in the season may also act as partial barriers to fire spread.

EXERCISE 2.

This exercise is intended as a classroom discussion. Discuss the type of barrier seen on each slide. For each barrier, discuss its effectiveness and possible hazards to firefighters.

V. HOW SLOPE PERCENT CAN BE DETERMINED OR ESTIMATED IN THE FIELD

A slope is an inclined ground surface that forms an angle with the horizontal plane (flat ground). The degree of inclination, steepness, is also called slope.

In the field, slope percent can be determined or estimated without the aid of a contour map.

There are three methods for determining or estimating slope percent; each will give the slope percent sufficiently for fire behavior predictions.

A. Clinometer

A clinometer is an instrument for measuring angles of slope (or tilt), elevation or inclination of an object with respect to gravity.

By sighting at a point on the slope, directly above or below you, the slope percent can be read directly from a clinometer.

1. Choose a point on the slope, at eye level, that will give a representative slope percent value.
2. The clinometer reads both in degrees and percent.
3. The larger number (right side scale) is slope percent.

B. Measurement

1. With a stick of 4 to 6 feet, prop one end into the slope.
2. Hold the other end so the stick is horizontal (level).
3. Apply the slope percent formula by dividing the distance the free end is vertically from the slope (rise in elevation), by the length of the stick (horizontal distance), and multiply by 100.

C. Slope Meter Estimate

1. Mount the slope meter on the small board in the belt weather kit.

2. Ensure that the edge closest to the 0 is mounted parallel to the edge of the board.

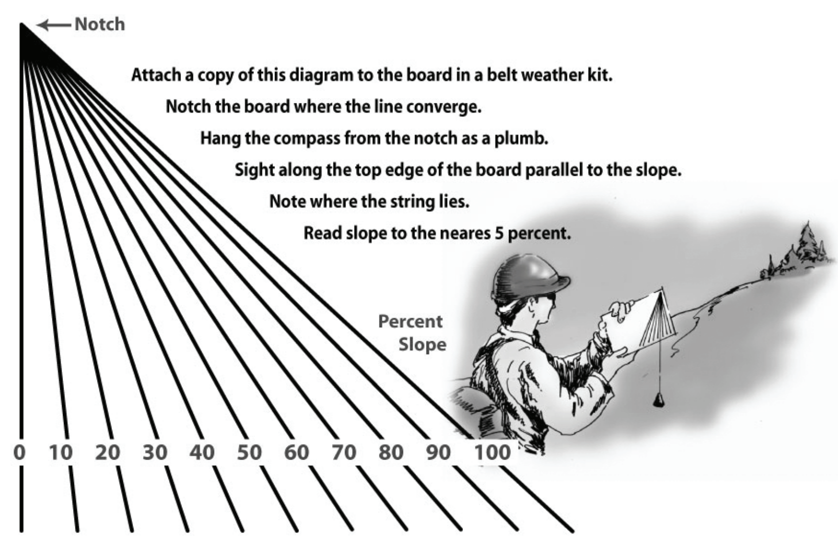
3. Attach or hold a weighted string at the point where all the lines converge.

    - Notching the edge of the board at this point will help secure the string.

    - A compass can act as the weight.

4. Use this tool like a clinometer – sight along the top edge at a point directly above you and at eye level on the slope.

5. Hold the board and pinch the string to the board. Read the slope percent indicated by the string.



Intermediate Wildland Fire Behavior, S-290

Unit 3 – Fuels

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Identify and describe basic wildland fuel characteristics.

2. Identify and describe seven characteristics of fuels that affect wildland fire behavior.

3. Identify and define by size class the four dead fuel timelag categories used to classify fuels.

4. Describe how fuel availability is essential to predicting wildland fire behavior.

5. Describe the fuel model concept and its utility for predicting wildland fire behavior.

I. FUEL CHARACTERISTICS

A. Fuel Make-up

Three of the seven factors in the fire environment that fireline personnel must monitor involve wildland fuels:

- Fuel characteristics
- Fuel moisture
- Fuel temperature

1. Fuels are any combustible material that:

    - Is living or dead
    - Is in or on the ground
    - Is in the air
    - Can ignite and burn

2. Fuels are found in almost infinite combinations of:

    - Kind
    - Amount
    - Size
    - Shape
    - Position
    - Arrangement

3. The fuel on a given acre may vary from a few hundred pounds of sparse grass to 100 or more tons of slash.

    It may consist of:

    - Dense conifer crowns
    - Deep litter and duff
    - Moss layers
    - Underground peat

    It may contain a mixture of any of these forming a fuel complex.

4. Potential fire behavior can be estimated by analyzing the physical properties and characteristics of fuels.

5. Topographic and weather factors must also be considered before rate of spread and general behavior of fires can be determined.

B. Fuel Levels and Components

A systematic approach to looking at the fuel complex is to divide it into three broad levels:

- Ground
- Surface
- Aerial fuels

Through on-the-job experience, we can generalize the typical fire behavior under normal fire season conditions and evaluate properties of each fuel level that affect ignition and combustion.

1. Ground fuels

All combustible materials lying beneath the surface:

- Deep duff
- Tree roots
- Rotten buried logs
- Other organic material

Ground fuels are important in relation to line construction and mopup operations.

- Because of their compactness, fire spread will be slowest–typically smoldering or creeping.

- Ground fuels have been known to hold fire through winter snows.

2. Surface fuels

All combustible materials lying on or immediately above the ground:

- Needles or leaves
- Duff
- Grass
- Small dead wood
- Downed logs
- Stumps
- Large limbs
- Shrubs to about six feet in height
- Litter

Surface fuels are less compact than ground fuels and have other characteristics more favorable for faster rates of spread.

If no aerial fuels are present, surface fuels have an open environment subject to stronger winds and more heating and drying by solar radiation.

Fires often “run” through this fuel level with higher rates of spread than if aerial fuels were present.

Since most wildfires ignite in and are carried by the surface fuels, this fuel level receives the most emphasis.

Surface fuels are important in terms of line construction and mop-up, most important regarding fire spread and fire behavior.

3. Aerial fuels

All green and dead materials located in the upper canopy:

- Tree branches and crowns
- Snags
- Hanging moss
- Tall shrubs

When aerial fuels are present, we are concerned with crown or canopy closure.

a. Open canopy

Timber stands with open canopies usually have a faster spreading surface fire than closed canopy stands.

- Torching of individual trees with possible spotting could occur.

- Unless very strong winds are present, crowning is unlikely without a closed canopy.

b. Closed canopy

Closed canopy stands that are greater than 6 feet in height (whether timber or tall shrubs), offer the best opportunity for a running crown fire.

- Few fires become running crown fires; however, these fires are very important due to the large amount of fuel consumed in very short periods of time.

- Canopy closure is usually given in percent. It is best demonstrated by looking at a forest from the air and seeing what percent of the ground is visible.

  If 25 percent of the ground is visible, there is 75 percent canopy closure.

Aerial fuels are important in terms of fire spread and fire behavior due to torching, crowning, and spotting.

II. SEVEN CHARACTERISTICS OF FUELS THAT AFFECT WILDLAND FIRE BEHAVIOR

There are seven principal characteristics of fuel components that give an indication of potential fire behavior within a fuels complex:

- Fuel loading
- Size and shape
- Compactness
- Horizontal continuity
- Vertical arrangement
- Moisture content
- Chemical content

These seven characteristics are then divided into two main categories:

- Physical and chemical characteristics (that remain constant during a given fire situation).

- Moisture content (which changes continually).

A. Fuel Loading

1. Definition

The amount of fuel present expressed quantitatively in terms of weight of fuel per unit area. This may be available fuel (consumable fuel) or total fuel and is usually dry weight.

Measured in tons/acre or pounds/acre (lbs/acre).

2. Fuel loadings vary greatly by fuel groups.

Examples of fuel loadings:

- Grass - <1 to 5 tons/acre
- Shrub - 2 to 80 tons/acre
- Slash - 10 to 200 tons/acre
- Timber litter - 4 to 12 tons/acre

When interpreting and predicting fire behavior, surface fuel loading is a concern; particularly those dead fuels that are less than 3 inches in diameter and live fuels of less than ¼ inch diameter.

Much of the vegetation on a site may not be available to carry fire due to its height above the ground or to high moisture levels.

3. Fuel loading by class size

Fuel loadings are generally separated by different sizes of live and dead fuel particles.

Dead fuels are broken into four size classes according to their diameter:

- Grasses/litter - 0 to ¼ inch in diameter
- Twigs and small stems – ¼ inch to 1 inch in diameter
- Branches - 1 inch to 3 inches in diameter
- Large stems, branches – 3 inches to 8 inches in diameter

B. Size and Shape

1. Surface-area-to-volume ratio

- This is the ratio of the surface area of a fuel to its volume, using the same linear unit for measuring volume; the higher the ratio, the finer the particle.
- Looking at surface-area-to-volume ratio is a method of characterizing the size and shape of fuels.
- Small fuels and flat fuels, like grasses, have a greater surface-area-to-volume ratio than larger fuels, like logs.

When starting campfires, wood stoves, or fireplaces, we know that small fuels ignite and sustain combustion easier than large pieces of fuel.

Less heat is required to remove fuel moisture and raise a small fuel particle to ignition temperature. The use of size classes is a way to categorize the surface-area-to-volume ratios of fuels.

Remember:

- Higher ratios burn more readily.
- Lower ratios do not burn as readily.

2. Firebrands

The size and shape of the firebrands affect the amount and distance of spotting.

Small embers ordinarily produce short-range spotting only, since they cannot sustain combustion for the period of time required in long-range transport.

Their flatness and greater surface-area-to-volume ratios have increased the aerodynamic qualities of the particles making it easier for convection columns to lift them to greater altitudes.

Examples:

- cedar fronds
- bark plates
- pine needles

These firebrands that have been lifted into convection columns and then deposited 10 miles or more downwind from the fire.

The shape of fuels is also important to spotting downslope by rolling firebrands.

Examples:

- pine cones
- round logs
- round yucca plants

These examples are particularly troublesome in their respective areas.

C. Compactness

1. Definition

Compactness can be simply defined as the spacing between fuel particles.

The closeness and physical arrangement of the fuel particles affects both ignition and combustion.

- Fuels that are closely compacted:
  - Have less surface area exposed.
  - Restrict oxygen.
  - Inhibit convective and radiant heat transfer.
  - In most cases, a slower rate of spread is expected when fuels are compacted.
- Loosely compacted fuels will normally react faster to moisture changes and have more oxygen available for combustion.
- A fire with a greater rate of spread can be expected when fuels are loosely compacted.

2. Fuel bed depth and orientation

Fuel bed depth is the average height of surface fuel that is contained in the combustion zone of a spreading fire front.

Orientation of the fuel refers to the horizontal or vertical orientation of the fuel array that carries the fire.

Fuel bed depth and orientation are significant fuel properties for predicting whether a fire will be ignited, its rate of spread, and its intensity.

Grasses and shrubs are vertically oriented fuel groups, which rapidly increase in depth with an increase in fuel load.

The timber litter and slash groups are horizontally oriented and slowly increase in depth as the load is increased.

Observations of the location and orientation of fuels in the field help one decide which fuel groups are represented.

D. Horizontal Continuity

1. Definition

Horizontal continuity is the horizontal distribution of fuels at various levels or planes.

These characteristics influence where a fire will spread, how fast it will spread, and whether the fire travels through surface fuels, aerial fuels, or both.

2. Continuous vs. patchy fuels

If the open areas in this slide are barren and void of any fuels, it will be difficult for fire to travel from one fuel island to another.

It would probably require a strong wind with spotting for fire to travel through such discontinuous or patchy fuels.

Such fire situations do occur, and what might appear to be natural firebreaks or barriers may not stop a fire's spread.

Continuous fuels, however, provide available fuels at one or more levels giving a fire opportunity to spread for great distances.

Horizontal continuity applies to all levels of the fuels complex, but the continuity of fine fuels is especially important to the spread of surface fires since wildland fires burn most often in this fuel level.

3. Horizontal continuity in aerial fuels and the effects of a closed versus open timber canopy.

   A forest canopy not only shades surface fuels and prolongs moisture retention but also greatly reduces wind speeds from levels above the canopy to levels near the surface.

   Generally, the greater the crown closure, the greater the wind speed reduction.

   This certainly does have an effect on surface fires burning in these closed environments.

   If torching out of individual trees occurs, however, we have an entirely new fire environment with which to be concerned.

E. Vertical Arrangement

1. Definition

   Fuels above ground and their vertical continuity, which influences fire reaching various levels or vegetation strata.

2. Ladder Fuels

   Fuels which provide vertical continuity between fuel layers allow fire to carry from surface fuels into the crowns of trees or shrubs with relative ease. They help initiate and assure the continuation of crowning

   When fuels are mostly vertically continuous, it is called a fuel ladder, or a ladder to transport fire into the canopy.

   Why must you worry if you see fuel ladders on your fire?

   In some mature timber situations, we need to be concerned with several levels of fuels that may help transport fire from the surface fuel to the crowns.

A sub canopy might consist of understory trees and larger regeneration.

- The canopy is made up of mature tree crowns perhaps over 100-feet tall.

- Fire may burn through one or more levels without burning the canopy.

Regardless of the maximum height of the fuels and the number of fuel levels involved, there is a concern with the vertical continuity.

The intensity of the surface fire and the live fuel moisture content usually determine whether fire will travel up through the green ladder fuels.

3. Reburn

A dangerous condition exists when a fire has only burned through the surface fuel level, drying the aerial fuels.

A slight change in the environment, and the fire can cause a reburn of the canopy—a very dangerous situation.

The hazard during this condition cannot be over emphasized.

Firefighters must consider the reburn potential before entering an area that has only partially consumed fuels.

F. Moisture Content

The quantity of moisture in fuel expressed as a percentage of the weight when thoroughly dried at 212 degrees F.

1. Fuel moisture content

   Fuel moisture content can vary in different fuel levels and thus influence whether these levels become involved with fire.

2. Live and dead fuel moisture contents

   Live fuels are frequently consumed by fire when there are enough dead, dry fuels present to support the fire, which can dry and ignite the live fuels.

   Fuel moisture, living or dead, plays a significant role in determining how quickly the fire will spread.

   In nature, fine dead fuel moisture very seldom gets below 3 or 4 percent.

   - Fine dead fuel moisture fluctuates considerably over time due to several environmental factors.

   - Live fuel moistures run much higher, perhaps 300 percent or more, but they change less rapidly than dead fuels.

3. Fine dead fuels

   Fine fuels are considered the primary carrier of a surface fire.

   Fine dead fuels less than ¼ inch, such as grass and needle/leaf litter, are most responsible for the spread of fire.

4. Live-to-dead ratio

The live-to-dead ratio becomes critically important when evaluating the potential for a fuel to burn.

The greater amount of dead fuel compared to live fuel, the more flammable the fuel.

Increased live-to-dead ratios are associated with over mature fuel complexes damaged from:

- Fire
- Drought
- Disease
- Insects
- Wind
- Snow
- Seasonal stress

The dead component of the fuel is extremely important since it is the dead material that carries the fire and heats the live component to ignition.

With insufficient dead fuels present, a live stand may not burn even under good burning conditions.

With a large dead fuel load, a live stand may burn very well even under modest conditions.

G. Chemical Content

1. Definition

All fuels, living or dead, contain fiber that is known as cellulose.

2. Fuels also contain chemicals and minerals that can enhance or retard combustion.

   Chemical contents include the presence of volatile substances such as:

   - Oils
   - Resins
   - Wax
   - Pitch

3. There are certain fuels having rather high amounts of these volatile substances that can contribute to:

   - Rapid rates of spread
   - High fire intensities
   - Prolonged burnout time

4. Certain fuels may be high in mineral content, which can reduce fire spread and intensity.

   A wildland firefighter is primarily concerned with the volatile substances that make the job more difficult.

   A few fuels such as duff and "cow pies" are excellent receptors of firebrands that hold over fire primarily due to their high mineral contents.

   The high mineral content in these fuels enhances smoldering at much lower ignition temperatures.

5. Volatile fuels

Some well known fuels in which volatile substances contribute greatly to fire intensity and fire spread are:

- Chaparral in the southwest
- Palmetto in the southeast
- Greasewood in the Pacific northwest
- Fountaingrass in Hawaii
- Pitchy stumps from some conifers
- Jack Pine in the Lake States
- Pitch Pine in the northeast

H. Fuel Characteristics Relation to Fire Behavior

1. Various fuel characteristics affect fire behavior:

- Compactness
- Loading
- Horizontal continuity
- Vertical arrangement
- Chemical content
- Size and shape
- Moisture content

Each of these seven characteristics contributes to one or more fire behavior processes.

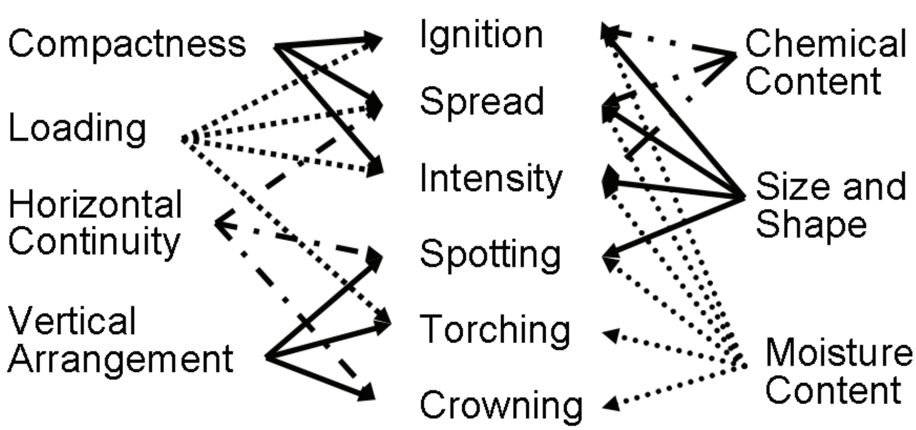
One concern is whether ignition will result in a sustaining fire.

2. The five fuel characteristics that most effect ignition:

- Compactness
- Loading
- Chemical content
- Size and shape
- Moisture content

3. There are six primary fire behavior characteristics involved with the rate of spread.

- Ignition
- Spread
- Intensity
- Spotting
- Torching
- Crowning



- What situations would a firefighter expect spotting, torching, or crowning?

- Which fuel characteristic affects all of the fire behavior characteristics?

III. THE FOUR DEAD FUEL TIMELAG CATEGORIES USED TO CLASSIFY FUELS

A. Timelag

Definition: Time needed under specified conditions for a fuel particle to lose about 63 percent of the difference between its initial moisture content and its equilibrium moisture content.

If conditions remain unchanged, a fuel will reach 95 percent of its equilibrium moisture content after four timelag periods.

B. Dead Fuel Timelag Categories

Various sizes of fuels are placed into convenient timelag categories or classes.

- l-hour
- 10-hour
- 100-hour
- 1000-hour

Which of these timelag fuels loses its moisture the fastest?

IV. HOW FUEL AVAILABILITY IS ESSENTIAL TO PREDICTING WILDLAND FIRE BEHAVIOR

A. Available Fuels

Available fuels are those that will ignite and support combustion at the flaming front under specific burning conditions.

B. Consumption of Various Fuels by Fires

- In a cured grass stand, nearly 100 percent of the fuels might be consumed by fire. These have a very high degree of availability.
- A stand of shrubs is seldom completely burned, but perhaps 5 to 95 percent is consumed.
- The stumps, logs, and larger limbs of slash are rarely totally burned; thus, consumption in slash might be 10 to 70 percent.
- In timber litter, standing trees are only partially burned, and overall fire consumption might be 5 to 25 percent.

C. Reasons for Consumption

Why does the amount of consumption vary in these previous examples?

One assumption might be that the larger the fuels, the less likely it is that they will be totally consumed by fire. More important is the assumption that some specific characteristics of the fuels made them unavailable for combustion.

The following play an important part in a fuel's availability to burn:

- Size
- Arrangement
- Moisture content
- Duration and intensity of the fire

Different fuel types have variations in fuel moisture. In addition, plants of the same fuel type can have variations in fuel moisture.

D. Fuel Moisture Effect on Availability

The moisture content of both the live and dead fuels is the primary factor determining fuel availability.

V. THE FUEL MODEL CONCEPT AND ITS UTILITY FOR PREDICTING WILDLAND FIRE BEHAVIOR

Fuels in the fire environment can vary greatly as to:

- Vertical arrangement
- Moisture content
- Chemical content
- Horizontal continuity
- Compactness
- Loading
- Size and shape

A better method of describing the fuels in the fire environment that considers the different combinations of fuel characteristics has been created through the use of a fuel model.

A. Definition of a Fuel Model

Simulated fuel complex for which all fuel descriptors required for the solution of a mathematical rate of spread model have been specified.

Fuel models are simply tools to help the user realistically estimate fire behavior.

Some components that are described include the seven fuel characteristics. Various combinations of these components make up the fuel models.

Although fuel models were developed as input to the fire spread model, they do provide the wildland firefighter a common way of describing the fuels.

Fuels are classified into 13 models:

- Grass (3 fuel models)
- Shrub (4 fuel models)
- Timber Litter (3 fuel models)
- Slash (3 fuel models)

For more information on fuel models, refer to Aids to Determining Fuel Models for Estimating Fire Behavior located on the student CD.

B. Major Fuel Groups

The fuel groups are used to describe fuel complexes to make fire behavior predictions. Wildland fuels are grouped into fuel types based on the primary fuel that carries the fire.

The four major fuel groups are:

- Grass
- Shrub
- Timber Litter
- Slash

Fuels vary in type from one area of the country to another and within the same area. One reason that types of fuels vary and elevation changes are the differences in the amount of water in the soil.

The fire behavior estimates given below are with 8 percent fine dead fuel moisture content, live fuel moisture when present at 100 percent, and a 5 mph midflame wind.

1. Grass group

   Grass is the primary carrier of the fire. Fuel bed depth may range between 1 foot and 2.5 feet deep.

   a. Grass fuel characteristics:

      - Fuel loading 300 pounds/acre to several tons/acre.
      - Size and shape generally less than 0.25 inches in diameter.
      - Compactness
      - Moisture content responds quickly to changes in relative humidity.

   b. Grass fire behavior characteristics:

      - Rapid burnout
      - Low intensity
      - Wind strongly affects fire
      - ROS 35 to 100+ chains/hour
      - Flame length (FL) 0 to 12 feet

2. Shrub group

Shrubs are the primary carrier of the fire. Fuel bed depth may range between 2 feet to 6 feet.

a. Shrub fuel characteristics:

- Fuel loading between 1 to 80+ tons/acre.
- Size and shape of mixed dead and live fuels with small leaves, most fuels are less than 1 inch in diameter.
- Compactness loosely layered to very deep.
- Moisture content of live fuels may be present.
- Live fuel changes according to the amount of precipitation received and the time of year.
- Chemical content in some fuels in this group will permit burning at higher fuel moistures.

b. Shrub fire behavior characteristics:

- Very low to extreme rates of spread are possible.
- ROS 18 to 75 ch/hr.
- FL 4 to 19 feet.

3. Timber litter group

Surface litter is the primary carrier. Fuel bed depth may range between 0.2 to 1 foot.

a. Timber fuel characteristics:

- Size and shape mixed litter, leaves, and needles to large branch wood.
- Compactness ranges from loose to tight.
- Vertical arrangement fuel bed depth less than 1 foot, typically less than 3 inches.
- Moisture content retained when litter compacted.

b. Timber fire behavior characteristics:

- Range from slow burning to running surface fires.
- Occasional torching to running crown fire possible.
- ROS 2 to 8 ch/hr.
- FL 1 to 5 feet.

4. Slash group

Slash is the primary carrier. Fuel depth may range between 1 to 3 feet.

a. Slash fuel characteristics:

- Size and shape all sizes.

- Fuel loading between 12 and 58 tons/acre.

b. Slash fire behavior characteristics:

- Moderate to rapid spread rates.

- Moderate to high intensities dependent on fuel arrangement.

- Firebrands may be generated and convectively lifted.

- Rolling material frequently ignites fuel below.

- ROS 6 to 14 ch/hr.

- FL 4 to 11 feet.

C. Group vs. Model

1. <u>Grass group</u>

Fuel model	1	Short grass (1 foot)
	2	Timber (grass and understory)
	3	Tall grass (2 feet)

2. <u>Shrub group</u>

Fuel model	4	Chaparral (6 feet)
	5	Short brush (2 feet)
	6	Intermediate brush
	7	Southern rough

3. <u>Timber litter group</u>

Fuel model	8	Closed timber litter
	9	Hardwood litter
	10	Timber (litter and understory)

4. <u>Slash group</u>

Fuel model	11	Light slash
	12	Moderate slash
	13	Heavy slash

VI. INTRODUCTION TO THE STANDARD FIRE BEHAVIOR FUEL MODELS

The new Standard Fire Behavior Fuel Models are sometimes referred to as "the 40 fuel models."

A. Model Parameters

1. Parameters of the new fuel models include:

   - Load by class and component
   - Surface-area-to-volume (SAV) ratio by class and component
   - Fuel model type (static or dynamic)
   - Fuelbed depth
   - Extinction moisture content
   - Fuel particle heat content

   This new set of standard fire behavior fuel models is designed to stand alone; none of the original 13 fire behavior fuel models is repeated in the new set.

   The original 13 fire behavior fuel models will still be available; they are still called fire behavior fuel models 1-13.

   Documentation and naming of the new fuel models refer to fuel or fuel types, not vegetation or vegetation types.

   For example, what was formerly termed a "chaparral" fuel model might now be called a "heavy load, tall brush" model, (because one fuel model can be applied in many vegetation types).

   Likewise, the fuel model selection guide does not refer to specific vegetation types except as necessary to illustrate an example.

2. Need for the new models

The original 13 fire behavior fuel models are for the severe period of the fire season when wildfires pose greater control problems.

Those fuel models have worked well for predicting spread rate and intensity of active fires at peak of fire season.

However, they have limitations for other purposes, including:

- Prescribed fire.
- Wildland fire use.
- Simulating the effects of fuel treatments on potential fire behavior.
- Simulating transition to crown fire using crown fire initiation models.

3. The new models:

- Improve the accuracy of fire behavior predictions outside of the severe period of the fire season.
- Increase the number of fuel models applicable in high-humidity areas.
- Increase the number of fuel models for forest litter and litter with grass or shrub understory.
- Increase the ability to simulate changes in fire behavior as a result of fuel treatment by offering more fuel model choices, especially in timber-dominated fuelbeds.

4. Seven major fuel groups for new models:

- Grass
- Grass – Shrub
- Shrub
- Timber – Understory
- Timber Litter
- Slash – Blowdown
- Non-Burnable

B. New Standard Fire Behavior Models

1. Grass (GR)

The primary carrier of fire in the GR fuel models is grass. Grass fuels can vary from heavily grazed grass stubble or sparse natural grass to dense grass more than 6 feet tall.

- GR1 - Short, sparse dry climate grass

- GR2 - Low load, dry climate grass

- GR3 - Low load, very coarse, humid climate grass

- GR4 - Moderate load, dry climate grass

- GR5 - Low load, humid climate grass

- GR6 - Moderate load, humid climate grass

- GR7 - High load, dry climate grass

- GR8 - High load, very coarse, humid climate grass

- GR9 - Very high load, humid climate grass

2. Grass-Shrub (GS)

The primary carrier of fire in the GS fuel models is grass and shrubs combined; both components are important in determining fire behavior

- GS1 - Low load, dry climate grass-shrub
- GS2 - Moderate load, dry climate grass-shrub
- GS3 - Moderate load, humid climate grass-shrub
- GS4 - High load, humid climate grass-shrub

3. Shrub (SH)

The primary carrier of fire in the SH fuel models is live and dead shrub twigs and foliage in combination with dead and down shrub litter.

- SH1 - Low load, dry climate shrub
- SH2 - Moderate load, dry climate shrub
- SH3 - Moderate load, humid climate shrub
- SH4 - Low load, humid climate timber-shrub
- SH5 - High load, dry climate shrub
- SH6 - Low load, humid climate shrub
- SH7 - Very high load, dry climate shrub
- SH8 - High load, humid climate shrub
- SH9 - Very high load, humid climate shrub

4. Timber-Understory (TU)

The primary carrier of fire in the TU fuel models is forest litter in combination with herbaceous or shrub fuels.

- TU1 - Low load, dry climate timber-grass-shrub
- TU2 - Moderate load, humid climate timber-shrub
- TU3 - Moderate load, humid climate timber-grass-shrub
- TU4 - Dwarf conifer with moss
- TU5 - Very high load, dry climate timber-shrub

5. Timber Litter (TL)

The primary carrier of fire in the TL fuel models is dead and down woody fuel. Live fuel, if present, has little effect on fire behavior.

- TL1 - Low load, compact conifer litter
- TL2 - Low load, broadleaf litter
- TL3 - Moderate load, conifer litter
- TL4 - Small downed logs
- TL5 - High load, conifer litter
- TL6 - High load, broadleaf litter
- TL7 - Large downed logs
- TL8 - Long-needle litter
- TL9 - Very high load, broadleaf litter

6. Slash-Blowdown (SB)

The primary carrier of fire in the SB fuel models is activity fuel or blowdown. Forested areas with heavy mortality may be modeled with SB fuel models

- SB1 - Low load activity fuel
- SB2 - Moderate load slash or low load blowdown
- SB3 - High load slash or moderate load blowdown
- SB4 - High load blowdown

7. Non-Burnable (NB)

These non-burnable "fuel models" are included to provide consistency in how the non-burnable portions of the landscape are displayed on a fuel model map.

- NB1 - urban/developed
- NB2 - snow/ice
- NB3 - agriculture
- NB8 - water
- NB9 - bare ground

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Unit 4 – Basic Weather Processes

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Describe the structure and composition of the atmosphere.

2. Define weather and list its elements.

3. Describe the sun-earth radiation budget and the earth's heat balance.

4. Describe factors affecting the temperature of the earth's surface and the lower atmosphere.

5. Describe the greenhouse effect and its influence on air temperature.

6. Describe temperature lag and the effect daily and seasonal temperature lags have on wildland fire behavior.

I. THE BASIC STRUCTURE AND COMPOSITION OF THE ATMOSPHERE

A. Our Atmosphere

Encircling the earth is a blanket of gases bound to it by the inward pull of gravity.

Similar to its oceans, the atmosphere is in constant motion, endlessly meandering and spiraling on its way around the globe.

The earth without its oxygen and moisture rich atmosphere would certainly resemble the inhospitable planets in our solar system.

1. The atmosphere:

- Provides us with life-giving air.

- Provides constant protection from the sun's dangerous ultraviolet radiation energy.

- Shields the earth from the onslaught of potentially destructive materials from interplanetary space.

- Its greenhouse gases store heat energy contributing to the favorable climatic conditions we enjoy today.

2. The atmosphere extends hundreds of miles above the earth's surface.

- When compared to the diameter of the earth of nearly 8,000 miles, our atmosphere is really quite thin.

- Ninety-nine percent of all atmospheric gases lie within 95,000 feet (18 miles) of the earth's surface.

  Because the upper portion of the atmosphere gradually thins with increasing altitude, it is impossible to say exactly where it ends and outer space begins.

B. Layers of the Atmosphere

Our atmosphere can be divided into many layers based on its change in temperature with altitude, by the gases that comprise it, and even by its electrical properties.

Based on its vertical temperature distribution, the layers are:

- Troposphere
- Stratosphere
- Mesosphere
- Thermosphere

On average, temperature decreases with increasing altitude in the troposphere and mesosphere, and increases with altitude in the stratosphere and thermosphere.

1. The troposphere

The lowest layer of the atmosphere varies in height from 50,000 to 65,000 feet (9-12 miles) above sea level over the tropics, to about 30,000 feet above sea level (6 miles) over the polar regions.

This variation in depth has been attributed to differences in the rotational speed of the earth and latitudinal change in the average temperature of the lower atmosphere.

2. The tropopause

The boundary separating the troposphere from the stratosphere is called the tropopause.

The tropopause:

- Varies in height above sea level from its highest elevation over the tropics to its lowest elevation over the polar regions.

- Normally marks the position of the polar and subtropical jet streams – high winds that meander in narrow channels generally from west to east across both the northern and southern hemispheres.

- Marks the upper limit of nearly all weather in our atmosphere.

Only the tallest thunderstorm clouds are able to reach the tropopause, but in rare instances, their overshooting anvil tops have been known to extend thousands of feet up into this isothermal (equal temperature) layer.

C. Composition of the Atmosphere

The earth's atmosphere is principally composed of gases and water vapor. Nearly three-quarters of all these atmospheric gases are concentrated in the troposphere.

1. Gases

Nitrogen occupies 78 percent and oxygen about 21 percent oxygen of the total volume of dry gases in the troposphere.

The remaining 1 percent of this volume includes:

- Argon
- Neon
- Helium
- Hydrogen
- Xenon
- Carbon dioxide

2. Water vapor

- Varies widely by region, for example, from coastal to intercontinental regions, and by changes in elevation.

- Varies significantly due to seasonal variations in air temperature.

- Is an extremely important element of the atmosphere.

- Forms into water and ice clouds that produce precipitation of various types.

- Stores and releases great quantities of heat energy that is used to power storms, such as thunderstorms and hurricanes.

- Approximately half of all water vapor is found within the lowest 18,000 feet (3 miles) of the atmosphere – the troposphere.

Differences in water vapor concentration create the following conditions:

- The concentration of this invisible gas varies greatly from place to place, and from time to time.

- In tropical locations, water vapor may account for up to 4 percent of the atmospheric gases.

- In colder polar regions, its concentration may be a mere fraction of a percent.

- Changes in the concentration and distribution of water vapor also have a substantial affect on the moisture content and flammability of surface fuels.

II. WEATHER AND ITS ELEMENTS

A. Wildland Fire Environmental Factors

Wildland fire behavior is strongly influenced by three environmental factors:

1. Topography

    - Terrain
    - Aspect
    - Elevation

2. Fuels

    - Fuel moisture
    - Fuel temperature
    - Fuel characteristics

3. Weather

    - Wind
    - Stability
    - Temperature
    - Relative humidity

    Of the three major components of the wildland fire behavior triangle, weather is the most variable over space and time.

    Because of its variability, weather can be difficult to predict, particularly at small scales and longer time periods.

B. What is Weather?

Weather is the short-term variations of the atmosphere. These variations or elements include:

- Air pressure
- Air temperature
- Relative humidity
- Wind
- Clouds
- Precipitation
- Visibility

Changes in one or more of these weather elements can have a significant effect on wildland fire behavior.

A basic knowledge and awareness of weather is essential for making critical fire management decisions.

According to the Standard Firefighting Orders in the NWCG Fireline Handbook, all firefighters should "keep informed on fire weather conditions and forecasts."

Weather and related concerns are also included in the 18 Watch Out Situations:

- #4 – "Unfamiliar with weather and local factors influencing wildland fire behavior."

- #14 – "Weather becoming hotter and drier."

- #15 – "Wind increases and/or changes direction."

The risk involved in fire suppression can be reduced if firefighters and fire managers pay attention and understand weather conditions that impact wildland fire behavior.

C. Atmospheric Pressure

Atmospheric pressure, or simply air pressure, is defined as the amount of force exerted by the weight of air molecules on a surface area.

This downward force or weight is the result of the pull of gravity.

Atmospheric pressure always decreases with increasing altitude; it decreases rapidly at first, then more slowly at higher levels.

The millibar is the most common pressure unit used today on surface and upper level weather maps and charts.

On average, air pressure ranges from near 1000 millibars at mean sea level to less than 1 millibar near the top of the atmosphere.

Another common pressure unit used in aviation and on television and radio broadcasts is inches of mercury.

1. Standard atmospheric pressure

- At mean sea level, the average, or standard, value for atmospheric pressure is 29.92 inches of mercury.

  This is equivalent to 1013.25 millibars.

- If we weigh a column of air with a cross section of 1 square inch, extending from mean sea level to the top of the atmosphere, it would weigh nearly 14.7 pounds per square inch at its base.

  This value also represents the standard atmospheric pressure.

2. Measuring air pressure

- The barometer is the instrument used to measure air pressure. It is a calibrated weather instrument used to measure the weight of the atmosphere on a surface area, normally one square inch in size.

- There are two types of barometers:

  - Mercury barometer
  - Aneroid barometer

3. Change in air pressure with elevation

Atmospheric pressure decreases rapidly with increasing altitude in the lower levels of the atmosphere.

On average, air pressure decreases approximately one inch of mercury every 1000 foot increase in elevation in the lowest 10,000 feet of the atmosphere.

