Air Force Weather
Qualification Training Package
Forecasting Weather
Elements
Trainee Workbook

Providing Standardized Training
to
“Exploit Weather for Battle”

Approved for Public Release;
Distribution Unlimited

AIR FORCE WEATHER AGENCY
TRAINING DIVISION
106 Peacekeeper Dr., Ste 2N3
Offutt Air Force Base NE 68113-4039
# Air Force Weather Qualification Training Package

## Foreword

Trainer's Guide, Evaluation Package

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### Subjects:
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- Sky Conditions
- Visibility
- Precipitation
- Obstruction to Vision
- Temperatures
- Pressure
- Turbulence
- Low-Level Wind Shear
- Icing

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TRAINEE WORKBOOK INSTRUCTIONS

• This QTP (Qualification Training Package) Trainee Workbook standardizes on-the-job training (OJT) for Air Force Weather (AFW) personnel. It breaks down subject matter by modules into teachable elements called task objectives. A Table of Contents is provided for quick reference to find needed modules.

• Workbook material includes a module overview and a list of task objectives required for minimum certification in this subject area. Each workbook module lists equipment and training references, prerequisites and safety considerations, estimated module training time, core training material and review questions, and a module review confirmation key.

• To facilitate learning and understanding, each QTP has three components: Trainee Workbook (TW), Trainer’s Guide (TG), and Evaluation Package (EP). The TW (this workbook) contains all subject matter material and references. The TG explains how each module and task objective is taught. Finally, the EP contains all task certifier written exams, performance applications, and confirmation keys to evaluate comprehension.

• Ensure your trainer thoroughly explains all three QTP documents and how to complete this training package.

• As you progress through each module, answer the review questions pertaining to that section. You will find the answers to these section review questions at the end of each module. Compare your response to the correct answer.

• After completing a module, your trainer will have a task certifier administer the appropriate portion of the EP. This task certifier will grade all responses. Should you score unsatisfactorily, restudy the module material. Your trainer will provide additional OJT in weak areas, after which you will retake the evaluation.

• After you successfully complete the Evaluation Package for each module, inform your trainer. He will get a task certifier who will perform a final certification checkride on the module.

• You are ultimately responsible for completing this QTP in the allotted time. If you cannot do so, let your trainer know ahead of time. If you think your trainer isn’t competent enough to teach the task objectives or is being unprofessional, then discuss this situation with your supervisor and/or unit training manager. A different trainer may be assigned.

• Routine corrections and minor updates to this document will be done via page changes. Urgent changes will be disseminated via message. Submit recommended TW improvements and/or corrections to HQ AFWA/DNT, 106 Peacekeeper Dr., Ste 2N3, Offutt AFB, NE 68113-4039.
MODULE 1 - SURFACE WINDS

TRAINEE’S NAME________________________________________

CFETP REFERENCE: 14.3.

MODULE OVERVIEW:
This module covers basic wind principles and procedures, rules, techniques, and rules-of-thumb needed to aid you in surface wind forecasting.

TRAINING OBJECTIVES:
- **OBJECTIVE 1**: Demonstrate that you understand the concepts, the general rules, techniques, rules of thumb, and principles and procedures concerning forecasting surface winds by answering questions with at least 80% accuracy.
- **OBJECTIVE 2**: Using practical weather data and scenarios, be able to demonstrate your ability to forecast surface winds by computing the correct solutions and providing answers to questions with at least 80% accuracy.

EQUIPMENT AND TRAINING REFERENCES:
- AFWA/TN-98/002, Meteorological Techniques
- AFMAN 15-124, Meteorological Codes
- AFMAN 15-111, Surface Weather Observations
- AFH 11-203, Volume 1, Weather for Aircrews
- METOC 50-1P-0002, Volume 5, Introduction to Forecasting: Forecast Charts and Forecasting Weather Elements
- Meteorology Today: An Introduction to Weather, Climate and the Environment
- SC 01W01A, Volume 3, Weather Element Forecasting, Flight Hazards, and Limited Data
- AWS/TR-79/006 (Revised), The Use of the Skew-T, Log P Diagram in Analysis and Forecasting
- Aerographer’s Mate 1 & C

PREREQUISITES AND SAFETY CONSIDERATIONS:
- Familiarity with the TAF code found in Chapter 1, AFMAN 15-124, Meteorological Codes
- Familiarity with the sections on winds found in AFMAN 15-111, Surface Weather Observations
• Be familiar with interpreting weather features using MetSat imagery
• Have a firm grasp on the analysis and prognosis rules and techniques discussed in the Analysis and Prognosis QTP

ESTIMATED MODULE TRAINING TIME: 2.5 Hours
CORE TRAINING MATERIAL AND REVIEW QUESTIONS

1.1. General Information

Temperature differences cause pressure differences, which in turn cause air movements. The winds resulting from these differences vary considerably from one geographical location to another. The following sections provide a brief refresher of the forces behind air movement (wind), wind types, and local wind patterns.

1.2. Forces That Affect Winds

There are four basic forces that affect the directional movement of air: pressure gradient force (PGF), Coriolis force, centrifugal/centripetal force, and frictional force. These forces, working together, affect the direction air moves.

1.2.1. Pressure Gradient Force

The variation of heating (and consequently the variations of pressure) from one locality to another is the initial factor that produces movement of air or wind. The most direct path from high to low pressure is the path along which the pressure is changing most rapidly. The rate of change is called the pressure gradient. PGF is the force that moves air from an area of high pressure to an area of low pressure as depicted in Figure 1-1. The velocity of the wind depends upon the pressure gradient. If the gradient is strong (weak), the wind speed is high (low).

![Figure 1-1. Pressure Gradient Force](image)

1.2.2. Coriolis Force

The Coriolis force is the “apparent” force that makes any mass, moving free of the Earth’s surface, appear to be deflected from its intended path. The Coriolis force deflects winds to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, due to the earth’s rotation. Coriolis only affect winds direction and has no effect on wind speed. The strength of the Coriolis effect varies with latitude.

- At the equator the effect is zero.
- Maximum bending occurs at the poles.
1.2.3. Centrifugal and Centripetal Forces

Centrifugal force throws an air parcel outward from the center of rotation (Figure 1-3). Its strength is directionally proportional to the speed and radius of rotation. Centripetal force, equal in magnitude and opposite in direction to the centrifugal force, attempts to keep the air parcel moving around a curved path (such as around curved height contours on a constant-pressure surface).

1.2.4. Frictional Force

An increase in friction causes a decrease in wind speed and subsequently a reduction in the Coriolis force (Figure 1-4). Consequently, the weaker Coriolis force no longer balances the PGF, and the wind blows across the isobars toward lower pressure. It may cause the wind to blow up to 50° across isobars over rugged terrain and 10° across isobars over water. The effect of frictional force reaches to about 1,500 feet above ground level (AGL) over smooth terrain and as much as 6,000 feet AGL over mountainous terrain.
1. The effect of Coriolis is greatest at the _______ (poles / equator).

2. With an increase in friction, the wind velocity _______ (increases / decreases).

1.3. Geostrophic Versus Gradient Winds

One of the things you need to understand is the differences between geostrophic and gradient winds, although they are often used interchangeably. Keep in mind that the biggest difference between the two is that the geostrophic wind is a theoretical whereas the gradient wind is an actual frictionless wind.

1.3.1. Geostrophic Wind

When the flow is purely geostrophic, it is assumed that there is no friction, the isobars are straight and evenly spaced, and the wind speed is constant. In the real atmosphere, isobars are rarely straight or evenly spaced, and the wind normally changes speed as it flows along. So, the geostrophic wind is usually only an approximation of the “real” wind. However, the approximation is generally close enough to help more clearly understand the behavior of the winds aloft.

1.3.2. Gradient Wind

Gradient winds are slightly more complex than geostrophic winds because they include the action of centripetal force (Figure 1-3). Centripetal force is always directed toward the center of rotation. Figure 1-5 shows the forces that produce gradient winds around high and low pressure centers.
Around a low, the gradient wind consists of the pressure gradient force (PGF) and centripetal force (CE) acting toward the center of rotation, while Coriolis force (CF) acts away from the center of the low. In a high pressure center, the Coriolis and centripetal forces are directed toward the center of the high, while the pressure gradient force is directed outward. This wind results from a balance between the pressure gradient force and the sum of the Coriolis and centripetal forces. It blows parallel to curved isobar. In the middle latitudes and tropics, this wind is a better approximation of the actual wind speed than the geostrophic wind speed.

- Typically, the gradient level wind is around 2,500 to 3,000 feet AGL.
- 925 mb is the level chart most used to estimate the gradient level except in mountainous or high terrain.

### 1.4. Local Winds

In the atmospheric circulation system, small-scale wind systems occur with the general circulation pattern. They are a result of the Earth’s rough surface and temperature differences between land and water. These small-scale circulations are frequently called local winds and have names that link them to the place where they occur.

The absence of a strong pressure gradient is typically necessary for the development of most of these often thermally-induced winds. Besides the pressure gradient, surface temperatures determine whether the temperature gradient is sufficient to induce such circulations as the land/sea breeze, or in the mountain or valley breezes case, whether the insolation or radiation is sufficient to develop the breeze. With forced circulations like the fall (glacier) and foehn (chinook) winds, the proper orientation and spacing of the isobars (which is a direct result of pressure gradient) is necessary to develop the winds.

#### 1.4.1. Sea (Lake) Breeze

A sea breeze occurs during the day when the air over the land becomes warm and rises, creating lower pressure. Since the air over the water is not warmed as rapidly or as much, the pressure is higher than over the land. When the pressure gradient is weak, the air flows from the higher pressure to the lower pressure or from sea to land. The sea breeze can last up to 2-3 hours after sunset (achieving maximum intensity at maximum
heating). There are lakes around the world that are large enough to create this process (depicted in Figure 1-6). Hence, these winds are called lake breezes.

![Figure 1-6. Sea Breeze Model](image)

**1.4.2. Land Breeze**

The land breeze occurs during the night if the land, because of radiation, becomes cooler than the sea. The cooler air over the land produces higher pressure than over the sea. This pressure, combined with the rising air currents over the sea from warmer air, moves the air from the land to the sea (from high pressure to low pressure). The land breeze is normally weaker (<10 knots) than the sea breeze. This process is depicted in Figure 1-7.

![Figure 1-7. Land Breeze Model](image)
1.4.3. Drainage Wind

A drainage wind occurs at night with strong cooling and a very weak pressure gradient. Due to variations in surface conditions, radiation cools the air in contact with the surface more rapidly at some locations than others. Since cooler air is heavier than warmer air, it sinks to lower elevations in sloping terrain. This requires only a very shallow slope and has been known to occur with slopes less than 200 feet. The wind created as the air moves downslope depends on the steepness of the slope and the amount of cooling. In the normal situation for strictly a drainage wind, the velocities rarely exceed 2 to 3 knots.

1.4.4. Mountain Breeze

The mountain breeze, a nighttime feature, is simply a stronger case of the drainage wind in mountainous areas. Nighttime radiation cools the air on the side of the mountain faster than the air in the valley. As the cooler air becomes denser it sinks toward the lower elevations and collects in the valleys as depicted in Figure 1-8. Typically, a mountain breeze may reach speeds of 11 to 13 knots, and the cooler air may extend several hundreds of feet in depth. In extreme cases, mountain breezes can reach speeds of 50 knots.

![Figure 1-8. Mountain Breeze](image)

Necessary factors for mountain breeze (katabatic flow - blowing down an incline) developments are:

- Terrain must be greater than 1,000 feet MSL.
- Skies must either be clear, or cloudy and rainy with nearly saturated air.
- Gradient wind must be less than 11 knots. Gradient winds greater than 11 knots overwhelm katabatic flow regardless of wind direction.

Areas where katabatic flow is enhanced are:

- Leeward slope because of the absence of the gradient wind. Windward slopes have weak to nonexistent katabatic flow.
- Poleward-facing slope because of lesser insolation during the day.
- Slopes with extensive cloudiness and precipitation because precipitation evaporation makes the air layer next to the slope neutral to negatively buoyant.
Indications that a mountain breeze has developed are:

- Mountain station reports wind direction to be downhill. Valley stations report wind direction to be down-valley.
- Fog and low stratus forms over valley, indicating presence of inversion.

1.4.5. Valley Breeze

The valley breeze is the opposite of the mountain breeze. It occurs during the day when the mountain heats faster than the valley. The air over the mountainside rises and is replaced by the air from the valley. This creates a wind up the side of the mountain as depicted in Figure 1-9 that usually averages about 13 knots. The best conditions for development of these winds are clear skies and weak pressure gradient. With these conditions, there is nothing to restrict the amount of heating.

![Figure 1-9. Valley Breeze](image)

Necessary factors for valley breeze (anabatic flow - blowing up an incline) developments are:

- Terrain must be greater than 1,000 feet above sea level.
- Weather must be clear to partly cloudy (less than 4/8 cloud cover).
- Gradient wind must be less than 11 knots. Gradient winds greater than 11 knots overwhelm anabatic flow regardless of wind direction.

Mountain regions where anabatic flow is enhanced are:

- Windward slopes because gradient wind is forced up the terrain.
- Equatorward-facing slopes because of greater insolation.

Indications that a valley breeze (anabatic flow) has developed are:

- Mountain slope station reports wind direction to be up valley.
- Cumulus clouds form over mountain tops and along ridges.
1.4.6. Foehn Wind

A foehn wind is a warm wind that flows down the leeside of mountains, raising the temperature as much as 50°F in just a few minutes at the base of the mountain. The name "foehn" originated in the Alps, and there are several names for this type of phenomenon in other parts of the world. To name a few, there are the chinook winds ("snow eater") in the Rockies and the Santa Ana winds in Southern California. The formation of this wind depends on warm, moist air rising on the windward side of the mountain. As the air rises, it expands and cools, and condensation (clouds and precipitation) occurs. When the air continues over the mountain top and descends on the leeward slopes, the downslope motion causes compression of the air and resultant adiabatic heating. Because of the compression and heating, the wind accelerates, thus increasing the heating even more. The result is a very strong and very warm wind at the base of the mountain. Figure 1-10 depicts this process.

![Figure 1-10. Foehn (Chinook) Wind](image)

1.4.7. Fall Wind

Typically the fall (or glacier) wind, a cold wind, originates in snow-covered mountains under high pressure. The air on the snow-covered mountains is cooled enough so that it remains colder than the valley air despite adiabatic warming upon descent. Near the edges of the mountains, the horizontal pressure gradient force, along with gravity, causes the cold air to flow across the isobars through gaps and saddles down to lower elevations. This colder, denser air descends rapidly to the valley below. If the wind is channeled through a restricted valley, it speeds up and has been known to reach 100 mph for days at a time. The temperature in the valley may drop more than 20°F when the breeze sets in. This process is depicted in Figure 1-11. Examples of fall winds are the mistral in the northwest Mediterranean (from France), the bora in the Adriatic Sea (from the Balkans), and the Columbia Gorge winds (Columbia River area in northwest CONUS).
3. (TRUE/FALSE) The absence of a strong pressure gradient is typically necessary for the development of most local, thermally-induced winds.

4. Using the figure below, sketch the expected surface wind flow pattern at 1500L (assuming no strong pressure exists).

5. In the figure below, what type of breeze exists at 0700L?
   a. Sea breeze   c. Land breeze
   b. Valley breeze d. Mountain breeze

6. The foehn wind is primarily a (warm / cold) wind while the fall wind is a (warm / cold) wind.
1.5. Wind Forecasting Techniques

Accurate wind forecasting is vital to air operations, ground combat operations, and base resource protection. Techniques and rules-of-thumb have been developed to aid you forecasting surface winds in order to accurately predict the onset, duration, and demise of this critical weather element. The following information covers non-convective surface wind forecasting specifically. Convective winds will be fully covered in the Convective Weather QTP. Let's begin with the definition of two techniques used for many years: persistence and extrapolation.

- **Persistence** - Persistence, by definition, means a "continued existence or occurrence." The persistence method of forecasting any weather element assumes that the conditions at the time of the forecast will not change. At most locations, when the synoptic pattern remains relatively unchanged; weather events follow daily cycles.

- **Extrapolation** - Extrapolation commonly refers to the forecasting of weather patterns or features based solely on past motions of those features (see Figure 1-12). An awareness of weather-producing systems in the local area, rates of movement, and changes in structure is required. Note: Persistence and extrapolation are not confined to wind forecasting, but rather, can be applied to most any weather element.

1.5.1. Frontal Winds

Frontal winds are usually forecast by extrapolation of the wind from an upstream station that has the same relative position with respect to the front that you anticipate your station to have at forecast time. This wind, assuming persistence of frontal characteristics, is a close approximation of your station’s wind in the future. Using Figure 1-12, as the front approaches point B you would expect the southwesterly winds at 25 knots occurring at point A to continue east and produce similar winds at point B.

Since changes in frontal characteristics affect the wind speeds, an account of them must be considered. Deepening or filling of the frontal trough can increase or decrease the winds, and changes in moisture content increase or decrease the cloud cover. Temperature contrast changes resulting from this or other causes alter wind speeds. Normally, there is less purely diurnal effect along a front than exists deeper within an air mass because diurnal temperature changes along the front are less pronounced. These things must be considered subjectively, but experience and local studies soon help to weigh these factors effectively in wind forecasting.
1.5.2. Diurnal Temperature Data

Surface winds may change as a result of diurnal temperature changes and temperature changes associated with the formation or destruction of low-level temperature inversions. Generally when the pressure gradient is weak, the maximum wind speeds occur during maximum heating, and the minimum wind speeds occur during maximum cooling. However, short periods of maximum gusts may also occur just as the inversion breaks, which may occur before maximum heating. The inversion, once set in the evening, does not allow higher wind speeds aloft to mix down to the surface. Winds usually stay light throughout the night and early morning until the surface inversion breaks.

Knowledge of a low-level inversion "break" time allows you to forecast development of surface winds during the day. If surface heating is not sufficient to break the inversion, forecast unchanged wind speeds. To determine inversion break time use a representative sounding:

- **Step 1:** Find the top of the radiation inversion as shown in Figure 1-13.
• **Step 2:** From the inversion top follow a representative isotherm down to the surface as shown in Figure 1-14.

![Figure 1-14. Step 2](image)

- **Step 3:** At the surface, determine the temperature that isotherm crosses as shown in Figure 1-15. This temperature represents the surface temperature corresponding to the inversion decay.

![Figure 1-15. Step 3](image)

When the inversion breaks, the following rules-of-thumb may be used:

- If winds gradually increase above the inversion (and the inversion is below 5,000 feet), expect maximum gusts during maximum heating to be 80% of the 5,000-foot wind speed.
- If winds do not gradually increase above the inversion, forecast 40% to 70% of the 5,000-foot wind speed to mix down to the surface.