Exercise 1
Our Atmosphere

Answer the questions dealing with our atmosphere.

1. Nearly all weather occurs within the:

   a. Tropopause
   b. Thermosphere
   c. Troposphere
   d. Hydrosphere

2. The instrument used to measure atmospheric pressure is called:

   a. sling psychrometer
   b. aneroid barometer
   c. mercury barometer
   d. pressure thermometer
   e. b and c

3. Nearly half the weight or mass of the atmosphere is concentrated:

   a. below the tropopause.
   b. above the troposphere.
   c. in the upper half of the atmosphere.
   d. in the lowest 18,000 feet of the troposphere.

4. On average, air pressure _________________ approximately ___________________ every 1000 foot increase in elevation within the lowest 10,000 feet of the atmosphere.

   a. increases, 1 inch of mercury
   b. decreases, 1 millibar of mercury
   c. decreases, 1 inch of mercury
   d. decreases, 1 inch of oxygen

III. THE SUN-EARTH RADIATION BUDGET AND THE EARTH'S HEAT BALANCE

A. What Drives Our Weather?

The sun is the principle source of light and heat energy for the earth and its atmosphere.

On a much smaller scale, heat also originates from large fires, and from other natural and human related energy-release processes.

This section will concentrate principally on the heat energy received from the sun and its effect on the atmosphere and the weather it produces.

B. Solar and Terrestrial Radiation

Energy released by the sun travels through space at the speed of light (186,000 miles per second), reaching the earth's atmosphere in the form of short wave or solar radiation.

Most of this solar radiation travels through the atmosphere and is then absorbed by the surface of the earth, causing it to warm.

Heat from the earth is then returned to the atmosphere as longwave or terrestrial radiation through the processes of conduction and convection.

C. The Solar-Earth Radiation Budget

The amount of solar radiation reaching the earth's surface varies depending upon location and atmospheric conditions.

On average:

- 51 percent of the solar radiation arriving at the top of the atmosphere reaches the earth's surface.

- Another 30 percent of the sun's energy is reflected or scattered back to space without ever heating the earth's surface.

- The remaining 19 percent of shortwave solar radiation is absorbed by clouds, dust particles and pollutants.

Of the total solar energy striking the top of the atmosphere, 70 percent of it is absorbed by the earth's surface, atmospheric gases, and clouds.

Solar heat stored by the earth's surface is then transferred to the atmosphere in the form of longwave terrestrial radiation; first by conduction and then convection.

D. The Earth's Heat Balance

Fortunately for us, the amount of radiant energy received from the sun equals the amount of longwave radiation transmitted by the earth and its atmosphere.

This balancing act between incoming versus outgoing radiation is what we refer to as the earth's heat balance.

A change in this heat balance, although small, will cause a change in temperature.

- Should incoming solar radiation exceed the earth's outgoing radiation, the earth and its atmosphere would warm.

- A reversal in this energy exchange results in cooling.

Even though a heat balance exists for the planet as a whole, regional surpluses and deficits in heat produce a wide range of temperatures across the planet.

For example, polar regions lose far more heat than they gain, while the tropical latitudes gain far more heat than they lose.

IV. FACTORS AFFECTING THE TEMPERATURE OF THE EARTH'S SURFACE AND LOWER ATMOSPHERE

The variation in temperature of the earth's surface and lower atmosphere is largely dependent on three factors:

- Solar angle and duration
- Atmospheric moisture and air pollutants
- Surface properties of terrain and vegetation

To understand the effects of solar angle and duration on surface and air temperature, we must first examine why we have seasons.

A. The Change in Seasons

We are all familiar with the four seasons that occur outside the tropics: winter, spring, summer, and fall.

These seasons are primarily caused by the tilt of the earth's axis which causes variations in the amount of solar radiation received by the northern and southern hemispheres.

1. The tilt of the axis is 23.5 degrees from the vertical, thus, the sun is:

    - Directly overhead at 23.5 degrees north latitude the first day of summer.

    - Directly overhead at 23.5 degrees south latitude the first day of winter.

    If the earth's axis was not tilted, the amount of radiation in the area on the earth would remain nearly constant throughout the year.

2. Because of the tilt:

- The suns rays strike the surface at a higher (more vertical) angle during the summer than the winter.
- More heat is received during the summer and temperatures are warmer.
- Less heat is received during the winter and temperatures are colder.
- The days are longer during the summer than the winter.

B. Solar Angle and Duration

Changes in solar angle and length of daylight strongly influence the amount of solar radiation striking a point on the earth's surface.

In general, the higher the solar angle and the longer the daylight, the greater the solar heating.

Solar angle and duration vary by latitude and because of variations in the local terrain.

C. Atmospheric Moisture and Air Pollutants

Clouds, water vapor, and air pollutants absorb, reflect and scatter both solar and terrestrial radiation.

Their presence and amount significantly affect the temperature of the earth's surface and its atmosphere.

D. Heat Loss at Night

Cloud cover and high humidity can have a significant effect on air temperature, especially at night.

Nights with cloud cover are generally warmer than nights without cloud cover.

The cloud cover acts like a blanket to reduce the loss of longwave terrestrial radiation to space.

The rate of heat loss or cooling at night also depends on the amount humidity or moisture in the air, and the height of the cloud cover above the ground.

The greater the humidity and the lower the clouds, the warmer the nighttime temperatures.

E. Surface Properties of Terrain and Vegetation

These properties influence the amount of heat energy absorbed and reflected by the terrain and vegetation.

Their effect on surface air temperature can be quite dramatic.

These properties are:

- Color and texture
- Transparency
- Conductivity
- Specific heat
- Evaporation
- Condensation

Their effect on surface air temperature can be dramatic also.

For example, the difference in temperature between a shoreline and a rocky cliff just 20 miles apart can be as much as 30 degrees because of the properties listed above.

1. Color and texture

   - Color and texture significantly affect the ability of a substance to absorb and reflect radiation.

     Rough textured, irregular, and dark colored materials are generally good absorbers of solar radiation.

   - Good absorbers of radiation are also good emitters of heat energy.

     Smooth, relatively uniform, and light colored materials are generally good reflectors of solar radiation.

2. Albedo

   Albedo refers to the ability of a substance to reflect light and heat energy.

   a. Low albedo

      Rough textured and dark colored materials:

      - Tree bark
      - Rocky cliff
      - Granite
      - Newly plowed field
      - Forest canopy
      - Surface of a lake at high sun angle

   b. High albedo

      Smooth and light colored materials:

      - Field of snow
      - Sandy soil
      - Surface of a lake at low sun angle

      Cloud tops have some of the highest albedos in nature.

3. Transparency

This property affects the distribution of light and heat energy through a substance. Water is transparent, while soil and rock are not.

Water will allow solar radiation to distribute to a much greater depth than soil, allowing this energy to disperse over a greater area.

The soil will concentrate this heat near the surface, resulting in a higher temperature.

4. Conductivity

Refers to the transfer of heat between molecules in contact with one another.

Heat is transferred from high (hot) to low (cold) energy regions by means of molecular activity.

5. Conductors and insulators

a. Conductors

Materials that allow for the efficient transfer of heat energy by means of molecular activity are referred as conductors.

Examples of good conductors:

- Metal
- Granite
- Sandstone

b. Insulators

Materials that are poor conductors of heat energy are called insulators.

Examples of good insulators:

- Dry air
- Wood
- Soil

6. Specific heat

The specific heat of a substance refers to its capacity to absorb, store and release heat energy.

The greater the specific heat capacity of a material, the longer it will take for it to gain and lose heat energy.

The specific heat capacity of all materials is compared to that of the most common element on earth – water.

a. Specific heat capacity of common materials

For comparison, the specific heat capacity of water is five times greater than for rock.

In other words, water has a greater capacity to store more heat energy for longer compared to that of rocks.

b. Regional variation in specific heat

On average, the specific heat capacity of the earth's surface and lower atmosphere varies widely from region to region, depending largely on the amount of moisture present.

The air over tropical and coastal regions has a higher specific heat capacity than the air over deserts, high mountain and arctic regions.

The cold air temperatures in arctic and mountainous regions will reduce the water vapor holding capacity of the atmosphere, and thereby lower the specific heat capacity of the air.

The lower the specific heat, the greater the variation in daily and seasonal air temperatures.

7. Evaporation and condensation

Both of the processes have a large effect on the heating and cooling of nearly all objects, especially the atmosphere.

a. Evaporation

Evaporation is the process where liquid changes to a vapor or gaseous state. During this process, heat energy is removed from the environment. Evaporation is a cooling process.

b. Condensation

Condensation is the process where water vapor changes to liquid. During this process, heat energy is added to the environment. Condensation is a warming process.

c. Evaporation and condensation in the environment

Besides removing heat from the environment, evaporation adds moisture to the atmosphere; moisture that is used to produce fog, clouds, and precipitation.

Heat (latent heat) added to the atmosphere during condensation is essential for the formation and growth of storms, such as thunderstorms and hurricanes.

V. THE GREENHOUSE EFFECT AND ITS INFLUENCE ON AIR TEMPERATURE

A. The Greenhouse Effect

The greenhouse effect is the ability of the atmosphere to retain infrared radiation (heat energy) through absorption by greenhouse gases, such as:

- Water vapor
- Carbon dioxide
- Methane
- Nitrous oxide

Without these critical greenhouse gases, the earth's radiant heat would escape to space without going into heating the atmosphere.

Should the atmosphere possess too much of these greenhouse gases, the earth would become unbearably hot.

B. The Influence on Air Temperature

Our atmosphere behaves similar to a glass paned greenhouse.

In a greenhouse, the glass allows visible solar radiation to come in, but inhibits to some degree the passage of outgoing infrared radiation.

In the atmosphere, most of the sun's energy passes unobstructed to the ground.

The small amount of radiation that does not reach the ground is reflected and scattered back to space by clouds, pollutants, and dust particles.

1. During the daytime:

   The incoming shortwave radiation most often exceeds the outgoing longwave radiation, causing the floor of the greenhouse and the surface of the earth to warm more than the overlying layer of air.

2. At night:

   The floor of the greenhouse cools rapidly within the incoming radiation.

   However, infrared heat trapped by the glass panes keeps the air above the floor from cooling too quickly.

   Remove a few of the panes, the cooling process would accelerate.

VI. TEMPERATURE LAG AND HOW DAILY AND SEASONAL TEMPERATURE LAGS AFFECT WILDLAND FIRE BEHAVIOR

The warmest and coldest times of the day and year rarely coincide with the times of maximum and minimum incoming solar radiation or insolation.

This difference in time between the maximum temperature and maximum insolation, and minimum temperature and minimum insolation is what is known as the temperature lag.

The lag in both daily and seasonal temperatures can be explained in the following manner.

- The earth loses heat continuously through longwave radiation.

- During some months of the year and some hours of the day, the incoming energy from the sun exceeds the outgoing energy of the earth. While this is occurring, the temperature will continue to rise, since the earth is receiving more heat than it is losing.

- The warmest temperature will occur at the time the incoming energy ceases to be greater than the outgoing. After that, temperatures will cool as the outgoing energy becomes greater than the incoming. Cooling will continue until the sun's energy again exceeds the earth's outgoing energy.

A. Seasonal Temperature Lag

In the Northern Hemisphere:

- The warmest annual temperatures commonly occur 3 to 5 weeks after the summer solstice (June 21).

- The coolest annual temperatures normally occur 3 to 5 weeks after the winter solstice (December 21).

This time difference or lag between the highest solar angles and warmest annual temperatures, and the lowest solar angles and coolest annual temperatures is what we call the seasonal temperature lag.

This seasonal lag in temperature often delays and even extends the warm season wildland fire season in many locations across North America.

Though solar radiation is most intense in June and early July (when solar angles are at their highest and daylight is at its longest), the peak wildland fire season in many areas normally coincides with the warmest temperatures and lowest relative humidities observed in late July, August, and even as late as September.

B. Daily Temperature Lag

During the warm summer season:

- The lowest daytime temperature normally occurs shortly after sunrise.

- The highest daily temperatures occur roughly 2 to 4 hours after solar noon.

This lag in solar angle and temperature is not as great during the cold winter season because of lower sun angles and much shorter days.

The time lag between sunrise and the minimum daily temperature often explains the delay or slow down in the growth of wildland fires. For several hours after sunrise, the air near the ground is usually slow to warm and relative humidities are slow to fall because of the slow response of the atmosphere to heating.

Cloud cover can further extend this morning temperature lag, possibly by several hours.

Likewise, during the warm summer season, the time lag between the highest solar angle at solar noon and the maximum daily temperature is often several hours.

Because of this lag, the period of peak wildland fire behavior often occurs during the middle or late afternoon when temperatures are at their highest and relative humidities are at their lowest.

Exercise 2
Factors Affecting Air Temperature

1. Why do dry climates usually have greater temperature differences between night and day than humid climates?

    a. The atmospheric pressure is usually lower.

    b. There is less water vapor in the air to hold in heat at night and reflect radiation during the day.

    c. Solar angle and duration are usually greater in dry climates.

    d. There is more vegetation to store heat energy from the sun.

2. The presence and thickness of clouds only affects the temperature at the earth's surface at night.

    a. True
    b. False

3. A dark soil has a lower albedo than a snow covered field.

    a. True
    b. False

4. Which substance has the highest specific heat capacity?

    a. Rock
    b. Iron
    c. Wood
    d. Water
    e. Dry Air

5. How does evaporation affect the atmosphere?

   a. It warms and moistens it.
   b. It cools and dries it.
   c. It cools and moistens it.
   d. It warms and dries it.

6. The greenhouse effect has what influence on temperature?

   a. It accounts for small daily and seasonal temperature variations in high humidity regions.

   b. It accounts for large daily and seasonal temperatures variations in high humidity regions.

   c. Answers 1 and 2 are both correct.

   d. Answers 1 and 2 are both incorrect.

7. Based on the normal daily temperature lag, when will the highest daytime temperature mostly likely occur during the summer?

   a. 11 a.m.
   b. Noon
   c. 3 p.m.
   d. 1 p.m.

VII. CONCLUSION

In this unit, we introduced basic atmospheric and energy properties that are essential in understanding why the weather behaves as it does. Weather has a significant influence on the ignition, spread and intensity of wildland fires. The more you know about weather and its effects on wildland fire, the safer your career as a firefighter will be.

Intermediate Wildland Fire Behavior, S-290

Unit 5 – Temperature and Humidity Relationships

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Describe the relationship between dry bulb temperature, wet bulb temperature, dew point temperature, and relative humidity.

2. Describe typical day and night (diurnal) variations in air temperature and relative humidity.

3. Determine relative humidity, dew point, and wet bulb temperatures using a psychrometric table.

4. Describe the effects of topography, vegetation, clouds, and wind on air temperature and relative humidity.

5. Describe the temperature and relative humidity characteristics of continental and maritime air masses.

I. Temperature

A. Temperature

Temperature is defined as the degree of hotness or coldness of a substance.

In weather, air temperature (dry bulb temperature) is measured.

Air temperature varies with time, horizontal distance, and height above the earth's surface.

1. Changes in air temperature near the surface of the earth are caused by:

   - The changing seasons

   - The alternations of night and day

   - Weather systems

2. Seasonal and diurnal temperature changes can be large and small, depending on:

   - Latitude

   - Elevation

   - Topography

   - Proximity to the moderating influences of nearby oceans or lakes

3. Abrupt changes in temperature can occur when weather systems transport colder and warmer air into a region.

    - Heating of the earth's surface and the atmosphere is primarily a result of solar radiation from the sun.

    - On a smaller scale, heat will be generated and transferred to the atmosphere by a large fire.

4. In the wildland fire environment:

    - Hot temperatures and direct sunlight can preheat fuels and bring them closer to their ignition point.

    - Cooler temperatures have the opposite effect.

    It is very important that firefighters monitor temperatures and especially temperature trends.

B. Temperature Measurements and Scales

Air temperature is measured with a thermometer calibrated to the Fahrenheit or Celsius scales.

In this course, all temperatures will be given in degrees Fahrenheit.

II. THE RELATIONSHIP BETWEEN DRY BULB TEMPERATURE, WET BULB TEMPERATURE, DEWPOINT TEMPERATURE, AND RELATIVE HUMIDITY

A. Describing Water Vapor in the Atmosphere

1. Moisture as vapor acts the same as any other gas.

   - It mixes with other gases in the air, and yet maintains its own identity and characteristics.

   - It stores an immense amount of energy in evaporation; this energy is later released in condensation.

2. Moisture in the atmosphere is continually changing its physical state:

   - Condensing into liquid
   - Freezing into ice
   - Melting into liquid water
   - Evaporating into gaseous water vapor
   - Condensing back to liquid

   These changes are all related to temperature.

The amount of moisture in the atmosphere affects fuel moisture by either wetting or drying the fuel.

Historically, the majority of large fires have not only occurred when temperatures were above average, but when relative humidities were unusually low.

Relative humidity thresholds for critical fire behavior will vary from one part of the country to the next and from one fuel type to the next.

In this course, wet bulb temperature, dewpoint temperature, and relative humidity will be used to describe atmospheric moisture.

B. Wet Bulb Temperature

The wet bulb temperature is defined as the lowest temperature to which the air can be cooled by evaporation.

- Wet bulb temperature facts

  The greater the difference between air temperature and wet bulb temperature, the drier the air.

  The air is considered moist when a small difference between air temperature and wet bulb temperature exists.

  The wet bulb temperature is read from a wet bulb thermometer.

  Both the wet bulb thermometer and dry bulb thermometer are normally mounted together. This weather instrument is called a psychrometer.

  The difference in degrees between the dry and wet bulb temperatures can be used to determine dewpoint and relative humidity using a psychrometric table.

  Do not confuse this term with <u>dewpoint.</u>

C. Dewpoint Temperature

The dewpoint is the temperature to which air must be cooled to reach saturation.

Like air temperature, dewpoint will be expressed in degrees F.

1. Dewpoint temperature facts

   When the air temperature becomes equal to the dewpoint temperature, the air has reached its saturation point.

   Further cooling causes some of the water vapor to condense into liquid droplets that form clouds, fog, or dew.

   When dewpoint is high (65° to 75°), there is much more water vapor in the air than when the dewpoint is low (20°).

2. Once the dewpoint (saturation point) has been met:

   - The air temperature no longer decreases unless the dewpoint temperature decreases.

   - The air temperature cannot drop below the dewpoint temperature.

3. Dewpoint is one of the most reliable methods for measuring atmospheric moisture.

   Absolute humidity is a more accurate method to represent atmospheric moisture, but is nearly impossible for the weather observer to measure. Thus, dewpoint is used instead.

   It is very important not to confuse dewpoint with wet bulb temperature.

D. Relative Humidity (RH)

Relative humidity is the ratio of the amount of moisture (water vapor) in the air, to the maximum amount of moisture that air could contain if it were saturated.

1. Relative humidity facts

   - Relative humidity is always expressed as a percentage.

   - It is important not to confuse this term with dewpoint.

   - The amount of moisture that fuels can absorb from or release to the air depends largely on relative humidity.

     – Light fuels, such as grass, gain and lose moisture quickly with changes in relative humidity.

     – Heavy fuels respond to humidity changes much more slowly.

2. Firefighters can usually see or feel most of the elements of weather such as wind, rain, and increasing temperatures.

   Small changes in relative humidity that cannot be felt or seen can have a significant impact on fire behavior.

3. Relative humidity thresholds for extreme fire behavior vary over time and space and are different for different fuel types.

   For example, fuels in the southeast part of the United States typically burn with considerably higher relative humidity than fuels in the western U.S.

III. TYPICAL DAY AND NIGHT (DIURNAL) VARIATIONS IN AIR TEMPERATURE AND RELATIVE HUMIDITY

A. Air Temperature, Dewpoint Temperature, and Relative Humidity Relationships

1. Temperature and relative humidity have an inverse relationship, assuming there is no change in dewpoint.

   - If temperature increases, relative humidity decreases.

   - If temperature decreases relative humidity increases.

2. A temperature of 90 °F, and a given dewpoint, yields an RH of 25%.

   - Assuming a constant dewpoint, the relative humidity:

     – Increases to 50% when the temperature drops to 70 °F.

     – Increases to 100% when the temperature drops to 50 °F.

3. Diurnal relationships between temperature and relative humidity can be depicted on a thermograph.

   As the temperature begins to increase, just after sunrise, the relative humidity begins to decrease, reaching its lowest point when the maximum temperature is realized.

   The relative humidity reaches its highest value when the overnight temperature reaches its minimum. This assumes the dewpoint has not changed over night.

   However, a sudden weather change (increase in cloud cover, thunderstorm outflow, cold front, foehn wind) can result in abrupt changes in temperature, dewpoint, and relative humidity.

As a general rule, for each 20°F increase in air temperature, the relative humidity decreases by about half. This assumes that the dewpoint is constant throughout the day; in reality, dewpoint temperatures often fluctuate.

4. Fluctuations in dewpoint may be a result of several factors.

   Dewpoint temperature may decrease with:

   - A break up/dissipation of an inversion.
   - The development of downslope wind.
   - Solar heating resulting in strong vertical mixing of the lower atmosphere

   Dewpoint temperature may increase with:

   - The passing showers and thunderstorms.
   - Wind flow off a body of water, such as a lake or ocean.
   - Evaporation of surface water or the melting of snow and ice.

5. A sharp rise and/or fall in dewpoint may also indicate that a more significant change in weather is occurring.

   - A rise in dewpoint indicates that atmospheric moisture is increasing.
   - A steady fall in dewpoint indicates that atmospheric moisture is decreasing.
   - A rise or fall in relative humidity might indicate a change in temperature and/or atmospheric moisture.

B. Important Facts to Remember About Dry Bulb, Wet Bulb, and Dewpoint

- The dry bulb, wet bulb and dewpoint temperatures will all be the same for saturated air. At that point, relative humidity will be 100 percent.

- If the air is not saturated, the dry bulb will be higher than the wet bulb, and the wet bulb higher than the dewpoint. Always.

EXERCISE 1

Match the terms with the appropriate definition.

___	Temperature	A.	The ratio of the amount of moisture in the air, to the maximum amount of moisture that air could contain if it were saturated.
___	Wet Bulb	B.	The temperature to which air must be cooled to reach saturation.
___	Dewpoint	C.	The lowest temperature to which air can be cooled by evaporation.
___	Relative Humidity	D.	The degree of hotness or coldness of a substance.

IV. DETERMINING RELATIVE HUMIDITY, DEWPOINT AND WET BULB TEMPERATURES USING A PSYCHROMETRIC TABLE

A sling psychrometer is a reliable and accurate instrument used to determine dry bulb and wet bulb temperatures.

The dry bulb and wet bulb temperatures are read from the psychrometer.

After the dry bulb and wet bulb temperatures are determined, a psychrometric table is used to determine the dewpoint temperature and relative humidity.

- The numbers located on the top row of the psychrometric table are the wet bulb temperatures.
- The numbers located in the far left column of the table are the dry bulb temperatures.
- Below the wet bulb temperatures and to the right of the dry bulb temperatures are boxes that contain the corresponding dewpoint temperatures and relative humidities.
- Within each box, the dewpoint is the top number and relative humidity is the bottom number.

EXERCISE 2

Use the psychrometric table on the next page and slide 26 to answer the following questions:

1. What is the relative humidity if the wet bulb temperature is 55°F, and the dry bulb is 85°F?

   a. 32 Percent
   b. 31 Percent
   c. 15 Percent
   d. 14 Percent

2. The dry bulb is 90°F and the wet bulb is 59°F.

   a. What is the dewpoint temperature?

   b. What is the relative humidity?

3. At 1400 the temperature is 83°F and the relative humidity 31 percent. What would the relative humidity be when the temperature rises to 90 °F at 1700 the same day?

   Relative Humidity: _______________

4. A temperature of 91°F and a relative humidity of 25 percent are recorded in a valley at 6,500 feet elevation. At the same time, the temperature at 7,800 feet is 81°F. What is the relative humidity at the higher elevation?

   Relative Humidity: _______________

Psychrometric Table

	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
81	-23 / 1	-5 / 3	5 / 5	12 / 7	17 / 9	22 / 11	26 / 13	30 / 16	33 / 18	36 / 20	39 / 22	42 / 25	44 / 27	46 / 30	48 / 32	50 / 35	52 / 37	54 / 40	56 / 43	58 / 45	60 / 48	61 / 51	63 / 54	64 / 57	66 / 60	68 / 64	69 / 67	70 / 70	72 / 74	73 / 77	75 / 81	76 / 84	77 / 88	78 / 92	80 / 96	81 / 100				
82	-40 / 1	-11 / 2	1 / 4	9 / 6	15 / 8	20 / 10	25 / 12	29 / 14	32 / 16	35 / 19	38 / 21	41 / 23	43 / 25	46 / 28	48 / 30	50 / 33	52 / 35	54 / 38	56 / 41	57 / 43	59 / 46	61 / 49	62 / 52	64 / 55	66 / 58	67 / 61	69 / 64	70 / 67	71 / 71	73 / 74	74 / 77	76 / 81	77 / 85	78 / 88	79 / 92	81 / 96	82 / 100			
83		-19 / 2	-3 / 3	6 / 5	13 / 7	19 / 9	23 / 11	27 / 13	31 / 15	34 / 17	37 / 19	40 / 22	42 / 24	45 / 26	47 / 29	49 / 31	51 / 33	53 / 36	55 / 38	57 / 41	59 / 44	60 / 47	62 / 49	64 / 52	65 / 55	67 / 58	68 / 61	70 / 64	71 / 68	73 / 71	74 / 74	75 / 78	77 / 81	78 / 85	79 / 88	80 / 92	82 / 96	83 / 100		
84		-31 / 1	-8 / 3	3 / 4	11 / 6	17 / 8	22 / 10	26 / 12	30 / 14	33 / 16	36 / 18	39 / 20	42 / 22	44 / 25	46 / 27	49 / 29	51 / 32	53 / 34	55 / 37	56 / 39	58 / 42	60 / 44	62 / 47	63 / 50	65 / 53	66 / 56	68 / 59	69 / 62	71 / 65	72 / 68	74 / 71	75 / 74	76 / 78	78 / 81	79 / 85	80 / 89	82 / 92	83 / 96	84 / 100	
85			-15 / 2	-1 / 4	8 / 5	14 / 7	20 / 9	24 / 11	28 / 13	32 / 15	35 / 17	38 / 19	41 / 21	43 / 23	46 / 25	48 / 28	50 / 30	52 / 32	54 / 35	56 / 37	58 / 40	59 / 42	61 / 45	63 / 48	64 / 50	66 / 53	68 / 56	69 / 59	70 / 62	72 / 65	73 / 68	75 / 71	76 / 75	77 / 78	79 / 81	80 / 85	81 / 89	83 / 92	84 / 96	85 / 100
86			-25 / 1	-6 / 3	5 / 4	12 / 6	18 / 8	23 / 10	27 / 12	31 / 14	34 / 16	37 / 18	40 / 20	42 / 22	45 / 24	47 / 26	49 / 28	51 / 31	53 / 33	55 / 35	57 / 38	59 / 40	61 / 43	62 / 45	64 / 48	66 / 51	67 / 54	69 / 56	70 / 59	72 / 62	73 / 65	74 / 68	76 / 72	77 / 75	78 / 78	80 / 82	81 / 85	82 / 89	84 / 92	85 / 96
87			-44	-12 / 2	1 / 4	9 / 5	16 / 7	21 / 9	26 / 11	29 / 13	33 / 14	36 / 16	39 / 18	42 / 20	44 / 22	46 / 25	49 / 27	51 / 29	53 / 31	55 / 33	57 / 36	59 / 38	60 / 41	62 / 43	64 / 46	65 / 48	67 / 51	68 / 54	70 / 57	71 / 60	73 / 63	74 / 66	75 / 69	77 / 72	78 / 75	79 / 78	81 / 82	82 / 85	83 / 89	85 / 92
88				-20 / 1	-3 / 3	7 / 5	14 / 6	19 / 8	24 / 10	28 / 12	32 / 13	35 / 15	38 / 17	41 / 19	43 / 21	46 / 23	48 / 25	50 / 27	52 / 30	54 / 32	56 / 34	58 / 36	60 / 39	62 / 41	63 / 44	65 / 46	66 / 49	68 / 52	69 / 54	71 / 57	72 / 60	74 / 63	75 / 66	77 / 69	78 / 72	79 / 75	81 / 79	82 / 82	83 / 85	84 / 89
89				-33 / 1	-8 / 2	3 / 4	11 / 5	17 / 7	22 / 9	27 / 11	30 / 12	34 / 14	37 / 16	40 / 18	43 / 20	45 / 22	47 / 24	50 / 26	52 / 28	54 / 30	56 / 32	58 / 35	59 / 37	61 / 39	63 / 42	64 / 44	66 / 47	68 / 49	69 / 52	71 / 55	72 / 58	73 / 60	75 / 63	76 / 66	78 / 69	79 / 72	80 / 76	82 / 79	83 / 82	84 / 86
90					-15 / 2	-1 / 3	8 / 5	15 / 6	21 / 8	25 / 10	29 / 11	33 / 13	36 / 15	39 / 17	42 / 19	44 / 21	47 / 22	49 / 25	51 / 27	53 / 29	55 / 31	57 / 33	59 / 35	61 / 38	62 / 40	64 / 42	66 / 45	67 / 47	69 / 50	70 / 52	72 / 55	73 / 58	75 / 61	76 / 64	77 / 67	79 / 70	80 / 73	81 / 76	83 / 79	84 / 82
91						-5 / 2	5 / 4	13 / 5	19 / 7	24 / 9	28 / 10	32 / 12	35 / 14	38 / 16	41 / 17	43 / 19	46 / 21	48 / 23	50 / 25	53 / 27	55 / 29	57 / 31	58 / 34	60 / 36	62 / 38	64 / 40	65 / 43	67 / 45	68 / 48	70 / 50	71 / 53	73 / 56	74 / 58	76 / 61	77 / 64	78 / 67	80 / 70	81 / 73	82 / 76	84 / 79
92						-11 / 2	2 / 3	10 / 5	17 / 6	22 / 8	27 / 10	30 / 11	34 / 13	37 / 15	40 / 16	43 / 18	45 / 20	48 / 22	50 / 24	52 / 26	54 / 28	56 / 30	58 / 32	60 / 34	61 / 36	63 / 39	65 / 41	66 / 43	68 / 46	70 / 48	71 / 51	73 / 53	74 / 56	75 / 59	77 / 61	78 / 64	79 / 67	81 / 70	82 / 73	83 / 76
93						-18 / 1	-2 / 3	8 / 4	15 / 6	20 / 7	25 / 9	29 / 10	33 / 12	36 / 14	39 / 15	42 / 17	44 / 19	47 / 21	49 / 23	51 / 24	53 / 26	55 / 28	57 / 30	59 / 33	61 / 35	63 / 37	64 / 39	66 / 41	68 / 44	69 / 46	71 / 49	72 / 51	74 / 54	75 / 56	76 / 59	78 / 62	79 / 64	81 / 67	82 / 70	83 / 73
94						-31 / 1	-7 / 2	4 / 3	12 / 5	18 / 6	23 / 8	28 / 9	32 / 11	35 / 13	38 / 14	41 / 16	44 / 18	46 / 20	49 / 21	51 / 23	53 / 25	55 / 27	57 / 29	59 / 31	61 / 33	62 / 35	64 / 37	66 / 40	67 / 42	69 / 44	70 / 47	72 / 49	73 / 51	75 / 54	76 / 57	78 / 59	79 / 62	80 / 65	82 / 68	83 / 71
95							-13 / 1	1 / 3	10 / 4	16 / 6	22 / 7	26 / 9	30 / 10	34 / 12	37 / 13	40 / 15	43 / 17	45 / 18	48 / 20	50 / 22	52 / 24	54 / 26	56 / 28	58 / 30	60 / 32	62 / 34	64 / 36	65 / 38	67 / 40	69 / 42	70 / 45	72 / 47	73 / 49	75 / 52	76 / 54	77 / 57	79 / 60	80 / 62	81 / 65	83 / 68
96							-22 / 1	-3 / 2	7 / 4	14 / 5	20 / 6	25 / 8	29 / 9	33 / 11	36 / 12	39 / 14	42 / 16	45 / 17	47 / 19	50 / 21	52 / 23	54 / 24	56 / 26	58 / 28	60 / 30	61 / 32	63 / 34	65 / 36	67 / 38	68 / 41	70 / 43	71 / 45	73 / 47	74 / 50	76 / 52	77 / 55	78 / 57	80 / 60	81 / 63	82 / 65
97							-38	-9 / 2	4 / 3	12 / 4	18 / 6	23 / 7	28 / 9	32 / 10	35 / 12	38 / 13	41 / 15	44 / 16	46 / 18	49 / 20	51 / 21	53 / 23	55 / 25	57 / 27	59 / 29	61 / 31	63 / 33	64 / 35	66 / 37	68 / 39	69 / 41	71 / 43	72 / 45	74 / 48	75 / 50	77 / 53	78 / 55	80 / 58	81 / 60	82 / 63
98								-16 / 1	0 / 2	9 / 4	16 / 5	22 / 6	26 / 8	30 / 9	34 / 11	37 / 12	40 / 14	43 / 15	46 / 17	48 / 19	50 / 20	53 / 22	55 / 24	57 / 26	59 / 27	61 / 29	62 / 31	64 / 33	66 / 35	67 / 37	69 / 39	71 / 41	72 / 44	74 / 46	75 / 48	76 / 51	78 / 53	79 / 55	81 / 58	82 / 60
99								-26 / 1	-5 / 2	6 / 3	14 / 4	20 / 6	25 / 7	29 / 9	33 / 10	36 / 11	39 / 13	42 / 14	45 / 16	48 / 18	50 / 19	52 / 21	54 / 23	56 / 24	58 / 26	60 / 28	62 / 30	64 / 32	65 / 34	67 / 36	69 / 38	70 / 40	72 / 42	73 / 44	75 / 46	76 / 49	78 / 51	79 / 53	80 / 56	82 / 58
100								-47	-10 / 1	3 / 3	11 / 4	18 / 5	23 / 7	28 / 8	32 / 9	35 / 11	39 / 12	42 / 14	44 / 15	47 / 17	49 / 18	51 / 20	54 / 21	56 / 23	58 / 25	60 / 27	61 / 28	63 / 30	65 / 32	67 / 34	68 / 36	70 / 38	71 / 40	73 / 42	74 / 44	76 / 47	77 / 49	79 / 51	80 / 54	81 / 56
101									-18 / 1	-1 / 2	9 / 3	16 / 5	22 / 6	26 / 7	31 / 9	34 / 10	38 / 11	41 / 13	43 / 14	46 / 16	49 / 17	51 / 19	53 / 20	55 / 22	57 / 24	59 / 25	61 / 27	63 / 29	65 / 31	66 / 33	68 / 35	70 / 37	71 / 39	73 / 41	74 / 43	76 / 45	77 / 47	78 / 49	80 / 52	81 / 54
102									-29	-6 / 2	6 / 3	14 / 4	20 / 5	24 / 7	29 / 8	33 / 9	37 / 11	40 / 12	43 / 13	45 / 15	48 / 16	50 / 18	53 / 19	55 / 21	57 / 23	59 / 24	61 / 26	62 / 28	64 / 29	66 / 31	68 / 33	69 / 35	71 / 37	72 / 39	74 / 41	75 / 43	77 / 45	78 / 47	80 / 50	81 / 52
103										-12 / 1	2 / 2	11 / 4	18 / 5	23 / 6	28 / 7	32 / 9	36 / 10	39 / 11	42 / 13	45 / 14	47 / 15	50 / 17	52 / 18	54 / 20	56 / 22	58 / 23	60 / 25	62 / 26	64 / 28	66 / 30	67 / 32	69 / 34	70 / 35	72 / 37	74 / 39	75 / 41	76 / 43	78 / 46	79 / 48	81 / 50
104										-20 / 1	-2 / 2	9 / 3	16 / 4	22 / 5	27 / 7	31 / 8	35 / 9	38 / 10	41 / 12	44 / 13	46 / 15	49 / 16	51 / 17	54 / 19	56 / 20	58 / 22	60 / 24	62 / 25	63 / 27	65 / 29	67 / 30	68 / 32	70 / 34	72 / 36	73 / 38	75 / 40	76 / 42	78 / 44	79 / 46	80 / 48
105										-33	-6 / 1	6 / 3	14 / 4	20 / 5	25 / 6	30 / 7	33 / 9	37 / 10	40 / 11	43 / 12	46 / 14	48 / 15	51 / 17	53 / 18	55 / 20	57 / 21	59 / 23	61 / 24	63 / 26	65 / 27	66 / 29	68 / 31	70 / 33	71 / 34	73 / 36	74 / 38	76 / 40	77 / 42	79 / 44	80 / 46

V. THE EFFECTS OF TOPOGRAPHY, VEGETATION, CLOUDS, AND WIND ON AIR TEMPERATURE AND RELATIVE HUMIDITY

A. Effects of Topography

The intensity of sunlight in complex terrain varies significantly from slope to slope, depending on slope angle and aspect.