### 1.5.3. Pressure Gradient Method

The pressure gradient can provide a reliable estimate of the actual wind in mid-latitudes. Use following steps (Figure 1-16 is an example) to convert an existing surface pressure gradient (millibars) into a representative gradient wind (knots).
• **Step 1:** Create a 6°-radius circle with the forecast location at the center.

• **Step 2:** Note pressure value at forecast location.

• **Step 3:** Note pressure value at edge of circle in direction system is coming from at right angles to isobars.

• **Step 4:** Find the difference in pressure (millibars) between the forecast location and the reference point.

• **Step 5:** Use the numerical difference (millibars) found to represent the wind speed in knots (e.g. using Figure 1-14, a 10 millibar difference = 10 knots).

• **Step 6:** The gradient wind will be approximately equal to the value derived in Step 5.

Now, to figure a representative gradient wind.

• Use 50% of the gradient wind as a forecast of the mean surface wind speed.

• Use 80%-100% of the gradient wind for daytime peak gusts.

• Wind direction follows isobars (adjust for friction, back about 15°).

![Figure 1-16. Pressure Gradient Method](image)

Note: The pressure gradient wind speed is inversely proportional to changes in latitude or air density (e.g., increasing latitude/air density = decreasing wind speed).

### 1.5.4. Geostrophic Wind Method

Using the geostrophic wind method described below can provide a good estimate of short-term surface winds. For best results, use this method in a 90-minute to 2-hour window from the valid time. Geostrophic winds are sensitive to changes in the pressure fields and do not work well in areas of strongly curved isobars. Use following steps to convert the geostrophic wind to estimated surface wind speeds.
• **Step 1:** Obtain a value of the geostrophic wind at the forecast location (see Figure 1-17.)

• **Step 2:** Convert the geostrophic wind speed to mean surface wind speed. Mean wind speed will be about 2/3 of the geostrophic wind speed during daytime period of maximum mixing (heating). The surface wind may not be representative if the geostrophic wind is less than 15 knots.

• **Step 3:** Adjust the geostrophic wind direction. In the Northern Hemisphere, by subtracting 10° over ocean areas and up to minus 50° over rugged terrain (this should be determined locally).

• **Step 4:** Now, consider the following:
  - Do not use geostrophic winds with nearby convection.
  - Use to forecast surface wind speeds after a frontal passage, but not to forecast wind shifts with frontal passage.
  - Surface winds may differ considerably from the geostrophic wind under a shallow inversion.
  - Geostrophic winds may overestimate the actual wind when a low-pressure center is within 200 miles of the area being evaluated.

Using Figure 1-17 for Ellsworth AFB, SD, the geostrophic wind speed is 20 knots from 290°. Using the steps, you estimate surface winds at 13 knots and more from the west-southwest, 240°-260° taking moderately rugged terrain into consideration (KRCA is just east of the Black Hills).

![Figure 1-17. National Weather Service Geostrophic Wind Chart](image-url)
1.6. Wind Forecasting Aids

Today, our technological advances have given us more tools and aids to use to forecast surface winds.

1.6.1. Forecast Model Guidance Example

Recall from the Forecast Models QTP that model output, both numerical and graphical (Figure 1-18 - MM5 Surface Wind Forecast on the top and MM5 Meteogram on the bottom) are objective tools used to forecast wind speed and direction. MM5 surface winds take elevations into account (note the uniform easterlies over water and low-lying land, but the variations from terrain over mountainous areas. As with all models, the information provided is only as good as the model itself--initialization and verification of the model is required to effectively use its output.

![Figure 1-18. Example MM5 Outputs - Surface Wind Forecast](image)

Figure 1-18. Example MM5 Outputs - Surface Wind Forecast
1.6.2. Using Satellite Imagery

Low-level cloud patterns from satellite imagery are valuable in forecasting surface winds, especially in data-sparse oceanic areas. Remember, identifying features such as cloud lines, cloud streets, shear lines, arcs, etc., can provide you with wind directions and/or speeds. Keep in mind that winds at cloud level may not be the same as the surface wind.

1.6.3. Using Weather Radar

Velocity products and the VAD Wind Profile (VWP) can be used to aid in surface wind forecasting. Gusty winds when an inversion breaks and wind shifts are just two features that can be determined using weather radar.

1.7. Forecasting Winds Rules of Thumb

As with most weather elements, military and civilian weather researchers and regular forecasters like you have developed rules of thumb (ROTs) over the years. The location you are forecasting for may require minor deviations due to local topography.

1.7.1. Empirical Rules

Here are a few empirical rules have been developed over the years to aid in surface wind forecasting. Of course, local terrain may have a direct impact on any of these rules.

- In southwest wind situations, average wind gusts will approximate 70% of the maximum wind observed in low-level wind data.
- In southwest wind situations, peak wind gusts can equal the highest wind speed reported in the low-level wind field. This usually occurs around maximum heating.
- In west-northwest wind situations, with moderate to strong cold air advection, peak speeds can exceed the highest value observed in the low-level wind field.
- Wind direction generally follows isobars over smooth terrain but may cross isobars by up to 50% over rough terrain due to friction.
- Winds blow night and day with little change under a strong gradient.
- Strong winds occur in areas of strong temperature gradients, behind a strong cold front for example.
- Often if the 1000 mb-500 mb thickness lines are parallel to the surface isobars. When the surface isobars are tightly packed, the surface winds will be enhanced.
1.7.2. Locally-Developed ROTs

Your unit(s) should have locally-developed techniques and rules-of-thumb for your forecast locations. These techniques and rules should be very specific and may be derived from larger scale techniques/rules tailored to your forecast location. For example, the following wind guidance was developed for a weather station in the northwestern United States.

- If the subsidence inversion is below 3,000, take the parcel up dry adiabatically until it crosses the temperature curve. Forecast the surface wind speed based on 80% of wind at that altitude.

- If the subsidence inversion will be broken and skies will be clear to partly cloudy, forecast the wind speed to be 50% of the 3,000 feet FDUS wind with gusts to 80% of the mean 3,000-foot/6,000-foot wind divided by 2.
  - Example: 3,000-foot wind is 20 knots and 6,000-foot wind is 30 knots. 50% of 20 = 10 knots. 20 + 30 = 50. 50 ÷ 2 = 25 knots; 80% of 25 knots = 20 knots. Your wind forecast would then be 10 knots gust 20 knots.

- If the subsidence inversion will be broken and skies will remain mostly cloudy or overcast, forecast wind speed at 50% of the 3,000-foot wind (no gusts).

1.7.3. Elevation Effects on Wind Speeds

A decrease of pressure and density of the air, and a decrease of friction with elevation causes wind speeds, on average, to increase about 1 to 2 knots for every 2,000 feet above sea level. Table 1-1 shows the increase in wind speed with elevation at specific temperatures.

- After making wind forecasts using other methods, adjust wind speeds for elevation using Table 1-1.

<table>
<thead>
<tr>
<th>Elevation (ft)</th>
<th>Temperature°C (°F)</th>
<th>Surface Wind 35 (kt)</th>
<th>Surface Wind 50 (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Speed at Altitude</td>
<td>Speed at Altitude</td>
</tr>
<tr>
<td>2000</td>
<td>7 (44)</td>
<td>36</td>
<td>52</td>
</tr>
<tr>
<td>4000</td>
<td>4 (38)</td>
<td>37</td>
<td>54</td>
</tr>
<tr>
<td>6000</td>
<td>0 (32)</td>
<td>39</td>
<td>56</td>
</tr>
<tr>
<td>8000</td>
<td>-3 (26)</td>
<td>40</td>
<td>58</td>
</tr>
<tr>
<td>10000</td>
<td>-7 (20)</td>
<td>41</td>
<td>59</td>
</tr>
<tr>
<td>12000</td>
<td>-10 (14)</td>
<td>42</td>
<td>61</td>
</tr>
<tr>
<td>14000</td>
<td>-13 (8)</td>
<td>43</td>
<td>64</td>
</tr>
</tbody>
</table>

Table 1-1. Elevation Effects
7. Using the pressure gradient method, you determined that you had a 20 mb difference between your location and a point upstream, what should be your representative mean surface wind and your expected peak gusts?
   a. 16 KTS with gusts 20 KTS
   b. 10 KTS with gusts 16-20 KTS
   c. 16 KTS with no gusts
   d. 10 KTS with no gusts

8. You looked at the MM5 3,000-foot and 6,000-foot winds progs for 24 hours from now. The 3,000-foot wind is 180° at 30 knots, and the 6,000-foot wind is 230° at 45 knots. What would be your best estimate of your 24-hour surface winds?
   a. 15 KTS with gusts 30 KTS
   b. 15 KTS with gusts 36 KTS
   c. 23 KTS with gusts 30 KTS
   d. 30 KTS with gusts 36 KTS

9. What must be accomplished prior to effectively using model output as an aid in wind forecasting?

10. _________ (TRUE/FALSE) Since you have a decrease of pressure, density of the air, and a decrease of friction with elevation, you need to decrease about 1 to 2 knots for every 2,000 feet above sea level.

11. _________ (TRUE/FALSE) In west-northwest wind situations, with moderate to strong cold air advection, peak speeds can exceed the highest value observed in the low-level wind field.

At this point, your trainer and/or certifier should answer any questions you, the trainee, have or to clarify any points you are still unclear on. Your trainer and/or certifier should also review local/regional rules-of-thumb and techniques developed in your AOR(s) with you.
MODULE 2 – SKY CONDITIONS

TRAINEE’S NAME__________________________________________

CFETP REFERENCE: 14.3.

MODULE OVERVIEW:
This module covers basic cloud formation principles and rules-of-thumb/techniques
derived to aid in cloud forecasting.

TRAINING OBJECTIVES:

• OBJECTIVE 1: Demonstrate that you understand general rules, techniques, rules of
  thumb, and principles and procedures concerning sky condition forecasting by
  providing correct answers to questions with at least 80% accuracy.

• OBJECTIVE 2: Using practical weather data and scenarios, be able to
demonstrate your ability to forecast sky conditions by computing the correct
solutions and providing answers to questions with at least 80% accuracy.

EQUIPMENT AND TRAINING REFERENCES:

• AFWA/TN-98/002, Meteorological Techniques

• AFMAN 15-124, Meteorological Codes

• AFMAN 15-111, Surface Weather Observations

• AFH 11-203, Volume 1, Weather for Aircrews

• METOC 50-1P-0002, Volume 5, Introduction to Forecasting: Forecast Charts
  and Forecasting Weather Elements

• Meteorology Today: An Introduction to Weather, Climate and the Environment

• SC 01W01A, Volume 3, Weather Element Forecasting, Flight Hazards, and
  Limited Data

• AWS/TR-79/006 (Revised), The Use of the Skew-T, Log P Diagram in Analysis
  and Forecasting

• Aerographer’s Mate 1 & C

PREREQUISITES AND SAFETY CONSIDERATIONS:

• Familiarity with the TAF code found in Chapter 1, AFMAN 15-124,
  Meteorological Codes
• Familiarity with the sections on sky conditions found in AFMAN 15-111, Surface Weather Observations
• Be familiar with interpreting weather features off MetSat imagery
• Have a firm grasp on the analysis and prognosis rules and techniques discussed in the Analysis and Prognosis QTP

ESTIMATED MODULE TRAINING TIME: 2.5 Hours
2.1. General Information
Forecasting cloud elements will undoubtedly take up a substantial portion of your forecast routine. Time must be spent determining cloud characteristics such as height, type, and amount, as well as formation and dissipation times. An understanding of the physical processes involved in cloud formation is required to correctly forecast cloud events.

2.2. Cloud Formation Ingredients
Three ingredients are required before clouds can form: condensation nuclei, moisture, and a cooling process.

2.2.1. Condensation Nuclei
Although the atmosphere is chiefly composed of gases and water vapor, the atmosphere also contains significant quantities of particles called condensation nuclei. Condensation nuclei are suspended particles of sea salt, dust, organic matter and smoke. The presence of condensation nuclei is necessary before condensation will occur.

2.2.2. Moisture
Obviously, moisture is needed or clouds would not form regardless of how much condensation nuclei is present or how much cooling was applied to the atmosphere. Moisture is supplied to the atmosphere by the process of evaporation. The moisture is then spread horizontally and vertically around the globe by wind currents.

2.2.3. Cooling Process
Finally, cloud formation requires a cooling process. The three cooling processes we will discuss in this QTP are radiational cooling, convective cooling, and mechanical cooling.

2.2.3.1. Radiational Cooling
The earth heats and cools faster than the surrounding air. At night the earth releases heat acquired during the day via long-wave radiation, thereby cooling rapidly. This long wave radiation does not heat the air, like short wave radiation from incoming solar rays during the day, and the air is cooled by contact with the cooler surface. This contact cooling lowers the temperature of the air near the surface causing a surface inversion to form. If the temperature of the air is cooled to its dew point, fog and/or stratus may form.

2.2.3.2. Convective Cooling
The lifting of air through the atmosphere because of surface heating is called convection. If a parcel of air is heated, it rises (the warm air is less dense than the relatively cooler air surrounding the parcel). As the parcel rises, it expands (due to decreased pressure) and cools until the temperature and dew point are the same (the saturation point). This point is the beginning of condensation. Convection ceases at the point that the parcel stops rising. Cumuliform clouds are formed in this way as depicted in Figure 2-1. Cloud bases are at the altitude of saturation (the CCL), and tops are at the point where the temperature of the surrounding air is the same as, or greater than, the temperature of the parcel of air.
The stability of the lifted air determines the type of clouds formed. Generally, convective clouds are formed when unstable air is lifted, and stratiform clouds are formed when stable air is lifted. The cloud types change when their environment changes. For example, cumulonimbus clouds frequently change to stratocumulus before dissipating. Stratus clouds may change to cumulus clouds in the afternoon, as surface heating induces instability.

![Figure 2-1. Convective Cooling](image)

2.2.3.3 Mechanical Cooling

Mechanical cooling (lifting) can be broken into two separate types, orographic and frontal. Both of these processes are considered mechanical means of cooling resulting in cloud formation.

- **Orographic** - As moist air is lifted over higher terrain (hills or mountains) it begins to cool and condense into clouds. The cloud type depends on the lapse rate (the rate of decrease in temperature with increase in height) of the air. If a weak lapse rate exists, then stratiform type cloudiness will form. If the lapse rate is steep then cumuliform type clouds will form. Orographically-induced clouds show little movement, and usually dissipate on the lee side of their source regions as depicted in Figure 2-2.
Figure 2-2. Orographic Lift

- **Frontal** - At a frontal surface, warmer less dense air is forced up the surface of a colder air mass as depicted in Figure 2-3. This lifting produces the same affect as orographically lifted air. If the airmass is shallow, the air may not be lifted high enough for it to reach its saturation point. This is often why little to no cloudiness is associated with arctic fronts. The type of cloud formation depends on the lapse rate. If the frontal slope is steep, cumuliform clouds will develop. If the slope is gradual, the clouds will usually be stratiform.

Figure 2-3. Frontal Lift
1. What are the three ingredients required for cloud formation?

2. What are two factors that determine the rate of cloud dissipation of clouds formed by radiational cooling?

3. Typically, cloud bases and tops formed by convective cooling can be found at what altitudes?

4. Describe the effect a shallow frontal slope has on cloud formation.

2.3. Forecast Aids

Incorrect cloud forecasts can cause aircraft diversions, delays in take-off, and mission aborts. It not only can cost valuable time and money, but in extreme cases, can cost lives. Accurate forecasting of clouds depends on the proper evaluation of atmospheric motion, temperature, moisture fields, stability, modification of air masses, distance from moisture source and topographical influence. Difficulty lies in quantifying the results of interactions between these elements and account for local effects. Fortunately, these difficulties can be minimized by several means.

2.3.1. Climatology

Recall from the Climatology QTP, climatology guidance is derived from decades of data and is a time-proven method that works well for forecasting clouds. Sources include Wind Stratified Conditional Climatology (WSCC) Tables and Modeled Ceiling/Visibility (MODCV), among others.

2.3.2. Extrapolation

Extrapolation is a very effective technique for short range cloud forecasting. To forecast clouds by heights or type simply advect the clouds downstream. Satellite imagery, radar, or nephanalysis can all be used for extrapolation of clouds.

2.3.3. Forecast Model Guidance

Recall from the Forecast Models QTP, model output, both numerical and graphical (Figure 2-4), are objective tools used to forecast weather elements, including clouds. As with all models, the information provided is only as good as the model itself. Initialization and verification of the model is required to effectively use its output.
Figure 2-4. MM5 Output - Cloud Forecast
2.3.4. Using Meteograms

The Forecast Models QTP covered the meteogram and how the models worked. In this section we will look at the weather that may be forecast using these models.

2.3.4.1. Cloud Evaluation Using Relative Humidity

Recall that Relative Humidity (RH) is used to determine the amount of cloud cover you may expect. Look at Table 2-1 below. You may compare these RH values to the amounts on the meteogram. You may notice how the MM5 algorithm shows clouds outlined. However, you can use interpretation based on the RH value. You may forecast an area of 80% as SCT, 90% should be forecast as BKN or OVC. Below, you see an example of how to use the meteogram to forecast sky condition. Another use of the RH is to combine values with upper-air temperatures to determine the potential for icing. Icing is covered more in detail.

**Example:** Refer to Figure 2-5 at the 14 Jul 18Z time period (red arrow). Here you see a 70% area around 2,200 feet MSL. A sky condition of FEW may be the forecast for this time period.

<table>
<thead>
<tr>
<th>T-Td Spread (°C)</th>
<th>Relative Humidity</th>
<th>Cloud Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2°</td>
<td>90-100%</td>
<td>Overcast</td>
</tr>
<tr>
<td>2-3°</td>
<td>80-90%</td>
<td>Broken variable Scattered</td>
</tr>
<tr>
<td>3-4°</td>
<td>70-80%</td>
<td>Scattered</td>
</tr>
<tr>
<td>5°</td>
<td>66-70%</td>
<td>Few</td>
</tr>
<tr>
<td>&gt;5°</td>
<td>&lt;65°</td>
<td>Clear</td>
</tr>
</tbody>
</table>

Table 2-1. Cloud Amount-Moisture Relationship
2.3.4.2. Dew Point Depression (DPD)

DPD is the number of degrees between the temperature and the dew point. You can find the DPD on the meteogram by looking for the section titled TDD. The color filled area is the DPD and may be used to determine the height of the convective cloud bases (Table 2-2 shows how to determine the height). This particular chart was developed for the central US, but may be adjusted to fit your particular station.