1. Slope exposure to sunlight affects local temperature and relative humidity. This influences the type and amount of vegetation, affecting fire behavior.

    - In the northern hemisphere, south slopes are typically much warmer, experience lower relative humidity, and lower soil moisture content due to their greater exposure to sunlight.

    - North slopes typically experience the coolest temperatures and highest relative humidity.

    - The ridge top difference in relative humidity is smaller near mountain tops because of greater mixing due to wind.

    - When fire moves onto a slope with a different aspect, changes in temperature, relative humidity, and resultant moisture content of fuels change the fire's intensity and rate of spread.

2. Elevation significantly affects temperature, relative humidity, and fire behavior.

   - In a well mixed atmosphere during the day, temperature typically decreases with an increase in elevation, with a corresponding rise in relative humidity.

   - The increase in relative humidity with elevation increases the moisture content of dead fuels at higher elevations.

   - The opposite is true at night, with the colder temperatures and higher relative humidities typically found in the valleys.

B. Effects of Vegetation

Vegetation affects temperature and relative humidity by intercepting incoming sunlight during the day and outgoing radiation at night.

1. Low or sparse vegetation produces little shade, thus has much less effect on temperature of the underlying surface than tall, dense vegetation which results in more shading.

2. Green foliage, because of respiration, photosynthesis, and evapotranspiration, does not heat up as much as bare ground or surface organic litter.

3. Temperature and relative humidity vary around trees.

   During the day:

   - The warmest temperatures and lowest relative humidity are found around the tree tops.

   - The coolest temperatures and highest relative humidity are found beneath the canopy in the shade.

The opposite is true at night:

- The coldest temperatures and highest relative humidity are found near tree top.

- The warmest temperatures and lowest relative humidity are found beneath the canopy.

C. Effects of Cloud Cover

1. Cloud cover affects temperature and relative humidity by:

   - Reflecting incoming sunlight during the day.

   - Intercepting outgoing long-wave terrestrial radiation at night.

2. During the day, cloud cover reflects incoming solar radiation, decreasing the amount of sunlight reaching the ground.

   Cloud cover can lower daytime temperatures by several degrees and increase relative humidity, thus decreasing fire behavior.

3. At night, heat lost at the surface is absorbed by cloud cover and re-directed back to the earth's surface.

   This process can result in higher nighttime temperatures and lower relative humidity.

D. Effects of Wind

Wind has a moderating effect on air temperature and relative humidity near the ground.

- During the day, wind effectively mixes cooler and more moist air aloft with air near the ground.

  - Wind tends to lower air temperature and raise relative humidity near the ground.

- At night, wind disrupts and minimizes radiational cooling at the surface and effectively mixes warmer, drier air aloft with air near the ground.

- On a clear, calm night, extensive radiational cooling takes place, and air near the ground will cool rapidly resulting in cooler temperatures and higher relative humidities.

E. Other Effects of Wind

Wind moving downslope warms and dries the air, while winds coming off a large body of water may dramatically increase relative humidity and lower the temperature.

Outflow winds from rain showers or thunderstorms can suddenly cool and moisten the air.

VI. THE TEMPERATURE AND RELATIVE HUMIDITY CHARACTERISTICS OF CONTINENTAL AND MARITIME AIR MASSES

A. Air mass

An air mass is a large body of air with “homogeneous” or similar temperature and moisture characteristics.

Air masses are identified by their locations of origin, maritime (over water) or continental (over land), and are further categorized by origin of polar or tropical.

B. Types of Maritime and Continental Air masses

- Maritime Polar (mP)
- Maritime Tropical (mT)
- Continental Artic (cA)
- Continental Polar (cP)
- Continental Tropical (cT)

Tropical air masses form in high pressure areas in warm, tropical regions.

- When tropical air masses form over oceans, they are warm and moist.

- When tropical air masses form over land, they are hot and dry.

Polar air masses form in high pressure areas in the polar and sub polar regions.

- A polar air mass that forms over water is cool and moist.

- A polar air mass that forms over land is cold and dry.

Depending on its characteristics, a changing air mass can either increase or decrease fire behavior.

Large fire growth or blowups are typically associated with a warm, dry, continental air mass, similar to conditions ahead of a trough or cold front.

Conversely, decreasing fire behavior is typically associated with a cooler and moister maritime polar air mass, such as found behind cold fronts.

It is important that firefighters understand the temperature and moisture characteristics of each type of air mass and fire behavior implications.

1. Maritime Polar (mP)

   Air originating from over cold oceanic regions:

   - North Pacific
   - Gulf of Alaska
   - North Atlantic

   Given its origin, this air mass is cold and moist.

2. Maritime Tropical (mT)

   Air originating from over warm oceanic regions:

   - Central Pacific
   - Gulf of California
   - Gulf of Mexico
   - Central Atlantic

   Given its origin, this air mass is warm and moist.

3. Continental Artic (cA)

   Air originating in the artic regions is extremely cold and dry.

4. Continental Polar (cP)

   Air originating from over large, often cold and dry continental land areas, such as northern portions of North America (Canada).

   Given its origin, this air mass is cold and dry.

5. Continental Tropical (cT)

   Air originating from over large, often warm and dry continental land areas, such as Central America (Mexico) or Southwest United States.

   Given its origin, this air mass is warm and dry.

EXERCISE 3

1. South facing slopes are typically:

   a. Cooler and drier than north facing slopes.
   b. Warmer and drier than north facing slopes.
   c. Cooler and moister than north facing slopes.
   d. Warmer and moister than north facing slopes.

2. Cloud cover at night:

   a. Keeps surface temperatures cooler than would otherwise be expected.
   b. Keeps surface temperatures warmer than would otherwise be expected.
   c. Has no effect on surface temperatures.

3. Stronger winds at night will:

   a. Lower air temperature and raise relative humidity near the ground.
   b. Keep temperatures warmer and relative humidity low.
   c. Keep temperatures cooler and relative humidity higher.
   d. Both a and b

4. A maritime polar air mass originates over:

   a. Large, often cold and dry, continental land areas.
   b. Warm oceanic regions such as the Central Pacific, of the Gulf California, the Gulf of Mexico, and the Central Atlantic.
   c. Cold oceanic regions such as the North Pacific, the Gulf of Alaska, and the North Atlantic.
   d. Large, often warm and dry continental land areas, such as Central America or Southwest United States.

5. A continental tropical air mass originates over:

   a. Large, often cold and dry, continental land areas.
   b. Warm oceanic regions such as the Central Pacific, of the Gulf California, the Gulf of Mexico, and the Central Atlantic.
   c. Cold oceanic regions such as the North Pacific, the Gulf of Alaska, and the North Atlantic.
   d. Large, often warm and dry continental land areas, such as Central America or Southwest United States.

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Unit 6 – Atmospheric Stability

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Describe the relationship among atmospheric pressure, temperature, density, and volume.

2. Describe temperature lapse rate and stability, and the different lapse rates used to determine the stability of the atmosphere.

3. Describe the effects of atmospheric stability on wildland fire behavior.

4. Name four types of temperature inversions and describe their influence on wildland fire behavior, including the thermal belt.

5. Name and describe the four lifting processes that can produce thunderstorms.

6. Describe the elements of a thunderstorm and its three stages of development.

7. Use visual indicators to describe the stability of the atmosphere.

8. Describe the four principle cloud groups, and identify the six clouds most often associated with critical wildland fire behavior.

I. INTRODUCTION

Up to now, our attention has been on temperature and the factors that influence its change on and near the earth's surface.

In this unit we will focus on air temperature in the third dimension, atmospheric stability, and how stability affects wildland fire behavior.

We will also discuss visual indicators commonly used to identify critical changes in atmospheric stability.

II. THE RELATIONSHIP AMONG ATMOSPHERIC PRESSURE, TEMPERATURE, DENSITY AND VOLUME

Our atmosphere is composed of numerous gases. This gaseous mixture includes **permanent dry air gases.** This is air assumed to contain no water vapor with a concentration that remains constant within a volume of atmosphere. These gases include:

- Nitrogen
- Oxygen
- Argon
- Helium
- Hydrogen
- Xenon

Nitrogen and oxygen account for 99 percent of all permanent dry air gases in the troposphere.

The remaining gases, called **variable gases**, vary in concentration within a volume of atmosphere over time and place. These gases include:

- Water vapor
- Carbon dioxide
- Methane
- Nitrous oxide
- Ozone

In this group of gases, **water vapor** is the most abundant, varying from a trace to 4 percent by volume.

A. The Behavior of Gases

Nearly all gases in the atmosphere respond uniformly to changes in temperature and pressure. For that reason, we can use the **ideal gas law,** which is based on a set of physical rules.

The relationship among pressure, temperature, and density (mass per volume) can be expressed by the ideal gas law equation:

$$\mathbf{P=(\rho)RT} \quad \text{or} \quad \mathbf{P = (m/V)RT}$$

where: **P** is pressure, ρ is density, **m** is the mass of the gas, **V** is volume, **R** is a gas constant, and **T** is the temperature.

Since **R is a constant**, we can ignore it and then simplify the equation as:

$$\mathbf{P \sim (\rho)T} \quad \text{or} \quad \mathbf{P \sim (m/V)T}$$

The term **(m/V)** represents the density **(ρ)** of the gas; while **~** is the symbol meaning "is proportional to."

B. Applying the Gas Law to Air in Motion

For the sake of simplicity, we refer to air in motion in terms of small units called **air parcels**.

An air parcel is simply a volume of air, large enough to contain a great number of molecules, but small enough so that its energy (heat) and mass (air molecules) are nearly constant within its boundaries.

Air parcels can be expanded and compressed, but outside air is not able to mix with air inside; essentially making an air parcel a sealed container.

Air parcels are commonly portrayed as 3-dimensional cubes or spheres.

C. Applying the Gas Law to Rising Air Parcels

Recall from Unit 4 that atmospheric pressure rapidly decreases with altitude in the lower atmosphere.

As an air parcel ascends through the lower atmosphere, its pressure will decrease in response to a lowering of atmospheric pressure with increasing altitude. Therefore, according to the gas law **as air pressure decreases**:

- its volume will increase
- its density will decrease
- its temperature will decrease

Rising air parcels will always <u>expand</u> and <u>cool</u>.

D. Applying the Gas Law to Sinking Air Parcels

As an air parcel descends through the lower atmosphere, its internal pressure will increase in response to an increase in atmospheric pressure with decreasing altitude.

Therefore, according to the gas law **as air** pressure **increases:**

- its volume will decrease
- its density will increase
- its temperature will increase

Sinking air parcels will always <u>compress</u> and <u>warm</u>.

E. Adiabatic Process

When an air parcel rises or sinks without any loss of energy or mass to the surrounding atmosphere, we refer to this condition as an **adiabatic process—**the energy and mass of an air parcel remains constant.

Exercise 1
Relationship Among Pressure, Temperature, Density, and Volume

Answer the following questions about the behavior of gases as described by the ideal gas law. You have five minutes to complete this exercise.

1. Water vapor is considered a:

   a. dry air gas
   b. permanent gas
   c. variable gas
   d. neutral gas

2. According to the ideal gas law, as air pressure increases:

   a. temperature and volume increase.
   b. temperature decreases and volume increases.
   c. temperature increases and volume decreases.
   d. temperature and volume decreases.

3. As an air parcel rises it:

   a. compresses, cools, and becomes more dense.
   b. expands, cools, and become more dense.
   c. expands, cools, and becomes less dense.
   d. compresses, cools, and becomes less dense.

4. As an air parcel sinks it:

   a. compresses, warms and becomes more dense.
   b. compresses, cools and becomes more dense.
   c. expands, warms and becomes less dense.
   d. compresses, warms and becomes less dense.

5. As an air parcel rises and sinks, its energy and mass remain constant. This describes:

   a. the adiabatic process
   b. the gas law
   c. sublimation
   d. none of the above

III. STABILITY AND THE THREE DIFFERENT TEMPERATURE LAPSE RATES USED TO IDENTIFY THE STABILITY OF THE ATMOSPHERE

A. Air in Motion

Our atmosphere is in constant motion. The rotation of the earth on its axis, together with large and small scale variations in pressure and temperature are what produce the horizontal and vertical movement of air in the atmosphere.

In Unit 4, we discussed how horizontal changes in pressure and temperature produce horizontally moving air called **wind**.

Wind occurs at all levels of the atmosphere. The types of winds, based on their location and how they are formed, will be discussed in great detail in Unit 7.

Our concern will be on vertically moving air which we refer to as **atmospheric stability**.

The magnitude or strength of wind is far greater than the vertical movement of air associated with atmospheric stability. However, their influence on the behavior of wildland fires is equally important.

B. What is Stability?

Stability is simply the resistance of the atmosphere to vertical motion. More precisely, it is the degree to which vertical motion in the atmosphere is enhanced or suppressed.

Depending on the vertical temperature profile of the atmosphere, air will either rise, sink, or remain at rest.

1. Three types of stability

Stability of varying types can exist simultaneously at different levels of the troposphere. Theses types are **unstable**, **stable,** and **neutral**. In general:

- An **unstable atmosphere** will enhance or encourage the vertical movement of air.

- A **stable atmosphere** will suppress or resist vertical motion.

- A **neutral atmosphere** will neither suppress nor enhance vertical motion.

a. An **unstable atmosphere** is one where the vertical temperature change or lapse rate is such that air parcels displaced upward or downward and will continue to accelerate from their level of origin.

An unstable atmosphere promotes the formation of updrafts and vertically developed clouds, such as the cumulus and cumulonimbus, or thunderstorm clouds.

b. A **stable atmosphere** is one where the vertical temperature change forces vertically moving air parcels to return to their level of origin where their temperature and density are similar to the surrounding atmosphere.

In a stable atmosphere, winds tend to be light, particularly over flat terrain and in mountain valleys. Visibilities may also be reduced due to poor vertical mixing, especially within the boundary layer.

In mountainous terrain, however, stable atmospheric conditions can and often do produce gusty ridgetop winds, and warm and dry downslope winds called **foehn** winds. These winds can have a serious effect on wildland fire behavior.

c. **Neutral stability** usually exists for only short periods of time during the transition between a stable and an unstable atmosphere.

In an atmosphere of neutral stability, little vertical air motion occurs. If this condition should exist through a deep layer of atmosphere, an air parcel's vertical motion will cease.

2. The effect of stability on wildland fire behavior

The following are some generalizations.

a. Unstable atmospheric conditions are most often associated with critical or extreme wildland fire behavior.

b. Stable atmospheric conditions tend to suppress or reduce the growth or intensity of wildland fire behavior.

c. Neutral atmospheric conditions are associated with neither critical nor suppressed wildland fire behavior.

C. Changing Atmospheric Stability

Stability changes almost continuously, due to daily fluctuations in the vertical temperature structure of the lower atmosphere.

There are four basic ways the stability of the atmosphere can be changed.

1. **For unstable conditions -** the atmosphere can either be warmed from below or cooled from above.

2. **For stable conditions -** the atmosphere can either be cooled from below or warmed from above.

D. Temperature Lapse Rate

A good understanding of atmospheric stability depends on our understanding of how air temperature can change vertically in the troposphere. To describe these changes, we will use the temperature lapse rate.

Temperature **lapse rate** is defined simply as the change in temperature with a change in altitude.

$$\frac{\text{Change in Temperature}}{\text{Change in Altitude}}$$

Temperature lapse rate is used to determine the stability of different layers in the atmosphere. It differs throughout the troposphere, particularly in the lowest 3000 feet above the ground where air temperature is strongly influenced by daytime solar heating and nighttime radiational cooling.

This lowest layer of the troposphere is called the **boundary layer**. We will often refer to this important layer near the ground.

Temperature normally decreases with increasing altitude in the troposphere. This represents the normal or "standard" change in temperature with altitude. However, air temperature can also increase with increasing altitude in the troposphere.

This reversal in the normal trend in temperature reduction with altitude is what we refer to as an **inversion**. More on inversions later in this unit.

Essentially, a **negative lapse rate** indicates a "normal" decrease in temperature with increasing altitude, while a **positive lapse rate** indicates an "inverted or "abnormal" increase in temperature with increasing altitude.

Meteorologists determine lapse rates by using radiosondes (weather observing balloons) and other observing systems.

E. Three Lapse Rates to Remember

Two different temperature lapse rates are used to determine the stability of the atmosphere. A third lapse rate does not.

Instead, this lapse rate is sometimes used to estimate or project a temperature for a point in space, such as on a mountain side.

The three lapse rates are:

- dry adiabatic lapse rate
- moist adiabatic lapse rate
- average lapse rate

1. Dry adiabatic lapse rate

As air cools its capacity to hold water vapor decreases, and as temperature decreases, relative humidity increases.

As long as a vertically moving air parcel remains unsaturated (its relative humidity remains less than 100 percent) it will cool or warm at a constant rate with its internal energy and mass (dry air and water vapor) remaining unchanged.

This is what we refer to as a “true” adiabatic process.

This rate of temperature change for rising and sinking unsaturated air parcels is called the **dry adiabatic lapse rate**.

For rising unsaturated or dry air parcels, the lapse rate is **-5.5ºF per 1000 feet**.

For sinking unsaturated or dry air parcels, the lapse rate is **+5.5ºF per 1000 feet.**

2. Moist adiabatic lapse rate

The adiabatic process becomes somewhat more complicated when it involves condensation. As stated above, all rising air parcels expand and cool, regardless if condensation occurs or not.

If a rising air parcel become saturated (its relative humidity equals 100 percent), further lifting results in condensation.

During condensation (cloud formation), rising air parcels lose mass, principally in the form of water vapor (cloud droplets and precipitation).

Heat energy (called **latent heat**) is also released to the parcel and its surroundings during condensation. This latent heat warms the parcel, however, not enough to reverse the cooling caused by expansion.

Instead of cooling at the rate of -5.5ºF per 1000 feet, a rising saturated air parcel cools at a slower rate of **-3.0ºF per 1000 feet** because of the introduction of latent heat.

We refer to this slower rate of cooling due to expansion as the **moist (or wet) adiabatic lapse rate**.

Because of the heat gain and loss of mass (principally water vapor) during condensation, the moist adiabatic lapse rate does not represent a "true" adiabatic process.

Thus, it is sometimes referred to as a **pseudoadiabatic lapse rate** where the prefix pseudo- means "closely resembling."

Sinking air parcels rarely warm at the moist adiabatic lapse. For example, once a saturated air parcel begins to sink down the lee slope of a mountain range, compression causes it to warm.

Once its relative humidity lowers to below 100 percent, the parcel will warm at the faster dry adiabatic lapse rate of +5.5ºF per 1000 feet.

This transition from the moist lapse rate to the dry lapse rate often occurs rather suddenly and usually near the top of the lee slope of a mountain range.

Radiosonde observations are plotted onto charts called **skew-T diagrams.**

These diagrams are used to depict the pressure, temperature, density, moisture and wind within a column of atmosphere above a point on the earth's surface.

Plotted skew-T diagrams are then used to determine temperature lapse rates and stability of the troposphere.

3. Average lapse rate

This generalized lapse rate represents the average vertical change in temperature for all layers of the lower atmosphere combined.

This lapse rate is about +/-3.5ºF per 1000 feet. The average lapse rate rarely matches the dry and moist lapse rates.

Because this lapse rate does not represent the "actual" temperature distribution for a specific column of atmosphere, it can not be used to determine the stability of a column of atmosphere.

But this lapse rate is useful in estimating or projecting the temperature and relative humidity at a level in the atmosphere or for a point on a mountain side.

Because of variations in topography, vegetation, wind, cloud cover, etc., avoid using this lapse rate to project temperatures more than 2000 feet above or below your location.

Here is an example using the average lapse rate to estimate or project a temperature near a wildfire on a mountain side.

- At a mountain observation site at 4,500 feet, the observed temperature is 94ºF.

- Using the average lapse rate, the temperature at a fire at 6,500 feet is projected to be 87 °F.

The relative humidity at the fire can also be estimated using the appropriate psychrometric table for the elevation, and the procedure discussed in Unit 5, assuming the same dewpoint at both locations.

A Day in the Life of a Rising Air Parcel

1. An unsaturated air parcel over a sun-drenched bare field has a temperature of 80º F.

2. Air over nearby fields covered with vegetation has an observed temperature of 74º F.

3. The warmer and less dense (lighter) air parcel accelerates upward, expanding and cooling at the dry lapse rate as the outside pressure decreases.

4. At 5000 feet, the air parcel has cooled to a temperature of 52.5º F.

5. The observed air temperature at that altitude is 49º F.

6. Still warmer and lighter than the surrounding air, the parcel continues to rise, cooling dry adiabatically to a temperature of 8.5º F at 13,000 feet.

7. At that altitude, the parcel is only slightly warmer than its surroundings, but it continues to rise at a much slower rate because of the very small difference in temperature between it and the surrounding air.

If the air parcel were to become saturated during its ascent, for example at 5000 feet, a cloud would form (assuming the parcel remained saturated as it continued to rise).

After becoming saturated, the parcel would then cool at the slower moist adiabatic lapse rate of -3.0º F per 1000 feet until condensation no longer occurred.

F. How Stable or Unstable is the Atmosphere?

The difference in temperature between an air parcel and the atmosphere at its same level will determine how fast an air parcel will ascend or descend.

The greater the temperature difference or gradient, the faster the parcel will either rise or fall.

This difference in temperature is also a very good indicator of how <u>stable</u> or <u>unstable</u> a layer of atmosphere is.

Large wildfires can produce exceedingly strong updrafts capable of lifting debris such as shrubs and trees hundreds of feet into the sky.

No doubt this is an example of critical wildland fire behavior produced by an extremely unstable atmosphere.

G. The Influence of Moisture on Stability

The amount of moisture or water vapor in the air also plays an important role in changing the stability of the troposphere.

Dry air is heavier than moist air or water vapor as indicated by their average molecular weights.

Adding water vapor to a column of air, displaces the heavier dry air molecules, and lowers the atmospheric pressure measured at the earth's surface.

Removing water vapor allows dry air molecules to return, increasing the weight of the column. This weight change would be indicated by higher air pressure at the earth's surface.

This difference in weight would explain why low humidity days are generally more stable, have fewer clouds and higher air pressure.

High humidity days are generally more unstable, have more clouds, and have a greater chance of precipitation and even thunderstorms. Greater moisture equates to greater instability.

Exercise 2
Air Flow over a Mountain Range

Using the illustration on slide 53 and the exercise information below, calculate the temperature of the air parcel moving up and down this mountain range.

Use visual indicators in the illustration to help you to select the appropriate lapse rate for your calculations.

You are allowed 10 minutes to complete this exercise. Students will share their answers and a short explanation as to how it was calculated, including the lapse rate used.

Exercise information:

An unsaturated air parcel with a temperature of 80° F is lifted from an elevation of 5,000 feet at Grand Junction up the windward slope of the mountain to the continental divide at 13,000 feet. Then the parcel moves down the leeward slope of the mountain, returning to its original elevation of 5,000 feet at Denver.

Along the way, the parcel becomes saturated as it passes through a precipitating cloud over the windward slope. Once over the divide, the parcel quickly becomes unsaturated as it begins to sink.

Calculate the parcel temperature at 8,000 feet on the windward slope using the dry lapse rate, at 13,000 feet using the moist lapse rate, and at 8,000 feet and 5,000 feet on the leeward slope using the dry lapse rate.

Decide which lapse rate to use with the help of visual indicators (clouds, no clouds) in the illustration.

8000 feet on west slope:
13,000 feet on the ridge:
8000 feet on east slope:
5000 feet at Denver:

Explain why the parcel temperature increased 12.5º F between Grand Junction and Denver; pointing out that the parcel started and ended at the same elevation.

Exercise 3
Lapse Rates and Atmospheric Stability

Answer the following questions dealing with temperature lapse rates and atmospheric stability.

1. Adding water vapor to an air parcel will make it:

   a. colder
   b. warmer
   c. lighter
   d. heavier

2. The observed temperature at a weather station at 3000 feet is 83º F. Project what the current temperature would be at a wildfire 1800 feet above that location.

   a. 77.6ºF
   b. 76.7ºF
   c. 73.1ºF
   d. 89.3ºF

3. A column of cold, dry air is ________ than a column of warm, humid air.

   a. heavier and generally more stable.

   b. lighter and generally more unstable.

   c. Both answers are correct.

   d. Neither answer is correct.

4. When a rising air parcel becomes saturated:

   a. it cools due to expansion at -5.5º F per 1000 feet.

   b. it cools due to compression at -5.5º F per 1000 feet.

   c. cooling due to expansion is offset by latent heat of condensation causing the parcel to cool at a slower rate of -3.0º F per 1000 feet.

   d. cooling due to expansion is offset by the latent heat of evaporation causing the parcel to cool at the rate of -5.5º F per 1000 feet.

5. Critical or extreme wildland fire behavior is most often associated with:

   a. stable atmospheric conditions.

   b. unstable atmospheric conditions.

IV. THE EFFECTS OF ATMOSPHERIC STABILITY ON WILDLAND FIRE BEHAVIOR

A. The Mixing Layer

The mixing layer, also called the convective mixing layer, is the lower level of the troposphere where surface heating mixes and vertically transports air molecules, water vapor and pollutants, such as smoke, potentially to thousands of feet above the ground.

The boundary layer located in the lower portion of the mixing layer during the daytime, becomes the mixing layer at night.

The mixing layer is generally:

- deepest or highest over the interior of continents and tropical regions, and
- shallowest or lowest over the oceans, coasts, and polar regions.

Over the continental United States, the maximum depth of the mixing layer varies from about ½ to 3½ miles on average.

The mixing layer is normally "capped" by a layer of very stable air, which limits the rise of vertically developed clouds and smoke columns.

The tops of tall smoke plumes, and cumulonimbus clouds spread out at the top of the mixing layer because of overlying layer of very stable air.

Thunderstorms with very strong updrafts are capable of rising well beyond the top of the mixing layer, and on rare occasions, to the base of the tropopause.

1. Evolution of the daytime mixing layer

The height of the mixing layer can vary widely from its lowest height early in the morning when the surface air is coolest, to its greatest heights by the middle of the afternoon when summertime temperatures are usually at their highest.

The height rise of the mixing layer during a typical intercontinental summer day.

- At sunrise, the mixing layer is shallow, possibly no more than a few hundred feet deep.
- Because of the early morning temperature lag, the surface air temperature is slow to increase; from 55º F at 0600 to 63º F by 0800.
- During this two hour period, the top of the mixing layer slowly rises to a height of 1500 feet above ground level. Any smoke produced by a smoldering wildland fire will likely remain trapped near the ground because of the shallow depth of the mixing layer.
- From 0800 to 1000, the top of the mixing layer continues its slow lift to a height of 2800 feet above ground level. However, during this same period, the surface air temperature rises 12 degrees!
- Even with the large increase in air temperature near the ground, fire behavior and intensity are likely to remain low prior to 1000 become of the continued low mixing layer depth. Smoke dispersal only slightly improves as surface winds begin to increase slightly in speed.
- Shortly after 1000, the nighttime temperature "inversion" suddenly breaks (inversions will be discussed in greater detail later in this unit), and the top of the mixing layer quickly rises to a altitude of 7400 feet above ground level by 1200.
- Notice that the dramatic increase in the height of mixing layer between 1000 and 1200 occurs with only a 5 degree increase in the surface air temperature.
- During this late morning period, wildland fire behavior suddenly increases as indicated by the sudden rise of the smoke column. Wind speeds increase, temperatures rise and relative humidities fall as warmer and drier air mixes down to the ground with the dissipation of the nighttime inversion.

- Finally, from 1200 to 1400 hours, the top of the mixing layer rises another 4600 feet to its maximum altitude of 12,000 feet above ground level. This jump in height occurred with only an 8 degree increase in surface air temperature. Maximum height of the mixing layer occurs at the time of maximum temperature around 1430 hours.

- By mid-afternoon, the smoke column reaches its maximum height and wildland fire behavior remains active because of high temperatures and low relative humidities.

2. Seasonal variation in the height of the mixing layer.

   a. The average height of the mixing layer is lowest during the cold winter months when daytime is shortest and sun angles are lowest.

   b. The average height of the mixing layer is highest during the warm summer months when daytime is longest and sun angles are at their highest.

   c. The average height of the mixing layer quickly rises during the spring as surface temperatures steadily increase with increasing daylight hours.

   d. The average height of the mixing layer quickly lowers in the autumn as surface temperature steadily fall with decreasing sunlight hours.

   e. Strong sinking or subsidence and warming of mid-level air will often lower the top of the mixing layer to levels well below those observed in the spring.

B. The Effects of Unstable Air on Wildland Fire Behavior

Unstable air can contribute to more active wildland fire behavior by increasing:

1. Likelihood of fire whirls and dust devils (both indicators of very unstable conditions near the ground).

2. Likelihood of gusty and erratic surface winds.

3. The height and strength of convection and smoke columns.

4. Likelihood of firebrands being lifted to great heights for long-range spotting and new fire starts.

C. The Effects of Stable Air on Wildland Fire Behavior

Stable air can contribute to less active wildland fire behavior by:

1. Limiting the rise of smoke columns; this will result in poor smoke dispersion and visibility.

2. Reducing the inflow of fresh air, thereby limiting growth of wildland fires and the development of the convective column.

3. Lowering surface wind speeds and fire spread rates except in mountainous and hilly terrain.

D. Haines Index

The Haines Index is a stability index that was specifically designed for fire weather use by Donald Haines of the USDA North Central Forest Experiment Station.

The Haines Index is calculated by combining the stability and dryness of the lower atmosphere into a number that correlates well with **large plume dominated fire growth.**

1. The **stability term** is determined by the temperature difference between two atmospheric levels (the temperature lapse rate).

2. The **dryness term** is determined by the temperature and dew point difference within a single lower layer of the atmosphere.

Due to large differences in elevation across the United States, three combinations of atmospheric layers are used to construct the Haines Index.

Much of the Eastern United States, excluding the Appalachian Mountains, uses 2,000 to 5,000 feet mean sea level (MSL) data.

The Great Plains and the Appalachian Mountains use 5,000 and 10,000 feet MSL data, and the Western United States uses 10,000 and 18,000 feet data.

The Haines Index ranges from 2 and 6.

- The drier and more unstable the lower atmosphere is, the higher the Haines Index.

- The more humid and stable the lower atmosphere, the lower the Haines Index.

A Haines Index of 2 or 3 indicates very low potential, 4 low potential, 5 moderate potential, and 6 high potential for large plume dominated fire growth.

Haines found that only 10 percent of large fires occurred when the index was very low, although 62 percent of the fire season days fell in the very low class.

Forty-five percent of large fires were associated with high class days even though only 6 percent of the days fell into that class. National Weather Service meteorologists across the country include the Haines Index on routine fire weather forecasts.

In summary, the drier and more unstable the lower atmosphere is, the higher the Haines Index; and the more humid and stable the lower atmosphere is, the lower the Haines Index.

V. FOUR TYPES OF TEMPERATURE INVERSIONS AND THEIR EFFECTS ON WILDLAND FIRE BEHAVIOR

A. What is a Temperature Inversion?

A **temperature inversion** is a layer of very stable air where temperature increases with an increase in altitude.

1. Temperatures in an inversion may increase as much as 15°F per 1,000 feet in altitude.

2. An inversion acts like a cap or lid to severely limit the upward movement of air.

3. Temperature inversions can exist at many levels in the troposphere. The strongest inversion or stable layer is located at the top of the troposphere called the tropopause.

4. Smoke rising from most fires will flatten and spread out horizontally at the first inversion layer encountered because of the loss of upward momentum.

5. Only the strongest updrafts associated with thunderstorms and very large fires manage to "punch" through this first inversion layer, and on rare occasions, may extend well up into the upper portions of the tropopause.

B. Four Types of Temperature Inversions

The following is a description of four types of temperature inversions:

- nighttime or radiation inversion
- frontal (air mass conversion) inversion
- marine inversion
- subsidence inversion

These inversion types are categorized by how they are formed and where they form in the atmosphere.

1. Nighttime or radiation inversion

The most common type of inversion. At night, air near the ground cools faster than the air above it, resulting in a nighttime or radiation inversion.

During the evening hours, the surface based nighttime or radiation inversion is weak and shallow, usually no more than a few hundred feet deep. As cold air drainage and radiational cooling continues overnight, the inversion strengthens and eventually reaches its maximum depth around sunrise when surface temperatures are at their lowest.

The depth of the nighttime or radiation inversion can range from several hundred feet to a few thousand feet. Factors such as **cloud cover, wind, precipitation, snow cover, valley** or **canyon width and depth,** and **time of year** can influence the depth and strength of the nighttime or radiation inversion.

Radiation or nighttime inversions are particularly strong in mountain valleys because of the enhanced cold air drainage in these locations. Cool, dense air flowing down from surrounding slopes and valley walls accumulates on the valley floor overnight.

This relatively cold and dense air displaces the relatively warmer and less dense air that was on the valley floor during the day.

Nighttime inversions in mountain valleys may reach depths of a few thousand feet with clear skies and very light or calm winds.

a. The effects of cloud cover and wind on nighttime or radiation inversions

- Nighttime or radiation inversions are deepest or strongest on clear nights with little or no wind. The lack of wind allows for a strong vertical temperature gradient to form. Without the wind, warmer and drier air aloft is unable to mix downward to the ground.

- Nighttime or radiation inversions are shallowest or weakest on cloudy, breezy nights. Warmer and drier air aloft is able to mix down to the ground when winds are present.

- The cloud cover reduces the amount of radiational cooling that would normally occur under a clear sky; resulting in warmer temperatures and lower relative humidities.

b. Dissipation of the nighttime or radiation inversion

- The inversion is strongest just after sunrise when the air near the ground is coldest.

  Fire intensity is low and smoke dispersal is poor. The smoke column over a smoldering fire hangs low, spreading out in all directions as surface winds are normally very light or calm.

- By mid-morning, the nighttime inversion weakens considerably as the air near the ground becomes nearly as warm as the air at the top of the inversion.

  Fire intensity gradually increases as light surface winds bring fresh oxygen to the fire. The smoke column begins to tilt upward and smoke dispersion improves as the top of the inversion rises.

- By late morning, the air near to the ground has become warmer than the air above the nighttime inversion, causing the inversion to dissipate or "break."

  When this occurs, there is often a sudden increase in fire behavior as air aloft rushes fresh oxygen to the fire. As the inversion breaks, the smoke column rises suddenly, becoming well formed and nearly vertical in appearance.

- Once the plume rises high enough, it begins to tilt in the direction of the general of transport winds, carrying small embers and fire brands down range from the fire.

c. What to expect when nighttime or radiation inversions break

- Winds often increase suddenly and possibly become gusty and erratic.

- Air temperature increases suddenly.

- Relative humidity decreases suddenly.

d. The thermal belt

There are several aspects of stable air that should be understood by the firefighter. One is the relationship of the nighttime or radiation inversion to thermal belts.

The **thermal belt** forms where the top of the nighttime or radiation inversion makes frequent contact with the valley wall or mountain slope.

On average, the nighttime temperature in this area is warmer than on the slopes above or below; this area typically experiences the least variation in diurnal temperature, and has the highest average temperature and lowest average relative humidity at night.

Thermal belts can, and often do, have a significant effect on wildland fire control efforts. The higher temperatures and lower relative humidities dry fuels out and create burning conditions that may become severe.

Overall, the thermal belt is the area on a valley wall or mountain slope with the greatest potential for wildfire.

Most important is the continued active burning during the night, while areas above and below the thermal belt are relatively quiet. Firefighters are often surprised by active burning in this area throughout the night.

e. Elevation and location of thermal belts

The elevation and location of the thermal belt varies by:

- locality
- time of year
- length of nighttime darkness
- size and steepness of the valley or canyon

The thermal belt tends to form at **lower elevations** on mountain slopes and valley walls during the **summer season** when shorter nights allow for less radiational cooling and cold air drainage.

The thermal belt tends to form at **higher elevations** on mountain slopes and valley walls during the **winter season** when longer nights allow for more radiational cooling and cold air drainage to produce nighttime or radiation inversions with greater depths.

Thermal belts may appear several thousand feet above the valley floor coinciding with the tops of these surface-based inversions.

The thermal belt tends to form at higher elevations on mountains slopes and the walls of **broad valleys** and **gently sloped canyons** where cold air draining off of nearby slopes can accumulate to great depths.

The thermal belt tends to form at lower elevations on mountain slopes and the walls of **narrow valleys** and **steep canyons** where strong drainage prevents cold air from accumulating to great depths.

2. Frontal inversion

The **frontal inversion** forms when a layer of relatively cold air near the ground moves under and displaces a layer of relatively warmer and less dense air. This inversion forming process occurs with the passage of a **cold front**.

A frontal inversion also forms when a layer of relatively warm, less dense air slides up and over a layer of colder more dense air near the ground. This inversion forming process occurs with the passage of a **warm front**.

The frontal inversions associated with cold fronts are normally stronger than those formed by warm fronts; however, frontal inversions associated with warm fronts are often more widespread, covering hundreds of miles.

The depth of a frontal inversion may vary from a few hundred feet near the surface frontal boundary, to several thousand behind the surface frontal boundary.

A layer of stratus type-clouds will often define the top of the frontal inversion during the daytime. Whereas at night, fog may form in the cooler, moist and stable air within the inversion layer.

If the inversion remains stationary over an area for more than a day or two, it will usually deepen and become stronger. If enough moisture is present, fog and low clouds will become widespread.

3. Marine inversion

The **marine inversion** is a common type of inversion found along the shorelines of large lakes, and along the coasts of continents, particularly the West coast of the United States.

The depth of the marine inversion may vary from a few hundred feet to several thousand feet.

Cool, moist and stable marine air beneath a layer of warm, dry and unstable air will frequently move over the lowlands along the West coast with the diurnal cycle of winds and temperature.

The marine inversion in these areas may persist during the day, but are strongest and most noticeable at night.

When the onshore flow or "marine push" becomes strong enough, the marine inversion may become deep enough to allow fog and low stratus-type clouds to spread hundreds of miles inland from the coast.

Marine layer air frequently penetrates the interior valleys and basins of western Washington, Oregon, and California, where fog and low clouds may linger for weeks at a time with weak winds and stable conditions.

Both marine and frontal inversions can have significant impacts on wildland fire behavior, mainly to reduce or suppress fire activity.

4. Subsidence inversion

A subsidence inversion is an increase in temperature with increasing height that is produced by the slow sinking motion of a layer of middle or high level air beneath a large high pressure ridge.

As this high altitude air sinks or "subsides," it warms by compression, producing a layer of warm, dry and very stable air. This inversion is enhanced by the vertical mixing of warm, unstable air from below.

Subsidence is a slow process that can occur over several days. During this time period, a subsidence inversion will grow stronger as it lowers and becomes progressively warmer and drier than the layer of air below it.

The top of mountain ranges will experience the warm, very dry conditions of a subsidence inversion first. If this condition persists, fuels dry out and burning conditions may become severe.

Poor smoke dispersal conditions may also develop below a lowering subsidence inversion.

Subsidence inversions are normally strongest during late summer and autumn, and on the north and east sides of strong high pressure ridges that remain over a region, sometimes for weeks at a time.

Subsidence inversions can have a significant effect on wildland fire behavior, mainly to reduce or suppress activity and smoke plume formation. This is not always the case with subsidence inversions as we will see next.

C. Subsidence and Foehn Winds

Winds on flat terrain are normally light in speed underneath large high pressure ridges and subsidence inversions.

In mountainous regions, these same atmospheric conditions can produce gusty warm and dry downslope winds called foehn winds, pronounced fōne or foone.

Foehn winds can have disastrous effects on wildland fires. Examples of more famous foehn winds include the Santa Ana and the Chinook.

Exercise 4
Stability and its Effects on Wildland Fire Behavior

Answer the following questions concerning stability and its effects on wildland fire behavior.

1. If a layer of air near the ground is determined to be stable during the morning, will it remain stable for the remainder of the day, and why?

   a. No. Because on a sunny day the air near the ground will likely become warmer than the air aloft.

   b. No. Because on a sunny day the air aloft will most likely become warmer than the air near the ground.

   c. Yes. If the sky remains cloudy the air near the ground will likely remain cooler than the air aloft.

   d. Answers B and C are correct.

   e. Answers A and C are correct.

2. Which of the following causes the atmosphere to become more unstable?

   a. Heating the atmosphere from below.
   b. Cooling the upper portion of the atmosphere.
   c. Heating the upper portion of the atmosphere.
   d. Answers A and B are correct.
   e. Answers B and C are correct.

3. Which of the following best describes an inversion?

   a. Air temperature increases with height.
   b. Air temperature decreases with height.
   c. It is a layer of stable air topped by a layer of unstable air.
   d. Answers A and C are correct.

4. Inversions in general are associated with which type of wildland fire behavior?

   a. Active
   b. Inactive

5. What should we expect when nighttime or radiation inversions break?

   a. A sudden drop in temperature and an increase in relative humidity.
   b. A sudden increase in wind and temperature, and a decrease in relative humidity.
   c. The sudden formation of clouds.
   d. A decrease in fire behavior because of a gradual decrease in wind speeds.

6. Thermal belts form:

   a. Where the bottom of the nighttime inversion frequently makes contact with the valley wall.
   b. Where the top of the nighttime inversion frequently makes contact with the valley wall.
   c. At lower elevations in the winter and at higher elevations in the summer.
   d. Answers B and C are correct.

VI. THE FOUR LIFTING PROCESSES THAT CAN PRODUCE THUNDERSTORMS

Up to this point we have discussed what happens to air when it rises and sinks, how different atmospheric conditions can cause changes in stability, and how temperature inversions can affect wildland fire behavior and control efforts.

We will now discuss ways air can be lifted to produce clouds, precipitation and even thunderstorms.

There are four major lifting processes found in the atmosphere. Any one of these lifting processes, in combination with favorable instability and moisture, is enough to produce a thunderstorm.

The four lifting processes are:

- Thermal or convective
- Orographic
- Frontal (air mass convergence)
- Jet stream

A. Thermal (Convective) Lift

Strong heating of air near the ground produces thermal updrafts or convective currents. As the air heats, it becomes less dense and begins to rise.

As it rises, it expands and cools. If the heated air contains enough moisture and rises high enough in the atmosphere, saturation will be reached and convective or cumulus-type clouds will form.

Thermal lifting is most common in the summer. In flat country, the greatest convective activity is over the hottest surfaces. In mountainous regions, it is aided by orographic lift (see next section) over the highest peaks and ridges.

B. Orographic (Terrain) Lift

Orographic lift simply refers to the lifting of air caused by mountains or higher terrain. Overall, orographic lift is caused by:

- Air being forced up a slope or valley by daytime heating, or
- By the upward deflection of air after colliding with a mountain barrier.

Air forced up by both methods will cool at the dry adiabatic lapse rate. If this air reaches its saturation point and it continues to rise, clouds develop. Orographic and thermal lifting often work together to produce tall, vertically developed cumulus clouds.

Orographic lift and the convergence of air over a ridge top or mountain peak will produce vertically developed clouds that often remain anchored over this elevated terrain until dissipating once afternoon heating has ended.

C. Frontal Lift (Air Mass Convergence)

The third process is frontal lifting. In this lifting process, two air masses of differing temperature and moisture characteristics collide, producing lift or upward motion where they intersect.

For reference, the leading edge of an advancing cold air mass is called a cold front, and the leading edge of an advancing warm air mass is a warm front.

The lift created by the **convergence** or the coming together of two air masses causes a reduction in air pressure in the lower troposphere. The reduced air pressure creates additional buoyancy (lift) which further enhances lift along the advancing frontal boundary.

The amount of frontal lift produced depends on a number of factors, including:

- The depth and speed of the advancing air mass, and
- How moist and unstable the air is in the vicinity of the converging air masses.

A colder air mass, because of its greater air density, will normally slide underneath and displace upward a warmer, lighter air mass.

Weak lifting produced by shallow and/or slow moving cold air masses typically creates low stratus-type clouds or fog, assuming the lifted air becomes saturated.

Strong lifting produced by deep and/or fast moving air masses typically creates tall, billowing cumulus-type clouds.

Under very unstable conditions, massive, towering cumulonimbus clouds and thunderstorms form.

Stratus-type clouds and fog are more likely to occur with the gentle frontal lifting produced when warmer, lighter air glides over a colder, heavier air mass. This occurs with passage of a warm front.

Convergence over Mountain Ridges - On a small scale, convergence occurs during the daytime, especially during the spring and summer, over mountain ridges when thermally or heat driven winds on opposing slopes come together. Towering convective-type clouds, such as the cumulonimbus, are an indication that mountain top convergence is occurring.

D. Jet Stream Lift

First, what is the **jet stream**? It is simply a channel of swiftly moving air often found at high altitudes of the troposphere.

It varies considerably in speed and direction as it rounds the top of large high pressure ridges and low pressure troughs.

Changes in the speed and direction of the jet stream, know as wind shear, produces the strong lifting motion associated with jet streams.

As high speed segments of the jet stream pass overhead, wind shear produces divergence (the horizontal spreading out of winds) at high levels of the troposphere.

This divergence causes a reduction in air density and air pressure aloft.

This pressure reduction at high levels of the troposphere causes air from lower levels to rise and literally fill in the "void" left behind by the diverging air flow aloft.

This chimney-like effect can be enhanced further by strong heating and air convergence (the coming together of air flow) at lower levels of the troposphere. When this occurs near a convective cloud, large fire, or thunderstorm updraft, ***explosive growth*** of these phenomena may occur.

A wildfire can quickly intensity and become plume dominated with the strong lift produced by a passing jet stream. Smoke columns from large fires have been known to gain great heights in a relatively short time under these conditions.

Wispy cirrus-type clouds high in the troposphere may be your only indication that jet stream winds are passing overhead.

Firefighters should watch for any visual indications of jet stream lift, such as the tops of thunderstorm clouds (cumulonimbus) being sheared off by strong winds aloft.

Exercise 5
Lifting Processes

1. Match the various lifting processes with their definitions.

_ Frontal	A.	Strong lifting produced by diverging winds and low air pressure aloft.
_ Jet Stream	B.	The rising of air currents as a result of surface heating.
_ Thermal	C.	Air that is forced to rise as it is pushed against mountainous terrain.
_ Orographic	D.	Lifting produced when two air mass converge.

2. Which best describes a subsidence inversion?

   a. Warming and drying aloft with sinking air; surface winds are light on flat terrain.

   b. When air is forced up a mountain slope causing mid-levels of the troposphere to become warmer and drier.

   c. Forms at night when the air near the ground cools faster than the air aloft; it is strongest in broad mountain valleys.

   d. Forms above an advancing cold air mass where cold, stable air is topped by warm, unstable air.

3. Which lifting process will cause an increase in wildland fire behavior and control efforts?

   a. Orographic
   b. Frontal
   c. Jet Stream
   d. Thermal
   e. All of the Above

4. Which lifting process can cause <u>explosive</u> growth in smoke columns and thunderstorms?

   a. Frontal
   b. Jet Stream
   c. Orographic
   d. Thermal

5. Lift produced by air colliding with a mountain slope is called:

   a. Thermal
   b. Frontal
   c. Orographic
   d. Topographic

VII. THE ELEMENTS OF A THUNDERSTORM AND ITS THREE STAGES OF DEVELOPMENT

A. The Thunderstorm

The **thunderstorm** is a local storm nearly always produced by a cumulonimbus cloud, and always accompanied by **lightning** and **thunder**.

The thunderstorm may produce strong straight-line or outflow winds, heavy rain, and hail. The more intense storms are also capable of tornadoes.

Other elements of the thunderstorm include an anvil, the spreading out top of the thunderstorm cloud, and strong updraft and downdrafts. Lightning produced by all thunderstorms may be cloud-to-ground, cloud-to-cloud, and cloud-to-air.

Lightning can carry either a negative charge or a positive charge. The negatively charged lightning strokes are far more common (about 90 percent), but the positively charged strokes (about 10 percent) are believed to produce most of the lightning ignited wildland fires in the United States.

A lifting mechanism (frontal, orographic, thermal, jet stream), **favorable instability** and **adequate moisture** are all necessary to produce a thunderstorm.

B. Three Stages of a Thunderstorm

Thunderstorms go through three stages of development and decay:

- cumulus
- mature
- dissipating

1. The cumulus stage

This is the early stage of a thunderstorm when rising columns of relatively moist and unstable air form clouds consisting of domes, mounts or towers, and upper parts resembling a cauliflower.

The sunlit parts of these clouds are mostly brilliant white, while their bases are relatively dark and flat in appearance.

This cloud grows vertically, often with only a single updraft. In its later development, this cloud will grow vertically into a towering cumulus cloud, capable of even stronger wind gusts.

Cloud towers can extend thousands of feet in the sky just before becoming a mature stage thunderstorm.

Precipitation is not produced during this stage, but gusty winds are relatively common, particularly on hot, sunny days when the cloud shadow produces a sharp temperature contrast on the ground.

2. The mature stage

The mature stage, the most active stage of the thunderstorm cycle, begins when **lightning** and **thunder** are first observed.

A strong **updraft** and **downdraft** will also form within the thunderstorm cloud during this stage.

The thunderstorm cloud, called a **cumulonimbus**, is exceptionally dense and vertically developed, forming either as a single cloud mass, or in a line of complex clouds.

The bases of mature thunderstorms are dark and ragged. An anvil-shaped top, composed entirely of ice crystals, forms at the top of the cloud. The anvil flattens out as it approaches the stable tropopause.

If the air beneath a thunderstorm is very dry, for example air with a relative humidity well below 30 percent, rain falling from the base of a thunderstorm in most cases will evaporate before reaching the ground.

This is a common occurrence in semi-arid regions in the western United States. Rain that evaporates before reaching the ground is called **virga**.

Lightning that is produced by a thunderstorm with very little rain or virga, is called **dry lightning**.

The evaporation of rain and hail near the base of the thunderstorm causes the surrounding air to cool rapidly. The air grows more dense as it cools, causing it to accelerate toward the ground as a downdraft.

Upon reaching the ground, this downdraft fans out in all directions as relatively cool and gusty outflow or "straightline" winds. The leading edge of these gusty winds is called a gust front.

Wind velocities of 20 to 30 mph are common, although gusts in excess of 60 mph are possible with large thunderstorms. Gust fronts can travel more than 10 miles from the thunderstorm, causing sudden changes in wind speed and direction along their path.

3. The dissipating stage

During this final stage, downdrafts exist through the entire cumulonimbus cloud. Without an updraft to supply the thunderstorm with a source of moisture and energy, the core of the thunderstorm collapses.

The resulting collapse causes a downward rush of rain-cooled air that can be as strong and gusty as downdraft winds during the mature stage.

Rainfall and lightning activity decrease rapidly during this stage, eventually ending as the thunderstorm downdraft dissipates.

C. Hazards to Firefighters

All three stages of the thunderstorm pose a hazard to the wildland firefighter.

It is the mature stage; however, that poses the greatest risk to personal safety, and potentially the greatest impact on wildland fire behavior.

Exercise 6
The Thunderstorm and its Stages

Answer the following questions about the thunderstorm and its stages of development and decay. There is only one correct answer for each question. You have five minutes to complete this exercise.

1. What are the three ingredients necessary to produce a thunderstorm?

   a. an anvil, lightning, and strong wind.

   b. a lifting mechanism, instability, and moisture.

   c. updrafts, downdrafts, and lightning

   d. all answers are correct.

2. The spreading out top of a cumulonimbus or thunderstorm cloud is called:

   a. a virga cloud
   b. an anvil
   c. an anchor cloud
   d. an updraft cloud

3. The mature stage of a thunderstorm begins:

   a. when gusty updraft winds form.
   b. when updrafts and downdrafts form.
   c. when virga ends.
   d. when lighting and thunder are first observed.
   e. answers b and d are correct.

4. Identify the thunderstorm stage with stage descriptors. (Choose the best answer.)

a. cumulus b. mature c. dissipating

_____________ downdraft only

_____________ greatest hazard to fire fighters

_____________ rain and lightning ends

_____________ updraft and downdraft

_____________ updraft only

_____________ thunder first heard

_____________ no precipitation

VIII. USING VISUAL INDICATORS TO DESCRIBE THE STABILITY OF THE ATMOSPHERE

Visual indicators are the easiest way to recognize whether the air is stable or unstable.

Alternate methods include consulting the fire weather forecast or a fire weather meteorologist.

In this course, we will concentrate on the visual indicators and discuss each.

A. Visual Indicators of Stable Air

1. Smoke column drifts apart after limited rise.

2. Clouds are in layers with little vertical development, such as stratus clouds.

3. Poor visibility in lower levels of the atmosphere due to an accumulation of smoke and haze.

4. The presence of fog.

5. Winds are normally light or calm on flat terrain and valley floors.

6. Mountain wave clouds indicating gusty winds on the mountain ridges and slopes above the nighttime or radiation inversion.

B. Visual Indicators of Unstable Air

1. Clouds grow vertically to great heights, such as towering cumulus, altocumulus castellanus and cumulonimbus.

2. Cumulus-type clouds often produce gusty and erratic surface winds.

3. Good visibility due to a well "mixed" atmosphere.

4. Smoke columns rise to great heights and are well formed.

5. Smoke columns may rise high enough to produce pyro-cumulus cloud tops.

6. Dust devils and firewhirls often form in areas of strong heating by the sun or by a fire.

Exercise 7
Visual Indicators of Stable and Unstable Air

Work in small groups for this exercise. Smoke columns are one of the better visual indicators of stable and unstable air. This exercise presents several atmospheric situations that students could encounter on a fire.

Using slide 114, write the number of the picture next to the correct description.

_ The atmosphere is unstable with wind shear and strong winds aloft.

_ A surface inversion or stable air at lower levels.

_ The atmosphere is unstable at all levels.

_ The stability of the lower atmosphere is neutral with moderate to strong surface winds.

_ An inversion and thermal belt exist on the slopes of this ridge, resulting in very stable air. Unstable conditions occur on the ridgetop.

_ The lower atmosphere is unstable with an inversion aloft.

Exercise 8
What Can Smoke Tell Us About the Stability of the Atmosphere?

Slides 116-118 are photographs of smoke columns. Provide a short answer to the following questions:

1. Is the atmosphere stable or unstable in this photo? At what levels?
2. If there is wind, where and approximately how strong? Weak? Moderate? Strong?
3. If there is an inversion, what type?

Answers:

Photo A: 1.
2.
3.

Photo B: 1.
2.
3.

Photo C: 1.
2.
3.

Photo D: 1.
2.
3.

Photo E: 1.
2.
3.

Photo F: 1.
2.
3.

Photo G: 1.
2.
3.

Photo H: 1.
2.
3.

Photo I: 1.
2.
3.

Photo J: 1.
2.
3.

Photo K: 1.
2.
3.

Photo L: 1.
2.
3.

IX. THE FOUR PRINCIPLE CLOUD GROUPS AND THE SIX CLOUDS MOST OFTEN ASSOCIATED WITH CRITICAL WILDLAND FIRE BEHAVIOR

In the last part of this unit we will examine clouds, their names, the families they belong to, how they can be used as visual indicators, and the six clouds critical to wildland firefighters.

Clouds come in all shapes and sizes, and exist at all levels of the troposphere. The formation and appearance of a cloud is strongly influenced by the stability of the atmosphere.

A. What is a Cloud?

A cloud is a visible collection of billions of minute water and/or ice particles suspended in the atmosphere above the earth's surface. A cloud in contact with the ground is called **fog**.

Clouds form in the atmosphere by either condensation within a rising column of air, or by cooling the air to the point of saturation. Does this sound familiar?

Clouds form under both stable and unstable atmospheric conditions, but not all clouds produce precipitation.

B. Classification of Clouds

Clouds are usually classified according to their appearance and the height of their bases above the ground.

There are basically three cloud groups.

For convenience, we list them in descending order in the troposphere:

1. high clouds > 20,000 ft
2. middle clouds 10,000 to 20,000 ft
3. low and vertically developed clouds < 6500 ft

*Vertically developed clouds 1500-10,000 ft.

We must exercise some caution when relying on the height of clouds for the purpose of classification. There is some seasonal and latitudinal variation, and there is some overlapping of the groups from time to time.

C. Clouds Preceding a Significant Weather Change

Two to three days before the arrival of a significant weather change, such as a cold front, high clouds begin filling the sky.

The weather system producing these high cirrus-type clouds, such as cirrostratus, may still be several hundred miles away.

One to two days before the significant weather change, middle clouds begin filling the sky. If the atmosphere becomes very unstable in advance of this weather system, middle clouds may form towers or turrets, such as the altocumulus castellanus.

Finally, several hours to a day before the arrival of the weather system, such as a cold front, low clouds begin filling the sky overhead. The lower atmosphere will usually become moist and unstable before the passage of a cold front.

If the pre-frontal atmosphere becomes very unstable, tall vertically developed clouds such as the cumulonimbus or thunderstorm clouds will form overhead.

D. Impact of Cloud Cover on Fire Behavior

The amount of cloud cover affects fire intensity. Generally, when daytime cloud cover is less than 50 percent, fires tend to be more active and flame heights are greater.

When daytime cloud cover is greater than 50 percent, fire activity tends to decrease and flame heights lower.

An increase in daytime cloud cover would lower surface air temperatures, which would have a stabilizing affect on the lower atmosphere and suppressing affect on the fire. Any change in the amount of cloud cover would also affect fuel moistures.

E. Critical Clouds for Firefighters

Several clouds are especially important to firefighters. Some of these can have a detrimental effect on a fire.

Other clouds, called indicator clouds, aid the firefighter. Recognizing these clouds early may help firefighters anticipate upcoming weather changes.

These critical clouds are:

- cumulonimbus or the thunderstorm cloud
- cirrostratus
- altocumulus castellanus
- altocumulus floccus
- altocumulus standing lenticularus
- stratus

1. Cumulonimbus or the thunderstorm

A real troublemaker and potentially the most dangerous cloud is the cumulonimbus or thunderstorm. By the time you notice this cloud, weather problems may already be occurring.

The cumulonimbus is an exceptionally dense and vertically developed cloud mass, occurring either as isolated cloud cells, or as a line or wall of cloud cells.

These clouds appear as mountains or huge billowing towers, with upper portions that are usually smooth, fibrous, or striated, and almost flattened. This flattened upper portion of the cumulonimbus is called the **anvil.**

Lightning, thunder, hail, and strong winds are often produced by these ragged, very dark-based convective clouds.

Thunderstorm wind gusts can reach speeds in excess of 60 mph. These winds will often spread out in all directions, traveling several miles from the core of the storm cloud.

The out rush of wind from cumulonimbus and thunderstorms often causes a sudden drop in temperature and a sudden rise in relative humidity.

2. Cirrostratus

Cirrostratus clouds are very high, wispy clouds that frequently precede a weather front or storm system.

These clouds thicken, increase, and lower as the frontal system approaches. They indicate a significant weather change in the next one to two days.

The following illustrates how cirrostratus clouds are formed. The tops of tall cumulonimbus clouds forming along a warm or cold front are blown downstream 500 miles or more by strong winds aloft.

Cirrostratus clouds precede both warm and cold fronts, but they are more extensive with warm fronts.

3. Altocumulus castellanus

Altocumulus castellanus clouds are middle level clouds that consist of cumuliform masses in the form of turrets or towers, usually arranged in lines.

They indicate unstable or very unstable conditions in the middle layers of the troposphere. When seen in the morning, these clouds are a very good indication that thunderstorms may develop later in the day.

4. Altocumulus floccus

Altocumulus floccus clouds are white or gray scattered tufts with rounded and slightly bulging upper parts. Some would say these look like a "flock of sheep" in the sky.

These clouds resemble small ragged cumulus and are often accompanied by fibrous trails of virga from their bases. They are also a sign of increasing moisture and instability at middle levels of the troposphere. They sometimes precede the formation of thunderstorms, particularly if they form in the early afternoon.

5. Altocumulus standing lenticularus

These often isolated lens-shaped clouds, sometimes resembling flying saucers, most often form above or in the lee of north-south oriented mountain ranges, and remain stationary, sometimes for more than a day.

Strong wave action in the lee of mountains may produce a series of lenticular or standing wave clouds a hundred miles or more downstream. These clouds also occur in regions lacking mountainous terrain, but are less common.

Altocumulus standing lenticularus are an indication of strong stable winds at middle levels of the atmosphere. However, firefighters should be aware that these clouds may also indicate the presence of strong and gusty foehn winds on the lee slope of a mountain.

The strength of these winds depends on the stability of the atmosphere and the time of day. Lee slope winds associated with altocumulus standing lenticularus typically are strongest at night and during the early morning hours when the lower atmosphere is most stable.

The strong and gusty foehn winds that form in the presence of these clouds can cause fires to spread rapidly and smoke plumes to shear. Spotting also becomes a serious concern.

6. Stratus

Stratus most commonly appear as a single, gray, fairly uniform, featureless layer of low cloud.

Occasionally, it can be dark or even threatening in appearance, although at most, it can produce only drizzle or very light rain.

Stratus clouds are frequently observed along the Pacific Coast of the United States during the summer, separating cooler marine air from the Pacific Ocean and hot, dry air over the interior valleys.

Stratus clouds are an indicator of stable and often moist air near the ground.

Exercise 9
Cloud Types and Descriptions

Match the following cloud types with the "best" descriptors.

a. Stratus	__	Formed with turrets and is an indicator of very unstable air at middle levels of the troposphere.
b. Cumulonimbus	__	An indicator of stable air at middle levels of the troposphere, and it is often associated with gusty winds in the lee of mountain ranges.
c. Altocumulus castellanus	__	Major concern to firefighters because of the potential for strong, gusty and erratic winds.
d. Altocumulus floccus	__	Scattered tufts with rounded and slightly bulging upper parts.
e. Cirrostratus	__	An indication of stable and often moist air near the ground.
f. Altocumulus lenticularus	__	An indication of a significant weather change in the next 2 to 3 days.

X. CONCLUSION

This unit has presented basic information to help you identify changes in atmospheric stability, and to understand what affect these changes can have on wildland fire behavior.

We recognize the atmosphere as a very dynamic system with a number of physical processes interacting to produce our weather.

Atmospheric stability is perhaps the least understood, but probably one of the most important aspects of meteorology for the wildland firefighter.

Intermediate Wildland Fire Behavior, S-290

Unit 7 – Wind Systems

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Define wind and wind direction.
2. Describe the effects of wind on wildland fire behavior.
3. Describe general winds around high pressure and low pressure systems.
4. Describe the cause and effect of local winds (slope/valley winds and land/sea breeze) on wildland fire behavior.
5. Describe typical diurnal slope and valley wind patterns, and identify these temporal patterns on a topographic map.
6. Describe critical winds and their impact on wildland fire behavior.
7. Identify three ways topography can alter wind direction and speed.
8. Describe general, local, and 20-foot and mid flame winds, and their relationship to each other.
9. Adjust wind speeds based on topographic location and calculate mid-flame wind speeds for the three main fuel types.

I. WIND AND WIND DIRECTION

Wind is the most critical factor affecting fire behavior, the most difficult to predict, and is the most variable in both time and space.

Wind variability (especially in complex terrain) can pose safety and fire control problems, which can result in firefighter fatalities.

In certain locales, winds behave quite predictably, but when fires become large, it is often because of an unusual or unpredicted wind situation.

A. Wind

1. Wind is defined as the horizontal movement of air or air in motion relative to the earth's surface.

   This movement of air (wind) is a result of both small scale and large scale temperature differences, which leads to both small scale and large scale pressure differences called a pressure gradient.

2. The stronger the pressure gradient, the stronger the wind.

   Winds exist over a range of scales, from the trade winds and midlatitude Westerlies that are characteristic of the earth's general circulation, to small eddies around obstacles or barriers.

3. Regardless of scale, the atmosphere in motion acts as a fluid, and is similar to water flowing in a stream.

   Water flowing in a stream will spill over or around an obstacle or barrier such as a rock.

   Similarly, air in motion will spill over or around a barrier such as a mountain.

4. Examples of large and small scale wind systems that influence wildland fire behavior:

   - General winds
   - Local winds (small-scale)
   - 20-foot winds (surface)
   - Midflame winds

B. Wind Direction

Wind direction is defined as the direction from which the wind is blowing.

- A north wind blows from north to south.
- A west wind blows from west to east.

If you are facing into the wind, name the wind from that direction.

II. THE EFFECTS OF WIND ON WILDLAND FIRE BEHAVIOR

Wind affects wildland fire in several ways:

- Wind carries away moisture-laden air and thus hastens the drying of wildland fuels.

- Once a fire ignites, wind aids combustion by increasing the supply of oxygen.

- Wind increases fire spread by carrying heat and burning embers to new fuels (spotting).

- Wind bends the flames closer to the unburned fuels, thus preheating the fuels ahead of the fire front.

- The direction of the fire spread and smoke transport are determined mostly by wind direction.

- Wind influences the amount of fuel consumed by affecting the residence time of the flaming front of the fire. The stronger the wind, the shorter the residence time and the less fuel is consumed.

III. GENERAL WINDS AND FLOW AROUND HIGH AND LOW PRESSURE SYSTEMS

General winds are those large-scale winds caused by the pressure gradients associated with highs and lows.

General winds are typically found at mid and upper levels of the troposphere, and are responsible for transporting weather systems around the world.

Heat gain is greater over the equatorial regions than heat loss, whereas heat loss is greater over the polar regions than heat gain.

This uneven distribution of temperature on a large (global) scale results in a north to south pressure difference or pressure gradient force.

If the earth did not rotate, this north to south pressure gradient force would lead to a single large circulation cell, with rising air over the equator traveling northward towards the poles, and subsiding air over the poles traveling southward toward the equator.

This circulation transfers air from the high pressure regions at the poles to the low pressure belt at the equator.

Because of the rotation of the earth, another force called the coriolis force causes large-scale moving air to deflect to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

The combination of the pressure gradient force and coriolis force results in several major wind belts.

A. General Wind Circulation Over the Northern Hemisphere

Because of the earth's rotation, the single cell circulation splits into three cells in each hemisphere.

1. The locations of the cells correspond to the alternating belts of high and low pressures.

    - The rising air over the equator does not reach the poles, but rather sinks at about 30° latitude, where a belt of high pressure is located.

    - The air moving southward from the pole rises when it reaches the subpolar low pressure belt at about 60° latitude, forming a second polar cell with warm air traveling northward aloft and cold air returning southward near the ground.

    - A third cell, between these two cells, offers a reverse circulation that carries air northward near the surface and southward aloft.

    It is these three cells of general circulation that correspond to both high and low pressure belts and bands of wind that encircle the globe.

2. Over the northern hemisphere, the predominate winds include:

- Northeast Trade Winds located from the equator to 30° latitude

- Westerlies located from 30° to 60° latitude

- Polar Easterlies located from 60° latitude to the pole

Because much of North America falls under the Westerlies, this wind belt has the greatest influence on our weather and fire behavior.

B. Jet Streams

1. Jet streams:

- Strong currents of air located within the Westerlies (30° to 60° latitude) that are produced by the pressure gradients between the poles and the equator.

- May be thousands of miles long, hundreds of miles wide, and thousands of feet deep.

- Jet stream winds are strongest in the upper troposphere at altitudes between 30,000 and 40,000 feet, where they may exceed 180 mph.

The jet stream is also referred to as the storm track.

2. The location, strength, and orientation of jet streams vary with the season and from day to day within a season.

- The polar jet is typically found over central Canada during the summer months where north-south temperature contrasts are greatest.

- In the winter, the polar jet shifts south over northern and central sections of the United States.

3. The polar jet is not the only jet stream that can be observed at one time.

   It is not uncommon to observe both a polar jet stream near the Canadian-U.S. border and a subtropical jet stream near 30° latitude during the winter and spring.

   Though other reasons may exist, the best known oceanic feature that can result in jet stream fluctuations is the El Nino Southern Oscillation (ENSO- El Nino versus La Nina).

C. General Wind Flow around Highs and Lows

On a large scale, waves are common in the general wind flow, with troughs and ridges making up a wavelike pattern around the globe.

1. A trough is an elongated area of relatively low atmospheric pressure, and is identified as an area of cyclonic (counterclockwise) wind flow.

   - The low pressure trough is located on the cold side or north of the jet stream.

2. A ridge is an elongated area of relatively high atmospheric pressure, and is identified as an area of anti-cyclonic (clockwise) wind flow.

   - The ridge of high pressure is located on the warm side or south of the jet stream.

D. High and Low Pressure Cells

Atmospheric pressure decreases towards the center of the low pressure, with the lowest pressure located at the center of the cell.

Atmospheric pressure increases towards the center of the high pressure, with the highest pressure located at the center of the cell.

1. A closer look at both the high pressure cell and low pressure cell reveals that air moves from high pressure to low pressure:

   - Air in a high pressure cell diverges at the surface from the center of a high pressure cell in a clockwise fashion towards the low.

   - Air in a low pressure cell moves counterclockwise and converges at the center of the low.

2. A surface map with lines that connect points of equal pressure (called isobars), allows meteorologists to locate high and low pressure cells, and other features such as fronts.

   a. The strength or speed of the air moving (wind) from high to low is determined by the pressure differences (a result of temperature differences) between the two cells.

      The isobars drawn on a map allow Meteorologists to not only locate the pressure cells, but determine their strength.

      The rate of change (distance between the lines) of the isobars over a given distance is referred to as the pressure gradient.

b. The wind is proportional to this pressure gradient:

- The weaker the pressure gradient (isobars far apart), the weaker the wind.

- The steeper (stronger) the pressure gradient (isobars close together), the stronger the winds.

E. Vertical Motions in Highs and Lows

Vertically, air in highs and lows is constantly in motion. Sinking air describes the vertical motion associated with a high pressure cell.

Once the sinking air reaches the earth's surface, the air diverges from the center of the high pressure cell and travels towards the center of the low pressure cell, with convergence of air at the center of the low.

The convergence at the center of the low results in rising air within the low pressure cell. At the top of the low, air diverges and moves toward the top of the high pressure cell.

Applying the ideal gas law to both pressure cells, sinking air within a high pressure compresses and warms, while rising air in a low pressure expands and cools. Because of this process, clear skies and dry conditions are typically associated with high pressure, and cloudy and wet conditions are associated with lows.

The vertical motions associated with highs and lows are characteristic of the vertical motion of a plume of smoke and gases associated with fire.

The plume of rising smoke and hot gases associated with a fire is a small-scale low pressure cell, with indraft air converging at the center of the cell and rising above the surface.

Small-scale high pressure is located on either side of the rising plume, with sinking air diverging towards the low (fire).

One can compare both the horizontal and vertical characteristics of high pressure ridges and low pressure troughs on a weather chart to ridges and valleys on a topographic map.

A ridge of high pressure on a weather chart is similar to a ridge on a topographic map, whereas a low pressure trough on a weather chart is similar to a valley on a topographic map.

Contour gradient on a topographic map is proportional to slope steepness, while isobar gradient is proportional to wind speed.

Analogous between weather maps and topographic contour maps:

- Contours (lines of equal elevation) and isobars (lines of equal pressure).
- Contour gradient proportional to slope steepness, while isobar gradient proportional to wind speed.
- Peaks/hills/mountains on a contour map are analogous to highs on a weather map, while valleys/basins are analogous to lows.

EXERCISE 1
Jet Streams, and Highs and Lows

1. Which of the following are true about jet streams?

   a. Jet streams are strong currents of air located within the Westerlies.

   b. Jet streams are produced by pressure gradients between poles and the equator.

   c. Jet stream wind speeds may exceed 180 mph.

   d. Jet stream locations may vary from day to day and season to season.

   e. All of the above

2. Wind flows clockwise around ______ pressure and counterclockwise around _______ pressure.

3. The stronger (steeper) the pressure gradient between high pressure and low pressure the:

   a. faster the wind speed

   b. slower the wind speed

4. Air in a low pressure cell:

   a. rises

   b. sinks

IV. THE CAUSE AND EFFECT OF LOCAL WINDS (SLOPE/VALLEY WINDS AND LAND/SEA BREEZE) ON WILDLAND FIRE BEHAVIOR

Local winds are found at lower levels of the troposphere. These local winds are induced by small-scale differences in air temperature and pressure.

Terrain has a very strong influence on local winds; the more varied the terrain, the greater the influence.

Local winds can be as important in fire behavior as the winds produced by the large-scale pressure patterns. In many areas, especially in complex terrain, local winds are the predominate daily winds.