Example: Many mornings you will be under clear skies but you know that cumulus will develop later in the day. To decide the height of the bases, find the dew point depression. You see at 14 Jul 18Z (red arrow), the temperature is 30°C (85°F) with a dew point of 19°C (66°F) for a DPD of 11°C. Then check the table (Table 2-2) to see that the height the clouds that time is around 4,400 feet.
<table>
<thead>
<tr>
<th>DPD (°C)</th>
<th>Estimated Cumulus Height (feet)</th>
<th>DPD (°C)</th>
<th>Estimated Cumulus Height (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>200</td>
<td>1.0</td>
<td>400</td>
</tr>
<tr>
<td>1.5</td>
<td>600</td>
<td>2.0</td>
<td>800</td>
</tr>
<tr>
<td>2.5</td>
<td>1,000</td>
<td>3.0</td>
<td>1,200</td>
</tr>
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<td>3.5</td>
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<td>3,400</td>
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<td>4,600</td>
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</tr>
<tr>
<td>12.5</td>
<td>5,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2-2. Base of Convective Clouds Using Surface Dew Point Depressions (DPD)**
5. What amount of cloud cover would you forecast for 16 Jul 09Z (red arrow)?

- CLR
- FEW at 700 feet
- SCT at 700 feet
- BKN-OVC at 700 feet

6. At what height should developing CU form at 14 Jul 16Z (red arrow)?
2.3.5. Weather Radar

The WSR-88D can be used as a short-term forecast aid in determining cloud base characteristics. For example, since scatterers are often more prevalent in and near clouds, the VAD Wind Profile (VWP) may be used in estimating the change of cloud bases as cloud layers approach or recede. The root mean square (RMS) error range determines the reliability of the data (scatterers), i.e., the RMS decreases as the amount of scatterers increases. RMS values of 4 knots or less (green plot) are considered the most reliable. If the wind plot on the VWP is red, the RMS value is often interpreted as a scattered (SCT) deck. Refer to the Weather Radar QTP for additional information about the use of the WSR-88D.

2.3.6. Satellite

Satellite imagery can be used to determine cloud type, amount, and movement. MetSat imagery is an observation that is more frequent than synoptic reports and provides data in areas lacking conventional data, such as over ocean, mountainous or desert regions. Animated looping allows systems to be put in motion. Cloud movement can be easily extrapolated with animated satellite imagery.

A MetSat image gives a more complete idea of the vertical structure of the atmosphere than one or two products. Low-, mid-, and upper-level clouds and features can be seen simultaneously allowing for determination of their relationship to each other.

2.3.7. Local Area Work Chart (LAWC)

An LAW allows a detailed look at potential cloud producing events. The following are some uses of an LAW (see Figure 2-7. Note: Green area represents regions of steady precipitation). Perform a nephanalysis (cloud layer analysis using set cloud ceiling height thresholds), then combine with an isobaric analysis to show the position of pressure systems in relation to clouds. Always use satellite imagery to refine your cloud areas since their boundaries often are between reporting stations. Overlaying or looping nephanalysis charts can give a graphic representation of cloud movement as well as deteriorating or improving ceilings. Areas of large pressure falls indicate the probable track of lows and associated clouds. Their movement is a combination of the system movement and the flow around the system. This, of course, assumes no development or dissipation. A streamline analysis on the LAW can be used to identify areas of convergence, indicating possible cloud development or intensification. Areas of increased dew points (isodrosotherm analysis) and decreasing clouds may indicate possible areas for radiational fog development.
2.3.8. Skew-T (RAOB) Data

Data plotted on a Skew T can help determine where cloud bases may form if certain conditions are met. Three levels, the Convective Condensation Level (CCL), Lifted Condensation Level (LCL), and Mixing Condensation Level (MCL) are usually derived and displayed automatically. However, recall from the Analysis and Prognosis QTP, they can also be manually calculated.

- **Convective Condensation Level (CCL)** - The CCL is the height at which a parcel of air, when heated sufficiently from below rises and becomes saturated. It often corresponds well to the height of cumulus cloud bases formed due to surface heating (convectively).

- **Lifted Condensation Level (LCL)** - The LCL is the height at which a parcel of moist air becomes saturated when "lifted" dry adiabatically. The lifting is brought about by air being forced up (lifted over) fronts and orographic (hilly and mountainous) surfaces. This level can be used as an estimate of cloud bases caused by mechanical lifting.

- **Mixing Condensation Level (MCL)** - The MCL is the lowest height at which saturation may occur if the near surface layer is or will be mixed completely by
wind action. Clouds formed in mixing layers are stratocumulus. Mixing layers, when approaching saturation, progress from clear skies to thin broken to overcast layers to dense overcast layers. Keep in mind, mixing will not begin to occur in the air mass unless certain changes occur. If the mixing process is expected because of increasing wind speeds with a frontal passage, an adjustment of the lower dew point and temperature curves is required to reflect the changes expected with frontal passage. If mixing is expected to occur after a radiation inversion breaks, an adjustment of the temperature curve to approximate the low-level temperature at that time is needed. In both cases, an adjustment of the vertical wind profile is required to determine the top of the mixing layer.

As you can see, several levels on a Skew-T may be used as indicators where cloud bases may form. In reality, more than one factor can combine to start cloud formation. A frontal surface moving through the area will provide mechanical lift, but daily heating may occur to add convective lift to the process. Increasing winds may add mixing to the process. These factors must be taken into consideration when applying the above techniques.

In theory, you can interpret cloud layers from the radiosonde observation’s (RAOB) temperature and dew point profiles where the sonde penetrated the clouds. In practice, this is sometimes difficult due to the variability of moisture content, advective and convective modifications, or the timeliness of the data; all have an impact on cloud amounts and coverage estimations. A series of rules for interpreting clouds from a RAOB have been developed.

- A cloud base may be indicated where the dew point depression decreases to 5°C or less. Typically, dew point depressions in clouds at temperatures of 0°C or above are 1° or 2°C; in clouds with temperatures from –10°C to –20°C, typical dew point depressions run about 4°C.
- The top of a cloud is usually indicated by an increase in dew point depression (decrease in RH).
- The cloud cover can be estimated from the dew point depression (see Table 2-1 in Section 2.3.4.2) and relative humidity (RH) using Table 2-3.

<table>
<thead>
<tr>
<th>RH (in %)</th>
<th>Expect Cloud Amount (in 8ths)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 65</td>
<td>0</td>
</tr>
<tr>
<td>70</td>
<td>1 to 2</td>
</tr>
<tr>
<td>75</td>
<td>3</td>
</tr>
<tr>
<td>80</td>
<td>4 to 5</td>
</tr>
<tr>
<td>85</td>
<td>6 to 7</td>
</tr>
<tr>
<td>≥ 90</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 2-3. Cloud Amount Using Relative Humidity
• Interpretation of cloud type from the thickness and altitude of the moist layer. If the moist layer is less than 4,000 feet thick, the cloud is stratus or stratocumulus; over 4,000 feet thick, the cloud is cumuliform.

2.3.9. Upper-Air Charts

Upper-air charts can be used to indicate the heights of moisture and clouds as well as dry regions. Movement of clouds may be detected by extrapolation of the upper-level winds. The relationship between surface systems and upper level features can give an idea of expected cloud types. Keep in mind, upper air charts should not be used as stand-alone products.

Figure 2-8. Satellite

Looking at the 850 mb chart in Figure 2-8, low-level moisture over the eastern half of the United States is apparent. However, in the southwestern United States and in Mexico where data sparse regions exist, incorporation of a corresponding satellite shot may be needed to identify the low-level moisture.

2.4. Forecast Rules of Thumb and Techniques

Over the years, relationships between clouds, upper-air, and other synoptic features have been identified through rules of thumb and techniques that we will cover in the section.

2.4.1. Rules of Thumb Using Upper Air and Synoptic Features

Below are some rules/techniques based on observed relationships between upper-air (700 mb and above) and synoptic weather features.

• When the contours at 700 mb are perpendicular to a surface cold front (inactive front), the band of weather associated with the front is narrow. There may be a band of clouds associated with a squall line ahead of the front.

• When the contours at 700 mb are parallel to a cold front (active front), the clouds and precipitation extend behind the front as far as the wind remains parallel to the front.
• Few clouds and very little weather are associated with a front if the 1,000-500 mb thickness lines or the 700 mb isotherms are nearly perpendicular to the cold front.

• Clouds and weather are most strongly associated with a front when the 1,000-500 mb thickness lines or the 700 mb isotherms are parallel to the cold front.

• Cloudiness and precipitation may be found (given sufficient vertical motion and moisture) under cyclonically-curved contours aloft no matter the presence or absence of surface features.

• In a cold air mass, the instability showers and cumuliform clouds occur only where the air is moving in a cyclonically-curved path.

• Warm front cloudiness and precipitation occur where the 700 mb wind flow is across the warm front from the warm side to the cold side and turning cyclonically or moving in a straight line.

• The 700 mb ridge line approximates the forward limit of pre-warm frontal middle and low-level cloudiness. The 500 mb ridge approximates the forward limit of the cirrus cloud shield. The sharper the anticyclonic turning of the ridge line, the more accurate this rule.

• In a warm air mass moving with a component from the south, cloudiness and precipitation is greatest under cyclonic turning.

• Clear skies occur when a current of air is moving from the north in a straight line or curving anticyclonically, and in a southward component when it is moving anticyclonically.

• Cloudiness and precipitation are likely in areas of strong positive vorticity advection (PVA) and clear skies are likely under areas of strong negative vorticity advection (NVA).

2.4.2. Cirrus Forecasting Using Upper Air and Synoptic Features

Forecasting cirrus may not always seem operationally significant, but many weather features, both surface and aloft, have been correlated with cirrus occurrence or formation. The following are rules/techniques developed for forecasting cirrus type clouds.

• Cirrus can normally be found 300 to 500 miles ahead of a surface warm front. The 500 mb ridge line ahead of the surface front is usually the forward limit of the cirrus.

• When a warm front has precipitation occurring ahead of it, there is a 60 % probability that cirrus is present above the precipitation.

• Cirrus observed with a cold front originates from either the cumulonimbus along and behind the front or from the convergence around an associated upper trough.

• The probability of cirrus occurrence is greatest when the wind at 300 mb is from the southwest or west and least when from the northeast or east.

• Extensive cirrostratus follows the passage of the surface ridge line.
• The top of the most extensive and thick layers of cirrus is at or within a few thousand feet of the tropopause height.

• The thickness of individual cirrus layers is most frequently 800 feet in the middle latitudes but may range up to 10,000 feet.

• Most of the more extensive and dense cirrus is on the high-pressure (equatorward, or south) side of the jet axis.

2.4.3. The Gayikian Method of Forecasting Cirrus

The Gayikian Method is a set of rules for forecasting cirrus. According to the method, there are two primary types of cirrus: advective and convective. Advective cirrus appears to have a relationship to the orientation, wavelength, and amplitude of the jet stream, isotachs, and the wind flow at a level just below the tropopause.

2.4.3.1. Advective Cirrus

The following rules may be used to forecast cirrus from the current analysis and the forecast 200 mb product.

• With no change in either wavelength or amplitude, forecast cirrus to exist in the same area relative to the jet that now exists. Cirrus generally spreads eastward.

• With increasing amplitude of the jet but with no change in jet wavelength, forecast cirrus to spread northward and diminish a little in the south, with the cirrus becoming denser.

• With decreasing jet amplitude but no change in jet wavelength, forecast the entire cirrus area to decrease and the cirrus to become less dense.

• With increasing jet wavelength but no change in jet amplitude, forecast cirrus to extend more east-to-west and less north-to-south, with the cirrus becoming less dense.

• With increasing jet wavelength and amplitude, forecast cirrus to spread northeastward with little change in density.

• With increasing jet wavelength but decreasing jet amplitude, cirrus tends to decrease and become less dense.

• With decreasing jet wavelength and no change in jet amplitude, the cirrus area decreases in the eastern portion, with no change in the cirrus density.

• With decreasing jet wavelength but increasing jet amplitude, the cirrus area decreases but tends to spread northward with a slight decrease in density.

• With decreasing jet wavelength and amplitude, the cirrus area decreases.

• If a upper level confluent area is developing, cirrus forms downstream near the point of inflection and builds, or forms, both upstream and downstream. Upstream from the point of maximum wind, the cirrus is stable and generally cirrostratus; downstream from the maximum wind it is unstable and generally cirrocumulus. The greatest density of the cirrus is at the point of the maximum wind.
• Cirrus begins to dissipate in areas of upper level divergence and the area of dissipation spreads upstream.

• Cirrus rarely exists in the area south of a jet trough, but a secondary area of cirrus may be present in the low center to the north. There is normally a clear area or band between this area and that to the east of the trough.

• Cirrus usually exists in the center and back part of a ridge, south of the jet.

• If the wind maximum (jet) crosses contours toward higher heights downstream, cirrus is more likely to exist than if the jet crosses contours toward lower heights.

• The presence of frontal or thunderstorm activity within the maximum cirrus area must be considered. The usual effect is to thicken the cirrus, lower the base, increase the height of the top, and extend the cirrus area more easterly.

• The height of the base and top of advective cirrus appears to have a close relationship to the vertical wind shear. Although no statistical evaluation has been determined, cirrus has been noted to be more prevalent with certain types of wind profiles. The height of the base and top of the cirrus layer can be determined from the following rules:
  • The greater the wind shear between cirrus bases and tops, the greater the density, the probability of occurrence, and the validity of this rule.
  • Cirrus is in layers and of low density with the total distance from the base of the lowest layer to the top of the highest layer being greater when the wind profile shows indistinct layers of maximum wind.
  • When there is no distinct wind shear in the profile, forecast no cirrus, or very thin layers of cirrus that are not visible from the ground and reduce horizontal flight visibility only a little.

2.4.3.2. Convective Cirrus

For purely convective cirrus the following rules can be applied:

• If straight-line or anticyclonic flow exists (at 300 to 200 mb) over the area downstream from a thunderstorm area, cirrus may appear the next day and advance ahead of the ridge line.

• If the contours over the area downstream are cyclonically curved, cirrus may or may not appear. It is more likely to appear if the flow is weak.

• Cirrus present due to thunderstorms usually dissipates within six hours following dissipation of the thunderstorm.

• There is no definite technique for finding the heights of convective cirrus, but the base may coincide with a good wind shift or shear and the top is often near the tropopause.
7. Using the WSR-88D VAD Wind Profile (VWP) below, what can you infer is happening between 9,000ft and 11,000ft beginning about 1042Z?

8. If the base is between the surface and 10,000 feet, the cloud is 

   a. Stratiform
   b. Cumuliform
   c. Both A and B
   d. None of the above

At this point, your trainer and/or certifier should answer any questions you, the trainee, have or to clarify any points you are still unclear on. Your trainer and/or certifier should also review local/regional rules-of-thumb and techniques developed in your AOR(s) with you.
MODULE 3 - VISIBILITY, PRECIPITATION AND OBSTRUCTIONS TO VISION

TRAINEE’S NAME__________________________________________

CFETP REFERENCE: 14.3.

MODULE OVERVIEW:
This module discusses forecasting visibility, precipitation and obstructions to vision terminology, concepts and rules. The trainee will apply this knowledge toward issuing a visibility, precipitation and obstructions to vision forecast. This module describes the conditions necessary to produce visibility-reducing weather and also discusses several techniques used in forecasting visibility.

TRAINING OBJECTIVES:

• OBJECTIVE 1: Answer questions to demonstrate your comprehension of the general rules, techniques, and principles and procedures of visibility forecasting with at least 80% accuracy.

• OBJECTIVE 2: Demonstrate that you understand the general rules, techniques, and principles and procedures concerning forecasting precipitation by answering questions with at least 80% accuracy.

• OBJECTIVE 3: Be able to show that you understand the general rules, techniques, principles and procedures of forecasting obstructions to vision by answering questions with least 80% accuracy.

• OBJECTIVE 4: Using either real-time weather data or canned scenarios, be able to provide solutions and answers to questions concerning forecasts of visibility, any applicable precipitation, and/or any obstruction(s) to vision with at least 80% accuracy.

EQUIPMENT AND TRAINING REFERENCES:

• AFWA/TN-98/002, Meteorological Techniques
• AFWAN 15-124, Meteorological Codes
• AFWAN 15-111, Surface Weather Observations
• AFH 11-203, Volume 1, Weather for Aircrews
• METOC 50-1P-0002, Volume 5, Introduction to Forecasting: Forecast Charts and Forecasting Weather Elements
• Meteorology Today: An Introduction to Weather, Climate and the Environment
- SC 01W01A, Volume 3, Weather Element Forecasting, Flight Hazards, and Limited Data
- AWS/TR-79/006 (Revised), The Use of the Skew-T, Log P Diagram in Analysis and Forecasting
- Aerographer’s Mate 1 & C
- AWS/FM-90/001, New Stability Indices and Fog Forecasting Techniques

**PREREQUISITES AND SAFETY CONSIDERATIONS:**

- Be familiar with interpreting weather features off MetSat imagery
- Have a firm grasp on the analysis and prognosis rules and techniques discussed in the Analysis and Prognosis QTP
- Familiarity with the TAF code found in Chapter 1, AFMAN 15-124, Meteorological Codes
- Familiarity with the sections on visibility, precipitation and obstructions to vision found in AFMAN 15-111, Surface Weather Observations

**ESTIMATED MODULE TRAINING TIME:** 2.5 Hours
CORE TRAINING MATERIAL AND REVIEW QUESTIONS

3.1. Surface Visibility

Accurately forecasting the exact visibility over the next few hours can be difficult; but when that time frame expands to 24 hours or more, accurately forecasting visibility can baffle even the most experienced forecaster. Even if the forecaster is confident that fog or any other obstructions to vision will be present, it is still challenging to predict what the exact visibility will be. Climatology provides trends and averages of a variety of weather parameters over a long period of time. Use climatology first to identify the prevailing ceiling and visibility for the location and time of interest. Even though you may be able to forecast the trend correctly, the difference between 4800 meters and 2400 meters could be the difference between mission accomplishment and mission delay.

When considering what type of obstruction to vision will hamper visibility, you as a forecaster must determine if it is a lithometeor (dry obstruction) or a hydrometeor (wet obstruction). Hydrometers, which can cause a reduction in surface visibility, fall into one of the following two categories: precipitation or fog. Lithometeor is the general term for particles suspended in a dry atmosphere. These include haze, smoke, dust, sand, and salt. Forecasting lithometeors and hydrometeors will be discussed in greater detail throughout this module.