A. Diurnal Mountain Wind Systems

Diurnal mountain winds develop over complex topography of all scales, from small hills to large mountains and are characterized by a reversal of wind direction twice per day.

The following winds make up the mountain wind system:

- Slope wind
- Along-valley wind
- Cross-valley wind
- Mountain-plain wind

Though there are exceptions, as a rule, wind flows upslope, upvalley, and from plain to mountain during the day.

At night, downslope, downvalley, and mountain to plain winds are predominate.

Diurnal mountain winds are produced by horizontal temperature differences that develop daily in complex terrain.

1. Upslope and upvalley wind

During the day, the warm air sheath next to a slope serves as a natural chimney and provides a path of least resistance for the upward flow of warm air known as the upslope wind.

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.

Upslope winds begin on east facing slopes early in morning, and eventually develop on west and southwest facing slopes by late morning and early afternoon.

Though there are exceptions, upslope wind speeds typically range from 3 to 8 mph.

The speed is determined by aspect and the duration of incoming solar radiation, with north facing slopes experiencing the weakest wind and west and southwest facing slopes experiencing the strongest winds.

Similar to slopes, valleys begin receiving incoming solar radiation early in the day.

The volume of air that is heated in a valley is much greater than over the air over a slope, thus upvalley winds typically do not begin until late morning and early afternoon.

As a valley heats, temperature and pressure differences develop within the valley or between a valley and a nearby plain, resulting in an upvalley wind flow ranging in speed from 10 to 15 mph by mid to late afternoon.

Once the upvalley wind develops, the upslope wind becomes less of a factor, no longer running parallel to the slope, but rather near perpendicular (cross slope) to the slope.

The combination of the upvalley wind component, upslope wind component, and slope steepness results in fire spread that includes a cross-slope and upslope component.

With an isolated hill or mountain away from valley influences, upslope winds will be predominate winds during the day.

2. Downslope and downvalley wind

When the slope becomes shaded or night comes, the entire process is reversed:

- A short transition period occurs as a slope goes into shadow.
- The upslope winds die.
- There is a period of relative calm.
- A gentle, smooth downslope flow begins.

Downslope winds are very shallow and may not be represented by a 20-foot surface wind speed.

The cooled dense air is stable, and the downslope flow tends to be quite smooth and slower than upslope winds, with speeds ranging from 2 to 5 mph.

The principal force here is gravity. Downslope winds usually continue throughout the night until morning.

The larger volume of air over the valley requires several hours of cooling before upvalley winds transition to downvalley winds, which typically occurs during the late evening hours but is dependent on the size of the valley.

Downvalley winds are usually shallower than the upvalley wind, with little or no turbulence because of the stable temperature structure of the air.

Downvalley winds are lighter than upvalley winds, with speeds ranging from 5 to 10 mph. These winds are strongest on cloudless nights.

3. Slope and valley wind transition facts

The upslope-upvalley and downslope-downvalley transitions are important for firefighters to recognize and understand.

The change in wind from downslope- downvalley to upslope-upvalley can rapidly change fire behavior from inactive to active in a matter of minutes.

Though slope plays a role, the upslope or upvalley wind does lead to faster uphill/upvalley fire spreads.

Downslope or downvalley winds seldom produce dangerous conditions. However, strong downslope or downvalley winds augmented by terrain or foehn winds can result in downhill runs.

B. Land and Sea Breeze Circulation

Temperature and pressure differences result in wind.

Land and sea breezes are also driven by horizontal temperature contrasts that develop between the sea and the adjacent land mass.

These temperature contrasts are a result of unequal heating and cooling rates of land and water.

If the same mass of water and same mass of land received the same heat input, the temperature of water will rise less than the temperature of land.

Incoming solar radiation is absorbed only in a shallow soil layer over land, but is distributed through a much deeper layer (more transparent) in the ocean or lake.

The temperature of a large body of water changes little between summer and winter and between day and night, whereas the temperature of a land mass experiences much larger fluctuations from day to night and season to season.

The temperature and pressure differences that develop across the coastlines or lakeshore drive the land and sea breezes.

When the atmosphere is warmer over the land than over the water, a low pressure forms over the land and a sea breeze (sometimes called a sea breeze front) flows onshore.

When the air over the water is warmer than air over the land, low pressure is found over the water with high pressure over land.

When this occurs, a land breeze will blow from land to sea.

Sea breezes are predominate during the day and the land breezes are common at night.

In the middle latitudes, sea-land temperature differences, and therefore sea and land breezes, are strongest in spring and summer.

In the summer, sea breezes are usually established by midmorning, after the land has warmed sufficiently.

Peak speeds are reached in the afternoon when the temperature contrasts are strongest.

The land breezes at night are typically weaker, due to weaker temperature contrasts between land and sea.

Typical speed of the sea breeze is 10 to 20 mph; however, it can locally attain 20 to 30 mph along the California, Oregon, and Washington coasts.

Wind-speeds with the land breeze are lighter than with the sea breeze, typically between 3 and 10 mph.

In the southeastern United States, lines of thunderstorms frequently develop along the sea breeze as it moves inland from the coast.

This results in strong shifting winds, cooler temperatures, higher relative humidities, and possibly thundershowers, weather very similar to cold fronts.

Strong shifting winds associated with these "sea breeze fronts" have caused control and safety problems on many fires in the Southeast.

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.

EXERCISE 2
Slope and Valley Wind

Answer the questions using the map on the next page.

1. Which slope (give point) will receive the early morning solar heat first, thus, upslope winds start first?

   Answer:

2. Which slope (give point) will receive solar heating latest in the afternoon, thus, slope winds continue the latest?

   Answer:

3. Which slope (give point) will receive the least solar heating, thus, lightest upslope winds throughout the day?

   Answer:

4. When will point C receive the strongest upvalley winds?

   Answer:

5. When will point C receive the strongest downvalley winds?

   Answer:

6. Which point will be most exposed to the general winds?

   Answer:

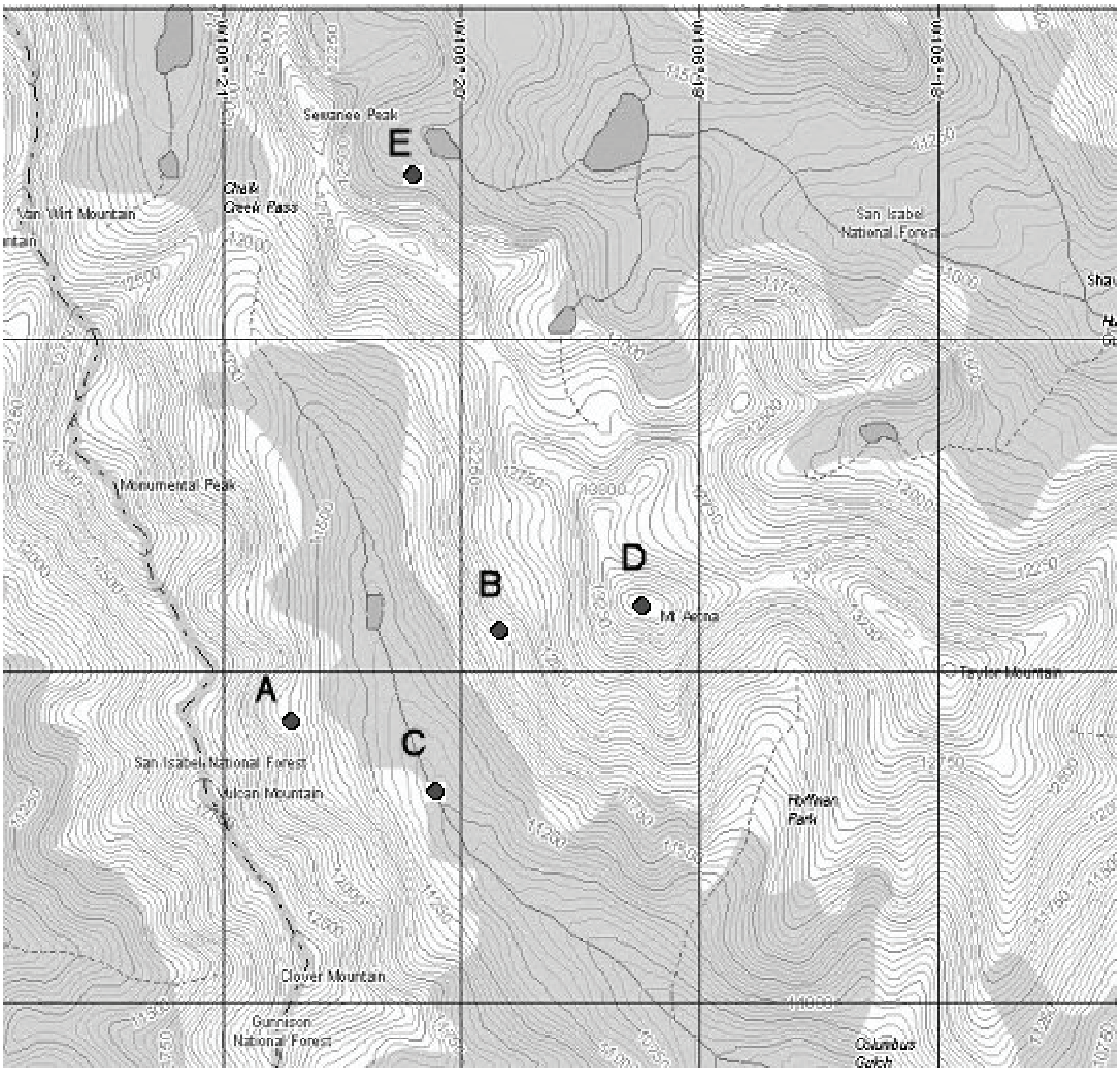
7. What time of day will upslope winds be strongest at point A?

   Answer:

8. What time of day will upslope winds be strongest at point B?

   Answer:

EXERCISE 2
Slope and Valley Wind



V. CRITICAL WINDS AND THEIR IMPACT ON WILDLAND FIRE BEHAVIOR

General and local wind systems may be considered a problem to firefighters; however, if wind speeds are low and the direction is consistent, the resultant fire behavior is usually predictable.

Firefighters can then develop strategies to execute safe and successful fire suppression activity.

If winds become so strong that fires experience rapid growth and firelines are lost, the safety of firefighters may be threatened and suppression efforts may have little impact on fire spread.

Critical winds are winds that totally dominate the fire environment and easily override the upslope/downslope and upvalley/downvalley winds. Examples of critical winds:

- Frontal winds
- Foehn winds
- Thunderstorm winds
- Whirlwinds
- Surfacing or low-level jets
- Glacier winds

A. Cold Front Winds

An air mass is a large body of air often more than a thousand miles across that has similar temperature and humidity characteristics throughout it.

The boundaries that separate the different air masses are called fronts. Weather fronts center and extend out of an area of low pressure.

The entire system moves—the low, the front(s), and the air masses, all being pushed along by the strong upper level belt of Westerlies.

Typical U.S. frontal systems move at 20 to 30 mph, but the speeds can be considerably faster or slower.

Cold fronts (a boundary separating a cold air mass from a warm air mass) are indicated by a blue line with blue triangles pointing in the direction of travel of the front.

Cold fronts usually migrate from west to east; however, a north to south movement is not uncommon, especially east of the Continental Divide.

Two characteristics make the cold front dangerous to firefighters:

- Directional wind shifts

- Increasing wind speeds

1. Pre-frontal conditions

   Assuming a west to east moving cold front, winds ahead of an approaching cold front gradually shift from the southeast, to south and eventually to the southwest just prior to the frontal passage.

   Wind speeds also increase gradually as the pressure gradient tightens closer to the front.

   Along with the shifting and increasing wind concern ahead and along the front, warm air pushes northward, resulting in unstable atmospheric conditions.

   Relative humidity values ahead of the front will vary from one location to the next, and are dependent on the type of air mass moving northward (Maritime or Continental).

   Pre-frontal conditions offer a favorable burning environment.

   Large fire growth and extreme fire behavior are often associated with pre-frontal conditions.

2. Post-frontal conditions

As the cold front passes, winds shift rapidly to west, then northwest.

Firefighters must be aware of the frontal passage and anticipate changing wind direction.

Wind speeds increase in strength and shift direction in a clockwise fashion as a front approaches. These winds usually become quite strong and gusty when the front passes an area.

The temperature cools rapidly, relative humidity increases and fire behavior typically decreases.

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 mph, but can be much higher with strong cold fronts.

3. North to south migrating fronts

Fronts that migrate north to south may result in a different wind shift as the front passes through compared to a front that moves west to east.

For example, northeast or east wind flow is common along the eastern slopes of the Rockies behind fronts that migrate southward out of Canada.

EXERCISE 3
Cold Front Winds

Answer the questions using the graph in the workbook.

1. Wind 100 miles ahead of the cold front at point C will be:

   a. Strong and from the northwest
   b. Light and from the northeast
   c. Light and from the southeast
   d. Moderate and from the southwest

2. Wind just ahead of the cold front at point B will be:

   a. Strong and from the southwest
   b. Strong and from the northwest
   c. Light and from the southeast
   d. Light and from the southwest

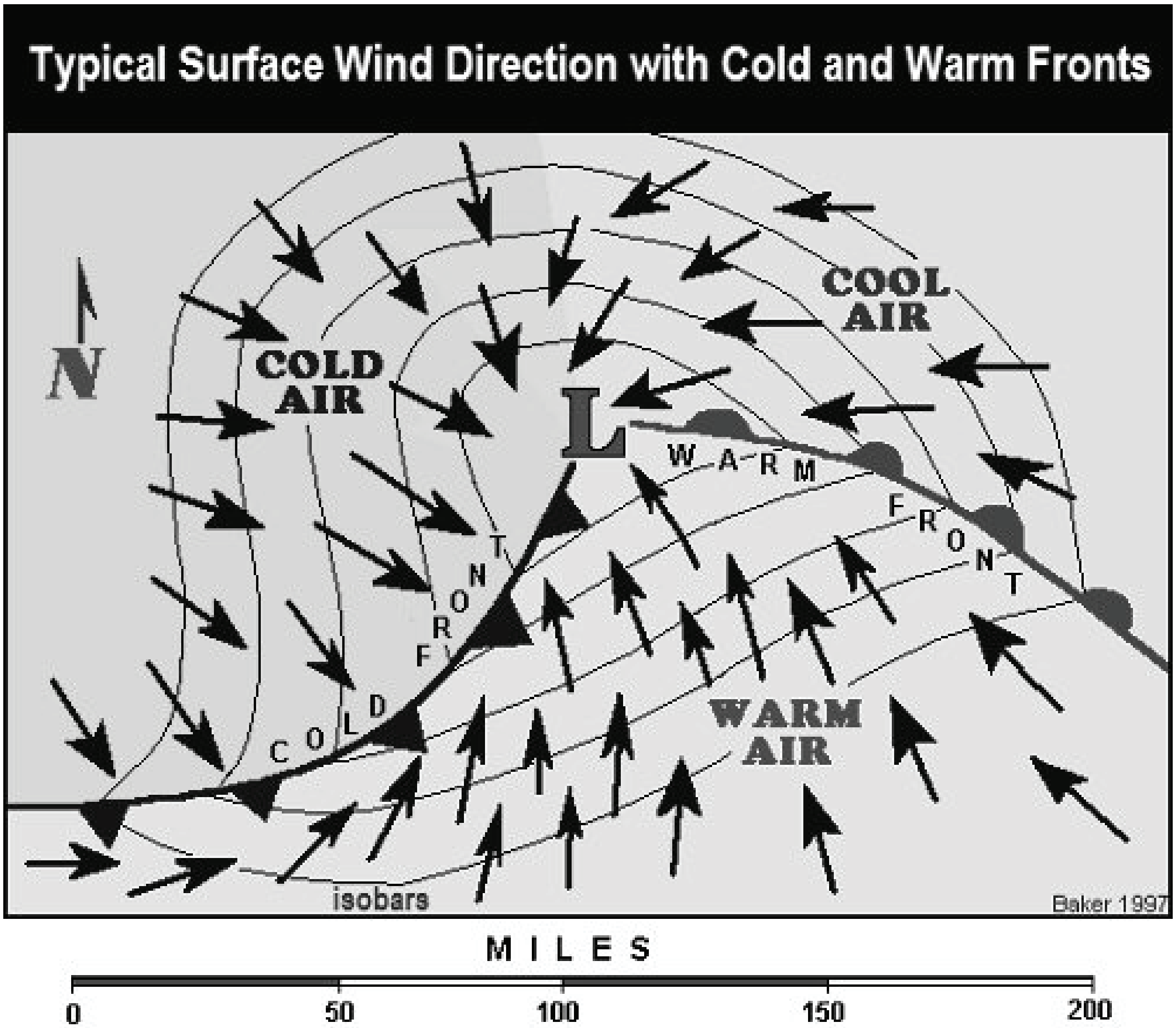
3. Wind just behind the cold front at point A will be:

   a. Strong and from the northwest
   b. Light and from the southwest
   c. Strong and from the southwest
   d. Strong and from the southeast

4. The most extreme fire behavior will likely occur at what point?

   a. Point A
   b. Point B
   c. Point C

EXERCISE 3
Cold Front Winds



B. Foehn Winds

Another type of wind that causes firefighters great concern is the foehn wind.

Foehn winds are strong, warm, and dry winds that originate from areas of high pressure in mountainous regions.

Subsidence or heavy air lowering within the high pressure cell may push up against a mountain range and speed up as it flows through passes and saddles, then down the lee slopes by gravity and pressure gradients.

As the air flows downslope it compresses and warms 5.5º F per 1000 feet.

The combination of warm temperatures, low relative humidity, and high wind speeds can cause high rates of fire spread and serious fire control problems.

Foehn wind speeds often reach 40 to 60 mph and some have been measured in excess of 90 mph.

Foehn winds tend to be stronger at night because they can then combine with local downslope and downvalley winds.

The two most commonly known foehn winds include the Chinook and Santa Ana.

Other known foehn winds include the Mono, Wasatch, East, and North.

1. Chinook winds

   This type of foehn wind is associated most with the east side of the Rocky Mountains during fall and winter.

   In the case of the Chinook wind, 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 warms at the rate of 5.5 degrees per 1,000.

   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, warm, and drying wind.

2. Santa Ana winds

   Santa Ana winds occur when the center of surface high pressure is located in the Great Basin.

   The Santa Ana winds blow out of the Mojave Desert through the Santa Clara River Valley and through Cajon and Banning Passes of Southern California toward the Pacific Ocean.

   Wildfires are very difficult to control when these strong, gusty, dry winds are at their strongest.

   The Santa Ana creates the most critical fire weather situations in areas of Southern California during fall and winter.

3. Movement of mountain waves

Movement of mountain waves can cause changes in the speed and direction of the foehn wind.

The strongest downslope wind occurs when the crest of the wave and associated wave cloud or Altocumulus Lenticularus (ACSL) are over the mountain ridge.

The crest of the wave may stay over the mountain ridge for several hours.

The foehn wind can reverse and weaken as the crest of the wave and associated wave cloud move overhead.

As the crest continues to propagate eastward downslope winds may resume, but may not be as strong as a new wave moves over the mountain ridge.

C. Thunderstorm Winds

1. Two characteristics of thunderstorms make them an important element in fire weather:

- The fire-starting potential caused by lightning strikes from cloud-to-ground.
- Thunderstorm indraft and downdraft winds.

A mature thunderstorm offers both indraft and downdraft winds.

Winds associated with mature thunderstorms, whether indrafts or downdrafts, can change both direction and speed suddenly, resulting in sudden changes in the rate and direction of spread of the fire, as well as in fire intensity.

2. Indraft wind speeds typically range from 10 to 20 mph, with higher gusts.

   - Because of evaporative cooling and acceleration due to gravity, downdraft winds are usually stronger than indraft winds, reaching speeds of 25 to 35 mph with gusts over 60 mph.

   - These winds are usually strongest in the direction the thunderstorm is moving.

3. The leading edge of the downdraft wind is referred to as the gust front.

   - Similar to a cold front, the thunderstorm gust front is the boundary between two dissimilar air masses.

   - In the case of a thunderstorm, it is the boundary between a cool air mass flowing out of the thunderstorm, and a warm air mass outside the periphery of the thunderstorm complex.

   - The gust front is marked by a wind shift, decrease in temperatures, and increase in RH.

4. Outflow winds:

   - Are strongest in the direction the storm is moving.

   - Are weakest in the opposite direction the storm is moving.

   - Typically spread radially 5 to 10 miles in all directions away from the cell; however, topography can alter the direction of the wind.

In complex terrain, thunderstorm outflow is typically channeled through valleys, canyons, and drainages.

Outflow winds on a flat plain spread out more evenly from the center of the cell.

5. Wet thunderstorms vs. dry thunderstorms

All thunderstorms should be considered a threat to fire operations. However, some thunderstorms may pose greater concerns to firefighter safety than others.

The majority of thunderstorms are classified as wet, producing 0.10 of an inch or more of precipitation.

Downdraft winds associated with wet thunderstorms are erratic and gusty, posing a threat to firefighters.

Cool and moist downdrafts from these storms can significantly decrease fire activity.

On the other hand, thunderstorms that produce less than a 0.10 of an inch of precipitation are classified as "Dry."

Dry thunderstorms are high based and develop in a hot and dry air mass environment.

The hot and dry air mass below the cloud base offers an environment in which extensive evaporative cooling occurs as rain falls from the thunderstorm.

Because the air just below cloud base becomes much cooler and heavier than the surrounding air, the cool parcel of air accelerates towards the surface of the earth, resulting in very strong outflow winds and unpredictable fire behavior.

Dry thunderstorm wind speeds in excess of 100 mph have been measured.

6. Downdraft indicators

With a dry thunderstorm you might see virga (rain evaporating before reaching the ground) hanging from a ragged, dark base.

Though rain may not be reaching the ground (virga) in the case of a dry thunderstorm, the thunderstorm downdraft has begun.

In the case of a wet thunderstorm, a visible dense rain shaft will reach to the ground, indicating the presence of a downdraft wind.

Finally, you might observe a dust cloud, as the first gusts from the thunderstorm spread out over the countryside.

7. Pyro-cumulus and the pyro-cumulonimbus

Heat rising from a fire can form a convective column strong enough to trigger the development of a cumulus cloud, even on an otherwise cloudless day.

Further development from the pyro-cumulus stage to the pyro-cumulonimbus (thunderstorm generated by heat from fire) stage may pose a great threat to firefighter safety.

Virga, or precipitation that falls from the pyro-cumulonimbus cell, can produce sudden and powerful downburst outflow winds (collapsing column) that can quickly change fire behavior.

Outflow from pyro-cumulonimbus has resulted in shelter deployment and firefighter fatalities. Onset of the outflow may occur with little or no warning.

Unlike a thunderstorm, visual indicators such as virga or a rain shaft associated with the pyro-cumulonimbus will likely be obscured by smoke; therefore, several minutes of advanced warning using visual indicators is not likely.

One common characteristic that has been observed prior to the onset of the outflow wind includes a relatively calm period as the indraft wind into the fire stops.

Because a pyro-cumulus or a pyro-cumulonimbus may be very difficult to observe or identify by firefighters in close proximity to the fire and obscuring smoke column, lookouts posted away from plume may prove beneficial.

D. Glacier Winds

Glacier winds are local downslope winds that impact locations adjacent to the base of glaciers.

Highest wind speeds occur around midday, driven by the difference in temperature between the air over the ice and the adjacent land.

The distance glacier winds extend across the adjacent land is related to this temperature difference, in addition to any channeling by the valley where the glacier resides.

Downslope winds of up to 50 mph have been noted to extend 10 miles from the bases of large glaciers in Alaska.

Glacier winds have been known to catch off guard firefighters who were expecting upslope winds as valley temperatures warmed.

E. Low-Level Jets

- Exhibit a jet profile in which maximum winds attain speeds of 25 to 35 mph at altitudes from 100 feet to several thousand feet above the ground.

- Can increase lift and result in a plume dominated fire.

- Are usually associated with large-scale events, such as low pressure troughs or the breakdown of an upper level high pressure system.

- Can surface and significantly increase rates of spread.

- Commonly form over the western Great Plains at night during the early spring and summer.

Though not as common, low-level jets form at night in the spring along the eastern slopes of the Sierra Nevada, and migrate northward along the Cascades in Oregon by morning.

F. Whirlwinds

Whirlwinds develop as the result of local effects, both topographic and atmospheric.

They are formed in a highly unstable lower atmosphere, triggered by some mechanical or other disturbance that initiates a whirling motion in the wind flow.

A whirlwind may remain stationary or move with the surface wind. If it breaks away from its heat source, it may die out, and another whirlwind may develop nearby.

In very light wind situations, the whirlwinds that do move tend to go toward higher ground.

Whirlwinds vary in size from just a few feet to over 100 feet in diameter, and to heights of nearly 4,000 feet.

There are various scales of whirlwinds, very few of which would totally dominate the fire environment.

1. Dust devils

   Dust devils occur on hot days over dry terrain when skies are clear and general winds are light.

   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 encourage local heating. This can lead to a "smoke filled" dust devil.

   Wind associated with a dust devil is very localized.

   On a small scale, wind speeds can be greater than 50 mph.

2. Firewhirls

   The firewhirl, which carries flames and burning materials up into its column, is usually caused by very high fire intensities in local areas.

   Firewhirls 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.

   Wind associated with a firewhirl is very localized. On a small scale, wind speeds can be greater than 50 mph; in extreme cases, greater than 100 mph.

   In these extreme cases, firewhirls have crossed into safe zones, and have burned and turned over vehicles.

VI. THREE WAYS TOPOGRAPHY CAN ALTER THE SPEED AND DIRECTION OF THE WIND

There are three ways that topography can affect the wind: mechanical, turbulent, or frictional.

A. Mechanical and/or Diverting Effects of Topography

The earth is solid and the atmosphere a fluid. When moving air collides with a topographic feature, such as a mountain range or peak, the air's motion must be modified, just like water in a river encountering boulders.

The following are all variations on this physical reality.

1. Directional channeling

   Mountains and their associated valleys provide channels that establish local wind direction.

   Airflow is guided by the topography into the principal drainage channels.

   Less-prominent features of the landscape have similar, though smaller scale, local mechanical effects on wind speed, direction, and turbulence.

2. Venturi effect

   Acceleration of air through a terrain constriction is called the Venturi or Bernoulli effect.

   When a valley or other channel has a substantial pressure gradient along its length and a topographic constriction at some point along the channel, air is accelerated through the constriction by the pressure drop across the constriction.

   Remember, air flows from higher toward lower pressure.

3. Mountain (orographic) waves

When strong winds move across a prominent mountain range in a direction perpendicular to the range, a wave forms above the ridge crest. This is most likely when the air mass is stable aloft.

These so called mountain (orographic) waves can extend many miles downstream as they gradually dampen out.

An excellent cloud indicator for mountain (orographic) waves is the Altocumulus Lenticular. This is a unique cloud that remains stationary as the air moves rapidly through it, and will be found over the ridgetop, or on the lee side of the range.

It is formed as moisture in the air moving upward into the wave condenses, while at the other end, downward motions warm the air and dry it out, dissipating the cloud.

Below the ridge line on the lee side, the air motions may be quite turbulent, and can plague air operations with serious updrafts and downdrafts.

The danger with mountain (orographic) waves is that as daily heating in the lee side basins progresses, the air there becomes increasingly unstable.

Quite often, the mixed layer will become deep enough to link up to the level of the mountain waves, and then pull the strong winds down to the surface. This has serious implications for fire behavior.

Another atmospheric factor that contributes is the presence of strong high pressure and associated subsidence on the windward side of the range.

Surfacing mountain waves have driven many large fires down the lee slopes of the Sierra Nevada into the basins of western Nevada.

B. Turbulent Effects

Whenever airflow is diverted over or around a prominent obstruction there will be a zone of turbulence.

1. Lee side turbulence or "eddying"

   - Zones of turbulence known as eddies will usually form on the lee side of a significant obstruction to the wind.

     – An example would be a rotor cloud (roll eddy) on the lee of the Sierra or Cascade crest.

   - These eddies may be in the vertical plane or the horizontal plane.

     – An example might be the horizontal eddies in the air spreading out after exiting a saddle area.

   - Important factors that determine the type of eddying that occurs are the:

     – Wind speed
     – Obstruction size and its orientation to the wind
     – Stability of the air

2. Strong winds in canyons

   Eddies often form at the confluence of tributaries during strong canyon or valley winds.

   Another turbulent place is to the lee of spur ridges extending down into the main canyon.

   This effect would be most pronounced during late afternoon, when local upcanyon winds are at their peak.

3. Thermal turbulence

This is caused by differential surface heating, and it can have a great deal of effect on the low-level wind.

Different land surfaces absorb, reflect, and radiate varying amounts of heat.

Warm air rises and mixes with other air moving across the terrain.

This mixing action has differing effects on surface winds, but often makes them gusty and erratic.

4. Ground level obstructions or irregularities

Low altitude wind turbulence can be caused by ground level irregularities such as rocky cliffs, trees, and valleys.

C. Frictional Drag

All types of winds are slowed down by the drag caused by friction as they approach the earth's surface.

Varying surface roughness causes varying amounts of frictional drag. Examples include:

- A wide variety of vegetative surfaces
- Terrain features
- Man-made structures

VII. THE RELATIONSHIP BETWEEN GENERAL WINDS, LOCAL WINDS, AND 20-FOOT SURFACE WINDS

- The 20-foot surface wind is:
  - The wind measured 20 feet above the ground in a clearing, or 20 feet above the average vegetation cover.
  - A result of either the general wind component or local wind component (or both).
- It can be expressed in the following relationship:

20-foot surface wind = general wind component + local wind component

VIII. ADJUST WIND SPEEDS BASED ON TOPOGRAPHIC LOCATION AND CALCULATE MID-FLAME WIND SPEEDS FOR THE THREE MAIN FUEL TYPES

A. Wind Adjustment for Topographic Locations

Firefighters will encounter some variations in wind as it blows across the lower foothill regions or intermediate hills of a mountain range.

Some basic wind adjustments may be required for hills hundreds of feet high (not thousands; simple rules cannot account for such large differences in elevation).

When there are no means of making an accurate reading of midslope winds, then the use of the following close approximation is acceptable.

Adapting a forecasted or observed wind speed from one location to fit the fire's current or expected location by applying basic adjustment factors can help improve the accuracy of fire behavior predictions.

1. Simple wind adjustments can be made using wind adjustment factors for different topographic locations.

   a. In the case of the windward slope, winds are typically greater on the upper slopes vs. the lower slopes by a factor of 2.

      For example, a measured 20-foot wind of 4 mph on the lower slope would be twice as fast on the upper slope, or 8 mph.

   b. On the lee slopes, wind can often be turbulent and wind estimations may not be reliable. However, when airflow is well mixed on sunny afternoons wind adjustments may apply.

      In the case of a lee slope, winds are typically greater on the upper slopes vs. the lower slopes by a factor of three.

      For example, a measured 20-foot wind of 5 mph on the lower slope would be three times as fast on the upper slope, or 15 mph.

   c. The lee winds on the upper slope are about ¾ of the winds on the windward upper slope.

      These adjustments are:

      - Only valid with slopes 30% or less and without sharp ridges.

      - Not valid with critical winds or nighttime downslope wind.

2. To simplify the wind adjustments for topographic locations, a wind adjustment table can be utilized.

3. For winds blowing over a series of hills, canyons or valleys, the variations in wind can be compared and adjustment factors may be utilized for windward slopes.

   Before firefighters utilize the wind adjustment factors, they should determine whether the wind is blowing across the hill (both windward and leeward), or is merely upslope on both sides.

   This can be accomplished by using visual indicators such as smoke. For example, smoke drifting upslope towards ridge top level would indicate predominate upslope winds.

   If the general wind flow is strong enough (typically greater than 10 mph) to flow across the hill (both windward and leeward side), smoke would be carried away downwind from the ridge top.

B. Calculating Mid-flame Wind Speeds For Three Main Fuel Types

Wind speed (over open, level ground) decreases rapidly as the wind drops closer to the earth's surface.

At ground zero, wind speed is reduced to near zero. This is the result of friction caused by the earth's surface.

Rough terrain and vegetation act to increase the amount of friction affecting wind speed, and thus its rate of decrease. The more friction, the faster the wind speed will decrease from speeds in the open.

When doing fire spread calculations, we need to use the wind speed that will directly affect the movement of the flaming front.

This wind at half the flame height is what we call mid-flame wind.

Mid-flame wind speed will be used in fire behavior calculations to determine the rate of spread of a wildfire.

EXERCISE 4
Matching Wind With its Definition

Match the various winds with their definitions.

___	Foehn Wind	A.	Large scale winds caused by the pressure gradients associated with highs and lows.
___	Frontal Wind	B.	The wind measured at the 20-foot level. It is often a combination of local and general wind components.
___	General Wind	C.	Small scale winds that occur due to heating and cooling of a natural incline of the ground.
___	Mid-flame Wind	D.	Smaller-scale winds that develop as a result of local temperature differences.
___	Surface Wind	E.	Winds caused by strong pressure gradients in the boundary area of two dissimilar air masses; characterized by shifting winds and increased velocities.
___	Local Wind	F.	The wind speed that affects a surface fire (roughly at eye level) that is used in the fire behavior spread calculations.
___	Slope Wind	G.	A dry wind with a strong down component, characteristic of mountainous regions. It is usually, but not always, a warm wind for the season.

Intermediate Wildland Fire Behavior, S-290

Unit 8 – Keeping Current with the Weather

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Identify the types, purpose, and elements of Predictive Service products.

2. Identify the types, purpose, and elements of National Weather Service products.

3. Identify ways in which firefighters can receive fire weather products and weather observations.

4. Describe the importance of Incident Meteorologists (IMET) and Fire Behavior Analysts (FBAN) on wildland fires.

I. FIRE MANAGEMENT NEEDS

Fire management needs include planning daily fire management activities, planning effective control actions on fires, and determining fire potential several days out.

The National Weather Service (NWS) and Predictive Services provide products that meet these needs.

II. TYPES, PURPOSE, AND ELEMENTS OF FIRE MANAGEMENT PREDICTIVE SERVICE PRODUCTS

A. Predictive Services

Predictive Services is a combined group of interagency land management fire intelligence coordinators or fire behavior analysts (FBANs), and fire meteorologists.

Each Geographic Area Coordinating Center (GACC) has a Predictive Services group to meet the needs of the geographic area.

Information from the GACCs is integrated into national level products by the National Interagency Coordinating Center (NICC) Predictive Services group.

1. Predictive Services monitors, analyzes, and predicts:

    - Fire weather
    - Fire danger
    - Interagency fire management resource impact

    This is accomplished through a range of combined fire weather/fire danger outlooks for predetermined predictive service zones based on Remote Automated Weather Station (RAWS) climatology and topography.

2. These products are targeted to:

- Aid resource related decision-making at the geographic area and national levels.

- Increase safety overall through an enhanced awareness of expected fire danger and increase in fire activity.

B. Summary of Standard Predictive Services Products

1. 7 Day Significant Fire Potential

This product is issued and posted on each GACC website daily during predetermined fire season dates for a geographic area or during significant fire activity.

It provides information on:

- Current and projected fire weather
- Fire danger
- Fire management resources

2. Monthly Fire Weather/Fire Danger Outlook

This product is completed every month, year-round, by each GACC, and submitted to the NICC five days prior to the beginning of that month.

Elements include:

- A brief discussion of predicted general weather/fire danger for the entire geographic area for the reporting period.

- A brief discussion on current geographic area fuel anomalies/fuel moisture conditions.

- A brief discussion on predicted temperature ranges and precipitation for the geographic area for the reporting period.

- A map graphically illustrating areas of below average, average, and above average fire potential.

3. Monthly National Wildland Fire Outlook

   This product is issued on the first days of each month, year-round, and is compiled from the GACCs Monthly Fire Weather/Fire Danger Outlook.

   Elements include:

   - Narratives for each geographic area.

   - Current and projected fire statistics.

     – These statistics helps maintain resource availability funding.

     – Allows national managers to monitor current and projected needs.

   - National map delineating areas of below, normal, and above normal fire potential.

4. Seasonal assessments

   a. Seasonal assessments are issued:

      - To inform fire management of current conditions and projected fire potential for the upcoming fire season at geographic area and national level.

      - Prior to onset of their fire season, with mid-season updates, or as deemed necessary.

b. The national level assessment summarizes geographic area level assessments.