3.2. Hydrometeors - Fog

At most locations, fog is the most common visibility restriction. The formation of fog results from air being brought to saturation by cooling or adding moisture. Fog and stratus are both products of condensation and saturation. As the relative humidity of the air increases, and the visibility decreases due the increase of water vapor in the air, the landscape becomes masked with a grayish tint. As the relative humidity gradually approaches 100%, the condensation particles grow larger, and condensation begins on the less-active nuclei. At this point, a large fraction of the available nuclei have water condensing onto them, causing the droplets to grow even bigger, until eventually they become visible to the naked eye. The increasing size and concentration of droplets further restricts visibility. There are three fog types: radiation, advection, and upslope fog.

3.2.1. Radiation Fog

Radiation fog can be defined as fog that forms over land when radiation cooling (cooling of the earth’s surface) reduces the air temperature to its saturation temperature (i.e., its dew point). Radiation fog is also known as ground fog or valley fog. This type of fog forms best on clear, cool nights when there is a shallow layer of moist air near the ground with a dryer layer above. As the ground begins to cool during the night, the moist air just above the earth’s surface also cools. As the ground continues to cool, a surface inversion forms. The moist lower layer quickly cools to its dew point temperature, and fogs forms. Therefore, radiation fogs are most common over land in late fall and winter.
Another factor promoting the formation of radiation fog is a light breeze of less than 5 knots. Although radiation fog forms in calm air, slight air movement brings more of the moist air in direct contact with the cold ground and the transfer of heat occurs more rapidly (mixing). On the other hand, a strong breeze prevents radiation fog from forming since it causes a mixing of the air near the surface with the drier air above. The ingredients of clear skies and light winds are associated with large high-pressure areas (anticyclones). Consequently, during the winter, when a high becomes stagnant over an area, radiation fog may form on many consecutive nights and generally reduce visibilities lower each night.

Because cold, heavy air drains downhill and collects in valley bottoms, we normally see radiation fog forming in low-lying areas. The cold air and high moisture content in river valleys make them extremely susceptible to radiation fog.

Radiation fogs form upward from the ground as the night progresses and are usually deepest around sunrise. However, fog may occasionally form after sunrise, especially when evaporation and mixing takes place near the surface. This usually occurs after a clear, calm night as radiational cooling brings the air temperature close to the dew point in a rather shallow layer above the ground. At the surface, the air be comes saturated, forming a thick blanket of dew on the grass. At daybreak, the sun's rays evaporate the dew, adding water vapor to the air. A light breeze then stirs the moist air with the drier air above causing saturation (and, hence, fog) to form in a shallow layer near the ground.

Often a shallow fog layer will dissipate or burn off by late morning or afternoon. Of course, the fog does not "burn off"; rather, sunlight penetrates the fog and warms the ground, causing the air temperature in contact with the ground to increase. The warm air rises and mixes with the foggy air above, which increases the temperature of the foggy air. In the slightly warmer air, some of the fog droplets evaporate, allowing more sunlight to reach the ground, which produces more heating, and soon the fog completely dissipates.

Satellite photographs show that a blanket of radiation fog tends to "burn off" around its edges first where the fog is usually thinnest and in contact with the surrounding dry air. Sunlight rapidly warms this region, causing the fog to dissipate as the warmer air mixes in toward the denser foggy area (see Figure 3-1).
3.2.2. Advection Fog

Cooling surface air to its saturation point may be accomplished by warm, moist air moving over a cold surface. The surface must be sufficiently cooler than the air above so that the transfer of heat from air to surface will cool the air to its dew point and produce fog. Fog that forms in this manner is called advection fog.

Sea fog is an advection fog that occurs where two ocean currents with different temperatures flow next to one another. Such is the case in the Atlantic Ocean off the coast of Newfoundland, where the cold southward flowing Labrador Current lies almost parallel to the warm northward-flowing Gulf Stream. Warm southerly air moving over the cold water produces fog in that region. Frequently that fog occurs on about two out of every three days during summer off the New England coast. Sea fog is notorious in the northern Gulf of Mexico, areas along portions of the US Pacific coast, along the west coast of Korea, and northern Japan.

Advection fog also forms over land. In winter in the United States, warm, moist air from the Gulf of Mexico moves northward over progressively colder and slightly elevated land. As the air cools to its saturation point, a fog forms in the southern and/or central United States. Because the cold ground is often the result of radiational cooling, the fog forming in this manner is sometimes called advection-radiation fog. During this same time of year, air moving across the warm Gulf Stream encounters the colder land of the British Isles and produces the thick fogs off the English coast. Similarly, fog forms as maritime air moves over an ice or snow surface. In extremely cold arctic air, ice crystals form instead of water droplets producing ice fog.

3.2.3. Upslope Fog

Upslope fog forms as moist air flows up along an elevated plain, knoll, hill, or mountain. Typically, upslope fog forms during the winter and spring on the eastern side of a mountain chain. As the air moves up the mountain slope it expands and cools, and if sufficiently moist, fog forms. Upslope fog that forms over a large area may last for many days.
1. Which of the following groups consist of lithometeors only?
   a. Fog, haze, blowing snow;
   b. Haze, blowing snow, dust, drizzle
   c. Smoke, drizzle, sand, fog
   d. Smoke, haze, dust, sand

2. What are the two ways fog usually forms?

3. Cooling surface air to its saturation point may be accomplished by warm, moist air moving over a cold surface. What type of fog is being discussed here?
   a. Advection fog
   b. Radiation fog
   c. Upslope fog

4. When we discuss fog “burn off,” what is actually happening?

3.3.3. Fog Forecasting
The following parameters and conditions (some developed by JJ George) have to be considered if you think that fog may reduce visibility:

- The synoptic situation
- Time of the year
- State of the earth’s surface
- Station climatology
- Stability of the lapse rate
- Stability for the lowest 50 to 150 mb of the atmosphere
- State of the hydrolapse (moist lapse rate) for the lowest 50 to 150 mb of the atmosphere
- Temperature
- Dew point depression
- Amount of cooling
- Winds
  - Wind direction
  - Wind velocity
3.3.1. **Forecasting Radiation Fog**

Radiation fog is the most common you should encounter. Here are a few conditions needed:

- Clear to partly cloudy skies at night. The less clouds, the better chance of fog
- Moist ground
- Light, but not calm winds (if the winds are calm, expect only surface dew to form)
- Suppressed daytime heating (cloudy)
- A late afternoon dew point depression of 20° F (12° C) or less
- In addition to the above conditions, the following can greatly aid fog formation:
  - A cooling rain during the day
  - The longer the nighttime the better

3.3.2. **Forecasting Advection Fog**

Here are a few tips that should be helpful if you think advection fog may affect your location:

- Moist air with higher dew points moving with light to moderate velocities over an underlying surface that becomes progressively colder downwind. This condition will produce fog over land or water areas.
- Maximum frequency of fog formation is seen with light winds (2-8 knots)
- Under light wind conditions, fog is relatively shallow and stable. With a surface inversion and lesser speeds results in a more shallow layer
- Winds in excess of 9-10 knots normally cause turbulent mixing, resulting in stratus.
- Cloudy days (keep the high temperature down) and clearing nights (allow maximum radiational cooling).

3.3.3. **Fog Dissipation**

Fog may dissipate due to increased solar radiation. In more commonly used terms, fog “burns off” after sunrise due to daytime heating. Other ways that the fog may dissipate due to heating are:

- Advection over a warmer surface.
- Adiabatic warming by subsidence (i.e., downslope).
- Turbulent mixing of the fog layer with adjacent warmer air aloft.
Fog may also dissipate if the moisture is removed (i.e. the air becomes drier). The air may become drier due to:

- Turbulent transfer of moisture upward.
- Turbulent mixing of the fog layer with adjacent drier air.
- Condensing out water vapor as rain, dew, or frost.

### 3.3.3.1. Satellite Clues

MetSat imagery, as we saw earlier in this module, is a valuable tool in detecting fog dissipation.

- Clouds erode from outer edges due to vertical mixing of surrounding warmer, drier air.
- Thicker (brighter) portions of clouds dissipate last.
- Fog is more persistent when:
  - Covered by cirrus
  - Over snow cover or cold water surface
  - Associated with upslope flow
- If a fog patch moves as it dissipates, the upstream edge dissipates faster than downstream edge.
- Visible brightness difference (fog versus clear regions) from digital data or enhanced image has been used to estimate time of fog dissipation

### 3.4. Hydrometeors - Precipitation

Forecasting restrictions to visibility caused by precipitation is a function of precipitation type and intensity. For precipitation to occur, two basic ingredients are necessary: moisture and a mechanism for lifting to expand and cool the air sufficiently to promote condensation. Lifting mechanisms include convection, orographic lifting, and frontal lifting. There are many techniques and methods available for forecasting precipitation.

Although there is no one strict rule of thumb relating the intensity of rain to expected visibility, you may use the following table (see Table 3-1) as a guide to forecast visibility based on the intensity of precipitation, especially snow. The table may also be used to estimate drizzle. A note of caution: The table should only be used with one form of precipitation at a particular time. If more than one form of precipitation is expected or the precipitation is expected to occur with an obstruction, then you should forecast a lower visibility than the one shown in the following table.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Visibility Limits (Statute Miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light rain showers</td>
<td>As low as 5 miles</td>
</tr>
<tr>
<td>Moderate rain showers</td>
<td>As low as 2 1/2 miles</td>
</tr>
<tr>
<td>Heavy rain showers</td>
<td>As low as 1/2 mile</td>
</tr>
<tr>
<td>Light snow showers</td>
<td>&gt; 1/2 mile</td>
</tr>
<tr>
<td>Moderate snow showers</td>
<td>&gt; 1/4 mile but &lt; 1/2 mile</td>
</tr>
<tr>
<td>Heavy snow showers</td>
<td>≤ 1/4 mile</td>
</tr>
</tbody>
</table>
3.5. Precipitation and Frontal Systems

Before you get into the precipitation forecast rules of thumb and techniques, you must understand the relationship between precipitation types, intensities, and amounts associated with frontal systems. Frontal systems do not have the same sequence of weather every time, but in the “classic” systems covered, you should get a feeling of how to forecast for the different types of fronts.

3.5.1. Cold Fronts

There are two types of cold fronts: slow moving or active cold fronts and fast moving or inactive cold fronts. You can quickly identify an active cold front by looking at the upper wind flow. The upper winds are parallel to the front, as are the isotherms. An inactive cold front will have the upper winds perpendicular to the front and the isotherms are not parallel, but are at an angle of about 30° to the front, usually crossing the cold front near its junction with the associated warm front.

3.5.1.1. Active Cold Fronts

With the slow moving cold front, there is a general upward motion of warm air along the entire frontal surface with pronounced lifting along the lower portion (closest to the surface) of the front. This results in widespread frontal cloudiness and precipitation at and behind the front caused by actual frontal lifting. See Figure 3-2.

The weather associated with the slow moving active cold front is dependent on the stability of the warm air mass.

- If the warm air is stable, a rather broad zone of altostratus and nimbostratus clouds will be accompanied by light to moderate rain, drizzle, and/or snow, provided there is sufficient moisture available. This type of weather may extend several hundred miles behind the front.
- If the warm air is unstable (or conditionally unstable), thunderstorms, rain and/or snow showers may develop within the cloudbank and may stretch up to 50 miles behind the surface front.
3.5.1.2. Inactive Cold Fronts

Inactive or fast moving cold fronts have a very steep frontal slope. This causes the warm air near the surface to be forced rapidly upward. At higher levels, air flows rapidly down the surface front and collides with the rising air near the surface. This causes a relatively narrow but often violent band of weather ahead of the front. The fast moving cold front is considered inactive because the lifting occurs only along and ahead of the front. See Figure 3-3.

If the warm air is moist and unstable, a line of convection develops 50 to 200 miles ahead of and parallel to the surface front. If the surface convergence is strong enough, often a squall line with powerful thunderstorms, heavy rainshowers and possibly large hail may develop.

If the warm air is stable, an overcast layer of altostratus clouds and light, steady precipitation may extend over a large area ahead of the front. Behind the front, unless the cold air is unstable and descending currents are weak, there are few clouds and little if any precipitation.
3.5.2. Warm Fronts

Steady precipitation is usually common with overrunning condition and the accompanying stratified clouds. Intermittent or continuous rain/snow is common as far as 300 miles ahead of a warm front. Surface rain, drizzle and snow are associated with the nimbostratus in the warm air above the frontal surface and with stratus in the cold air. If the warm air is convectively unstable, showers and thunderstorms may occur in addition to the steady precipitation. The amount and type of precipitation vary with the characteristics of the air masses involved and depending on whether the front is active or inactive. Figure 3-4 shows the typical precipitation pattern with warm front.
If the winds associated with a warm front increase with height and become perpendicular to the front, then the front is classified as an active warm front. This active warm front produces strong overrunning and pronounced prefrontal clouds and precipitation. This overrunning air is moist and stable and nimbostratus clouds with continuous light to moderate precipitation can be expected up to 300 miles ahead of the warm front.

![Figure 3-5. Stable Overrunning](image)

When the overrunning air is moist and unstable, cumulus and cumulonimbus clouds are frequently imbedded in the nimbostratus and altostratus clouds producing pockets of stronger showers and thunderstorms around the continuous precipitation. This is called the inactive warm front.

Inactive warm fronts, characterized by broken cirrus and altocumulus clouds are produced by a decrease of winds with heights that are perpendicular to the front. When the overrunning air is warm and dry, it must be lifted to relatively high altitudes before condensation occurs; thus, forming mid and high clouds.

![Figure 3-6. Unstable Overrunning](image)
3.5.3. Occluded Fronts

An occluded front is the combination of two fronts. They form when a cold front overtakes the warm front and forces it aloft. There are two types of occlusions, a cold occlusion and a warm occlusion. The type of occlusion is determined by the temperature difference between the cold air in advance of the warm front. Listed below is a quick reference table (Table 3-2) in helping you identify occlusions.

<table>
<thead>
<tr>
<th>Winds</th>
<th>Before Passing</th>
<th>While Passing</th>
<th>After Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>southeast-south</td>
<td>variable</td>
<td>colder</td>
</tr>
<tr>
<td>Cold Type</td>
<td>cold-cool</td>
<td>dropping</td>
<td>colder</td>
</tr>
<tr>
<td>Warm Type</td>
<td>cold</td>
<td>rising</td>
<td>usually rising</td>
</tr>
<tr>
<td>Pressure</td>
<td>usually falling</td>
<td>low point</td>
<td>colder</td>
</tr>
<tr>
<td>Clouds</td>
<td>m, C, A, Ni</td>
<td></td>
<td>Ni, A or scattered C</td>
</tr>
<tr>
<td>Precipitation</td>
<td>light, moderate or heavy precipitation</td>
<td>light, moderate or heavy continuous precipitation or showers</td>
<td>light-to-moderate precipitation followed by general clearing</td>
</tr>
<tr>
<td>Visibility</td>
<td>poor in precipitation</td>
<td>poor in precipitation</td>
<td>improving</td>
</tr>
<tr>
<td>Dew Point</td>
<td>steady</td>
<td>usually light drop, especially if cold-occluded</td>
<td>small, although may rise a bit if warm-occluded</td>
</tr>
</tbody>
</table>

Table 3-2. Occlusion Identification Techniques

3.5.3.1. Cold Occlusions

In the beginning stages of a cold occlusion, the weather and clouds ahead of the occlusion are very similar to that of a warm front, but the weather near the surface position of the occluded front is closer to the weather you would expect with a cold front.

As the occlusion matures, the warm air is lifted to greater heights and the warm front and prefrontal clouds disappear. Most of the precipitation occurs just ahead of the occlusion. Clearing behind the occlusion is usually rapid, especially if the occlusion is in the advanced stage. Otherwise, clearing may not occur until after the passage of the warm front aloft. See Figure 3-7 for the vertical and horizontal depiction of a cold occlusion.

Figure 3-7. Structure of a Cold Occlusion
3.5.3.2. Warm Occlusions

A warm occlusion forms when the air in advance of the warm front is colder than the air to the rear of the cold front. When the cold air of the cold front overtakes the warm front, it moves up over this colder air in the form of an upper cold front.

![Figure 3-8. Structure of a Warm Occlusion](image)

The weather associated with warm occlusions has the characteristics of both warm and cold fronts. The order of clouds ahead of the occlusion is similar to the sequence of clouds ahead of a warm front. The cold front type weather occurs near the top of the upper cold front. If either the warm or cool air that is lifted is moist and unstable, showers, and sometimes, even thunderstorms may develop. The intensity of the weather along the upper front decreases the further away from the location of the over running fronts.

Precipitation types change rapidly in occlusions and are usually most severe during the initial stages. However, when the warm air is lifted to higher and higher altitudes, the precipitation activity diminishes. When showers and thunderstorms occur, they are found just ahead and with the upper cold front. Normally, there is clearing weather after passage of the upper front, but this is not always the case.

5. __________ (TRUE/FALSE) With a slow moving active cold front, there is a general upward motion of warm air along the entire frontal surface with pronounced lifting along the lower portion (closest to the surface) of the front—resulting in cloudiness and precipitation at and ahead of the front.

6. If the warm air mass associated with a slow moving active cold front is stable, what kind of precipitation will accompany the nimbostratus and altostratus?
7. In general, what kind of precipitation would you expect with a warm front?

8. If winds associated with a front increase with height and becomes perpendicular. What kind of front do you have?
   a. Active warm front
   b. Inactive warm front
   c. Both active and inactive warm fronts
   d. None of the above

3.6. Forecasting Precipitation Type

A big challenge for forecasters often is, “Will it rain or will it snow?” This kind of decision has a huge impact on operations. Here are a few methods and rules used to forecast precipitation type.

3.6.1. Forecasting Precipitation Type Using Freezing Levels

Forecasters often use the freezing level to determine the type of precipitation (see Table 3-3). The forecast is based on the assumption that the freezing level must be lower than 1,000 feet above the surface for most of the precipitation reaching the ground to be snow. However, forecasters must understand the complex thermodynamic changes occurring in the low-levels to correctly forecast tricky winter precipitation situations. For example, the freezing level often lowers 500 to 1,000 feet during first 1 1/2 hours after precipitation begins, due to evaporative cooling. When saturation occurs, cooling ceases and freezing levels rise to their original heights within 3 hours. With strong warm-air advection, the freezing level rises as much as a few thousand feet in a 6 to 8-hour period. Table 3-4 shows the probability of snow compared to the freezing level above the surface.

<table>
<thead>
<tr>
<th>Freezing Level</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2,000 feet</td>
<td>Rain</td>
</tr>
<tr>
<td>&lt;1,000 feet</td>
<td>Snow</td>
</tr>
<tr>
<td>1,000 to 2,000 feet</td>
<td>Mixed</td>
</tr>
</tbody>
</table>

Table 3-3. Forecasting Precipitation Type Using Freezing Level
### Table 3-4. Probability of Snowfall Based on Height of Freezing Level

<table>
<thead>
<tr>
<th>Height of Freezing Level above Ground</th>
<th>Probability Precipitation will Fall as Snow</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 mb</td>
<td>90%</td>
</tr>
<tr>
<td>25 mb</td>
<td>70%</td>
</tr>
<tr>
<td>35 mb</td>
<td>50%</td>
</tr>
<tr>
<td>45 mb</td>
<td>30%</td>
</tr>
<tr>
<td>61 mb</td>
<td>10%</td>
</tr>
</tbody>
</table>

3.6.2. Forecasting Precipitation Type Using Temperatures

Forecasting the precipitation type by using temperatures is a little more difficult. Table 3-5 gives some temperature thresholds that work much of the time. The low-level temperatures (surface or 1000 mb and 850 mb) are very important. Some locations have also determined local 925 mb temperature thresholds, but a standard temperature has not been determined as of this writing.

- If the surface temperatures are below freezing, precipitation will be:
  - Snow if upper levels indicate snow.
  - Freezing rain if upper levels indicate rain.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Rain</th>
<th>Mixed</th>
<th>Snow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Temperature</td>
<td>&gt;40° F (5° C)</td>
<td>35 to 40° F</td>
<td>&lt;35° F (2 ° C)</td>
</tr>
<tr>
<td>Surface Dew Point</td>
<td>&gt;35° F (2° C)</td>
<td>25 to 35° F</td>
<td>&lt;25° F (-4° C)</td>
</tr>
<tr>
<td>850 mb Temperature</td>
<td>&gt;5° C</td>
<td>1 to 5° C</td>
<td>&lt;1° C</td>
</tr>
<tr>
<td>700 mb Temperature</td>
<td>&gt;-5° C</td>
<td>-5 to –9° C</td>
<td>&lt;-9° C</td>
</tr>
<tr>
<td>500 mb N of 40° N and Mountains</td>
<td>&gt;-25° C</td>
<td>-25 to –29° C</td>
<td>&lt;-29° C</td>
</tr>
<tr>
<td>500 mb S of 40° N</td>
<td>&gt;-15° C</td>
<td>-15 to –19° C</td>
<td>&lt;-19° C</td>
</tr>
</tbody>
</table>

Table 3-5. Precipitation Type Using Temperature
3.6.3. Forecasting Precipitation Type Using Thickness

The following rules of thumb for forecasting precipitation type using thickness and temperatures have been time-tested. Designed mainly for the central US, adjustments have to be made for different locations differ in different regions, dependent upon latitude and local effects (elevation, mountains, oceans, etc.). Forecasting the type of precipitation using thickness is relatively easy if you the thresholds in Table 3-6. The low levels (1000-850 mb and 1000-700 mb) are very important.

- Values listed under threshold should be considered as 50% probability of either rain or snow.
- Values under snow indicate precipitation nearly all snow for lower values.
- Definitely forecast snow if upper levels thicknesses indicate snow.
- Values under rain indicate precipitation nearly all rain for higher values.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Flurries</th>
<th>Snow</th>
<th>Threshold</th>
<th>Rain</th>
</tr>
</thead>
<tbody>
<tr>
<td>850-500 mb</td>
<td></td>
<td></td>
<td>4,050 m</td>
<td></td>
</tr>
<tr>
<td>850-700 mb</td>
<td></td>
<td>1,520 m</td>
<td>1,540 m</td>
<td>1,555 m</td>
</tr>
<tr>
<td>1000-500 mb</td>
<td>5,240 m</td>
<td>5,360 m</td>
<td>5,400 m</td>
<td>5,490 m</td>
</tr>
<tr>
<td>1000-700 mb</td>
<td></td>
<td>2,800 m</td>
<td>2,840 m</td>
<td>2,870 m</td>
</tr>
<tr>
<td>1000-850 mb</td>
<td></td>
<td>1,275 m</td>
<td>1,300 m</td>
<td>1,325 m</td>
</tr>
</tbody>
</table>

Table 3-6. Precipitation Type Using Thickness

3.6.3.1. Using Skew-T to Identify Potential Precipitation Types

The following methods use the number of freezing levels to forecast the type of precipitation expected at the surface. Each one considers the change of state of precipitation from liquid-to-solid or solid-to-liquid as it falls through the atmosphere.

- **Single Freezing Level**
  If the freezing level equals or exceeds 1,200 feet above ground level (AGL), forecast liquid precipitation. If the freezing level is less than or equal to 600 feet AGL, forecast solid precipitation. If the freezing level is between 600 and 1,200 feet AGL, forecast mixed precipitation.

- **Multiple Freezing Levels**
  When there are multiple freezing levels, warm layers exist where the temperature is above freezing. The thickness of the warm and cold layers affects the precipitation type at the surface. If the warm layer is greater than 1,200 feet thick and the cold layer (temperatures below freezing) closest to the surface is less than or equal to 1,500 feet thick, forecast freezing rain. Conversely, if the warm layer is greater than 1,200 feet thick and the cold layer closest to the surface is greater than or equal to 1,500
feet thick, forecast ice pellets. Finally, if the warm layer is between 600 and 1,200 feet thick, forecast ice pellets regardless of the height of the lower freezing level.

3.6.4. Rain

As mentioned above, if the freezing level closest to the surface is $\geq$ 1,200 feet AGL, forecast liquid precipitation (single freezing level). You can see that in the figure below, the lowest 1,200 feet is in the warm air (above freezing) and any precipitation that falls will be rain. Always keep in mind what we mentioned in the first paragraph, that warm or cold advection along with evaporative cooling will affect the height of the freezing level. Many “can’t miss” forecasts were missed because the forecaster didn’t take into account the low-level temperature advection. Refer to Figure 3-9 as a sample rain Skew-T sounding.

![Figure 3-9. Example Skew-T Indicating Rain](image)

3.6.5. Freezing Precipitation

Forecasting freezing precipitation can be one of the most daunting challenges a forecaster will face. The “windows of opportunities” are actually quite small for this phenomenon. If the thickness of the warm layer is too deep, all you will get is rain. Too shallow, and all that will fall is frozen precipitation, such as snow or ice pellets. The smallest variations in temperature (as little as tenths of degrees) can mean a difference between rain, freezing rain, ice pellets, and snow.

Freezing rain occurs less frequently than other winter weather events and falls in very narrow bands, usually not more than 30 miles wide. It is essential to use the Skew-T when determining the vertical temperature profile for use in forecasting freezing precipitation. See Figure 3-10.
The basic conditions necessary for freezing precipitation to occur are a shallow layer of sub-freezing air near the ground with warmer, moist air overriding it (providing the air is sufficiently moist to produce steady precipitation). Ideally, freezing precipitation occurs ahead of a warm front, which is moving over a cold (below freezing) surface. This situation usually produces a widespread area of freezing precipitation due to the advection of warm moist air over the frontal boundary.

Other notable areas favorable for synoptic scale freezing precipitation are north of a stationary boundary as moist air overruns an arctic or polar air mass and to the rear of a continental polar/arctic cold front wedging in under warmer moist air.

### 3.6.7. Snow

A snow Skew-T will look similar to the one in Figure 3-11 below. The entire air mass is well below freezing. Any precipitation that falls will fall as frozen precipitation.

### 3.6.8. Ice Pellets

Ice pellets must have a deep cold pocket near the surface and a warm pocket aloft between 600-1,200 feet thick. As partially melted snow falls into the cold air, it refreezes into ice pellets. This usually occurs in narrow zones between areas of freezing precipitation and snow.
Figure 3-12. Example Skew-T Indicating Ice Pellets

The above Skew-T (Figure 3-12) is a little more challenging. At first glance, you may think that it may either be mixed precipitation or freezing rain. However, if you closely examine the height of the freezing level, you will see that it is approximately 1,500 feet above the ground with a 1,500-foot warm layer above that. Any snow that falls through this thick (1,500 feet) warm layer will melt into rain drops which in turn will refreeze into ice pellets as it falls through the deep cold layer (also 1,500 feet).

3.6.9. Mixed Precipitation

The above Skew-T is an example that shows probable mixed precipitation. This is due to the fact that the freezing level is between 600 and 1,200 feet deep. The warm air is not deep enough to cause all the frozen precipitation to melt completely.

Figure 3-13. Example Skew-T Showing Mixed Precipitation

9. What is the probability that precipitation will fall as snow if the height of the freezing level above the ground is 25 mb?
   a. 50%
   b. 60%
   c. 70%
   d. 90%
10. Your station is located at 35° N. Your surface temperature is 33° F with a dew point of 24° F. Aloft, you have an 850 mb temperature of 1° C, a temperature at 700 mb of –5° C, and a temperature of –14° C at 500 mb. What kind of precipitation should fall at your location?

   a. Rain
   b. Freezing rain
   c. Mixed rain and snow
   d. Ice pellets
   e. Snow

11. __________ (TRUE/FALSE) The freezing level should be between 600 and 1,200 feet for mixed precipitation.

12. What type of precipitation should you forecast with a 1000-500 mb thickness of 5330 meters and a 1000-850 mb thickness of 1275 meters?

3.7. Rain Forecasting Rules of Thumb and Techniques

There are several tools and techniques that you can use to help determine if you are going to get just a few drops of rain or a deluge. Many of these tools and techniques are listed in AFWA/TN-98/002, which covers forecasting precipitation. In this QTP we are going to go over a few of the ones that may be used in just about any region.

3.7.1. Cloud-Top Temperatures

The thickness of the cloud layer aloft and the temperatures in the upper-levels of clouds are usually closely related to the type and intensity of precipitation observed at the surface, particularly in the mid-latitudes (see Table 3-7). Climatology reveals the following:

- In 87% of the cases where drizzle was reported at the surface, the cloud-top temperatures were colder than –5° C.
- In 95% of the cases during continuous rain or snow and in 81% of the cases of intermittent rain or snow, the cloud-top temperatures were colder than –12° C; In 63% of the cases, cloud-top temperatures were colder than –20° C.

![Table 3-7. Relationship Between Cloud-Top Temperatures and the Probability of Showery Precipitation](image)

- 0° to -12°C: Slight possibility
- -13° to -40°C: Likely
- Below -40°C: Almost certain
3.7.2. Dew Point Depressions
Dew point depressions of less than or equal to 2° C on the 850 mb and 700 mb forecast products are a good indication of both overcast skies and potential precipitation, assuming there is potential for upward vertical motion.

3.7.3. Radar Signatures Associated with Heavy Rain
Monitoring Doppler and conventional weather radars is the best way to detect the potential for heavy rains and flooding. Pay particular attention to the signatures below:

- Rapidly growing echoes
- Slow-moving echoes
- Persistency (long lasting)
- Train echoes (echoes that move repeatedly over the same area)
- Tropical cyclones
- Slow moving lines
- Line Echo Wave Patterns (LEWPs)
- Converging echoes and lines

3.7.4. Satellite Signatures
MetSat imagery is a valuable tool to use in evaluating heavy rainfall potential. Consider forecasting heavy rains when any of the following parameters or signatures occur:

- Quasi-stationary thunderstorm systems, those that regenerate, and those that move over the same area
- Rapid horizontal expansion of thunderstorm anvil. Infrared (IR) imagery picks this up best
- Rapid vertical growth of convective clouds
- Thunderstorm tops colder than –62° C
- Overshooting tops
- Merging of convective cloud lines and thunderstorms
- Mesoscale Convective Complexes (MCCs)
- Thunderstorm anvil that stretch out in a thin narrow band and parallel to the upper-level wind flow. Studies show that thunderstorms will continue to regenerate slightly upstream from the original cells until the upper level wind pattern changes.
3.8. Drizzle Forecasting Rules of Thumb and Techniques

The basic requirements for significant drizzle are:

- A cloud layer or fog depth at least 2,000-feet thick.
- Clouds or fog must persist several hours to allow droplets time to form.
- Upward vertical motion to maintain the cloud layer or fog.
- A source of moisture to maintain the clouds or fog.

Note: Light drizzle can fall from radiation fog or sea fog without the help of upward vertical motions.

Except for the upward vertical motion, the requirements for drizzle can be determined by inspecting various weather products. Vertical motion at 700 mb is generally not relevant to fog and stratus. The vertical motion of concern is near the ground. Identify it by drawing streamlines on 925 mb charts to locate and track local axes of confluence. Drizzle onset is faster and more likely with stronger confluence. Sometimes, upslope flow produces the gentle vertical motion needed without observations that indicate local confluence. Similarly, persistent large-scale southerly flow naturally converges as it moves northward and can provide the needed low-level gentle upward motion. In the United States, southerly flow from the subtropical high will generally begin to converge the further it moves north. The lift associated with the front supplies the needed upward motion to generate large areas of fog and stratus with drizzle. In many of these instances, it is possible to observe the onset of drizzle at stations upstream and to extrapolate its movement. Extrapolation may serve only to improve timing on arrival of conditions.

3.9. Snow Forecasting Rules of Thumb and Techniques

Other than thunderstorms, which will be covered in the Convective Weather QTP, snow has probably had more studies and investigations completed than any other hydrometeor. Thus, there are plenty of rules of thumb and techniques.

3.9.1. General Guidance

The following are a few of the more common rules of thumb and techniques concerning heavy snow forecasting have been developed over the years:

- The average relative humidity for the layer from the surface to 500 mb must be at least 70 to 80% in order to get significant synoptic-scale precipitation.
- Snowfalls greater than 2 inches are associated with warm air advection and positive vorticity advection, assuming adequate moisture is available (except for lake and orographic effects).
- Most precipitation occurs within the 65% (or higher) relative humidity areas on model forecast charts. Similarly, most heavy precipitation occurs within the 80% (or higher) relative humidity area.
- The 850 mb -5°C isotherm usually bisects the area that receives heavy snow accumulation during the subsequent 12 hours.
• Heavy snow occurs in the area north of the 850 mb 0°C isotherm and south of the 850 mb -5°C dew point line or the 700 mb -10°C dew point line.

• Precipitation begins as the 700 mb ridgeline passes overhead. Snow usually ends at the 700 mb trough line (and in some cases, at the 500 mb trough line).

• The snow begins with passage of 500 mb ridge and ends at the 500 mb trough line or under a 500 mb closed low, and/or slightly downstream of the inflection point from where the 500 mb flow changes from cyclonic to anticyclonic.

• Heavy snow occurs to the left of the track of 850 mb low center where the 850 mb dew point is in range of -5°C to 0°C.

• The heavy snow band is along 60-180 nm left of the track of the surface low.

3.9.2. Forecasting the Location of Heavy Snow Relative to Synoptic Features

How can you determine the location of the heavy snow band for a moving low pressure system? Table 3-8 is a compilation of the rules concerning snowfall relative to synoptic patterns.

![Table 3-8. Synoptic Snowstorm Types](image-url)
Table 3-9 is a summarization of distances from different features where you would expect the heaviest snow band.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Down Stream Distance</th>
<th>Area Lateral Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 mb vorticity max</td>
<td>6.5° to 7°</td>
<td>2.5° to the left of path</td>
</tr>
<tr>
<td>Surface low-pressure center</td>
<td>5°</td>
<td>2.5° to the left of path</td>
</tr>
<tr>
<td>500 mb low center</td>
<td>1° of inflection point</td>
<td>Along track</td>
</tr>
<tr>
<td>700 mb low center</td>
<td></td>
<td>Along track</td>
</tr>
<tr>
<td>500 mb 12-hr height fall</td>
<td></td>
<td>Left of track</td>
</tr>
<tr>
<td>Intersection of 850 and 500 mb maximum wind axes</td>
<td></td>
<td>Along track</td>
</tr>
<tr>
<td>850 mb low center</td>
<td>3° to 12°</td>
<td>1° to 4° to the left</td>
</tr>
</tbody>
</table>

**Table 3-9. Location of Heaviest Snow Relative to Synoptic Features**

3.9.3. Vorticity and Heavy Snow Band Width

You typically find the heavy snow band along and left of the associated vorticity center track. Use the following thresholds to determine how wide your band will be.

- If the vorticity is <14, the band of heavy snow is < 150 miles wide.
- If the vorticity is 15 to 23, the heavy snow band is about ≥ 150 to 200 miles wide.
- If the vorticity is >24, the heavy snow band is about 225 miles wide.

3.9.4. Determining Snowfall Rates and Accumulation Using Weather and Visibility

Upstream visibility measurements can be used to estimate snowfall rates and average snow accumulations (see Table 3-10) assuming no changes are forecast.

Note: Strong surface winds may contribute to restricted visibility due to blowing snow.

<table>
<thead>
<tr>
<th>Average Accumulation (inches/hour)</th>
<th>Weather (snowfall rate)</th>
<th>Visibility (mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 inches/hour</td>
<td>Light</td>
<td>&gt; 5/8 mile</td>
</tr>
<tr>
<td>1 to 1.2 inches/hour</td>
<td>Moderate</td>
<td>5/16 to 5/8 mile</td>
</tr>
<tr>
<td>1.6 inches/hour</td>
<td>Heavy</td>
<td>&lt; 5/16 mile</td>
</tr>
</tbody>
</table>

**Table 3-10. Snowfall Accumulation Rates Based on Visibility**
3.9.5. Snow Index Using 200 mb Warm Advection (Cook Index)

This method, also known as the Cook Index, is generally most effective between October and March. It uses warm-air advection at 200 mb to forecast the snowfall amounts for the next 24 hours. Warm-air advection at 200 mb is the key indicator because the 200 mb warm pocket usually coincides with the 500 mb vorticity maximum, particularly in well-developed systems. Thus, warm-air advection at 200 mb is a way to measure weather system strength (see Figure 3-15).

Warm air normally occurs in the 200 mb troughs and the cold air occurs in the 200 mb ridges. Temperatures are usually -40° to -45° C in strong troughs and are -65° C or colder in strong ridges. Temperatures typically remain in the -50° C range with weaker systems. Generally at 200 mb, the direction and movement of the 500 mb vorticity maximum is parallel to a line connecting the 200 mb warm and cold pockets. Two exceptions to this are in the case of large-scale cyclonic flow over North America associated with rapidly moving short waves, or cutoff lows in the southwest United States that have remained nearly stationary for the previous 24 hours. If the storm is not well developed vertically (i.e., weak 200 mb temperature contrasts), heavy snow usually does not occur. If dynamics are strong, moisture usually advects into the storm.

When there is warm-air advection at 700 mb into a snow threat area, the total average snow accumulation for the next 24 hours (providing the column of air is cold enough for snow) is given, in inches, by the following: Determine the amount of warm air advection at 200 mb by taking the difference (° C) between the warm core in the trough and the cold core in the ridge area; then divide by 2, ignoring the units. If the indicated warm air advection extends less than 6° latitude (360 nm) upstream from the forecast area, the precipitation is usually of short duration.