The content in geographic area versions includes:

- executive summary
- introduction and objectives
- current situations (leading up to time report is written)
- comparison of current and historical conditions
- climate, weather, fire forecasts/outlooks
- predicted fire occurrence and resource needs
- future scenarios and probabilities
- considerations, concerns and management implications
- summary and recommendations

5. Other products and services

Different GACCs provide a variety of other products and services that may be useful such as:

- Weather briefings.
- Daily summaries of NWS fire weather forecasts, both graphical and text.
- Long term precipitation monitoring.
- Smoke management summaries.

- Spot forecasts for planned burns and smoke management (mainly California).

- Incident Meteorologist (IMET) or technical specialist support on wildfires or prescribed burns.

Firefighters should visit with their local predictive services group to determine what services are being provided.

III. TYPES, PURPOSE, AND ELEMENTS OF NATIONAL WEATHER SERVICE PRODUCTS

There are over 120 National Weather Service offices nationwide that provide different types of forecasts including public forecasts and aviation forecasts.

Another major NWS program includes the fire weather program. The NWS provides a core suite of standardized fire weather products and services nationwide, but allows for optional products at regional and local offices' discretion.

At each Weather Forecast Office (WFO), a meteorologist is designated as the fire weather program leader and among their duties maintains the fire weather program for their office.

A. Fire Weather Planning Forecasts

Fire Weather Planning Forecasts (FWF) are zone-type products used by land management personnel primarily for input in decision-making related to pre-suppression and other planning.

- Fire Weather Planning Forecasts
- NFDRS Forecasts
- Smoke Management Forecasts
- Spot Weather Forecasts
- Fire Weather Watches and Red Flag Warnings
- Wildland Fire Danger Statements

1. These forecasts can be in either tabular or narrative format.

   - They are issued at least once daily during the local fire season and are updated when a Fire Weather Watch or a Red Flag Warning is issued.

   - They can also be updated when the meteorologist feels the current forecast has become unrepresentative of expected weather conditions.

2. Though there may be some differences from one part of the U.S. to another, the FWF should include:

   a. Fire weather headline and discussion

      The fire weather headline highlights the most significant weather elements or change, including any Fire Weather Watches or Red Flag Warnings that will impact the forecast area, usually within the first 24 hours.

      For example, the headline may read "Hot and Dry This Afternoon" or "Increasing Dry Thunderstorms Today."

      The fire weather discussion is used to support the headline and give a general idea of the overall weather regime that will impact the forecast area.

      The discussion is typically short and detailed, highlighting the forecast elements that will impact fire operation (strong winds, hot and dry, unstable).

   b. Sky and weather

      This element typically includes sky/cloud cover and the probability of precipitation for the forecast period.

      For example: MOSTLY CLOUDY WITH A 20% CHANCE OF RAIN.

c. Temperature

In complex terrain, a 10 degree temperature range across a large fire weather zone is common.

Smaller ranges are used in zones where there's little elevation difference.

d. Relative humidity

Similar to temperature, in complex terrain, a 10 percent relative humidity range across a large fire weather zone is common.

Smaller ranges are used in zones where there is little elevation difference.

e. Surface (20-foot) wind speed and direction

A 10 mph range is commonly used for wind speed across a large fire weather zone.

Gusts are typically included. Surface winds may include both valley and ridge top in complex terrain.

Fire weather planning forecasts use an 8 point compass for wind direction (N, NE, E, SE, S, SW, W, NW).

f. 3 to 7 day extended forecast

The 3 to 7 day extended forecast contains less detail than the first 36 to 48 hours of the forecast.

A 3 to 7 day extended forecast may be included after the last forecast period in each fire weather zone or may be included at the end of the fire weather planning forecast for the entire forecast area.

3. Other optional forecast elements

Based on the needs of fire management other optional forecast elements may be included in the fire weather planning forecast.

a. Optional elements may include:

- Haines Index
- Ridge Top Winds
- Mixing Heights
- Transport Winds
- Dispersion
- Clearing Index
- Chance of Wetting Rain

b. Lightning Activity Level (LAL)

Lightning activity level is a numerical rating of 1 to 6, keyed to the frequency and character of cloud-to-ground lightning, forecasted or observed on a rating area during the rating period.

The following information is a brief description of LALs 1 through 6.

- LAL 1: No thunderstorms

- LAL 2: Isolated thunderstorms

- LAL 3: Widely scattered thunderstorms

- LAL 4: Scattered thunderstorms

- LAL 5: Numerous thunderstorms

- LAL 6: Same as LAL 3 except thunderstorms are dry (no rain reaches the ground).

  - Has the potential for extreme fire activity.

  - Is normally highlighted in fire weather forecasts with a Red Flag Warning.

  - Fire management should communicate their needs to their local NWS offices.

B. Spot Weather Forecasts

A spot forecast is a site specific 24-36 hour forecast issued to fit time, topography, and weather of a specific location.

1. The spot forecast can be requested for:

   - Wildfires
   - Prescribed burns
   - Spray projects
   - Tree planting
   - Other special projects

   NWS Spot (an interactive graphic request/ reply web-based program) is the national standard for requesting and issuing spot forecasts and should be used when possible.

2. NWS Spot requires entry of a variety of information:

   - Project name
   - Requesting agency
   - Location
   - Fuel type
   - On-site weather observations
   - Forecast elements
   - Remarks
   - Submission of the spot request

3. The spot forecast returned to you should include:

   a. Time period for which the forecast is valid

   b. Topographic maps of location of unit

   c. Elevation and aspect

   d. Fuel type

   e. On-site weather observations

   f. Requested parameters:

      - Forecast weather/sky conditions

        – Is more specific to the location.

      - Temperature

        – Is more specific to the location.

        – A 5 degree temperature range is typically used rather than a 10 degree that's used in the FWF.

      - Relative humidity

        – Is specific to the location.

        – A 5% range is typically used rather than a 10% that's used in the FWF.

- Wind speed and direction (20-foot or eye level)
  - Is more specific to the location.
  - A 5 mph range is typically used rather than 10 mph.
  - Significant gusts are included.
  - An 8 point cardinal direction is used.
- Stability and smoke dispersal potential (optional)
- Feedback (optional)

4. To obtain good spot weather forecasts, there are four essential steps to be taken.

   a. Take and record representative weather observations on the fire.

   b. Complete the NWS Spot request form.

   c. Transmit the NWS Spot request form.

   d. Provide meteorologist feedback on accuracy of forecast.

   The last step is not required by the meteorologist. It can help the forecaster improve on subsequent spot forecasts for the fire. As a result, the last step is essential to getting the best forecast.

C. Fire Weather Watches/Red Flag Warnings

A fire weather watch or red flag warning is issued when the combination of dry fuels and weather conditions supports extreme fire behavior or ignition is occurring or expected to occur.

1. Fire Weather Watch

   a. Issued when there is a high potential for the development of a Red Flag Event.

   b. A Fire Weather Watch is generally issued 24 to 72 hours in advance of the expected onset of criteria.

   c. A Watch may be issued (or continued) in the first 12-hour time period for dry thunderstorm events.

2. Red Flag warning

   a. A red flag warning is used to warn of an impending, or occurring red flag event.

      Its issuance denotes a high degree of confidence that red flag event criteria will occur in 24 hours or less.

   b. The criteria for fire weather watches and red flag warnings may be based on locally or regionally established thresholds.

      Red flag events typically require the combination of high to extreme fire danger and a critical fire weather pattern such as:

      - Dry lightning

      - The first lightning after an extremely dry period.

- Unusually low relative humidity.

- Very dry and unstable air (high Haines Index).

- Very strong and shifting winds that may or not be associated with a cold front.

The determination of these critical fire weather patterns is a cooperative effort between the fire management agencies and the fire weather office.

The criteria for red flag events may vary from region to region.

D. Smoke Management Forecast

1. NWS meteorologists issue smoke management forecasts at the request of land management agencies.

   These forecasts may be:

   - Issued on a routine basis
   - Issued as needed
   - Narrative in format
   - Tabular in format
   - Combination of both formats

   Meteorologists may include the smoke management forecast as part of another weather product (for instance, the FWF) or as a separate product.

2. The requester and the responsible NWS office should establish:

   - Content
   - Format
   - Frequency of issuance
   - Dissemination method

3. This product may contain:

- Forecasts of the transport winds
- Variability of transport winds with height and time
- Air mass stability
- Air dispersion and measures of dispersion
- Mixing heights
- Variations with time
- Other smoke management related parameters

E. Rangeland/Grassland Fire Danger Statement

This is a miscellaneous product which provides advisory information on rangeland and/or grassland fire potential or conditions.

Land management and NWS personnel should establish the contents, format, frequency of issuance, dissemination, etc. This product may be issued on a routine or non-routine basis.

IV. WAYS IN WHICH FIREFIGHTERS CAN RECEIVE FIRE WEATHER PRODUCTS AND WEATHER OBSERVATIONS

A. The Internet and other Sources of Communication

Firefighters should be familiar with the different sources available for gathering or requesting fire weather information such as:

- Fire weather planning forecasts
- Spot forecasts
- 7-day significant fire potential products
- Weather observations

The Internet will be the main source for gathering fire weather information when in an office environment or computer/internet resources are available on the incident.

Fire management personnel should utilize national and local predictive services and National Weather Service homepages for operational and planning needs.

Most of these web sites are standardized and are simple to navigate through.

Alternative sources for gathering or receiving fire weather information include phone or radio communication with local interagency dispatch centers.

B. Real-time Observation Monitor and Analysis Network (ROMAN)

ROMAN is a weather observation retrieval web application, developed and maintained as a partnership between the University of Utah, federal land management agencies, and the National Weather Service.

It allows fire management to display complete or portions of weather observations (NWS, RAWS, DOT sites) in almost real-time.

V. THE IMPORTANCE OF HAVING AN INCIDENT METEOROLOGIST AND FIRE BEHAVIOR ANALYST FOR ON-SITE SUPPORT

A. On-Site Incident Support

1. Incident Meteorologist (IMET)

Certified IMETs can be requested to provide on-site fire support for Incident Command Teams. IMETs issue detailed incident specific forecasts written only for the immediate area of the incident.

These forecasts include all the meteorological parameters of other forecasts but with the added emphasis on time and location differences.

In the field, the meteorologist can personally observe the influence fuels and topography have on the weather at the site. As a result, this is the most specific and accurate type of forecast available.

2. Fire Behavior Analyst (FBAN)

A primary use of weather forecasts and data collected on a wildfire is for input into fire behavior predictions.

Fire behavior predictions are necessary for the safety of firefighters and other people who may be threatened by wildfires, and for developing plans to fight wildfires.

The plans section on a wildland fire, or specifically the FBAN, is responsible for calculating predicted fire behavior.

3. Responsibilities of Fire Behavior Analyst and Incident Meteorologist on Wildfires

When an incident meteorologist and a fire behavior analyst are on a wildfire, the meteorologist works with the fire behavior analyst.

- The fire behavior analyst makes fireline observations and notes fire behavior factors affecting the wildfire.

- The meteorologist prepares the most detailed weather forecast possible for the fire area.

- The fire behavior analyst then prepares his fire behavior forecast using all fire behavior and weather information available.

B. Fire Behavior Forecast

A fire behavior forecast includes a short weather summary followed by considerable detail on fire behavior.

It also identifies periods when erratic wildland fire behavior activities are expected and recommends precautions to be taken as a result of these.

This forecast is prepared for each shift by a fire behavior analyst to meet the planning needs of the fire overhead organization.

The fire behavior forecast:

1. Interprets wildland fire calculations.

2. Describes expected wildland fire behavior by areas of the fire.

3. Identifies hazards due to wildland fire for ground and aircraft activities.

A good fire behavior forecast is a valuable planning tool and places strong emphasis on safety. This forecast is usually distributed to overhead personnel at the beginning of each shift.

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Unit 9 – Observing the Weather

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Describe when, how often, and where to take weather observations on wildland fires.

2. Describe the importance of having field observers or other fire personnel assigned as lookouts for potentially hazardous weather and wildland fire behavior conditions.

3. Demonstrate the correct use and maintenance of the belt weather kit in the field.

I. WEATHER OBSERVATIONS

A. Observing the Weather

The main objective of this unit is taking accurate weather observations using the belt weather kit. Some of the more common weather observing stations and handheld weather meters used by wildland firefighting personnel will also be discussed.

B. Weather Observations in the Field

Firefighters may obtain weather observations from sources placed near wildland fires.

1. Remote Automated Weather Stations (RAWS)

RAWS are operated by federal and state land management agencies for the purpose of providing continuous and reliable weather observations, generally in remote areas.

RAWS observations can be obtained from the Bureau of Land Management Internet website, or from a number of other secondary websites.

RAWS weather data includes:

- Temperature
- Dewpoint
- Relative humidity
- Wind speed and direction at 20 feet above the vegetative cover over a two minute or ten minute period.
- Peak wind gusts
- Rainfall amount and duration
- Solar radiation

2. Portable weather stations

These lightweight, mobile weather stations are normally assembled and monitored by IMETs dispatched to wildland fires.

Weather data gathered from these units are used to prepare fire weather forecasts and a historical record of weather at a fire.

The data are also used by the IMET to inform the FBAN, the incident overhead team, and firefighting personnel of changing local weather conditions.

3. Belt weather kits and handheld observing equipment

These instruments are small enough to be portable and used by observers in the field.

The instruments may measure temperature and wind speeds at eye level as well as calculate relative humidity.

4. Beaufort wind scale

If there is no access to a RAWS or handheld wind meter, surface or 20-foot winds can be estimated by using the Beaufort Wind Scale (page 9.5).

Beaufort Wind Scale
Estimating 20-Foot Wind Speeds

Wind Speeds (mph)	Nomenclature
<3	**Very light** – smoke rises nearly vertically. Leaves of quaking aspen in constant motion; small branches of bushes sway; slender branches and twigs of trees move gently; tall grasses and weeds sway and bend with wind; wind vane barely moves.
4-7	**Light** – trees of pole size in the open sway gently; wind felt distinctly on face; loose scraps of paper move; wind flutters small flag.
8-12	**Gentle breeze** – trees of pole size in the open sway very noticeably; large branches of pole size trees in the open toss; tops of trees in dense stands sway; wind extends small flag; a few crested waves form on lakes.
13-18	**Moderate breeze** – trees of pole size in the open sway violently; whole trees in dense stands sway noticeably; dust is raised on the road.
19-24	**Fresh** – branchlets are broken from trees; inconvenience is felt in walking against wind.
25-31	**Strong** – tree damage increases with occasional breaking of exposed tops and branches; progress impeded when walking against wind; light structural damage.
32-38	**Moderate gale** – severe damage to tree tops; very difficult to walk into wind; significant structural damage occurs.
>38	**Fresh gale** – surfaced strong Santa Ana; intense stress on all exposed objects; vegetation, buildings; canopy offers virtually no protection; wind flow is systematic in disturbing everything in its path.

II. WHEN, HOW OFTEN, AND WHERE TO TAKE WEATHER OBSERVATIONS ON WILDLAND FIRES

There is much you can do to monitor the weather on wildland fires using the tools in the belt weather kit, handheld weather meters, and some basic observing skills. It is also important to know when, how often, and where to take observations, either visually or with instruments.

A. When and How Often to Take Observations

1. Normally, observations should be taken:

   - Whenever the weather is undergoing a significant change.
   - At the coldest and warmest times of the day.
   - At the most humid and driest times of the day.
   - When the need demands that you document even subtle and short duration weather changes.

2. Observations should be taken on wildland fires when the following critical weather conditions exist, regardless of the time of day or night:

   - Formation and dissipation of thunderstorms.
   - Rapidly changing weather conditions associated with an approaching cold front.
   - Formation and dissipation of surface based temperature inversions.
   - Changes in atmospheric stability
   - Wind shifts
   - Sudden or large changes in relative humidity and air temperature.

- The formation or presence of clouds are significant to firefighters:

  – cumulonimbus
  – altocumulus standing lenticularus
  – altocumulus castellanus
  – altocumulus floccus
  – stratus
  – jet stream cirrus

3. Observations should also be taken when daily extremes in temperature and relative humidity occur.

   - In inland areas during the summer months, this is usually about 0600 in the morning and 1600 in the afternoon.

   - This may require taking frequent observations (hourly, half-hourly, every 10 minutes, etc.).

B. Where to Take Observations

The preferred locations to take observations are in areas representative of fireline conditions.

<u>**Never**</u> jeopardize your <u>**safety**</u> for an observation.

1. **Avoid** taking observations:

   - In “the black” or burned area because weather elements can be significantly modified, and therefore, unrepresentative of the conditions under which the fire will burn.

   - In areas sheltered from the fire, such as behind a cliff (point A) or near a large body of water (point B).

   - That is too far from the fire (point C) to be representative of fireline conditions.

2. Select a **safe** location.

Preferably at an elevation similar to the fireline, or in an area that is representative of the weather, topography, and/or fuel conditions that the fire will burn.

- On small wildland fires

  A single observer may be all that is needed when the terrain is similar, and/or when the fuels are light or widely spaced.

- On large wildland fires

  Often in complex or dangerous terrain and/or fuels, several observers should be positioned in problem areas around the fire.

III. THE IMPORTANCE OF HAVING FIELD OBSERVERS OR OTHER FIRE PERSONNEL ASSIGNED AS LOOKOUTS FOR POTENTIALLY HAZARDOUS WEATHER AND WILDLAND FIRE BEHAVIOR CONDITIONS

A. Weather Observations

When one or more critical weather conditions are forecast to develop or worsen, potentially creating serious control and safety problems, it is important to establish a **safety weather watch** on the fire.

B. Safety Weather Watch

A safety weather watch requires one or more observers to be posted at strategic locations around a fire to detect and warn fire personnel of impending critical weather changes that may significantly affect the fire.

1. These observers should:

   - Have an unobstructed view of changing weather and fire behavior conditions.

   - Be able to communicate rapidly with fire command and other field personnel.

2. The safety weather watch observers must be able to:

   - Detect shifts in wind speed and direction before they affect the fire.

   - Provide adequate warning time to fire personnel.

     This can mean placing the observer between the fire and the wind source at a considerable distance from the fire.

3. In the case of approaching cold fronts, observers have been located up to 20 miles west of a fire.

   The observer must have clear and rapid communication with personnel at the fire.

4. Other reasons for the safety weather watch:

   - Input into spot weather forecasts.

   - To document the weather that occurred on the incident.

   - To better relate burning conditions to the weather.

   - To verify the accuracy of both weather and fire behavior forecasts.

C. While on a Wildland Fire or a Prescribed Burn

Always anticipate a sudden change in the weather and fire behavior, and be prepared to respond quickly and wisely to these changes. A sudden change in the weather can create dangerous, if not deadly, fire behavior, sometimes in just a matter of a few minutes!

When on the fireline, do not expect to have access to the latest fire weather forecasts, warnings, or observations. It is up to **you** to maintain a basic weather watch for your safety and those around you.

IV. THE CORRECT USE AND MAINTENANCE OF THE BELT WEATHER KIT IN THE FIELD

A. Taking Weather Observations in the Field

1. Handheld weather meters

Properly maintained handheld weather meters may provide users with an accurate alternative to measuring eye-level weather conditions in a timely manner.

These battery-powered, digital display devices vary widely in price and sophistication, and in the number of weather elements they record.

There are many handheld weather meters to choose from. They are capable of taking measurements of many, if not all, of the following weather elements:

- Wind speed at eye level
- Air temperature
- Relative humidity
- Dewpoint and wet-bulb temperatures
- Barometric pressure
- Heat index
- Wind chill

Some handheld meters are also able to calculate altitude in both feet and meters using an aneroid altimeter.

2. Belt weather kit

This kit remains as the standard and most accurate set of basic weather observing tools used by fire personnel on wildland fires, prescribed burns, and fire use.

Besides being durable, reliable, and accurate, the belt weather kit requires no batteries.

Unlike some handheld meters, the instruments in the belt weather kit have little problem performing in extreme weather conditions.

B. Components of a Belt Weather Kit

The red nylon case, which can be attached to your belt, contains all the weather instruments and miscellaneous items needed to take a basic weather observation.

1. The two principle instruments in the kit are:

- The sling psychrometer
- The wind speed meter

2. Other items contained in the kit are:

- The psychrometric tables for determining relative humidity
- A small bottle of distilled water
- Pencil
- Recording pad
- Compass

C. Taking Observations With a Belt Weather Kit

When taking an observation with a belt weather kit, standard procedures must be followed to correctly measure the weather elements.

1. The sling psychrometer

   When removing the psychrometer from the protective case, be sure not to touch the cotton muslin sock covering the wet-bulb thermometer.

   - Oil and dirt from your fingers may be transferred to the muslin sock.

   - Touching the muslin sock may severely reduce its capacity to absorb moisture.

2. Measuring dry bulb and wet-bulb temperatures using the sling psychrometer

   a. Stand in an open area away from objects that might be struck during whirling.

   b. Face the wind in a way that avoids exposing the thermometers to your body heat <u>and</u> direct sunlight.

      - Shade the psychrometer as much as possible.

      - If in open country, use your body to shade the psychrometer from direct sunlight.

   c. Saturate the wet-bulb wick with clean, distilled or mineral-free water.

      - Be sure to completely saturate the wick. If the muslin wick is not completely saturated, it will result in a wet-bulb temperature that is <u>too high</u>.

d. Grasp the handle of the sling psychrometer and hold your forearm parallel to the ground; ventilate the psychrometer by whirling it at arm’s length at a constant speed.

- Spinning it too fast will cause the wet-bulb wick to dry prematurely.

e. Whirl the psychrometer using a smooth wrist action for one minute.

- Note the wet-bulb temperature.

f. Continue whirling for another 30 seconds, and then take a second wet-bulb reading.

- If this temperature is lower than the first reading, continue to whirl and read the wet-bulb thermometer every five to ten seconds until it will go no lower.

- Record this lowest wet-bulb temperature.

- If the wet-bulb is not read at its lowest point, the calculated relative humidity will be too high.

g. Read and record the dry bulb immediately after the lowest wet-bulb reading is obtained.

h. Determine the relative humidity and dew point temperature using the appropriate psychrometric table for your elevation.

3. Use the sling psychrometer to check the accuracy of all handheld weather meters.

   a. All handheld weather meters should be checked for accuracy, particularly when they are used under extreme weather conditions.

      For example, when it is either:

      - very warm
      - very cool
      - very dry
      - very moist

   b. Handheld meters should also be checked for accuracy when in use at high elevations.

   c. Check using a side-by-side observation.

      - For temperature and relative humidity accuracy checks, remember to allow your handheld instrument to sit and ventilate to fully acclimate to its surroundings.

      - If you take the handheld instrument out of your pack or vest and take a reading right away, it will not give you an accurate reading.

4. Determining eye-level wind speed using the wind speed meter in the belt weather kit.

   a. Face the wind and hold the meter at arm's length near eye level.

      - The calibrated wind speed scale should be facing you.

   b. Hold the meter about midway from either end.

      - Be careful not to block the two holes at the bottom or the small hole in the top stem.

   c. Check the small plastic white ball to see if it is moving freely in the tube.

      - If it is not, refer to the belt weather kit maintenance portion of this unit.

      - If it is, determine a one-minute average wind speed by observing the ball bouncing between 2 and 9 mph.

      - If the ball stays within this range, use the low wind speed scale on the left.

   d. If the ball is rising up near 10 mph on the left scale, cover the top red stem with your finger and read from the high wind speed scale on the right.

e. To obtain a reading, observe the height attained by the ball in relation to the appropriate wind speed scale.

- As the height of the ball usually varies even during a short time, a certain amount of subjective averaging is necessary to obtain a value.

- Observe for one minute and note the average wind speed and the peak gust.

5. Determining wind direction using the compass

Before using the belt weather kit compass, check for damage and be sure the needle is free spinning.

Next, proceed with the following simple steps to determine wind direction.

a. Be sure the proper declination for your area is set on the compass.

- This may require orienting the north cardinal point on your compass several degrees from magnetic north.

b. Take a reading to the nearest cardinal point (N, NE, E, SE, S, SW, W, NW).

- Remember, the wind direction is the direction the wind is <u>from</u>.

c. The direction should also be noted as down canyon, upslope, etc.

6. Recording your weather observation

Observations are recorded in the mobile fire weather observer's record pad provided with the belt weather kit.

Each observation should be entered on a separate observation slip which allows for the following entries:

- Date
- Location
- Elevation
- Aspect
- Exposure
- Cover type
- Stand density
- Time of observation
- Dry and wet-bulb temperatures
- Relative humidity
- Wind speed and direction
- Additional remarks
    - Percent of cloud cover
    - Type of clouds
    - Cumulus buildups
    - Position and movement of thunderstorms
    - Inversions and other significant information (fire whirls, dust devils, virga, dust clouds, lightning, fog)

D. Maintenance of the Belt Weather Kit

Information on how to maintain the belt weather kit is provided in the publication "Weather Station Handbook - An Interagency Guide for Wildland Managers" by Arnold I. Finklin and William C. Fischer.

Standard maintenance procedures:

1. Wind speed meter

   a. Cleaning

      - Clean outer shell with a damp cloth.

      - The inner tube should be cleaned with a pipe cleaner.

      - Clean the pinhole in the top stem with the small nylon bristle provided with the meter.

      - This small hole must remain open to maintain correct wind speed measurements.

   b. Drying

      - If moisture enters the inner tube, the white plastic ball may not move freely in the tube.

      - To remove moisture in the tube, unscrew the metal plug and carefully remove the white ball.

      - Clean the tube with a pipe cleaner.

      - After all moisture has been removed, reinsert the ball and fasten the plug.

c. Removing static

- A static electricity charge may also cause the ball to stick in the tube.

- This can be corrected by moving a pipe cleaner up and down in the tube.

- Follow the procedure given for cleaning or drying the tube.

2. Sling psychrometer

a. Changing the wick on the wet-bulb thermometer

- The wick on the wet-bulb thermometer should be changed once every four weeks if the instrument is used daily.

- If it is used irregularly, change the wick at the first sign of dirt, discoloration, or difficulty in wetting.

- New wicking should be cut in a 1.5 inch length so it extends well above and below the thermometer bulb.

- To obtain a snug fit on the bulb, use extra-strength white sewing thread to tie the wick above and below the bulb.

b. Cleaning

- Clean the thermometers with vinegar to remove any dirt or any stubborn mineral deposits.

Exercise
Maintenance and Use of the Belt Weather Kit

Work in groups at different locations to take the observation (anywhere outside, such as under a tree, near a building, on a black top parking lot, on a wet lawn, near a stream, etc.).

Each group uses the belt weather kit to measure the dry-bulb and wet-bulb temperatures using the sling psychrometer. Determine the relative humidity and dewpoint temperature using appropriate psychrometric table for your elevation. Each group takes a minute average wind speed with the wind meter.

Record your observations, including wind direction with any additional remarks, in the observation log book. Once your group has taken a complete observation, return to the classroom to compare observations and where each observation was taken. After completing this exercise, return all belt weather kits.

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Unit 10 – Fuel Moisture

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Define critical live fuel moisture and the thresholds for various fuel types.

2. Identify three methods for obtaining live fuel moisture.

3. Describe the relationships between relative humidity, wind, and moisture content of fine and large fuels.

4. Explain how the amount and duration of precipitation and soil moisture affect moisture content of fine and large fuels.

5. Define the fuel moisture timelag concept and its value to firefighters and fire managers.

6. Describe how fuel moisture is determined for dead fuels in each of the four timelag categories.

7. Define moisture of extinction, how it varies in natural fuel complexes, and how it affects wildland fire ignition and spread.

8. Determine fuel moisture content for fine dead 1-hour timelag fuels from fuel moisture tables during daylight conditions.

I. FUEL MOISTURE

The fuel moisture content in natural fuels is an important factor to fuels availability for fire ignition and combustion. Most fuel complexes contain a combination of dead and live fuels; thus, a wide range of moisture contents occurs within these fuels.

Since all fuels may not be involved in a flaming front or be consumed by fire, our analysis of fuel complexes must determine which fuels will be responsible for the spread of fire.

A. Natural Fuels and Their Moisture Contents

Fuel complexes vary greatly by areas or regions with extremes ranging from sparsely vegetated deserts, to rain forests with lush vegetation, to parched timber lands. If we view each as a potential fire environment, our immediate assessments must include fuel assessments and fuel moisture contents.

We would expect desert fuels to be dry for extended periods, but is there enough fuel to carry fire? The rain forest has abundant fuels that are generally too wet or too green to burn, but infrequently these areas do have fires.

Extended summer drought periods occasionally make our timber lands extremely dry, sometimes to the point of being "explosive," should fires occur. Generally, when fuel moisture content is high, fires ignite and burn poorly, if at all; and when it is low, fires start easily, and spread and burn rapidly.

Fuel moisture contents are frequently some place between the two extremes and fluctuate with changes in weather and seasons. During normal fire seasons, firefighters and fire managers have experienced times when rapidly spreading fires suddenly stop, perhaps even go out, due to changes in fuels and moisture contents.

These fuels may have been on a different aspect, had a later curing date, or experienced a sudden change in relative humidity.

B. Definition

Fuel moisture content is the amount of water in a fuel, expressed as a percent of the oven dry weight of that fuel.

If there were no moisture at all in the fuels, as if dried in an oven, the fuel moisture content would be zero percent.

Fuels can be weighed before and after drying in an oven, and percent can be determined by dividing the difference between the wet and dry weights by the dry weight.

C. Types of Fuel Moisture

There are two types of fuel moisture that are relevant.

1. Live fuel moisture is the moisture in all living plants.

   A living cell can hold up to three times its weight in water.

   - Moisture content in these fuels can range from 30% to 300%.
   - These variations are attributable to changes in the season, aspect, and individual species differences.

2. Dead fuel includes dead plants like annual grasses as well as dead woody plants, litter found in forests, and slash.

   - Fuel moistures in these fuels can range from 2% to 30% and can change quickly over both time and space.
   - They will be more directly influenced by changes in weather and topography.

D. How Fuel Moisture Affects Combustion

Fuel moisture plays a critical role in the start and spread of wildland fires. When a fuel burns, it is actually the gases that are burning.

In a solid organic fuel, such as typical wildland fuels, the temperature at which combustible gases are generated is around 400° F.

But at what temperature does water turn to a gas?

As a fuel is heated, it first begins to give off water vapor once it approaches 212° F.

This process consumes energy from the ignition source and the water vapors dilute the combustible gases.

If the ignition source has sufficient energy, it will drive off enough of the fuel moisture to a point where the fuels' combustible gases can sustain combustion.

Before a fuel can burn, the moisture in it must be converted to vapor through the heat process.

The greater the moisture content, the higher the heat temperatures required to dry the fuel.

The presence of moist fuel can affect the rate and direction that a wildland fire spreads. High moisture content slows the burning process since heat from the fire must first expel moisture.

Remember, fuel moisture is one of the seven wildland environmental factors which must be continuously monitored for safety reasons.

II. CRITICAL LIVE FUEL MOISTURE AND THE THRESHOLDS FOR VARIOUS FUEL TYPES

The moisture content of live fuels can have a dramatic effect on fire behavior.

If live fuel moistures are high, such as during spring green-up when foliage is new, then the live fuels may not burn at all.

In late summer or autumn, they can reach levels where they can have a critical and explosive contribution to the overall fire behavior.

A. Living Fuels

Living fuel includes herbaceous plants and woody plant material.

1. Herbaceous plants are either perennial (sprout from the base), or annuals (develop from seed each year).

   Herbaceous plants are relatively soft or succulent and do not develop woody, persistent tissue.

   Woody plant material is small enough to be consumed in the flaming front of a fire; this mostly includes leaves, needles, and twigs. Herbaceous plants die each year, thus producing more dead fine fuels.

   In grasses, perennials usually cure out later than the annuals; this is an important factor in assessing fire potential. All living fuels will have different characteristics, which will ultimately influence how they will ignite and burn.

   For example, their physiological properties will dictate how they take in and store moisture from the environment, especially from soil. Their chemical content influences how flammable and at what temperature their combustible gases will ignite.

2. Deciduous plants produce dead, fine fuels; whereas, most evergreen plants that retain their needles or leaves more than one season may have substantially reduced moisture contents.

   Coniferous woody vegetation also produces dead fine fuels through needle casts.

B. Variations in Live Fuels

Live fuel moisture levels change relatively slowly over time, but can vary significantly across the landscape.

1. Moisture content in new plant growth follows a general pattern.

   - When the plant growth begins in spring, the moisture content of new plant material rises rapidly to a peak value.
   - This peak value is often greater than 200 percent of its dry weight value.
   - The moisture content in older foliage and twigs also increases, but reaches a peak value lower than that found in the new growth.
   - Increases in the moisture content of the woody larger stems and trunks are relatively low.
   - Moisture content in new growth will remain high as long as adequate moisture is available.
   - During the summer and fall, the moisture content decrease until it reaches a minimum.

2. The moisture level then remains at a generally low level until the growth cycle begins again in the spring.

   This live fuel moisture cycle can fluctuate.

   When considering specific plant species and specific sites, significant variations can occur in this pattern.

   These changes can take place because of:

   - Physiological activity of the plants

   - Soil moisture (influenced by ground water, streams, and precipitation)

   - Soil temperature

   - Air humidity and temperature

   Some other less dynamic factors that may affect the live fuel moisture can include slope aspect, steepness of slope, and elevation.

3. During winter and early spring, if precipitation is deficient, there will be less new growth and the peak moisture content will be lower than usual.

   The moisture decline following the peak value will be more rapid and may reach a lower point in the late summer or fall.

   Soil and air temperatures affect the time new growth begins and peak level of moisture content attained.

   When the weather in late winter and spring is warm, the new growth will begin earlier and very often obtain a higher level of moisture.

   Cold weather generally causes the reverse to happen.

In sub-arctic continental environments, such as Alaska, this general pattern can be delayed as the increased solar radiation frees more water from the frozen ground as the summer progresses.

New growth or new foliage initially has a very high moisture content in early summer but it decreases rapidly as the summer progresses.

C. Perennial and Annual Herbaceous Vegetation

Perennial and annual herbaceous vegetation, such as grasses, are a primary contributor to fire problems in many areas of the country.

The amount of vegetation and the time of curing usually vary from year to year. Some perennial grasses never cure.

1. In the grass fuel group, the ratio of live-to-dead grass greatly influences fire spread.

   - Normally at least ⅓ of the grasses must be dead before the fuel will carry fire.

   - Grass color can be used with caution as an indicator of vegetative development.

2. One such species is *Bromus tectorum,* commonly called cheatgrass or annual brome.

   Although most common on dry areas of the west, it can be found in almost every state and is present in most continents of the world.

   Cheatgrass is a primary contributor to, and usually dictates, the severity of fire seasons on range lands in the Great Basin area of the United States.

Cheatgrass stands normally cure out by early summer to produce abundant, fine, flashy fuels, which are frequently termed "explosive" when fuel moistures are very low.

In some fuel types, coloration of the plant is an excellent indicator of its stage of development and probable moisture content range.

As cheatgrass goes into its curing stage, it turns from green to purple; then, finally, it develops a straw color as it cures and its moisture content declines and fluctuates with changing weather factors.

Note fuel moisture in the living stage—above 100 percent; the curing or transition stage—30 to 100 percent; and the dead stage—below 30 percent.

Fire will not ordinarily carry through cheatgrass until it reaches the dead stage and moisture contents drop below 30 percent.

The moisture contents in the three stages for cheatgrass would appear to be somewhat lower than these indicated in the live fuel estimates. This should be used only as a general guide as there will be some variation by species.

D. Fuel Models with Live Fuels

One of the tools to help understand and predict the role of live fuels in fire behavior can be found in the fuel models.

Five of the 13 fuel models contain live fuels that can contribute significantly to fire behavior.

- There is one herbaceous (grass) model, Fuel Model 2, which is timber with a grass understory.

- There are three shrub fuel models with a live fuel component:
  - Fuel Model 4, which is 6 foot Chaparral
  - Fuel Model 5, which is brush generally 2 feet high
  - Fuel Model 7, which includes Southern Rough
- There is one timber litter model, Fuel Model 10, which has a significant live component in its understory.

E. Crown Fires

One of the most significant ways live fuels impact the fire environment is via crown fires.

Crown fires are those fires that involve the live crowns or canopies of trees and shrubs.

Generally, for crown fires to occur there needs to be sufficient surface fire in the dead fuels and adequately low live fuel moistures in the crown.

Live fuel moistures generally change slowly over time in response to changing seasonal and large scale weather conditions.

There is one exception to this during a fire—preheating from the fire itself.

It is important to be aware that the ability of live fuels to ignite and burn aggressively may change throughout the burn period as the surface fire increases in intensity and provides adequate convectional and radiational heating of the live fuels.