- If there is cold-air advection at 700 mb into the snow threat area (or if it’s observed within 8° of latitude (480 nm) of the forecast area at 700 mb), the total snow accumulation is estimated by dividing the amount of warm-air advection at 200 mb by 4.

- The maximum snowfall occurs near the coldest 200 mb temperature found downstream from the warmest 200 mb temperature.

![Figure 3-15. Snow Index Using 200 mb Warm Advection](image)
Example: The Cook Index uses warm and cold pockets at 200 mb, with the warm pocket upstream. If the warm pocket is ill-defined, use the vorticity max center temperature at 200 mb as the warm pocket. Warm and cold pockets must be no more than 14° latitude (840 nm) apart in 24 hours and 21° (1,260 nm) apart in 36 hours. Take the temperature difference between the warm and cold pockets at 200 mb. Maximum snowfall is the temperature difference with the average 1/2 the temperature difference. If cold air advection at 700 mb is within 8° latitude (480 nm), use 1/4 of the difference. The heavy snow swath is mostly parallel to the 200 mb contours. Notes of caution: Do not forecast heavy snow beneath strong confluence area nor south of surface lows. With northwest flow aloft, systems move rapidly and produces snowfall of less than 2 inches. Using Figure 3-8, there is 10° of WAA (warm pocket to cold pocket), so the average snowfall is 5 inches with a max of 10 inches. Use other rules to determine exactly where.

3.9.6. Using RADAR to Determine Snow Intensities

Another way of determining visibility while it’s snowing is to correlate the dBZ return on the WSR-88D with snow intensity (see Table 3-11). Remember that intensity of snow is directly related to visibility as long as this is the only phenomenon occurring at the time. In general, snow giving radar returns between -4 and -28 dBZ is most likely not reaching the ground. The following are general guidelines to help determine snow intensity:

<table>
<thead>
<tr>
<th>Radar Returns</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4 dBZ to +4 dBZ</td>
<td>Flurries</td>
</tr>
<tr>
<td>+4 dBZ to +16 dBZ</td>
<td>Light Snow</td>
</tr>
<tr>
<td>+16 dBZ and higher</td>
<td>More Significant Snowfall</td>
</tr>
</tbody>
</table>

Table 3-11. Radar Returns and Snow Intensity

3.9.7. Forecasting Snow Begin and End Times

Here are some rules to determine the begin and end times of snow.

- Snow begins as the 700 mb ridge passes overhead (often rain at first)
- Snow ends at 700 mb trough line (some cases the 500 mb trough line)
- Heavy snow begins with the 500 mb ridge line and ends when the inflection point passes
- Snow occurs at the 500 mb inflection point downstream from the trough under the max wind
- Trough temperatures usually will be -20° C or colder

3.9.8. Forecasting Snowfall Amounts Using Numerical Outputs

This is a forecast snowfall amount method developed as a quick, practical way to estimate snowfall amount using the numerical model output (FOUM/FOUE/FOUW/FXPA) bulletins and a water equivalent conversion table already in use as an observing aid. Typically, snowfall amounts are estimated on the basis of a 1:10 ratio. However, you may use another ratio if it is more representative for your station or the snowfall event. Table 3-8 in temperature and can help you fine tune snowfall forecasts.
Example: You are forecasting for McConnell AFB, KS and are expecting a big change in the weather regime within 24-36 hours as a Colorado type Low will move across the southern Great Plains and south of McConnell. You know it is going to snow and the Wing Commander wants an estimate of how much. Looking at surface and upper air charts, it looks like McConnell will be in the swath of heavy snowfall. The surface low will pass between 100 and 125 miles south of the base. The vorticity center, with a value of +17, will also pass south. The 1000-500 mb 5340 thickness line will be over the station.

The TOP FOUM bulletin shows:

<table>
<thead>
<tr>
<th>TTPTTR1R2R3</th>
<th>VVVLI</th>
<th>PSDDFF</th>
<th>HHT1T3T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOP</td>
<td>42 37 12</td>
<td>000 05</td>
<td>27 1613</td>
</tr>
<tr>
<td>06 000 56 43 20</td>
<td>003 03</td>
<td>23 1719</td>
<td>34 96 93 91</td>
</tr>
<tr>
<td>12 000 63 51 27</td>
<td>007 02</td>
<td>21 1723</td>
<td>35 97 94 91</td>
</tr>
<tr>
<td>18 000 68 62 39</td>
<td>008 02</td>
<td>13 1433</td>
<td>36 98 94 91</td>
</tr>
<tr>
<td>24 007 73 77 62</td>
<td>019 01</td>
<td>08 1036</td>
<td>35 99 94 91</td>
</tr>
<tr>
<td>30 013 82 83 75</td>
<td>021 01</td>
<td>02 0737</td>
<td>35 98 93 90</td>
</tr>
<tr>
<td>36 006 94 92 83</td>
<td>011 00</td>
<td>04 0233</td>
<td>34 96 92 89</td>
</tr>
<tr>
<td>42 000 98 97 91</td>
<td>010 99</td>
<td>13 3428</td>
<td>34 94 92 89</td>
</tr>
<tr>
<td>48 000 89 86 71</td>
<td>-09 04</td>
<td>20 3223</td>
<td>31 93 89 85</td>
</tr>
</tbody>
</table>

The FOUM bulletin shows a precipitation total (PTT) of .26 for the period of the snow event. A typical 1:10 ratio would yield 2.6 inches of snow. However, you forecast the temperature to be around 31°F at the start of snowfall, and down to 24°F by the time the snowfall ends. From the table, a temperature of 31°F will yield the typical 1:10 ratio, but a temperature of 24°F indicates a 1:15 ratio. Figure an average temperature of 27°F—a 1:15 ratio. This indicates a better estimate would be around 4 inches (.26 x 15) of snow versus 2.6 inches (.26 x 10). Base response actions may be different for 4 inches rather than the lesser amount and save money and lessen mission degradation.
<table>
<thead>
<tr>
<th>Meltwater Equivalent (WE) In Inches</th>
<th>New Snowfall (Inches)</th>
<th>Temperature °F (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trace</td>
<td>Trace</td>
<td>0.1 0.2 0.0 0.4 0.5 1.0</td>
</tr>
<tr>
<td>.01</td>
<td>0.1 0.2 0.0 0.4 0.5 1.0</td>
<td></td>
</tr>
<tr>
<td>.02</td>
<td>0.2 0.3 0.4 0.6 0.8 2.0</td>
<td></td>
</tr>
<tr>
<td>.03</td>
<td>0.3 0.5 0.6 0.9 1.2 2.0</td>
<td></td>
</tr>
<tr>
<td>.04</td>
<td>0.4 0.6 0.8 1.2 1.2 2.0</td>
<td></td>
</tr>
<tr>
<td>.05</td>
<td>0.5 0.8 1.0 1.5 2.0 2.0</td>
<td></td>
</tr>
<tr>
<td>.06</td>
<td>0.6 0.9 1.2 1.8 2.4 3.0</td>
<td></td>
</tr>
<tr>
<td>.07</td>
<td>0.7 1.1 1.4 2.1 2.8 3.5</td>
<td></td>
</tr>
<tr>
<td>.08</td>
<td>0.8 1.2 1.6 2.4 3.2 4.0</td>
<td></td>
</tr>
<tr>
<td>.09</td>
<td>0.9 1.4 1.8 2.7 3.6 4.5</td>
<td></td>
</tr>
<tr>
<td>.10</td>
<td>1.0 1.5 2.0 3.0 4.0 5.0</td>
<td></td>
</tr>
<tr>
<td>.11</td>
<td>1.1 1.7 2.2 3.3 4.4 5.5</td>
<td></td>
</tr>
<tr>
<td>.12</td>
<td>1.2 1.8 2.4 3.6 4.8 6.0</td>
<td></td>
</tr>
<tr>
<td>.13</td>
<td>1.3 2.0 2.6 3.9 5.2 6.5</td>
<td></td>
</tr>
<tr>
<td>.15</td>
<td>1.5 2.3 3.0 4.5 6.0 7.5</td>
<td></td>
</tr>
<tr>
<td>.16</td>
<td>1.6 2.4 3.2 4.8 6.4 8.0</td>
<td></td>
</tr>
<tr>
<td>.17</td>
<td>1.7 2.6 3.4 5.1 6.8 8.5</td>
<td></td>
</tr>
<tr>
<td>.18</td>
<td>1.8 2.7 3.6 5.4 7.2 9.0</td>
<td></td>
</tr>
<tr>
<td>.19</td>
<td>1.9 2.9 3.8 5.7 7.6 9.5</td>
<td></td>
</tr>
<tr>
<td>.20</td>
<td>2.0 3.0 4.0 6.0 8.0 10.0</td>
<td></td>
</tr>
<tr>
<td>.21</td>
<td>2.1 3.1 4.2 6.3 8.4 10.5</td>
<td></td>
</tr>
<tr>
<td>.22</td>
<td>2.2 3.3 4.4 6.6 8.8 11.0</td>
<td></td>
</tr>
<tr>
<td>.23</td>
<td>2.3 3.4 4.6 6.9 9.2 11.5</td>
<td></td>
</tr>
<tr>
<td>.24</td>
<td>2.4 3.6 4.8 7.2 9.6 12.0</td>
<td></td>
</tr>
<tr>
<td>.25</td>
<td>2.5 3.8 5.0 7.5 10.0 12.5</td>
<td></td>
</tr>
<tr>
<td>.30</td>
<td>3.0 4.5 6.0 9.0 12.0 15.0</td>
<td></td>
</tr>
<tr>
<td>.35</td>
<td>3.5 5.3 7.0 10.5 14.0 17.5</td>
<td></td>
</tr>
<tr>
<td>.40</td>
<td>4.0 6.0 8.0 12.0 16.0 20.0</td>
<td></td>
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<tr>
<td>.45</td>
<td>4.5 6.8 9.0 13.5 18.0 22.5</td>
<td></td>
</tr>
<tr>
<td>.50</td>
<td>5.0 7.5 10.0 15.0 20.0 25.0</td>
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<tr>
<td>.60</td>
<td>6.0 9.0 12.0 18.0 24.0 30.0</td>
<td></td>
</tr>
<tr>
<td>.70</td>
<td>7.0 10.5 14.0 21.0 28.0 35.0</td>
<td></td>
</tr>
<tr>
<td>.80</td>
<td>8.0 12.0 16.0 24.0 32.0 40.0</td>
<td></td>
</tr>
<tr>
<td>.90</td>
<td>9.0 13.5 18.0 27.0 36.0 45.0</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>10.0 15.0 20.0 30.0 40.0 50.0</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>20.0 30.0 40.0 60.0 80.0 100.0</td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td>30.0 45.0 60.0 90.0 120.0 150.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WE Ratio</th>
<th>1:10</th>
<th>1:15</th>
<th>1:20</th>
<th>1:30</th>
<th>1:40</th>
<th>1:50</th>
<th>1:100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note: For temperatures above 34° F (1° C) or for slushy, wet snow, a 1:8 ratio may be appropriate, e.g. .10&quot; WE = 0.8&quot; snowfall, .15&quot;WE = 0.1&quot; snowfall.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3-8. New Snowfall to Meltwater Equivalent (WE) Conversion Table
13. While on a deployment to Europe, you notice the cloud-top temperatures are \(-46^\circ C\), what is the probability of showers?

14. For significant drizzle to occur, how deep should the fog or cloud layer be?

15. One way to determine visibility while it’s snowing is to correlate the dBZ return on the WSR-88D with snow intensity. What type of snow intensity would you forecast if you were getting +10dBz returns?

16. __________ (TRUE/FALSE) An anticipated low has slowed down. An upstream station had a visibility of <5/16 mile in snow for two hours instead of one. You anticipate the same conditions at your location. Your 4-inch snowfall should be upgraded at least to 6 inches. Why?

### 3.10. Blowing Snow Forecasting Rules of Thumb and Techniques

The occurrence of blowing snow depends on the state of the snow surface and the wind speed. If there is newly fallen snow and it is dry and fluffy, a forecast of strong winds (>15 kts) should be accompanied by a forecast of reduced visibility due to blowing snow. The condition of the snow and the strength of the wind determine the degree to which the visibility is reduced. Use locally derived rules to assess the wind speed needed to restrict visibility based on the elements typical of your location. If your unit has not developed local rules of thumb, use the following rules to guide you as you create your forecast:

- Snow cover that has previously been subjected to wind movement (either blowing or drifting) will produce a less severe visibility restriction than snow not previously blown.
- Snow that fell when temperatures were near freezing will not blow readily but may blow with very strong winds.
- Snow pack, which has been undisturbed for a long period of time, will be stabilized by long term internal changes.
- Within a given blowing snow period, increases (decreases) in wind speed are generally associated with decreasing (increasing) visibilities.
- Loose snow becomes blowing snow at wind speeds of 10-15 knots or greater.
- The degree of visibility restriction depends on the terrain, wind speed and snow composition.
- Fresh snow will normally be loose at temperatures of \(-20^\circ C\) (\(-4^\circ F\)) or less.
- Snow exposed to sunlight (SCT - BKN) for 3 days will have a crust and will not drift or blow (Remember, the crust is not uniform on snowfields, shadows and vegetation can retard snow crust).
If snow falls onto a snow pack that has already crusted, only the added snow will blow and drift.

### 3.11. Lithometeors - Haze

Haze normally restrict visibility to between 3 and 6 miles, but can occasionally reduce visibility to less than 1 mile, especially around and near metropolitan areas or under a strong inversion for several days or more. Dry haze usually dissipates and visibility begins to improve when the atmosphere becomes thermally unstable or wind speeds increase. This can occur with heating, advection or turbulent mixing. Salt haze along coastal areas reduces visibilities to 4-6 miles when wind speeds increase to above 15 knots.

Haze, like fog, requires a stable environment. Haze is an accumulation of very fine dust or salt particles (which are so small that they cannot be individually seen by the naked eye) in the atmosphere; they do not block light, instead they cause light rays to scatter. Haze generally restricts visibility to no less than 3 miles except in large metropolitan areas. Dry haze particles produce a bluish color when viewed against a dark background, but look yellowish when viewed against a lighter background. This light-scattering phenomenon (called Mie scattering) also causes the visual ranges within a uniformly dense layer of haze to vary depending on whether the observer is looking into the sun or away from it. Typically, dry haze occurs under a stable atmospheric layer and significantly affects visibility. As a rule, industrial areas and coastal areas are most conducive to dry haze formation.

#### 3.11.1. Satellite Indicators

Haze and pollution (smog) will appear on MetSat imagery in stable conditions with light winds.

- **VIS:** Haze appears as dull, filmy, and diffuse with a light to medium gray shade. It is easier to see over dark terrain.
- **IR:** Haze appears only if it is at high altitudes or in large concentrations. Contamination is a major consideration.

#### 3.11.2. Dissipation of Haze

Haze usually dissipates, as the atmosphere becomes unstable. Heating of the atmosphere by an increase of solar radiation and/or warm air advection may cause instability. Turbulent mixing may also disturb the stable atmosphere.

### 3.12. Lithometeors - Smoke

Smoke is fine ash particles suspended in the atmosphere. When smoke is present, the sun appears red at sunrise and sunset, and has a reddish tinge during daytime. Smoke at a distance, such as from a forest fire, usually has a light grayish or bluish color and is evenly distributed in the air. Smoke is usually seen as a layer unless you are very close to the source or the atmosphere is extremely stable.

#### 3.12.1. Dissipation of Smoke

The conditions needed for the dissipation of smoke is similar to that of haze. The only difference is that the source of the smoke needs to be eliminated before all the smoke will dissipate. Caution: Residual ash in the air can be the condensation nuclei needed for new fog formation.
3.13. Lithometeors - Blowing Sand and Dust

Blowing sand and dust is basically a function of the wind speed and direction along with the soil composition and moisture content. The degree of restriction often differs between stations. Hot, dry and windy locations as you might expect are the areas most susceptible for these phenomena. Favorable conditions for blowing dust and sand are found in desert regions and in areas where the surface has been disturbed by activities such as military operations, construction, etc (refer to Table 3-12). Arid and semi-arid locations in CONUS (typically west of roughly 97° W) are subject to dust and/or sand storms either due to high winds ahead and behind fronts or ahead of high-based LP (dry) thunderstorms. Drought regions, in conjunction with haphazard irrigation practices are also likely places where blowing dust and sand can be found. Winds greater than 15 knots are required to raise and transport significant amounts of fine dust (Saudi Arabia, Iraq/Iran, and Sahara Desert). Winds greater than 25 knots are required to raise and transport sand/soil. The most severe cases of blowing dust/sand are associated with desert thunderstorm outflow boundaries (called "haboobs" in the Middle East). High winds behind a cold front can blow sand or dust hundreds of miles horizontally and thousands of feet aloft. Once this fine dust is lifted, it may remain suspended for days after the wind subsides. This is common in the Far East with the “Yellow Wind.”

As mentioned above, forecasting blowing sand and dust differs for every station, and are predominately local problems. Check for the availability of local forecast studies to find out more about forecasting blowing sand and dust.

Caution: Blowing dust and sand are hazardous to aircraft and machinery even if visibility is not restricted. Dust and sand get into moving parts and scratch or score surfaces causing wear and tear of the parts.
Figure 3-16. Multi-Channel Satellite Images of a Dust Storm

<table>
<thead>
<tr>
<th>Parameter or Condition</th>
<th>Favorable When</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location With Respect to Source Region</td>
<td>Located Downstream and in Close Proximity</td>
</tr>
<tr>
<td>Agricultural Practices</td>
<td>Soil Left Unprotected</td>
</tr>
<tr>
<td>Previous Dry Years</td>
<td>Plant Cover Reduced</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>$\geq 30$ kt</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>Southwest Through Northwest (Dust Source Upstream)</td>
</tr>
<tr>
<td>Cold Front</td>
<td>Passes Through the Area</td>
</tr>
<tr>
<td>Squall Line</td>
<td>Passes Through the Area</td>
</tr>
<tr>
<td>Leeside Trough</td>
<td>Deepening and Increasing Winds</td>
</tr>
<tr>
<td>Thunderstorm</td>
<td>Mature Storm in Local Area or Generates Blowing Dust Upstream</td>
</tr>
<tr>
<td>Whirlwind</td>
<td>In Local Area</td>
</tr>
<tr>
<td>Time of Day</td>
<td>1200 to 1900L</td>
</tr>
<tr>
<td>Surface Dew Point Depression</td>
<td>$\geq 10^\circ$C</td>
</tr>
<tr>
<td>Potential Advection</td>
<td>Blowing Dust Generated Upstream</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>$\geq 10$ kt</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>Along Trajectory of the Generated Dust</td>
</tr>
<tr>
<td>Synoptic Situation</td>
<td>Ensures the Wind Trajectory Continues to Advect Dust</td>
</tr>
</tbody>
</table>

Table 3-9. Favorable Conditions for Blowing Dust and Sand

17. Which of the following statements is FALSE?
   a. If snow falls onto a snow pack that has already crusted, only the added snow will blow and drift.
   b. Snow exposed to sunlight (SCT - BKN) for 3 days will not have a crust, and so it is subject to drift or blow.
   c. Loose snow becomes blowing snow at wind speeds of 10-15 knots or greater.
   d. Fresh snow will normally be loose at temperatures of -20\(^\circ\)C (-4\(^\circ\)F) or less.
18. Haze is an accumulation of ____________________________ in the atmosphere.