Researchers have examined various fuels and have determined some critical live fuel moistures. Critical live fuel moistures can be defined as *the moisture content at which sustained, fast spreading, high intensity wildfires occur.*

These generalities should serve as warning points when the live fuels begin to approach the percentages indicated. The whole fire environment has to be considered because other factors such as wind speed, slope, and dead fuel moisture may have contributing or confounding effects.

III. THREE METHODS FOR OBTAINING LIVE FUEL MOISTURES

A. Estimation Based on Time of Year

Since live fuels generally respond to seasonal changes, it can be useful to estimate the live fuel moisture based on the time of the year.

Appendix B of the Fireline Handbook has a table which correlates the stages of growth, the time of year, and the average live fuel moisture (these are approximate for an average year).

You will need to be observant of your local conditions to be aware of how the actual live fuel moistures in your area may deviate from what's suggested in the table.

These stages and their average moisture contents are a contributing factor to determining fire potential.

The following can contribute to abnormal fire seasons or burning conditions by decreasing moisture contents in live fuels and/or producing additional dead fuels within a fuels complex.

- Long drought periods
- Natural disease, insects
- Annuals curing out early in the season
- Harvesting of timber and other vegetation
- Blowdown, ice storms

B. Sample Collection

The most accurate method of determining live fuel moisture is actually collecting and analyzing samples from your area of concern.

Be sure to sample the fresh new growth of the year as well as the perennial older growth.

Also consider elevation, aspect, and species differences in sample selection. Once collected, weigh it, dry it, and weigh it again.

Use standard formula for calculating fuel moisture:

(Wet weight – dry weight)/dry weight)

C. Online Data Sources

The Wildland Fire Assessment System (WFAS) provides various data on subjects such as:

- Live fuel moisture
- Drought indices
- Relative greenness

It can be very useful in understanding the live fuel moistures in your area at a given time.

IV. THE RELATIONSHIPS BETWEEN RELATIVE HUMIDITY, WIND, AND MOISTURE CONTENT OF FINE AND LARGE FUELS

A. Fuel Moisture Exchange with the Atmosphere

Water always moves from higher concentrations to lower concentrations, in a constant effort to establish balance. This is called osmosis.

1. Fuels are constantly exchanging moisture with the surrounding air.

   - During periods of high humidity and precipitation there is a net gain in fuel moisture.

   - When the air is dry, with low humidity, fuels are giving up more moisture to the air than they receive.

2. Several factors influence the rate of moisture exchange between fuels and the air:

   - Difference in water vapor pressure between fuels and air

   - Presence or absence of wind

   - Size of fuels

   - Compactness of fuels

   - Proximity of fuels to damp soil

B. Equilibrium Moisture Content

If the moisture content in the atmosphere remained constant for a period of time, the fuels and the air would eventually achieve equal vapor pressures.

This is called equilibrium moisture content, which occurs when there is no net gain or loss of moisture between fuels and the surrounding air. This can occur in small, fine fuels, but rarely occurs in larger fuels, as the time required to reach equilibrium in larger fuels is much longer.

C. Environmental Factors Influencing Fuel Moisture

Fuel moisture is directly influenced by temperature, relative humidity, and precipitation. Wind alters the exchange of moisture between the fuels and the air.

Other site factors of weather and topography influence atmospheric temperatures and relative humidity. Each of these site factors indirectly affects fuel moisture and must be considered in making estimations of fuel moisture content.

1. Shade versus unshaded effects on fuel temperatures

During sunny daylight hours, temperatures at the earth's surface can reach 160° F in unshaded areas but can be considerably less in shaded areas.

That temperature decreases very rapidly a few feet above the surface where air is mixing. At five feet above the surface, the air temperature may be 85 degrees as observed in a weather instrument shelter.

Relative humidity is much lower where temperatures reach 160°; thus, in this example, fine dead fuel moisture at the surface will be considerably lower—3 percent in the open, unshaded area, as opposed to 8 percent in a shaded area.

2. Aspect

South slopes obviously receive more heating during the daytime than north slopes, thus:

- Temperatures are higher
- Relative humidity is lower
- Fuel moisture ordinarily is lower on the south slopes

During the summer, level ground receives about the same intense heating as south aspects. When darkness comes, temperature differences on various aspects diminish.

By early morning, temperature, relative humidity, and fine fuel moisture values have mostly stabilized.

At night, temperatures on south slopes and valley bottoms may be much different due to surface inversions and the effects of thermal belts.

East aspects reach their lowest fuel moisture contents by early afternoon; whereas, southwest aspects have the lowest afternoon fuel moisture contents.

Normally, south and southwest aspects have the lowest average fuel moisture contents.

3. Elevation

The accepted "normal" temperature lapse rate is about 3½° F decrease per 1,000 foot of elevation rise.

As temperature decreases with elevation, the relative humidity increases. Together with later snow melt dates, later curing dates, and higher green to dead fuel ratios at higher elevations, the overall fuel moisture differences can be very significant to fire ignition and spread rates.

D. Slope

The steepness of slopes is a factor in the amount of solar radiation received on various aspects. This affects the fuel moisture content of fuels on various slopes.

Surfaces perpendicular to incoming radiation receive considerably more heating than slopes that are almost parallel to these heat rays.

The angle at which solar radiation hits various surfaces changes throughout the day and with the time of year.

The steepness or percent slope on north aspects is particularly important, as there may be times of the year when such slopes receive no direct solar heating at all.

E. Wind

Wind is a factor influencing fuel moisture by helping fuels to reach equilibrium moisture content with the atmosphere at a faster rate.

How do winds speed up the drying or the evaporation process?

During calm air conditions, the air next to the fuels tends to become saturated with water vapor, decreasing the evaporation rate of moisture from the fuel.

Wind removes this saturated air, continually replacing it with drier air and thus speeding up the evaporation process. But moderate or strong winds may affect surface temperatures of fuels in the open and thereby influence surface fuel moisture.

During daytime heating, wind may replace the warm air layers immediately adjacent to fuel surfaces with cooler air. This raises the relative humidity in that area and lowers the fuel-surface temperature. Fuel drying is thereby reduced.

At night, turbulent mixing may prevent surface air temperatures from reaching the dew point, thus restricting the increase of surface fuel moisture.

Foehn winds are frequently referred to as drying winds because they are so often accompanied by rapid drying of fuels. In the case of the foehn, it is warm and extremely dry air that is responsible for desiccation.

The important role of the wind is to keep that warm, dry air flowing at a rapid rate so that it does not become moist by contact with the surface either by day or night.

When moist winds blow over dry fuels they bring in a continuous supply of moisture to maintain a pressure gradient favorable for fuel moisture increase. Remember, wind has quite varied and complex effects on fuel moisture.

V. HOW THE AMOUNT AND DURATION OF PRECIPITATION AND SOIL MOISTURE AFFECT MOISTURE CONTENT OF FINE AND LARGE FUELS

Precipitation can raise fine dead fuel moisture more rapidly than any other factor. The amount and duration of the precipitation are considerations when predicting fuel moisture increases in various size fuels.

A. Fine Dead Fuels

Fine, dead fuels react very rapidly to precipitation and reach their saturation points quickly.

- Additional rainfall has little effect on the fuels.
- More rainfall can be responsible for wetting the soils in contact with fuels, thus keeping those fuels damper for a longer period and prolonging the effects of the rainfall.

B. Large Dead Fuels

Large, dead fuels react more slowly to precipitation since much of the rain may run off the fuel.

- Fuels continue to absorb moisture throughout the duration of precipitation.

- Duration is more important than amount.

C. Comparison of Precipitation Duration Effects

The horizontal axis represents hours of continuous precipitation, while the vertical axis is fuel moisture content in percent.

The dashed line representing l-hour timelag (fine) fuels starts at 5 percent, rises rapidly, and reaches 30 percent moisture content within the first hour.

The broken diagonal line representing 10-hour timelag fuels starts at 8 percent and increases at a slower rate, but reaches 30 percent moisture content after 6 hours.

The solid line, that represents 100-hour (large) fuels starts at 12 percent and only reaches 20 percent after 16 hours of continuous precipitation.

The data used to prepare this chart represent average western fuel situations with standing and down, dead fuels.

Although heavy rains penetrate vegetative canopies better to reach understory fuels, the moisture absorption rate into fuels is mostly fixed.

Consequently, excessive amounts of rainfall run off the fuels. A wetting rain will penetrate fuels better than high relative humidity in the air. Having free water on the surface of fuels induces a higher absorption rate than high humidities in the air.

VI. THE FUEL MOISTURE TIMELAG CONCEPT AND ITS VALUE TO FIREFIGHTERS AND FIRE MANAGERS

A. Definition

Time needed under specified conditions for a fuel particle to lose about 63 percent of the difference between its initial moisture content and its equilibrium moisture content.

When body temperature is taken orally, the thermometer must be left under the tongue for approximately three minutes so that the instrument can adjust to its new environment.

Three minutes is the timelag for an oral thermometer.

1. Timelag is a common occurrence in nature.

    - Fuels require a time period to adjust.

    - The gain or loss of moisture does not occur at a constant rate.

    - When conditions change, fuels respond quickly at first.

2. The change in moisture content becomes slower as the fuel moisture gets closer to the equilibrium moisture content.

    - In nature, fuel takes five timelag periods for 95 percent of the change to occur, but most of the change occurs in the first timelag period.

    - With a greater surface-area-to-volume ratio, the timelag of fine fuels is short and they reach their equilibrium moisture content quickly.

3. Large fuels have a longer timelag.

   - They will not reach an equilibrium moisture content since environmental conditions do not stay constant.

   - It is still worthwhile to classify fuels according to their timelag.

B. Timelag and Fuel Size Relationship

1. Timelag is related to fuel size

   On the horizontal axis, we have the size of branchwood in inches of diameter.

   The vertical axis gives us timelag in days.

   - Fuels of 1.4 inches in diameter have a timelag of 48 hours or two days.

   - Fuels 2 inches in diameter have a timelag of 4 days and so on.

   This means that if the air was kept at a constant point drier than the fuels, it would take four days' time for 2 inch branchwood to lose ⅔ of the difference between its initial moisture content and the equilibrium moisture content.

   What is the appropriate timelag for 8 inch diameter branchwood?

2. Reaction times of two different size fuels

The timelag concept can be observed by comparing the reaction times to wetting and drying for two different size fuels.

The fuels are ½-inch sticks and a 12-inch log.

During a typical fire season with a week of dry weather, the fuel moisture in ½-inch dead fuels will be considerably less than the moisture content of a 12-inch log.

This is because the timelag period is much shorter in the ½ inch sticks.

If the fuels experience a day with precipitation, the moisture content of both will go up, but note the rates at which they absorb moisture.

The 12-inch log is still gaining moisture after the rain has stopped, perhaps because of free water and wet soils resulting from the rainfall.

The ½-inch sticks gain moisture rapidly, but also lose it rapidly when temperatures and relative humidity return to normal.

Wildland fuels come in many shapes and sizes, and we will never see a fuel complex of homogeneous fuel.

A pure grass stand comes closest to being a homogeneous fuel.

The wide variety of fuel components and changes in the weather make it virtually impossible for an entire complex to be at equilibrium moisture content at the same time.

C. Dead Fuel Timelag Categories

For the purpose of predicting fire behavior, it is acceptable to use estimates for the moisture content of the fuel sizes that contribute most to fire spread.

Dead fuels are grouped into four size classes based on timelag:

- l-hour timelag fuels: 0 to 1/4 inch diameter

- 10-hour timelag fuels: 1/4 inch to 1 inch diameter

- 100-hour timelag fuels: 1 inch to 3 inches diameter

- 1000-hour timelag fuels: 3 inches to 8 inches diameter

The Wildland Fire Assessment System website has national maps depicting observed and/or calculated fuel moistures for three of the four timelag categories: 10-hour, 100-hour, and 1000-hour (1-hour is not shown because it changes hourly).

Thousand hour fuels are used in the National Fire Danger Rating System, but not for making fire behavior predictions. They are an indicator of drought.

D. Fine Dead Fuel Moisture (FDFM)

Although it's helpful to have current estimates of fuel moisture in each of the four categories, we are most concerned with the l-hour group, which includes all fine or small fuels up to ¼-inch in diameter.

This is the group that:

- Mostly determines whether a fire will start and continue to spread.

- Is constantly changing with changes in relative humidity.

It is possible to predict these changes, and thus fire behavior, for different periods of the day and night.

With no major air mass changes, relative humidity typically rises during the night with lowering temperatures until it reaches the highest humidity just about sunrise.

Relative humidity then usually starts to drop with rising temperatures until the lowest humidity is reached during mid-afternoon.

The fine dead fuel moisture curve follows the relative humidity curve with a short timelag of about 1 hour.

Surface litter, as well as other fine dead fuels lying directly on the ground, can exhibit a slower moisture exchange rate because of reduced air circulation in compact fuels and soil moisture exchange with the fuels.

VII. HOW FUEL MOISTURE IS DETERMINED FOR DEAD FUELS IN EACH OF THE FOUR TIMELAG CATEGORIES

Following are ways in which fuel moisture contents can be determined for each of the timelag categories:

- 1-hour timelag fuels
  - Fuel moisture charts
  - Rough estimate of relative humidity divided by 5
  - National Fire Danger Rating System (NFDRS) values
  - Drying oven and scales

- 10-hour timelag fuels
  - Fuel moisture sticks
  - Calibrated moisture meters
  - NFDRS values
  - Drying oven and scales

- 100-hour timelag fuels
  - Calibrated moisture meters
  - NFDRS values
  - Drying oven and scales

- 1000-hour timelag fuels
  - Calibrated moisture meters
  - NFDRS values
  - Drying oven and scales

Determining fuel moisture percents for 100-hour and 1,000-hour timelag fuels gives managers an indication of drought conditions and overall severity of a fire season.

The 10-hour fuels are much more important in making fire behavior predictions than 100-hour fuels, but not nearly as important as 1-hour fuels.

One-hour fuels are the primary carrier of the fire.

VIII. MOISTURE OF EXTINCTION, HOW IT VARIES IN NATURAL FUEL COMPLEXES, AND HOW IT AFFECTS WILDLAND FIRE IGNITION AND SPREAD

Fire spreads as a result of fuels ahead of the fire being preheated to their ignition point.

Heat is required to drive moisture from fuels before they can support combustion.

At some point, fuel moisture content can slow combustion and the preheating of new fuels; thus, ignition temperature in new fuels is not reached.

A. Definition

What is the point where fine dead fuel moisture discourages combustion and fire spread?

We call it the moisture of extinction. It is defined as the fuel moisture content at which a fire will not spread, or spreads only sporadically.

1. The moisture of extinction varies by fuel situation and is dependent on various fuels characteristics such as:

   - Fuel loading
   - Fuel size
   - Arrangement
   - Chemical content

2. Moisture of extinction:

   - Is lowest (around 12 percent) for light grasses such as cheatgrass.

   - Tends to be higher (around 30 percent) for more compacted fuels such as needle litter.

   - Is around 40 percent for southern rough fuels.

Does this mean a going fire will stop spreading when the moisture of extinction is reached? Not necessarily.

A fire that is already spreading on a wide front and producing significant intensities may not respond when moisture of extinction is reached as an initiating fire would.

Thus, a burnout may not spread while the main fire continues in a run.

B. Moisture of Extinction for the Fire Behavior Fuel Groups

Moisture of extinction ranges for each fuel group:

Fuel Model 1 – Short grass 12%
Fuel Model 2 – Timber........................ 15%
Fuel Model 3 – Tall grass.................... 25%
Fuel Model 4 – Chaparral.................... 20%
Fuel Model 5 – Brush.......................... 20%
Fuel Model 6 – Dormant brush 25%
Fuel Model 7 – Southern Rough 40%
Fuel Model 8 – Closed timber litter 30%
Fuel Model 9 – Hardwood litter.......... 25%
Fuel Model 10 – Timber...................... 25%
Fuel Model 11 – Light slash................ 15%
Fuel Model 12 – Medium slash........... 20%
Fuel Model 13 – Heavy slash............. 25%

Fuels such as shrubs with high chemical contents can burn at much higher fuel moistures.

IX. FUEL MOISTURE CONTENT FOR FINE DEAD 1-HOUR TIMELAG FUELS FROM FUEL MOISTURE TABLES DURING DAYLIGHT CONDITIONS

A. Fine Dead Fuel Moisture Tables

Eight inputs are needed to calculate the fine dead fuel moisture:

- Dry bulb temperature
- Relative humidity
- Month
- Shaded or unshaded
- Time of day
- Slope
- Aspect
- Site location

All inputs can be entered on the Fine Dead Fuel Moisture worksheet. The temperature and relative humidity are necessary to determine the **reference fuel moisture.**

The other inputs are necessary to determine the **fuel moisture correction**.

1. Reference Fuel Moisture Table (Table 2)

   Determine a reference fuel moisture (RFM) by selecting the appropriate dry bulb temperature and relative humidity from Table 2.

   Table 2 is for RFM during daytime hours. You must know both dry bulb temperature and relative humidity from your site.

   Notice the ranges of temperatures on the left, and ranges of humidities across the top.

   With the appropriate temperature range, move horizontally until you intersect with the column for the appropriate humidity ranges at the top.

   At this intersection you have a RFM content percent. This value is entered in line 6 of the Fine Dead Fuel Moisture Worksheet.

2. Fine Dead Fuel Moisture Content Corrections For Day

   Determine a fuel moisture correction (FMC) value from the tables by considering the:

   - Month
   - Cloud and/or canopy cover shading
   - Time of day
   - Site location elevation difference
   - Aspect
   - Slope percent

The correction value is then added to the RFM to get the adjusted fine dead fuel moisture (FDFM).

Table 3 gives you correction values for the months of May, June, and July; this table is only valid for those three months.

Notice that there are two sections to the table. The top section is for unshaded surface fuels, while the bottom part is for shaded surface fuels.

After making the proper selections of aspect and slope on the left, and time of day from the top, you will find FMC value at the point of intersection.

This value is entered in line 13 of the Fine Dead Fuel Moisture Worksheet.

Fine Dead Fuel Moisture Correction Tables 4 and 5 are used for the months of February, March, April/August, September, October, and November, December, January, respectively.

Make sure you are using the correct monthly table.

B. Site Location

There is one other input that warrants additional explanation – **site location** or elevation change on your worksheet.

1. This is based roughly on the lapse rate, which is approximately 3.5° F per 1,000 under average dry conditions.

   If the atmosphere is very unstable, we learned that the lapse rate, or change in temperature over elevation, could be as much as 5.5° F per 1,000, or even more.

2. This comes into play as we consider the location of where we are taking our weather readings relative to where the fire is.

    - If the fire is either 1,000 feet above or below the location where the weather is taken, we do not need to make any adjustments; it is presumed that the temperature within that 2,000 feet will be within an acceptable variation.

    - If the fire is greater than 1,000 feet and less than 2,000 feet either above or below us, we can and do need to make an adjustment.

3. Elevations greater than 2,000 feet above or below the predicted site will require a new temperature and relative humidity reading.

    - If the fire is either 1,000 feet above or below the location where the weather is taken, then we use the **L** column from the table.

    - If the fire is greater than 1,000 feet and less than 2,000 **Above** us, we use the values in the **A** column from the table.

    - If the fire is greater than 1,000 feet and less than 2,000 **Below** us, we use the values in the **B** column from the table.

C. Interpretations of Fire Behavior

The "Severe Fire Behavior Potential Related to Relative Humidity and Fuel Moisture Content" table describes some general fire behavior characteristics that might occur with various fuel moisture levels in 1-hour and 10-hour fuels. Remember, this table is only for the western U.S.

Fine Dead Fuel Moisture Worksheet

INPUT

0	Projection Point	____	____	____
1	Day Time Calculation	D	D	D
2	Dry Bulb Temperature, °F	____	____	____
3	Wet Bulb Temperature, °F	____	____	____
4	Dew Point, °F	____	____	____
5	Relative Humidity, %	____	____	____
6	Reference Fuel Moisture (RFM), % (From Table 1)	____	____	____
7	Month	____	____	____
8	Unshaded (U) or Shaded (S) (Circle)	U/S	U/S	U/S
9	Time	____	____	____
10	Elevation Change (Circle) B=1,000 to 2,000 feet below site L= ± 1,000 feet of site location A=1,000 to 2,000 feet above site	B/L/A	B/L/A	B/L/A
11	Aspect (N,E,S,W)	____	____	____
12	Slope, %	____	____	____
13	Fuel Moisture Correction (FMC), % (From Table 2, 3, or 4)	____	____	____

OUTPUT

1	Fine Dead Fuel Moisture (FDFM), % (Line 6 + Line 13)	____	____	____

EXERCISE
Calculating Fine Dead 1-Hour Fuel Moisture

Use the fine dead fuel moisture calculation tables and worksheet to complete the questions.

1. What is the reference fuel moisture (RFM) for the following daytime situations?

   a. Temperature 85 °F, relative humidity 22 percent

      RFM ____

   b. Temperature 60 °F, relative humidity 62 percent

      RFM ____

2. What are the fuel moisture correction (FMC) values for the following situations?

   a. August 20, at 1200, mid-slope location, east aspect, and cloudy sky (shaded fuels)

      FMC ____

   b. May 10, at 1400, south aspect, 20 percent slope, clear with unshaded fuels.

      FMC ____

3. What is the fine dead (1-hour) fuel moisture (FDFM) content at the following fire locations? Record your solution on the fine dead fuel moisture worksheet. Read the next two situations carefully!

   a. It is November 19, at 1500. Fuels are exposed to the sun on a west aspect. Readings from a belt weather kit taken 1,500 feet below the fire give a dry bulb temperature of 92 °F, and a relative humidity of 16 percent. The slope is 40 percent.

      RFM ____ + FMC ____ = FDFM ____

   b. It is October 12, at 1700. Fuels are shaded on a north aspect, but under clear skies. Readings from a belt weather kit taken 1,400 feet above the fire give a dry bulb temperature of 75 °F, and a relative humidity of 28 percent. The slope is 20 percent.

      RFM ____ + FMC ____ = FDFM ____

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Unit 11 – Extreme Wildland Fire Behavior

OBJECTIVES:

Upon completion of this unit, students will be able to:

1. Describe the four common denominators of fire behavior on tragedy wildland fires.

2. Describe extreme fire behavior characteristics and recognize fire environment influences that contribute to extreme fire behavior.

3. Describe the three stages of crown fire development and identify the key factors and indicators leading to crown fire development.

4. Identify the three factors that contribute to the spotting problem and describe the conditions associated with each factor.

5. Define the probability of ignition, describe its use, and determine it using tables.

6. Define firewhirls (vortices), the conditions under which they are likely to develop, and their implications to wildland fire behavior.

7. Explain the difference between wind-driven and plume-dominated fires.

I. FOUR COMMON DENOMINATORS OF FIRE BEHAVIOR ON TRAGEDY FIRES

In 1976, Carl C. Wilson did a study on "Fatal and Near Fatal Forest Fires – The Common Denominators." His conclusions found that such fires often occur:

- On relatively small fires or deceptively quiet areas of large fires.
- In relatively light fuels, such as grass, herbs, and light brush.
- When there is an unexpected shift in wind direction or in wind speed.
- When fire responds to topographic conditions and runs uphill.

These four common denominators underscore the concept of alignment.

These are the fires that are relatively benign or routine, but suddenly "explode" or "blow-up." This sudden and dramatic change in fire behavior is a result of this alignment between forces.

II. EXTREME FIRE BEHAVIOR CHARACTERISTICS AND FIRE ENVIRONMENT INFLUENCES THAT CONTRIBUTE TO EXTREME FIRE BEHAVIOR

A. Extreme Fire Behavior

Extreme fire results when several of the components of the fire environment interact.

It is a convergence or an alignment where there are abundant fuels with sufficiently low moistures, and the winds strong enough or slope steep enough.

In many cases, the atmosphere is very unstable (Haines of 5 or 6).

Extreme fire behavior is generally defined as a level of fire behavior that often precludes any fire suppression action. It usually involves one or more of the following characteristics:

- High rate of spread and frontal fire intensity
- Crowning
- Prolific spotting
- Presence of large firewhirls
- Well-established convection column

Fires exhibiting such phenomena often behave in an erratic, sometimes dangerous manner.

Other terms used to describe extreme fire behavior include “blow-up” and fire behavior in the third dimension.

B. Contributing Factors

Extreme fire behavior usually results from a combination of environmental factors.

Common factors contributing to the development and reinforcement of extreme fire behavior:

- Available fuels
- Wind
- Low fuel moistures
- Unstable atmosphere

1. Available fuels

The micro-climate and soil conditions will determine the fuel complex that occurs at a particular site.

The vegetative stage of development, as well as disturbances to the vegetation (blow down, frost, insect kill, etc.), can predispose the fuel complex to various amounts and ratios of dead and live fuels.

Seasonal and diurnal changes will affect the fuel moistures and temperatures, making fuels available (drought).

a. Large quantities of readily available fuels will generate intensities capable of:

- Producing rapid rates of spread.
- Lofting of firebrands.
- The upward/downward movement of air in convective dynamics.

b. Fuels characteristics to assess:

- Continuous fine fuels
- Heavy loading
- Ladder fuels
- Tight crown spacing (<20 ft.)
- Special conditions:
  - firebrand sources
  - numerous snags
  - preheated canopy
  - frost and bug kill
  - high dead to live ratio

2. Wind

   a. Extreme fire behavior has been associated with strong winds including but not limited to:

      - Frontal
      - Thunderstorm
      - Foehn winds

      Winds supply additional oxygen to the fire combustion process increasing fire intensity.

      Wind also increases radiation and convective heat transfer by bending flames closer to fuels ahead of the flaming front.

      Firebrands can be mass transported by the wind and contribute to spotting ahead of the main fire.

   b. Wind indicators to observe:

      - Surface winds above 10 mph
      - Lenticular clouds
      - High, fast moving clouds
      - Approaching cold fronts
      - Cumulonimbus development
      - Sudden calm
      - Battling or shifting winds

3. Low fuel moistures and relative humidities

   Dry air in the lower levels of the atmosphere is associated with low relative humidities.

   These conditions lower dead fuel moistures and increase fuels that are available for combustion.

   If these conditions persist, the larger dead fuels will become affected as well as fine dead fuels.

4. Unstable atmosphere

   An unstable atmosphere contributes to the vertical motion of the air.

   a. Upward and downward air movement will have the same effects as wind on the fire:

      - Supplying oxygen to combustion.

      - Increasing radiant and convective heat transfer effectiveness.

      - Transporting firebrands.

      Given the proper combination of wind speeds and fire intensity, instability directly leads to a wildland fire environment that is dominated by the convective column, or plume, itself.

   b. Indicators of an unstable atmosphere to observe:

      - Good visibility
      - Gusty winds and dust devils
      - Cumulus clouds
      - Castellanus clouds in the a.m.
      - Smoke rises straight up
      - Inversion beginning to lift

5. Fires are most likely to blow-up when the following conditions exist simultaneously:

   a. Fuels are dry and plentiful (drought).

   b. The atmosphere is either unstable or was unstable for some hours, and possibly days, prior to the fire.

   c. The wind speed of the free air is 18 mph or greater at an elevation equal to, or not much above, the elevation of the fire.

III. THE THREE STAGES OF CROWN FIRE DEVELOPMENT AND THE KEY FACTORS AND INDICATORS LEADING TO CROWN FIRE DEVELOPMENT

Crown fires are one of the most spectacular fire behavior phenomena that wildland fires exhibit.

They are one of the fastest spreading of all wildland fires, releasing tremendous amounts of heat energy in a relatively short period of time.

Crown fire spread rates exceeding 7 miles/hour and flame lengths over 150 feet have been recorded.

Until 1990, fire behavior prediction methods were not available to estimate crown fire spread rates or intensities.

When we talk about crowns, we are referring to aerial level fuels. This not only includes the tree canopies, but the canopies of tall shrubs:

- Chaparral
- Oak brush
- Palmetto/gallberry
- Pine plantations
- Areas of reproduction

A. Stages of Crown Fire Development

Crown fire development occurs as a dynamic progression.

This progression has three recognizable stages, identified by the crown fire's dependency on the surface fire.

A high intensity surface fire and/or a canopy (crown) close to the surface enables the fire to move into the aerial fuels.

Crown fires begin as an individual torching tree and can continue to a fire burning independent of the surface fire.

Often, a crown fire will move back and forth through these stages with changes in the wildland fire environment. All three stages may not occur.

1. Passive crown fire

   A passive crown fire is the involvement of one or, at most, just a few trees.

   Commonly, this type of behavior is referred to as "torching."

   The passive crown fire is entirely at the mercy of the surface fire. The surface fire, through its intensity and/or ladder fuels, engages aerial fuels.

   Any fire spread between canopies is short lived and confined to canopies that are intertwined.

2. Active crown fire

   Actively burning in the crowns and advancing with the surface fire.

   In the active crown fire stage, the crowning remains dependant on the heat from the surface fire for continued spread.

   Mass transfer of heat occurs between individual tree or shrub canopies as fire spreads through the aerial fuels.

   At times, the surface fire precedes the crown fire, preheating and igniting the aerial fuels above.

   Other times, the crown fire races ahead of the surface fire, creating spot fires that surge to reinforce the ignition of more surface and aerial fuels.

   A pulsating spread rate is commonly observed.

3. Independent crown fire

Sustained independent crown fires are uncommon but important.

Occasionally, the active crown fire will outrun its reinforcing surface fire, but these periods are normally of short duration both in time and space.

With independent crown fires, the combustion process and heat transfer mechanisms take place in the aerial fuels.

The surface fire spread results from the crown fire spread. This stage of crown fire presents the greatest suppression challenge.

B. Conditions Contributing to Crown Fires

Various fire environmental conditions under which crown fires are likely to occur can be observed and monitored.

These conditions can be viewed as those that affect crown flammability and those that affect heat transfer mechanisms between and among fuel levels.

1. Crown flammability

Crown flammability depends on similar characteristics that affect other fuel beds.

The primary difference is the additional cooling and loss of heat transfer through the base of the crown.

Of particular importance in crown fire activity are the following characteristics.

a. Fine dead fuel moisture

There are normally quite a lot of dead fuels intermixed with a live canopy.

Like with shrubs, the live-to-dead fuel ratio will determine fire activity. Low fine dead fuel moistures will promote crown flammability.

b. Live foliar moisture

Live foliar moisture content is primarily determined by plant phenology or stage of development and tends to follow seasonal trends.

In late fall, shrub and perennial grass moisture may be low and remain low until spring "green-up."

Foliar moisture contents in mature conifer needles change little through the season reaching lowest values just prior to the flush of new needles at high moisture contents.

One of the classic crown fires occurred with foliar moistures at 110 percent (Mack Lake Fire, 1980).

Many western states' crown fires have occurred when foliar moistures were greater.

Some live southern fuels burn very well at high foliar moisture contents.

While drought may or may not be reflected in live foliar moisture contents, crown fuels are more likely to burn when soil moisture reserves are very low.

c. Foliage flammability

The volatiles in the foliar fuels will, of course, influence crown flammability.

Various species throughout the country are known to produce high intensities when consumed.

Examples:

- Palmetto/gallberry in the southeast
- Chamise in southern California
- Jack pine in the lake states

d. Crown closure

Crown closure is the aerial fuels' equivalent of compactness.

A crown closure of 75 percent or more will improve the heat transfer mechanisms of convection and radiation from crown to crown.

Less closure allows heat to be lost.

2. Surface to crown heat transfer

The initiating crown fire begins on the ground.

The preheated aerial fuels are brought to ignition from the surface fire burning below.

The ability for heat to be transferred from the surface fire to the aerial fuels is crown fire activity.

a. Surface fire intensity

With greater surface fire intensities, more heat is produced which can be transferred into the aerial fuels.

The following contribute to high fire intensities:

- Heavy loadings
- Optimum compactness
- Low moisture contents
- Atmospheric instability

b. Vertical arrangement

Ladder fuels and a low crown height serve fire spread by reducing the heat transfer distance between the surface fire and the aerial fuels.

c. Steepness of slope

Slope also reduces the heat transfer distance between the surface fire below and the canopy of the tree or shrubs uphill.

3. Crown to crown heat transfer

The active and independent crown fire spreads from crown to crown.

Heat transfer between the aerial fuels is imperative to this spread.

a. Crown spacing

Crown spacing of 20 feet or less (roughly 100 trees per acre or more) will permit convective and radiant heat transfer to take place at a level where fire spread can be maintained through the aerial fuels.

b. Crown level winds

Crown level winds are an excellent indicator for crown fire activity.

Strong winds of 20 mi/h or greater (20-foot winds above the surrounding vegetation) are normally necessary to sustain active and independent crown fires in the absence of steep slopes.

c. Steepness of slope

Surface fire spread is increased by the steepness of slopes; so is crown fire spread.

The effect of slope on heat transfer in aerial fuels is much the same as in surface fuels.

C. Sustained Crown Fire Runs

With the right conditions, an active or independent crown fire can sustain a run in excess of 20 miles (Canyon Creek Fire, 1988).

Normally, a change in the fire environment will cause the fire to return to the surface until the environmental conditions become suitable for the initiation of crown fire activity. This often is a diurnal occurrence.

To sustain a crown fire run, the following conditions are needed:

1. Low fuel moistures.

2. Relatively close crown spacing.

3. Strong winds and/or steep slopes.

4. The ability to spot ahead in discontinuous fuels.

IV. FACTORS THAT CONTRIBUTE TO THE SPOTTING PROBLEM AND THE CONDITIONS ASSOCIATED WITH EACH FACTOR

A. Contributing Factors

There are eight contributing factors to the spotting problem; they fall into three areas.

1. Firebrand source

   a. Probability of production

   The distance a spot fire starts from the fire front depends on the fire's ability to loft the firebrand into the prevailing winds.

   The probability that a fire will attain the required intensities depends on:

   - Surface fuels
   - Burning conditions
   - Overstory species
   - Crown spacing

   In a surface fire, the canopy intercepts the upward travel of a firebrand limiting the spotting problem.

   b. Number of firebrands

   Not all firebrands initiate a fire. Because they either burn out before landing, or have no environment to support spread (even if they land glowing), most firebrands produced do not develop into spot fires.

   The more firebrands the source can generate, the better the chances are for one of them to initiate a spot fire.

c. Type of firebrands

The airfoil properties of the firebrand determine its ability to be transported by convection and the wind.

Low density and high surface area give the firebrand the best chance for long distance transportation.

The firebrand must be of sufficient size to continue glowing as it settles back to the ground.

2. Transportation

a. Convective lifting

The intense convective rising of air in the flame structure itself and the buoyant plume above the flame loft the firebrand from the burning fuel.

The more intense the fire (longer flames) the higher the firebrand will rise.

b. Wind field

Once the firebrand is lofted to its ultimate height, it begins to follow a trajectory determined by the firebrand's shape, mass, and wind field to its final downwind destination.

3. Receiving fuels and environment

a. Receptive fuel

Firebrands must land on fine, dry fuels (litter, duff, rotten wood), in order to ignite these receiving fuels and initiate a spot fire.

b. Probability of ignition

The probability of ignition is a rating of the probability that a firebrand will cause a fire.

c. Environmental conditions

In its new environment, the initiated spot fire must encounter fuels, fuel moisture, wind, and slope that favor fire spread in order to become a problem.

B. Short-Range vs. Long-Range Spotting

The combined results of convective lifting and the wind field dictate the maximum distance a spot fire can occur from the fire front.

Usually, distances are broken into two categories: short- and long-range spotting. Spotting distances greater than 15 miles have been recorded when the contributing conditions have been extreme.

The difference between short- and long-range spotting is more a factor of whether the new spot fire has time to develop as a separate fire before being overrun by the initiating fire rather than a particular distance.

1. Short-range spotting

Strong surface winds and limited convective lifting result in firebrand destinations near the fire front.

Commonly, spot fires generated by short-range spotting will be overrun by the main fire before increasing the main fire spread rate.

Fire spread rates through patchy fuels are similar to spread rates through continuous fuels because of short-range spotting.

2. Long-range spotting

Large, aerodynamic, glowing firebrands, strong convective lifting, and a wind field enabling maximum height and transportation support long-range spotting.

Running crown fires and large firewhirls are well known for their ability to supply the needed lifting power.

3. Determining spot fire locations

By observing the convection column, you can determine the direction and, to some extent, the distance firebrands can be transported.

The spotting problem depends on many other factors. A good adage: "Where there is one, there are probably more."