19. Haze generally restricts visibility to no less than ___________ miles except in large metropolitan areas.
   
   a. 5  
   b. 4  
   c. 3  
   d. 2  

20. How does haze usually dissipate?

3.14. Air Refueling In-Flight Visibility

In these days of rapid deployment to global “hot spots,” many air refueling missions occur. Could you determine in-flight visibility? The most critical time during air refueling, as far as in-flight visibility is concerned, is just prior to and during hookup when hookup must be accomplished visually. Once hookup is accomplished, in-flight visibility should not interfere with the refueling operation. Aircrews base the current GO/NO GO decision for air refueling on in-flight visibility of less than 1 nautical mile. Aircraft involved in air refueling operations will often descend or ascend within the 5,000-foot air refueling route (AR) window to seek better in-flight visibility. Usually aircrews conduct air refueling operations at altitudes generally above 23,000 feet with an altitude of 29,000 feet considered optimum. In-flight visibility is optimal (7+ nautical miles) when the AR is cloud free, but many ARs tend to cover several hundred miles. Most of the time in certain AORs, clouds are likely to be present along a portion of a given AR. Use the following rules of thumb gleaned from several “old” sources.

3.14.1. Cloud Cover

This rule uses cloud cover amount for determining in-cloud flight visibility when the cloud deck is assumed to be greater than or equal to 2,000 feet in thickness.

   - Clear -- 7+ nautical miles  
   - 3/8 or less -- More than 3 nautical miles  
   - 3/8 to 5/8 -- 1 to 3 nautical miles  
   - 6/8 to 8/8 -- Less than 1 nautical mile

3.14.2. Temperature/Dew Point Depressions

Another rule of thumb for determining in-cloud flight visibility is by using temperatures. When the temperature is below -30° C, then the in-cloud flight visibility will be a 1/2 nautical mile for each degree of dew point depression.

   **Example:** A dew point depression of 4° C (SCT to BKN) would yield an in-cloud flight visibility of 2 nautical miles, and a dew point depression of 1° C (OVC) would yield 1/2 nautical mile.
3.14.3. Cloud Thickness
In-cloud flight visibility may be approximated based upon cirriform cloud thickness. Keep in mind that the vertical visibility in thin cirrus is usually better than the horizontal visibility. Even though ground observers can see up through the cirrus or pilots can see the ground through it, the horizontal visibility in the cirrus may be limited. Common rules of thumb are:

- If the cloud deck is thin-broken to thin-overcast, forecast 1-2 nautical miles in-cloud flight visibility.
- If the cloud deck is thicker (i.e., opaque, broken to overcast), forecast 1/2 nautical mile in-cloud flight visibility.

3.14.4. Thunderstorm Cirrus
Due to the variability in conditions, thunderstorm cirrus is possibly the most difficult in-cloud flight visibility to forecast for. This cirrus ranges from layered and sporadic (i.e., patchy) too thick and dense. Some common rules of forecasting in-cloud flight visibility are:

- If there is no significant cloud cover (3/8 or less) at flight level, forecast at least 3 nautical miles in-flight visibility.
- If there is significant cloud cover (4/8 or more) but at least 2,000 feet vertical airspace with 3/8 or less clouds between layers, forecast 1 to 3 nautical miles in-flight visibility.

3.15. Whiteout Conditions
Whiteout is a visibility-restricting phenomenon that is neither a lithometeor nor a hydrometer. A whiteout occurs when a uniformly overcast layer of clouds overlies a snow- or ice-covered surface. Most whiteouts occur when the cloud deck is relatively low, and the sun angle is at about 20° above the horizon. Cloud layers break up and diffuse parallel rays from the sun so that they strike the snow surface from many angles. This diffused light reflects back and forth between the snow and clouds until the amount of light coming through the clouds equals the amount reflected off the snow, completely eliminating shadows. The result is a loss of depth perception and an inability to distinguish between the ground and the sky (i.e., there is no horizon). Low-level flights and landings in these conditions become very dangerous (see Figure 3-17). There are currently no known forecasting rules of thumb or techniques for whiteouts.

---

Figure 3-17. Whiteout Conditions
21. _________ (TRUE/FALSE) As far as in-flight visibility is concerned, the most critical time during air refueling is the actual air refueling after hookup.

22. An air refueling mission is scheduled at FL260. The OAT is –34° C and a dew point depression of 7 C°. Will the mission have 1 nautical mile in-flight visibility?

23. Under what conditions do most whiteouts occur?

At this point, your trainer and/or certifier should answer any questions you, the trainee, have or to clarify any points you are still unclear on. Your trainer and/or certifier should also review local/regional rules-of-thumb and techniques developed in your AOR(s) with you.
MODULE 4 - TEMPERATURES

TRAINEE’S NAME______________________________

CFETP REFERENCE: 14.3.

MODULE OVERVIEW:
This module discusses temperature concepts, principles and processes, techniques, and rules of thumbs that apply toward making a temperature forecast. Also discussed in this module are the variables influencing temperature change (indices of “apparent” temperatures).

TRAINING OBJECTIVES:

- **OBJECTIVE 1**: Be able to demonstrate that you understand the general rules, techniques, principles and procedures of forecasting temperatures by answering questions with least 80% accuracy.

- **OBJECTIVE 2**: Using either real-time weather data or canned scenarios, be able to provide solutions and answers to questions concerning different temperature parameters with at least 80% accuracy.

EQUIPMENT AND TRAINING REFERENCES:

- AFWA/TN-98/002, *Meteorological Techniques*
- AFMAN 15-124, *Meteorological Codes*
- AFMAN 15-111, *Surface Weather Observations*
- AFH 11-203, Volume 1, *Weather for Aircrews*
- METOC 50-1P-0002, Volume 5, *Introduction to Forecasting: Forecast Charts and Forecasting Weather Elements*
- *Meteorology Today: An Introduction to Weather, Climate and the Environment*
- SC 01W01A, Volume 3, *Weather Element Forecasting, Flight Hazards, and Limited Data*
- AWS/TR-79/006 (Revised), *The Use of the Skew-T, Log P Diagram in Analysis and Forecasting*
- Aerographer’s Mate 1 & C
PREREQUISITES AND SAFETY CONSIDERATIONS:

- Be familiar with interpreting weather features off MetSat imagery
- Have a firm grasp on the analysis and prognosis rules and techniques discussed in the Analysis and Prognosis QTP
- Familiarity with the TAF code found in Chapter 1, AFMAN 15-124, *Meteorological Codes*
- Familiarity with the sections on temperatures found in AFMAN 15-111, *Surface Weather Observations*

ESTIMATED MODULE TRAINING TIME: 2.5 Hours
CORE TRAINING MATERIAL AND REVIEW QUESTIONS

4.1. Temperature

A temperature forecast is one of the most frequently requested services that you will provide. Temperature plays a big role in the lives of every person on installations or in the field. Air temperature affects the abilities of people trying to accomplish the mission as well as the equipment they operate, so it’s very important to forecast this phenomena accurately. There are several factors to consider when it comes to forecasting air temperatures. They are insolation and radiation, advection, mixing, and adiabatic process.

4.1.1. Insolation and Radiation

Insolation is defined as the incoming solar radiation that reaches the earth or atmosphere. Insolation is probably the biggest factor when considering the temperature forecast. Stations at low latitudes (closer to the equator) receive more heat during the day than stations at high latitudes (closer to the poles). Expect more daytime heating in the summer months than in the winter months, since during the summer months the sun's rays are more direct and reach the earth for a longer period of time (see Figure 4-1). Normally, there is a net gain of heat during the day and a net loss at night. Consequently the maximum temperature is usually reached during the day, and the minimum at night.

![Figure 4-1. The Sun and Temperatures](image)

4.1.2.1. Effects of Cloud Cover on Insolation

Cloud cover affects how much insolation reaches the earth’s surface. Temperature forecasts must be made only after the amount of cloudiness is determined. Clouds reduce the amount of short-wave radiation reaching the surface of the earth and thus reduces the amount of terrestrial radiation reflected back into the atmosphere causing daytime temperature readings to be relatively lower than normally expected. Cloud cover at night will prevent the escape of terrestrial radiation into space and cause the retransmission of long wave radiation from the cloud bases back towards the surface, much like a greenhouse. This causes the nighttime temperatures to be relatively higher. The stability of the lapse rate has a marked effect on insolation and terrestrial radiation. With a stable lapse rate, there is less vertical extent to beat; therefore, surface hearing takes place more rapidly. The opposite is true with an
unstable lapse rate. An inversion results in less cooling, since the surface temperature is lower than that of the inversion layer; that is, at some point the energy radiated by the surface is balanced by that radiated by the inversion layer.

4.1.2.2. Effect of Snow Cover on Insolation

As incoming solar radiation reaches the earth’s surface, much of it is absorbed and re-radiated. This causes air near the earth’s surface to warm. If snow is present on the ground, some of the sun’s energy melts the snow, but a lot of radiation is reflected away by the snow as shortwave radiation that doesn’t heat the air (see Figure 4-2). The combination of these two factors means that there is less energy available to heat the earth’s surface. The temperatures will rise more slowly than they would if there was no snow on the ground.

![Figure 4-2. Insolation and Snow Cover](image)

4.1.2. Advection

One of the biggest factors affecting temperature is the advection of air. Advection is particularly marked in its effect on temperature with frontal passage. If a frontal passage is expected during the forecast period, the temperature must be considered. Advection within an air mass may also be important. This is particularly true of sea and land breezes and mountain breezes. They affect the maximum and minimum temperatures and their time of occurrence.

4.1.2.1. Effect of High and Low Pressure Centers on Forecast Temperatures

The position of low and high pressure and the accompanying circulation will greatly influence your temperature forecast.

If your station is located on the west side of a high pressure center, then the winds will generally be from the south, which usually means warmer temperatures. If your station is located on the east side of the high pressure, then your temperatures will typically be less due to the cool northerly flow. Refer to Figure 4-3.
The best way to forecast temperatures with frontal passages is by extrapolation. Using the current surface product and forecast products, determine the position that your station will have relative to the front at forecast time. Determine the current temperature from a station having the same relative position with respect to the front that your station will have at forecast time. Modify this temperature for terrain cover, elevation difference, changes in cloud cover, and additional time that the new air has spent over warmer or cooler ground, and you have a close approximation of the temperature that you can expect.

Remember that the time of day the front passes your station has some influence on the temperature change. Also, keep in mind that a cold front having little cloudiness associated with it may show only a small temperature discontinuity across the front during the hours of maximum cooling, and a large temperature discontinuity during maximum heating.

**Figure 4-3. Temperature Advection Around A High Pressure Cell**

In the vicinity of a low-pressure center, it is critical to your temperature forecast to fully understand what kind of advection will be occurring during your forecast period. A simple model of an unstable wave is seen in Figure 4-4. Simply stated, if you’re on the east side of the cold front, then you are in the warm sector, and your temperatures should rise until frontal passage. If you’re west of the cold front, then you will have cold air advection over your station, and your temperatures will typically fall. If your station is located north of the warm front, then you will be in the relatively cooler air mass until passage of the warm front, which should cause your temperatures to increase.

**Figure 4-4. Temperature Advection Around A Low**
4.1.3. Mixing

Vertical heat transport is another temperature factor that you must consider. Wind speeds are a major factor in vertical heat transport. Condensation and evaporation are also forms of the vertical heat transfer process. Entrainment figures prominently in the condensation and evaporation mixing processes.

4.1.3.1. Mixing Effect of Wind on Forecast Temperature

The mixing process is effected considerably by the speed of the wind. With strong wind conditions, the amount of heating and cooling at the surface is reduced over conditions with light or calm wind, since the heat energy gained or lost is distributed, in windy conditions, through a deeper layer of the atmosphere. At night, under clear skies, the earth cools by radiating heat into space. Since the strongest cooling takes place near the surface of the earth, a temperature inversion sets up near 3,000 feet. If the winds are strong enough they may weaken or inhibit the formation of the inversion.

This mixing effect is illustrated in Figure 4-5. The stronger winds aloft will cause the air to spin clockwise forcing warmer air towards the surface. This overturning air is how the relatively warmer air is brought towards the surface on windy nights (cold air aloft mixes the same way and generally mixes to the surface better than warm air due to warm air buoyancy).

![Figure 4-5. Effect of Wind on Temperature](image)

4.1.3.2. Evaporation and Condensation Effects on Temperature

When rain falls through the air, evaporation occurs, taking heat from the surrounding air. In the case of strong thunderstorms, the cold air is entrained by water and/or hails towards the surface--resulting in temperature drops of 30° F or more. After the rain ends, evaporation continues to cool temperatures.
The temperature may also be affected by the condensation process. This is frequently observed during fog formation. The temperature raises a degree or so because of the release of the latent heat. Typically, when snow or rain (condensation process) falls ahead of a warm front, some latent heat is released. This falling precipitation entrains the warmer ambient air to the surface. Thus, you see temperature rises while it is raining or snowing at your location. This is a point to consider when you have freezing rain or drizzle affecting operations and need to determine when it will warm to above freezing.

1. List four factors to consider when it comes to forecasting air temperatures.

2. Why there is more daytime heating in the summer months than in the winter months?

3. __________ (TRUE/FALSE) Clouds reduce the amount of short wave radiation reaching the surface of the earth and thus reduces the amount of terrestrial radiation reflected back into the atmosphere causing daytime temperatures to be lower than if no clouds were present.

4. __________ (TRUE/FALSE) Cloud cover at night will prevent the escape of terrestrial radiation into space and cause the transmission of long wave radiation from the cloud bases back towards the surface, much like a greenhouse. This causes the nighttime temperatures to be relatively cooler than if no clouds were present.

4.2. Maximum Temperature Forecasting

Maximum temperatures can be determined several ways. Of course, besides the methods below, many stations have developed subjective and/or objective techniques for forecasting maximum temperatures. Where local forecast techniques exist, use them, but for the location where no local techniques exist, use the following ways to make a maximum temperature forecast.

4.2.1. Advection Method

The advection method is normally the best method to use if a frontal passage is anticipated. Use the following steps to approximate your maximum temperature under the approaching air mass.

- On the current surface product, select a station that typifies the air you expect over your station at forecast time (trajectory bulletins can assist you in determining where the air over your station is coming from).
- Use the maximum temperature reported by that station as the first estimate of your station’s maximum temperature.
- Modify the first estimate for adiabatic effects by determining the difference in station elevation. Add 5.4° F for each 1,000 feet of elevation your station is below the
station (Figure 4-6), or subtract an equal amount for each 1,000 feet of elevation your station is above the other station (Figure 4-6).

- Consider the cloud cover that is expected and how it will alter the effects of insolation. If precipitation or evaporation is anticipated, consider how either condition effects the temperature. Modify your forecast temperature accordingly.

![Figure 4-6. Elevation Effects on Temperature Advection](image)

**Example:** If you are located at station B and the flow was from station A, then you would need to subtract 5.4° F from 68° F as your first guess at a high temperature. If you are located at point A, and the flow was from point B, then you need to add 5.4° F to get an indication of the expected high temperature.

### 4.2.2. Skew-T

There are several time-honored ways to forecast maximum temperatures using the Skew-T. Although you can use the manual Skew-T (hand plotted), but most stations rely on automated Skew-Ts. These methods are just as effective.

#### 4.2.2.1. CLR to SCT Method

Use the following method to forecast maximum temperature under clear to scattered skies if you are not expecting an air mass change and the sounding represents the air you expect over your station during maximum heating. The temperature you read at the surface is a good estimate of the afternoon maximum temperature if few or no clouds develop.

**Note:** In Europe, north of the Alps, this method only works from mid-March through mid-September.

- Use an early morning sounding.
- Follow the dry adiabat from the 850 mb temperature down to the surface (see Figure 4-7). Use 700 mb if the station elevation is above the 850 mb level.
4.2.2.2. BKN to OVC Method

This method is also known as Moist Method. Use this method to forecast maximum temperature under broken to overcast skies if you are not expecting an air mass change and the sounding represents the air you expect over your station during maximum heating.

- Use an early morning sounding.
- Follow the moist adiabat from the 850 mb or 5,000-foot temperature down to the surface. Use 700 mb if the station elevation is above the 850 mb level (refer to Figure 4-8).
- The temperature you read at the surface is a good estimate of the afternoon maximum temperature.
4.2.2.3. Approaching Warm Front Method

Use the following method to forecast maximum temperature with the approach of a warm front.

- Forecast the 850 mb (700 mb if you are at a high altitude) temperature. Consider temperature advection at that level.
- Follow the dry adiabat from the 850 mb or 5,000-foot temperature down to the surface. Use 700 mb if the station elevation is above the 850 mb level.
- The temperature that you read at the surface typifies the afternoon maximum temperature.

4.2.2.4. Inversion Method

Use the following method to forecast maximum temperature if an inversion is present or forecast (see Figure 4-9), if you are not expecting an air mass change, and the sounding represents the air you expect over your station during maximum heating.

- Use the early morning sounding for your station.
- Use the top of a nocturnal surface inversion (warmest part of the inversion).
- Follow the dry adiabat down to the surface.
- The temperature that you read at the surface typifies the afternoon maximum temperature.

(Note: This method is most effective under CLR or SCT conditions in late spring or early autumn.)

Figure 4-9. Forecast Max Temperature Using Dry Sounding (Inversion Present)
4.3. Minimum Temperature Forecasting

Minimum temperatures are much more difficult to forecast than maximum temperatures. Many stations have tried to develop objective techniques for forecasting this feature, and some have succeeded. Where local forecast techniques exist, these should be used, but for the station where no local techniques exist, the problem of making the minimum forecast may be approached in several ways.

4.3.1. Skew-T

Use the Skew-T method to derive a minimum temperature forecast as long as you are not expecting a change in air mass.