4. Numerous spots

Frequent spot fires is one of the 18 Watchouts. We generally consider frequent in terms of a rate faster than crews can suppress them.

Besides being a safety concern, frequent spot fires is a good indicator of intensifying conditions.

Although innocent at conception, as spot fires begin to grow, they start to interact with each other, adding air flow and heat energy to their environment.

Their combined effect is greater than the sum of their individual effects. The increasing intensities can bring the fire out of a closed environment and into the open.

During extreme fires, a pulsating fire spread, generated by the combining of spot fires, can often be observed. Frequent spotting is definitely a "Watch Out" situation. The spotting problem should always be monitored.

V. PROBABILITY OF IGNITION

A. Definition

Probability of ignition is a rating of the probability that a glowing firebrand will cause a fire, providing it lands on receptive fuels.

1. It is not related to the likelihood of a firebrand being produced, or:

    - Being the right size and shape to be transported still glowing by convection and/or winds.

    - Having available fuels where it lands.

2. It states the chance (probability) that the firebrand will cause an ignition when the right kind of firebrand lands on the right kind of fuel.

    - When the probability of ignition is 70 percent, if 10 glowing firebrands land on receptive fuels (grass, needles, punky wood) there will be seven ignitions.

    - Whether a wildland fire actually results from the ignition depends on the fire environment.

B. Probability of Ignition Table

The probability of ignition is determined from:

- Fuel shading
- Fine dead fuel moisture
- Dry bulb temperature

Choose the table half with the correct fuel shading, either less than, or more than, 50 percent cloud and/or canopy cover. Read the probability of ignition at the intersection of the proper fine dead fuel moisture column and dry bulb temperature row.

EXERCISE 1.

Use the tables on the slides to determine probability of ignition for the following:

#1 – Clear day, no canopy cover

- Fine dead fuel moisture = 5%
- Dry bulb temperature = 86 °F
- Probability of ignition =

#2 – Clear day, dense canopy

- Fine dead fuel moisture = 6%
- Dry bulb temperature = 75 °F
- Probability of ignition =

Remember: Probability of ignition relates only to the chance of initial ignition.

VI. FIREWHIRLS (VORTICES), THE CONDITIONS UNDER WHICH THEY ARE LIKELY TO DEVELOP, AND THEIR IMPLICATIONS TO WILDLAND FIRE BEHAVIOR

A. Definition

A firewhirl/vortex is defined as a spinning, moving column of ascending air rising from a vortex and carrying aloft smoke, debris and fire.

Firewhirls belong to the same family as tornadoes and dust devils. The vortex action becomes strongest at the center.

B. Types of Vortices

Vortices are divided into two groups named according to the orientation of the axes of rotation: horizontal and vertical vortices.

They are formed by some heat source and initiating swirl.

1. Horizontal vortices

Horizontal vortices are a phenomenon of extreme burning conditions.

There are two types of horizontal vortices:

- One type occurs on the surface along the flanks of wildfires and directly impacts the safety of line personnel.

- The second type occurs in the column and can affect air operation near the fire.

Extreme burning conditions are a denominator of all vortices.

Horizontal vortices and the transverse vortex tend to form more readily in low to moderate wind speeds over flat or gentle terrain.

2. Vertical vortices

Vertical vortices are referred to as dust devils or whirlwinds. When the whirling mass of air includes the fire's flames the vortex is called a firewhirl.

The vertical vortices are further subdivided into types based on the triggering mechanisms.

a. Thermally-driven vortices that are encountered on hot days and/or intense portions of the wildland fire.

b. Convection column vortices produced by unequal convective activity in various portions of the convection column.

c. Wake type vortices occurring on the lee sides of physical obstructions to wind movement (ridge tops, trees, convection columns).

C. When and Where to Expect Firewhirls

1. Firewhirls are the result of local events or processes.

   These involve the heating of lower atmospheric layers and generation of local vorticity or swirling of the local airflow.

   Occurrence of whirls is directly related to thermal instability; they occur more frequently when the air mass is unstable to a considerable height.

2. Assess the potential for firewhirls by watching for evidence of dust devils and light winds.

   The earliest evidence should occur on east slopes, followed by the south, and then the west.

   North slopes, because of lower insulation levels, will be more uncertain sites for firewhirl occurrence.

3. The following factors can contribute to firewhirl generation on any slope:

   - Large angle of incidence for solar radiation (sun nearly perpendicular to slope).

   - Minimum cloudiness, therefore, greater instability.

   - Low humidity, therefore, greater transparency.

   - Dry exposed soil or a burned over area and therefore a potentially strong heat source.

   - Light winds below a critical level; say 5 mph at the 30 foot level.

4. Light winds are also indicators of instability along with:

   - Smoke rising to great heights without spreading.

   - Clouds growing vertically, of cumulus type; towering cumulus suggest a greater extent of instability.

   - Rough, bumpy air felt in aircraft.

   As the day progresses into late afternoon, more of these factors come into play and the likelihood of firewhirls increases.

   However, a change from no clouds to two - or three-tenths cloud cover can significantly reduce whirl activity.

   Expect firewhirls in any burned area as upslope winds develop and the fire builds up, providing additional buoyancy.

   If prevailing winds blow across the ridges, they will enhance the occurrence of firewhirls.

5. The firewhirls can occur wherever wind eddies can be expected.

   Up canyon and down canyon winds can generate eddies:

   - Behind spur ridges
   - At sharp bends in the canyon
   - Where two or more canyons join

   Should a weather change occur and an air mass differing in temperature, windspeed, and direction move over your area, you can expect firewhirls where wind shear is set up.

   Hot spots can also trigger firewhirls; they tend to occur at points where slopes change or fuel quantity increases abruptly or in ravines or box canyons.

   Should the fire build an active, strong convection column, look for firewhirls downwind of the column as wake-type eddies or as vortices generated up in the convection column.

6. Firewhirls can occur due to a number of mechanisms.

   - They can be so small they don't affect fire control in a significant way.

   - The appearance of small whirls suggests bigger ones are possible.

7. Precautions should be taken to contain spot fires and to alert fire crews to avoid sighted firewhirls.

   - The duration of a firewhirl may be only a few minutes, but some have lasted over an hour.

   - They tend to move across or up slopes.

   - As surface winds reach 5 mph or more, the firewhirls tend to move with the wind.

D. Implications to Wildland Fire Behavior

1. The vertical vortex or firewhirl action is that of a concentrated localized wind.

    - Windspeeds greater than 100 mph are not uncommon in the center of the vortex.

    - The vortex aids in the spread of fire through heat and mass transfer as the vortex moves along the surface lofting firebrands into the ambient air flow.

    - Horizontal and transverse vortex development, movement, and dissipation are difficult to predict, as is the vortex's effect on fire behavior.

2. Some general indicators for the formation of horizontal vortices are:

    - Extreme burning conditions

    - Low to moderate wind speeds

    - Flat or gentle terrain

3. The critical concern about these phenomena is:

    - They occur on the flanks of rapidly growing or large fires.

    - They can occur over a large area or be just large enough to trap a single engine or crew.

    - Unless we are aware of this event, we can put firefighters at risk in flanking action against rapidly growing fires, exhibiting crowning, and other extreme fire behavior indicators.

VII. THE DIFFERENCE BETWEEN WIND-DRIVEN AND PLUME-DOMINATED FIRES

Extreme wildland fires can be classified as having one of two unique behavior patterns: wind-driven or plume-dominated.

The distinction is in which force is strongest.

- In a wind-driven event, the power of the wind is greater than the power of the fire.
- When the power of the fire is greater than the power of the wind, a plume-dominated pattern is exhibited.

A. Wind-Driven Fire

Most of the fires that escape initial attack and those that became the large fires in history have been wind-driven.

In wind-driven events, there are several indicators which enable us to determine or predict probable fire behavior.

- Since spread is a function of the windspeed and direction, we can see where the fire will go and into what types of fuel.
  - Wind shifts can pose serious threats to safety.
- The convection column is typically fractured (bent over by the wind).
  - This drives the convective heat into the fuels ahead increasing spread and intensity.
- Spotting is almost always downwind and is a major contributor to spread rates.
  - As the fire grows, spotting could become long range creating new fires miles ahead of the original fire.

- Regardless of topography, when fuel moistures are low, a crown fire is almost always sustained when driven by strong winds.

The wind provides the additional energy to transform wind-driven events involving length and width to plume-dominated events which bring in the third dimension—the atmosphere above and around the fire.

B. Plume-Dominated Fire

The plume-dominated fire's activity is a result of the convective activity of the plume (convection column) itself.

Consequently, fire spread rate and direction is very unpredictable. Spotting is normally short ranged but in all directions.

Two mechanisms for convective air flow are recognized.

1. Indrafts

The first mechanism is the flow of air into the low pressure created during convection column development.

The indrafts provide the flame front with more oxygen, increase convective heat transfer to preheat fuels and aid in spotting.

This is the classic cycle of reinforcement: the increase in wind increases fire intensity and, in turn, the greater intensity increases convective activity and the preheating of fuels.

2. Downbursts

The second mechanism is the downbursts beneath the convection column.

Downbursts are quite similar to thunderstorm winds.

As the convection column builds, the rising air cools and precipitation is formed.

The surrounding air is cooled through evaporation and rushes forcefully to the ground. Once the downburst hits the ground, the wind effects spread out in all directions from the column's base.

Indicators of this mechanism's development:

- The appearance of virga and/or rain
- The development of a strong convection column
- A calm as the indrafts turn to downbursts

Remember, these indicators have occurred prior to fatalities on several fires and should draw immediate attention!

A three-dimensional fire will usually begin as a wind-driven fire, transitioning to a plume-dominated fire when its convective activity overcomes the wind field.

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Unit 12 – Gauging Fire Behavior and Guiding Fireline Decisions

OBJECTIVES:

Firefighters using fireline observations and fireline practical techniques will be able to:

1. Describe how to apply fire behavior information to safety and suppression decisions.

2. Demonstrate how to calculate the size of safety zones.

3. Identify the importance of changes in fire behavior to firefighter safety.

4. Discuss what drives large changes and identify the "next big change."

5. Demonstrate a simple but systematic method for gauging change and estimating fire spread time.

6. Identify other fire behavior prediction tools.

I. FIRE BEHAVIOR AFFECTS SAFETY AND SUPPRESSION DECISIONS

A. Basic Fire Behavior Measures

1. Flame Length (FL) is a measure of how fast energy is being released at the flame front.

2. Rate-of-Spread (ROS) is a measure of how fast the fire front is moving.

B. Flame Length is a Useful Gauge for Limitations on Suppression Methods and Safe Zone Size.

1. FL is the distance from middle of flaming zone to average flame tip.

2. Apply FL to choice of tactics and to safe zone dimensions.

3. Fire suppression limitations

- 0 to 4 feet
- 4 to 8 feet
- 8-11 feet
- Over 11 feet

C. Fire Characteristics Charts

1. This chart combines heat-per-unit area with ROS to give the rate at which heat is being released at the flaming front.

   The more energy the fuel can yield, and/or the faster it is released, the higher is the fire intensity and its flame lengths.

2. Heat/Area is given in Btu per square foot of area. The heat produced by the fuel depends on the fuel loading and the fuel moisture.

3. ROS, in ch/hr, is a measure of how fast the fire is consuming the fuel and releasing heat.

4. The Fireline Intensity (FLI) is given as the Btu released in a foot-wide section of the flaming front per minute. Each FLI has a corresponding flame length.

5. Example: A fire consuming fuels with 500 Btu/ft^2 at a ROS of 100 ch/hr has a FLI of 1000 Btu/ft-min and FL of 11 feet.

6. A second chart covers heavier fuels.

D. Safety Zone Calculations

1. Definition of a Safety Zone

2. Definition of a Deployment Zone

3. Safety zone guidelines

   - Avoid locations downwind of the fire.
   - Avoid chimneys, saddles, narrow canyons.
   - Take advantage of heat barriers.
   - Burn out safety zones before fire approach.

4. Assumptions and configurations regarding safety zones

   - Calculations assume ‘worst case’ where the safety zone will be surrounded by fire and will receive the same heat flux from all sides.
   - Space is sufficient for a crew of three persons.

- Heat flux on a circular safety zone will be greater than if the zone extends along the flaming front.

- FL assumed to be flame height

- Distance separation is between firefighter and the flaming front.

5. Safety zone equations and calculations

   - Distance separation = 4 X flame height

   - Greater distance for more than three people and an engine

   - Example: Flame height = 20 feet distance separation (radius) = 4 X 20 = 80 ft zone width (diameter) = 2 X 80 = 160 ft

   - A table gives distance separation and safety zone area for a given flame height…assuming no wind or slope.

   - Extra people, convective heat from wind or slope will increase the needed distance separation.

E. Rate-of Spread is Critical to Firefighter Safety and Effectiveness.

1. Defining ROS and spread time.

   - ROS—rate of advance the flame front

     – Can be in absolute terms (example: ft/min)

     – Can be in relative terms (example: 2X faster)

     – Both measures can be useful

   - Spread time—time it will take the fire to move a given distance; depends on ROS.

2. ROS is a key safety and suppression factor.

   - If a fire can catch you it can hurt you.

   - ROS dictates timeliness of control actions.

3. Changes in ROS are of great importance.

   - Compare the ROS before with ROS after a change…how much faster or slower?

   - The ROS-ratio is the measure of how much change.

   - A visual example illustrates ROS-ratio.

   - ROS-ratio is a very useful measure. It can indicate the degree of coming danger, and can be used to predict future fire spread time.

   - Fire spread-times can be predicted. Spread times are the time it takes the fire to move a certain distance (but 'spread rates' are distance covered in a certain time). This slide depicts the complete application of the *FireLine Assessment MEthod* (FLAME).

     Spread times are a very practical measure to work with on the fireline. Observe the time it takes the fire to spread a certain distance (using natural yardsticks such as the slope-length).

     The fire will spread that same distance in less time if it speeds up, and more time if it slows down.

     The predicted 'spread time' for that distance is the observed spread time divided by the ROS-ratio if the fire is to move faster, or multiplied by the ROS-ratio if the fire slows down.

- What might a certain change in ROS mean? ROS changes of 60X and more have accompanied fatalities. Much larger changes in ROS are possible.

  – 60X, means spread taking place over "hours" can take place in "minutes."

  – 500X, represents the comparison between walking speed and Mach 2.

  – Change may not occur right away, and may take a while, *but always be aware, change is coming.*

4. First consider "current" fire behavior.

   - The current fire behavior demonstrates the effects of current fuels, terrain, and weather—provides a baseline—if nothing changes neither will the fire behavior, and prediction is easy.

   - Some factors, such as live fuel moisture or 10-hour FM do not change rapidly, and do not cause large, sudden changes—they are important contributors overall, but vary over longer time scales.

   - But things can and do change, often quickly, and so does the fire behavior.

5. Unforeseen changes kill firefighters.

   - Rapid, large increase in fire ROS is a common denominator in fatality fires.

   - ROS increases of 60X and more have been associated with fatality incidents.

   - To be safe requires firefighters to foresee changes well ahead (not to simply notice change as it occurs) and to have a sense of the size of the change—to understand both "current" and "expected" fire behavior.

6. Quotes from fatality fires reveal an over reliance on impressions of current fire behavior and a tendency to not foresee the coming dangerous fire behavior.

   - Spanish Ranch 1979, 4 fatalities
   - Dude 1990, 6 fatalities
   - South Canyon 1994, 14 fatalities
   - 30 Mile 2001, 4 fatalities
   - Cramer 2003, 2 fatalities
   - Tuolumne 2004, 1 fatality

II. FORESEEING CHANGES IN FIRE BEHAVIOR

A. Understand the Factors That Drive Large, Sudden Changes.

1. Anticipating the "next big change" is critical to firefighter safety.

   - Expecting to simply notice the changes in time to react is not good enough.

   - Look ahead at the factors that cause big changes.

2. Looking ahead to the changes supports LCES.

   - Lookouts: What to be looking for, and using the most appropriate lookout locations.

   - Communications: What key things to communicate and how often.

   - Escape routes: Where and how long.

   - Safety zones: Close enough and big enough.

B. Focusing on the Dominant Change-Makers

1. Many factors affect fire behavior, but just a few are the dominant drivers of sudden large changes.

   We focus on changes that can occur over minutes to an hour or so, even though such changes may not begin until hours later.

2. The largest single change-maker is effective wind speed (EWS), which can cause ROS changes of 200X or more.

3. The next largest change-maker is fuel type, producing up to 15X or greater changes in ROS.

4. Short-term fine-fuel moisture changes can produce up to about 1.6X changes in ROS, usually less; most importantly they affect the potential for crown fire and spotting. They help to fine-tune spread time predictions.

5. Consider some typical kinds of fire behavior events associated with large, sudden changes, examples of the "next big change," using simple sketches.

   Depicting current and expected situations guides a firefighter to make a complete fire behavior assessment.

   - Wind change

   - Fuel-type change

   - Slope reversals (wind, slope, and fuel change); some favorable, some dangerous

III. GAUGING THE CHANGES IN FIRE BEHAVIOR

A. How Each Factor Affects ROS

1. A scaled diagram can help develop a sense of change to expect as conditions change.

2. Specific guidelines will allow us to consider any change in fuel type, wind, or slope.

B. Scaled Diagrams Illustrate the Effects of Changes in Find Dead Fuel Moisture (FDFM).

C. Changes in Fuel-Type Produce Large Changes in Fire Behavior.

1. There are three broad fuel groupings, **based on group similarity in ROS**, each easily recognizable in the field.

   - Litter
   - Crown foliage (including both brush and trees)
   - Grass

2. Each fuel type has an ROS range that is distinct from the others.

   For given conditions of moisture, wind, and slope:

   - Litter is the “slowest” fuel.
   - Crown foliage about 4X faster than litter.
   - Grass about 3X or 4X faster than crown foliage.
   - Overall the ROS range between litter and grass fuel types averages about 15X.

3. Fuel type often changes over different aspects.

   Look ahead to where the fire is going and to what fuel types it will move into.

4. Transition from surface fuels (commonly litter) to crown fuels is a very important change in fuel type.

   This vertical spread can occur very rapidly; it requires fire spread of only feet.

5. Practical crown fire potential indicators (pay close attention to these and the indicators presented in the section on crown fire):

   - Seasonal drought period prevails
   - Overall drought makes matters worse
   - Recent crown fire (other, or same, fire)
   - Relative Humidity 35%-20%, or less (especially RH below 20% for the western U.S.)
   - Backing fire produces torching (a dead giveaway that headfire can crown)
   - Fire moving up ladder fuels
   - Torching and short crown runs

D. Changes in EWS Drive Huge Changes in Fire Behavior.

EWS includes the effect of slope, but for now think of EWS as the mid-flame wind speed (MFWS).

1. Wind variations are of critical importance, and we must understand and account for them for this all-important factor we must understand several things:

   - How wind varies from place to place.

   - How wind on the flames varies with fuel type.

   - How to account for slope.

2. Wind speed is the component of the wind that is actually pushing the flames into new fuel.

3. Changes in wind speed are expressed as the ratio of the larger wind to the smaller wind, the effective-wind-speed ratio (EWS-ratio)—it is an idea made simple enough with a few examples.

   The degree of change in effective wind (EWS-ratio) is a good measure of the change in ROS, over a range of actual wind speeds.

   For example, doubling the EWS from 3 to 6 has about the same effect on a fire's ROS as does doubling the EWS from 8 to 16.

   To find the EWS-ratio divide the larger wind speed by the smaller wind speed; a look-up table does the same job. EWS then goes into the ROS-ratio table.

   The calculation of EWS-ratio is done by table look-up. In this example, the bigger wind is 6 and the smaller wind is 2… a tripling of EWS.

   Of course, the arithmetic can be done without using the table.

4. A visual sense of the effects of a 2X change in wind speed on ROS and FL.

   The effect of doubling wind speed is very similar in all fuel types.

5. A visual sense of the effects of a 3X change in slope on ROS and FL.

   The effect of an increase in slope is very similar in all fuel types. The slopes illustrated here range from ‘rolling terrain’ to steep canyon sides.

6. Slope affects forward fire spread much the same way as wind does, by increasing the effectiveness of heat transfer to new fuels, essentially like some additional upslope wind.

   - A steeper slope is the equivalent of more wind.

   - For upslope spread, add the following wind speed to the actual upslope mid-flame wind speed.

     – slopes less than 20%, no addition

     – slopes 20% to 40% add 1 mph

     – slopes 40% to 60% add 2 mph

     – slopes 60% to 80% add 3 mph

     – slopes over 80% add 5

   - Combine slope equivalent with the MFWS to get the effective wind speed, EWS.

   - For wind blowing steadily down the slope subtract the effect of slope.

E. Compare the Magnitude of the Factors Considered on Producing Short-Term Changes in ROS.

While all factors influence fire behavior the largest drivers of large, sudden changes in fire ROS are fuel-type and EWS.

IV. INTRODUCTION TO FIRELINE ASSESSMENT METHOD (FLAME)

This FLAME introduction, the "Basics" covers change in fuel type and in effective wind speed, and ends with a look at FLAME application to a fatality case.

A. Overall FLAME Purpose

1. Assessing current and expected fire behavior; a systematic method.

2. Fire science in fireline-practical form.

3. Enhances situational awareness.

4. To serve a variety of students, and a range of needs that change over one's career.

5. FLAME predictions and observed ROS-ratios in fatality fires.

   Overall agreement is fairly good, even though many assumptions underlie both the FLAME and reconstructed ROS-ratios.

B. Assessing the Effects of the "Next Big Change" Can be Done With a Simple and Systematic Application of Fire Behavior Science.

- Applying fire behavior science in a simple, fireline-practical tool to predict change (a tool that has many of the same limitations as the fire models do).

- Practice with a method that conditions firefighters to making systematic and complete fire behavior assessments. A systematic approach is very important.

1. The method for predicting ROS changes will follow simple steps. The facts needed are the expected changes in the dominant change-makers: fuel type, effective wind speed, and sometimes RH.

2. Obtain the magnitude of change in ROS (from a look-up table) using the changes in fuel type and wind speed.

   Estimate changes in flame length from the fuel and from the change in ROS (recall the information from the Fire Environment unit).

   Assess and express change as the ROS-ratio. The ROS-ratio compares current to expected fire spread rates. For example, a change in ROS from 60 to 10 has ROS-ratio = 60/10 = 6X.

3. Obtain ROS-ratio from a lookup table. The table essentially combines the effects of fuel-type and wind on ROS; multiplied in the main table (divided in the cases in rightmost two columns).

C. The Assessment is Applied in Three Successive Stages.

1. Initial application: identifies the next big change that will occur; requiring the firefighter to depict current and expected fire behavior situations.

2. Standard application: Input RH, fuel-type, and wind (the key factors); assesses the magnitude of the change in the ROS, the ROS-ratio (a measure of potential danger).

3. Full application: Combines the expected change in ROS with observation of the ongoing fire spread to predict the future fire spread (a basis for escape planning and for tactics).

The FLAME worksheet follows those three application stages. The worksheet guides a systematic approach, and can provide valuable documentation for later review, training, or accident investigation.

V. LEARNING TO APPLY FLAME

Examples and practice are the best way to learn the process. In this section, the exercise examples address cases of potentially dangerous changes.

A. Assessing Changes in Fuel Type with FLAME

1. Illustration #1: Fire spreads up a slope and moves from grass into litter.

   - The effective wind speed is not changing.
   - Fire ROS will decrease about 14X in the litter.

2. Exercise #1: Fire spreads out of litter and into brush crown.

   - The effective wind speed is not changing.
   - The fire ROS will increase about 4X in the brush.

B. Wind Change Comparisons

Wind changes are due to "weather changes" over time and <u>also</u> to variations from place to place in the terrain.

1. Using the table, adjust a 12 mph wind on the upper windward slope to the lower windward slope.

   - Choose "1 → ½" based on the wind adjustment diagram and wind speed 12.

   - The wind on the lower slope will be about 6 mph.

2. Similar to wind adjustments factors based on topographic locations, wind adjustment factors for determining mid-flame wind speed are based on three main fuel types including litter, crowns, and grass.

   - When determining the mid-flame wind speed for litter, an adjustment factor of ¼ to the 20-foot wind speed should be used.

     For example, 20-foot wind speed of 20 mph would adjust to 5 mph for a litter fuel type.

   - For crowns, the measured 20-foot wind should be used for the mid-flame wind speed, with no adjustment downward or upward.

   - For grass fuel types, ¾ of the 20-foot should be used.

     For example, a measured 20 mph wind at the 20-foot level would adjust to 15 mph in a grass fuel type.

   An observed eye-level wind can be adjusted to fit litter or crown fuel types. The wind adjustment table can be used to simplify the calculations.

3. Using mid-flame wind adjustment, adjust an eye-level observation of 16 mph over open ground to fit the litter fuel type under a stand of trees.

   - Choose "¾ → ¼" based on the wind adjustment diagram and wind speed 16.

   - The wind in the litter fuel will be about 5 mph.

4. The weather changes over time are best anticipated from what you have learned about fire weather and from forecasts.

   - Many wind changes result from weather changes, and can be anticipated from your knowledge of fire weather processes or from weather forecasts.

   - Wind also varies from place to place in complex terrain, even if the overall weather is not changing.

   It is a challenge, but wind variation must be taken into account in assessing fire behavior—it can be a huge factor.

   The variations from place to place can be estimated with information presented below.

   - Speed of the wind driving the fire often changes <u>dramatically</u> from place to place, and can produce large changes in fire behavior. We need to account for those changes.

   - Wind speed is typically greater on upper slopes vs. lower slopes when it blows into or up the slope.

     The hills identified in the slide are topographic features hundreds of feet in relief, not major mountain ranges thousands of feet high.

- The estimates of wind-speed variation used in this slide are best applied in relatively deep, well mixed, non-stratified air flows such as occur on a typical sunny afternoon, where winds blow across the terrain obstacles.

  – Guideline: wind speed on lower slope is about ½ of what it is on the upper slope (upper and lower refer to roughly the top and bottom thirds).

  – The contrast in speed between upper and lower slopes tends to be greater the steeper the slope.

  – Midslope wind speeds will fall between those on the upper and lower slopes, about ¾ of ridgetop.

- Where wind blows across the hills, the speeds on the lee-slope (the sheltered side), are greatly affected; considering the effects of such sheltering is complicated, but worth the effort.

- Smoke drift can provide an indication that wind is blowing across the hills and not simply up the slopes.

- Forecasts of ridgetop/general winds of 10 mph or greater are also a good indication of winds blowing across the terrain features.

- Lee-slope wind speeds are usually less than those on the windward slope.

- Expect turbulence and variability on lee slopes; there are no universally applicable guidelines.

- Always use relevant on-site observations when possible; smoke drift and the Beaufort scale can be helpful.

- Direct observation of the fire can often reveal the effective wind. For example, if the fire is backing, the EWS is taken as ½ mph.

- For hills (of hundreds of feet of relief), slopes 30% or less, and without sharp ridges, wind speeds can be estimated from these quantitative guidelines.

- Note: The 30% slope limit applies only to winds on the lee side, not the windward side.

- Adjust the observed or predicted wind from one location to fit the conditions at the fire location.

- Each ridge and valley across which the wind is blowing will show similar patterns of wind speed variation.

- Winds of critical concern and downslope winds are best estimated from forecasted wind speeds, not from adjustments.

- Wind Wizard is a computer program that models wind flow over terrain. Here it illustrates wind flow over a ridge in green arrows, scaled to indicate wind speed.

  The yellow arrows are from the wind speed guidelines presented in the section (Pocket Wind Wizard). They can be seen to match the Wind Wizard simulation closely.

5. The wind driving the fire is the wind at roughly flame level—the mid-flame wind speed (MFWS); it is affected by flame height above the ground and by the sheltering effects of vegetation.

   Once you have the wind for the right location in the terrain, adjust it to flame level. The worksheet follows this sequence.

   - For crown fire in trees and tall brush use the 20-foot wind speed.

   - For fires in open fuels such as grass and short brush use eye-level wind speeds, or ¾ of the 20-foot wind speed.

   - For fires in litter or other short fuels under a stand use ⅓ of the eye-level wind or ¼ of the 20-foot wind speed.

     Here it is assumed that the eye-level wind speed was observed at a site open to the wind and not within a stand of trees or brush.

   - For example, a crown-level (20-foot) wind of 12 mph would be about 9 mph at eye-level, and about 3 mph at litter-level under a stand of trees.

   - Adjust the wind observed or predicted for the fire's location to the appropriate mid-flame level.

     This scale summarizes the adjustments. A table can do the arithmetic of the adjustment.

6. For fires that are backing or flanking the EWS is taken as a constant.

   Backing-fire spread is driven largely by radiation and conduction within the fuel bed, and is relatively insensitive to wind and slope.

- For backing fires into the wind or down the slope the EWS is taken as ½ mph.

  The value ½ mph for the backing-fire EWS is derived from BEHAVEPlus model data.

  Both grass and litter show EWS about ½ mph for backing fires.

- For flanking fires with wind mostly a neutral influence the EWS is taken as 1 mph.

- When you use "back" or "flank" in the EWS table the value of EWS (either ½ or 1) is built in and is used to find the EWS-ratio.

7. Illustration #2: Winds surface on a fire, as from <u>inversion-breaking or mountain waves</u>.

8. Exercise #2: <u>Winds above an inversion are mixed down</u> to the surface and cause a significant wind speed increase and change in wind direction.

C. The Slope contribution to Effective Wind Speed

Combining the effect of slope with mid-flame wind speed gives the EWS, a measure of the total influence of wind and slope on ROS.

1. Slope affects forward fire spread much the same way as wind does, by increasing the effectiveness of heat transfer to new fuels…essentially like some additional upslope wind.

   - A steeper slope is the equivalent of more wind.

- Add the following wind speed to the actual upslope mid-flame wind speed component.

  - slopes less than 20%, no addition

  - slopes 20% to 40% add 1 mph

  - slopes 40% to 60% add 2 mph

  - slopes 60% to 80% add 3 mph

  - slopes over 80% add 5

- For wind blowing steadily down the slope you can subtract the effect of slope.

- Shortcut: if the upslope wind speed (in mph) is at least ½ of the slope (in %), neglect the slope correction, because it is relatively small.

  For example a wind speed of 15 mph on a 30% slope would be an EWS of only 16 mph with the effect of slope added in, which is not an important difference.

2. Illustration #3: Fire spreads across flats and onto a slope, feeling both a change in wind and in slope.

   Crown fuels, so no calculation of effect of RH change. Bracket the EWS in the table (here 2½) and read the ROS-ratio in between (3X).

3. Exercise #3: Changes in both wind and slope, a slope reversal. This exercise takes place on the lower portion of the slope; lee vs. windward-slope winds.

D. Combined Changes in Fuel-Type and Wind

Applied on the FLAME Worksheet and the ROS-Ratio Table, the same as individual effects.

1. Illustration #4: Slope reversal: Fire backs down a slope in litter, crosses a drainage and is driven by wind up the next slope in brush.

   - Backing fire is in litter fuel type with an EWS = ½ mph

   - Upslope fire will feel the combined effects of wind at crown level, and the slope, as well as the change to the faster fuel type (litter to crown foliage), 140X.

2. Exercise #4: Litter fire on a lower slope transitions to crown fire on the upper slope.

   - The change from litter to crown fuels will result in an increase in ROS of about 4X.

   - The wind on the flames will increase by a factor of almost 5X.

   - The combined changes in fuel and wind will increase the ROS by 30X.

3. Exercise #5: Flanking fire in litter sheltered at base of slope moves out into grass on the wind-exposed slope

   - The change from litter to grass fuel will result in an increase in ROS of about 15X.

   - The wind on the flames will increase by a factor of 8X.

   - The combined changes in fuel and wind will increase the ROS by 180X.

4. On the fireline always continue to observe after you make your prediction; note how things compare to what you expect. When the expected fire behavior develops look ahead to the next big change.

5. You can make a rough estimate of the actual ROS (not the change in ROS) by applying these simple guidelines. They are derived from the FLAME curves for each fuel type.

VI. REAL-WORLD CASE STUDY - THE SOUTH CANYON FIRE

Use the description of the fire behavior setting and events do not judge the decisions of the firefighters.

Considering how FLAME might have been applied in this situation, and the kind of fire behavior information that can be developed.

Case Study Points:

- Long backing phase (current behavior) could have provided a firefighter a baseline of observed ROS.
- Completing a FLAME worksheet could have prompted seeking a current forecast and brought attention to:
  - Increased winds
  - The nature of the next big change
  - The need for better-placed lookouts
- Complete application of FLAME could provide a very realistic timetable for expected (upslope) fire spread.

A. South Canyon Fire (<u>cold front passage</u>)

Sheltering from topography and vegetation hid wind increases from crews working on the fireline.

- Observed current fire behavior
- Area overview
- FLAME application
- EWS-ratio (slope is not used here)
- ROS-ratio lookup
- Implementing LCES
- Anticipating the cold front
- Potential value of FLAME assess

B. Addressing Probable and Possible Changes

You can use the FLAME information in different ways, depending on whether you are addressing a fairly certain expected change, or just a possible change.

1. For changes likely to occur, plan for that change—in your safety, LCES, and tactics.

   Such cases can include inversion erosion and mixing, cold fronts, sea breeze, slope/canyon winds.

2. For possible changes, monitor carefully, and make a contingency plan should the change become more likely.

   Such cases include winds associated with thunderstorms, surfacing waves, gusts across the flank.

3. When would you apply FLAME?

- When first arriving at a fire.
- When going on shift.
- When a next big change occurs in the fire environment.

FLAME should not be applied in place of ongoing situational awareness but as a tool to enhance overall awareness. You have been introduced to the basic, but most important, elements of the FLAME process. To become more proficient, you can utilize the supplemental training available with the FLAME online self paced learning module at http://training.nwcg.gov/online.html

VII. OTHER AVAILABLE FIRE BEHAVIOR PROCESSORS

A. Appendix B of the Fireline Handbook Provides Forms and Tables for Estimating the Actual ROS.

1. The Fire Behavior worksheet can be used to record inputs and outputs.

2. The inputs indicate which table to utilize, and the outputs are read from the table.

3. An example:

- Fuel: grass, Model 1
- FDFM: 6%
- Slope: 45%
- Mid-flame wind speed: 4 mph
- Predicted ROS: 96 ch/r, FL 4.6 ft

B. Nomograms are Groups of Graphs that Provide the Same Type of Information as the Tables of Appendix B, but use Graphs for Inputs and Outputs.

1. Inputs are similar to those shown on the Appendix B worksheet.

2. Using the same inputs as the Appendix B example above, gives a basic output ROS of about 90 ch/hr.

3. The upper right hand graph then becomes a "Hauling Chart" and gives FL and FLI.

4. For fuels that have a live component, such as Model 5 brush, there is a choice of "S-curves" in the upper right graph. Otherwise the process is the same as before.

C. BEHAVEPlus is the Computer-Based Fire Behavior Prediction System.

1. Inputs are similar to those shown on the Appendix B Worksheet.

2. Outputs are similar to those shown on the Appendix B worksheet.

3. There are now 40 fuel models for the BEHAVEPlus in addition to the original 13 fuel models.

D. Canadian Forest Fire Behavior Prediction System (CFFBPS)

Used mainly in:

- Canada
- Alaska
- The Lake States (Michigan, Minnesota, etc.)
- Areas of the Pacific Northwest

E. Comparison of Processors

1. FLAME

- 2 inputs
  - Fuel-type and EWS
  - Observation of current fire spread
- 1 main table, 3 diagrams (for wind speed and slope)
- Outputs
  - Change in ROS
  - Predicts fire spread time
- Builds on the ongoing fire behavior

2. Appendix B

- Uses 6 inputs
- 114 pages of tables
- Up to 9 outputs, including ROS and FL

3. Nomograms

- Uses 6 inputs
- 26 nomograms (over 100 graphs) and several input tables
- Outputs ROS, H/A, and FL

4. BEHAVEPlus

- Uses 6 inputs
- Computer based
- Many outputs, including ROS and FL

Appendix B, Nomograms, and BEHAVEPlus predictions do not account for current fire behavior, but use expected conditions only.

VIII. CLOSING THOUGHTS

Learning to use fire behavior processors takes time and effort. The safety of firefighters and fire suppression success depends on making good assessments of fire behavior and foreseeing the next big change in time to plan for it.

Fire behavior is not simple; you will get "fooled" sometimes. Evaluate your predictions; it will enhance the value of your fire behavior experience and above all try to understand what is happening in the fire environment.

With practice and fire experience using processors and recognizing indicators associated with situational awareness will get quicker and easier.