- Use the mid-afternoon upper-air sounding.
- Follow the moist adiabat from the 850 mb dew point temperature to the surface. The temperature that you read at the surface typifies the minimum temperature. Use 700 mb if the station elevation is above the 850 mb level. Refer to Figure 4-10.

4.3.2. Persistence

If little or no change is expected within an air mass such as cloud cover or advection, then persistence can be used as a method for determining your minimum temperature. The minimum temperature today will be very close to the minimum tomorrow.

4.3.3. British Method

This formula once again works best when there is very little change in the air mass. Take the maximum dew point of the day and add it to the maximum temperature of the day, divide by 2 and subtract 9.

\[ T_{\text{min}} = \left( T_{d(\text{max})} + T_{(\text{max})} \right) ÷ 2 - 9 \]
4.3.4. Craddock’s Minimum Temperature Method

This method was developed to improve minimum temperature and fog forecasting in England in the 1950s and adjusted and updated by an AFW forecaster for current use. This technique works well, but is restricted to a stagnant air mass. This method utilizes temperatures and wind speeds (wind speeds to determine a cloud (C) value). It should be used in addition to other tools. The modified formula in °F is as follows.

\[ T_{\text{min}} = 0.32T + 0.55T_d + 2.12 + C \]

where: \( T \) = 1200 UTC temperature, \( T_d \) = 1200 UTC dew point temperature, and \( C \) = value determined from Table 4-2

<table>
<thead>
<tr>
<th>Mean Forecast Surface Wind</th>
<th>Mean Forecast Cloud Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>3</td>
</tr>
<tr>
<td>&lt; 10 kts</td>
<td>-3</td>
</tr>
<tr>
<td>≥ 10 kts</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 4-2. Craddock’s Minimum Temperature “C” Determination

4.3.5. Meteograms

Recall from the Forecast Models QTP model output, both numerical and graphical (Figure 4-11), are objective tools used to forecast weather elements, including maximum and minimum temperature forecasts. As with all models, the information provided is only as good as the model itself; initialization and verification of the model is required to effectively use its output.

Figure 4-11. Temperature Section from Meteogram
5. When using the advection method to forecast maximum temperatures, you need to add ______ °F for every ______ feet your station is below the station that you are using as the advection model source. You need to subtract ______ °F for each ______ feet your station is above the station that you are using as the advection model source.

6. What is the expected max temperature based on the Skew-T below, assuming there is no change in air mass?

![Skew-T diagram]

a. 47° F  
b. 49° F  
c. 50° F  
d. 56° F

7. What would you expect the low temperature to be based on the above Skew-T?

a. 32° F  
b. 39° F  
c. 46°F  
d. 47° F

8. If the dew point at max temperature is 48° F and the max temperature was 58° F, what would you expect the low temperature to be based on the British method of forecasting low temperatures?
4.4. Forecasting Temperatures Rules of Thumb

It is possible to make an accurate temperature forecast without the information available in most weather stations. You should always combine station and area climatology with a thorough knowledge of the local terrain and its effects on weather to understand physical processes controlling local weather. The following rules of thumb should be used if surface observations are the primary or only tool.

- Plot hourly temperatures and dew points (time on the X-axis and temperature on the Y-axis) to establish station diurnal trend curves. It may take several days to establish a firm pattern, but this is an excellent limited data temperature-forecasting tool.
- Use the dew point at the time of the maximum temperature as the forecast minimum temperature for the next night if skies are primarily clear and no change in air mass is expected.
- Subtract the average diurnal variation for the month from the maximum temperature to estimate a minimum temperature when little change is expected in the cloud cover or air mass. Add it to the minimum temperature for estimating the maximum temperature.
- Consider the effects of an unusually moist or dry ground. Solar radiation evaporates moisture in or on the ground first, before heating the surface. This inhibits the daytime maximum heating. A wet soil heats up and cools down much slower than a dry soil.
- Consider the effects of snow cover (if any). Expect lower temperatures if there is snow cover. Air masses advected over an area with snow cover cool if the air mass is warmer than the ground. Snow reflects solar radiation and limits surface heating.
- Light winds allow for increased heating during the day. Wind speeds above 10 knots decrease the daily maximum temperature by 1° C (2° F) or more due to the turbulent mixing down of cooler air from aloft. For surface winds above 35 knots, the high temperature can be 3° C (5° F) lower.
- A moist atmosphere decreases the daily temperature range. For example, the spread between daily maximum and minimum temperatures ranges from only 3° to 5° C (5° to 10° F) in a wet-season tropical forest to over 28° C (50° F) in interior deserts.
- Note pressure trends to help anticipate approaching fronts. Plotting hourly pressures allows diurnal pressure curves to be established. Large variations from the norm could indicate approaching frontal systems or pressure centers.
- High winds and cooling. As stated earlier in this module, high winds retard cooling due to turbulent mixing. At night, due to more rapid cooling of the air in the lowest levels, the air mixed down is normally warmer than air near the ground surface. One rule of thumb is to add 1° C (2° F) to the low temperature forecast if the winds are to be around 15 knots and up to 3° C (5° F) for winds of 35 knots or greater. This technique does not consider warm or cold advection.
- High relative humidity (80% or greater) in the low-levels may inhibit cooling, because moisture is an efficient long-wave heat trapper. A humid night may be 3° C (5° F) warmer than a drier night. This rule is especially important near a large body of water.
4.5. Temperature Indices

While we are concerned about maximum and minimum temperature forecasting, you must know about the “apparent” temperatures that affect personnel that, in turn, may degrade the mission. Different temperature indices have been developed over the years. In some locations around the globe, it's possible to have both a heat index and a wind chill the same day! Here, you will learn how to determine a few easy temperature indices.

4.5.1. Temperature-Humidity Index (THI)

To accurately express the comfort or discomfort caused by the air at various temperatures (see Figure 4-12), it is necessary to take into account the amount of moisture present. The NWS uses the THI to gauge the impact of the environment on humans. The formula for completing the index follows:

\[
\text{THI} = 0.4 (T + Tw) + 15.0
\]

where \( T \) is the dry-bulb temperature and \( Tw \) is the wet-bulb temperature (both in °F).

![Figure 4-12. THI](image)

4.5.2. Wet-Bulb Globe Temperature (WGBT)

The Wet-Bulb Globe Temperature (WGBT) was developed because the dry-bulb (free air) temperature alone does not provide a realistic guide to the effects of heat--the dry bulb does not take humidity and heat radiation into effect. The computation of the WGBT involves 3 thermometers and is normally determined and disseminated by medical or disaster preparedness personnel and not AFW personnel. However, AFW personnel should know what is involved in computing it. The WGBT is computed by adding 70% of the wet-bulb temperature, 20% of the black globe temperature and 10% of the dry-bulb temperature.

\[
\text{WGBT} = 0.7 \text{WB} + 0.2 \text{BG} + 0.1 \text{DB}
\]

where \( \text{WB} \) = wet-bulb temperature, \( \text{BG} \) = black-globe temperature, \( \text{DB} \) = dry-bulb temperature

Note: Wear of heavy body armor or NBC gear adds 6° C (11° F) to WGBT activity.
4.5.2. Heat Index (HI)

The heat index (HI), also known as apparent temperature, is the result of extensive environmental studies. Determine the heat index by inputting air temperature and relative humidity (RH) into Figure 4-13. Like the THI, it considers the combined effects of high air temperatures and atmospheric moisture on human physiology.

![Heat Index Chart](chart.png)

**Figure 4-13. HI Chart**
4.5.3. Heat Stress Index (HSI)

A variation of the heat index, which uses the air temperature and relative humidity, is the heat stress index (HSI). The heat stress index may be the easiest to determine simply because you use air and dew point temperatures (refer to Figure 4-14) without having to determine the RH. Like the THI, it considers the combined effects of high air temperatures and atmospheric moisture (measurement by dew point) on human physiology.

<table>
<thead>
<tr>
<th>Danger Category</th>
<th>Apparent Temperature (°F)</th>
<th>Heat Syndrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV. Extreme Danger</td>
<td>&gt; 130°F</td>
<td>Heatstroke or sunstroke imminent.</td>
</tr>
<tr>
<td>III. Danger</td>
<td>109 - 129°F</td>
<td>Sunstroke, heat cramps, or heat exhaustion likely. Heatstroke possible with prolonged exposure and physical activity.</td>
</tr>
<tr>
<td>II. Extreme Caution</td>
<td>90 - 109°F</td>
<td>Sunstroke, heat cramps, and heat exhaustion possible with prolonged exposure and physical activity.</td>
</tr>
<tr>
<td>I. Caution</td>
<td>80 - 90°F</td>
<td>Fatigue possible with prolonged exposure and physical activity.</td>
</tr>
</tbody>
</table>

**Figure 4-14. HSI Chart**

Note: Degree of heat stress may vary with age, health, and body characteristics. Exposure to full sunshine can increase Heat Index values by up to 15°F.
4.5.4. Wind Chill

Wind chill is a frequently requested parameter during the winter months. Wind chill temperature combines the effects of low air temperatures with additional heat losses caused by the wind’s removal of the warm layer of air trapped in contact with skin. The faster the wind blows, the faster the layer of warm air is carried away. To calculate the forecast wind chill temperature, enter the forecast temperature and the forecast wind speed into the chart shown in Figure 4-15.

<table>
<thead>
<tr>
<th>Danger Category</th>
<th>Apparent Wind Chill Temperature (°F)</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV. Extreme Danger</td>
<td>&lt; -65</td>
<td>Exposed Flesh May Freeze Within 30 Seconds</td>
</tr>
<tr>
<td>III. Danger</td>
<td>&gt; -65 &lt; 25</td>
<td>Frostbite Likely. Exposed Flesh May Freeze Within 1 Minute. Limit Outdoor Activity.</td>
</tr>
<tr>
<td>II. Caution</td>
<td>&gt; 25 &lt; 10</td>
<td>Frostbite Possible. Increasing Danger.</td>
</tr>
<tr>
<td>I. Caution</td>
<td>&gt; 10 &lt; 40</td>
<td>Unpleasant. Little Danger.</td>
</tr>
</tbody>
</table>

Note: Degree of wind chill effect may vary with age, health, and body characteristics. Effects listed for properly clothed average person.

<table>
<thead>
<tr>
<th>Wind Speed (Knots)</th>
<th>0-3</th>
<th>3-6</th>
<th>7-10</th>
<th>11-15</th>
<th>16-19</th>
<th>18-23</th>
<th>24-28</th>
<th>29-32</th>
<th>33-36</th>
<th>37-40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Wind Chill Temperature (°F)</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>40</td>
<td>34</td>
<td>28</td>
<td>23</td>
<td>18</td>
<td>14</td>
<td>9</td>
<td>3</td>
<td>-2</td>
<td>-8</td>
<td>-11</td>
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<tr>
<td>30</td>
<td>30</td>
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<td>20</td>
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<td>11</td>
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<td>10</td>
<td>6</td>
<td>2</td>
<td>-2</td>
<td>-10</td>
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<td>-23</td>
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<td>-10</td>
<td>-17</td>
<td>-23</td>
<td>-27</td>
<td>-30</td>
<td>-33</td>
</tr>
</tbody>
</table>

Note: Wind speeds above 40 knots have little added effect.

Figure 4-15. Wind Chill Chart

4.6. Maximum and Minimum Temperatures Using Climatology

Lastly, let’s discuss using climatology for forecasting maximum and minimum temperatures. Before attempting temperature forecasts for your station, you have to be familiar with the climatology for the season. It is not wise to forecast a maximum temperature of 70° F when history shows that, for the particular season, no temperature above 60° F has ever been recorded. Climatological records help establish boundaries for temperature forecasts. To justify temperature forecasts that exceed the boundaries requires indications are especially favorable for the extremes. Using climatology as a guide, keep your forecasts within the maximums and minimums unless you have sound meteorological reasoning to forecast record temperatures. Climatology sources are covered in more detail in the Climatology QTP.
As mentioned earlier in this module, check persistence first. Review station observations for trends from the previous day. Check upper air and surface charts for potential cold or warm air advection and strength of approaching frontal systems, as appropriate. You must always consider advection when deciding on your temperature forecast. If your analysis shows neutral temperature advection, you know that forecast temperature changes will not be due to advection. So, you can investigate other factors. It is important to look at temperature advection not only at the surface, but also at the upper levels to give you an idea of what the vertical temperature profile will be at a specified time in the future.

9. __________ (TRUE/FALSE) Light winds allow for decreased heating during the day, and higher wind speeds above 10 knots increase the daily maximum temperature.

10. You are forecasting for Bicycle Lake AAF at Ft. Irwin, CA. With no airmass change expected (clear nighttime skies) and noticing that the dew point at the maximum heating was 47°F, what could you expect the next morning’s low temperature to be?

11. Using the Heat Stress Index Chart (Figure 4-14), what will the heat index be if your temperature is 97°F and the dew point is 76°F?

12. Using the Wind Chill Chart (Figure 4-15), what will the wind chill factor be if the temperature is 5°F and the wind is 15 knots?

13. You get a quick tasking to provide a maximum temperature for a location in Venezuela. You give a temperature of 95°F without looking at any climatology. Is that wise?

At this point, your trainer and/or certifier should answer any questions you, the trainee, have or to clarify any points you are still unclear on. Your trainer and/or certifier should also review local/regional rules-of-thumb and techniques developed in your AOR(s) with you.
MODULE 5- PRESSURE

TRAINEE’S NAME________________________________________

CFETP REFERENCE: 14.3.

MODULE OVERVIEW:
This module discusses altimetry terminology, concepts and rules and makes the trainee apply this knowledge toward making a forecast of various pressure parameters. This module begins with a general discussion of pressure and how it affects flight safety. We will then discuss how to calculate as well as forecast altimeter settings, pressure altitude, density altitude, sea-level pressure and D-values.

TRAINING OBJECTIVES:

• OBJECTIVE 1: Show your comprehension of the general rules, techniques, principles and procedures concerning pressure forecasting pressure by answering questions with least 80% accuracy.

• OBJECTIVE 2: Using either real-time weather data or canned scenarios, provide solutions and answers to questions concerning different pressure parameters with at least 80% accuracy as compared to the predetermined master solution.

EQUIPMENT AND TRAINING REFERENCES:

• AFWA/TN-98/002, Meteorological Techniques
• AFMAN 15-124, Meteorological Codes
• AFMAN 15-111, Surface Weather Observations
• AFH 11-203, Volume 1, Weather for Aircrews
• METOC 50-1P-0002, Volume 5, Introduction to Forecasting: Forecast Charts and Forecasting Weather Elements
• Meteorology Today: An Introduction to Weather, Climate and the Environment
• SC 01W01A, Volume 3, Weather Element Forecasting, Flight Hazards, and Limited Data
• AWS/TR-79/006 (Revised), The Use of the Skew-T, Log P Diagram in Analysis and Forecasting
• Aerographer’s Mate 1 & C
• AWS/TR-79/005, Forecasting Altimeter Settings
• AWS TR 165, Forecasting Density Altitude
PREREQUISITES AND SAFETY CONSIDERATIONS:

• Be familiar with interpreting weather features off MetSat imagery
• Have a firm grasp on the analysis and prognosis rules and techniques discussed in the Analysis and Prognosis QTP
• Familiarity with the TAF code found in Chapter 1, AFMAN 15-124, Meteorological Codes
• Familiarity with the sections on pressure found in AFMAN 15-111, Surface Weather Observations

ESTIMATED MODULE TRAINING TIME: 2.5 Hours
CORE TRAINING MATERIAL AND REVIEW QUESTIONS

5.1. Air Pressure

The weight of the air molecules that surround us exerts force on the earth’s surface. The amount of force exerted over an area of surface is called atmospheric pressure or simply air pressure. The pressure at any level in the atmosphere may be measured in terms of the total weight of the air above any point. As we climb in elevations, fewer air molecules are above us; hence, atmospheric pressure always decreases with increasing heights.

The three major parameters used to determine correct height are altimeter settings, D-values, and pressure altitude. Occasionally, you may be asked to provide a fourth parameter, density altitude for heavy airlift and rotary aircraft missions at high altitude and/or high air temperature locations.

5.2. Altimeter Setting (ALSTG)

An altimeter is an barometer calibrated to indicate altitude instead of pressure. When the altimeter is properly set, the altitude indicated corresponds to the equivalent pressure in the standard atmosphere. Thus, the altimeter is always indicating a pressure height and not an actual height. For example, when the aircraft is flying at the 500 mb surface, the altimeter indicates that the height in MSL of the aircraft is 18,289 feet, whether it is or not. As you probably realize, this can create hazards for both the pilot and forecaster who are not careful in determining altimeter settings and setting altimeters accordingly. The major errors in altimeter settings come from the difference of the actual atmosphere from the standard atmosphere caused by temperature and/or pressure.

At and above FL180 (18,000 feet mean sea level), where height above ground level (AGL) and in most locations terrain avoidance is not a primary concern, pilots are required to set their pressure altimeter to 29.92 inches of mercury (in Hg). This standard mean sea level (MSL) pressure is used to ensure proper aircraft separation in the vertical. Below FL180, pilots use observed and forecast altimeter settings to ensure that their actual height AGL is known.

Although the forecast altimeter setting is expressed as QNH in the TAF code, there’s a possibility you might run across a different “Q” signal in overseas forecasts. Table 5-1 shows and discusses how to interpret the “Q” signals.

<table>
<thead>
<tr>
<th>Altimeter Setting</th>
<th>Corresponding Pressure Altimeter Reading On the Ground</th>
<th>Corresponding Pressure Altimeter Reading In the Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>QNE (29.92 inches of Hg or 1013.25 mb)</td>
<td>Airfield pressure altitude</td>
<td>Altitude of aircraft in a standard atmosphere.</td>
</tr>
<tr>
<td>QNH (Station pressure reduced to sea-level)</td>
<td>Airfield elevation above sea-level</td>
<td>Altitude of aircraft above sea-level without consideration of temperature.</td>
</tr>
<tr>
<td>QLH (Actual station pressure)</td>
<td>Zero elevation</td>
<td>Altitude of aircraft above ground without consideration of temperature.</td>
</tr>
</tbody>
</table>

Table 5-1. “Q” Signals
5.2.1. Possible Altimeter Setting Errors

The error caused by the deviation of actual sea-level pressure from 29.92 inches of mercury (standard SLP) is corrected by adjusting the altimeter setting in the aircraft. Altimeter setting is the pressure of the reporting station, in inches of mercury, converted or altered, to make the altimeter read zero elevation at sea level. In other words, it shows the station elevation when the aircraft is on the ground at the station. Although the correct altimeter setting is used at takeoff, the altitude indicated during a cross-country flight and at the time of landing is usually in error. This is caused by the variation of pressure enroute and at the destination. Before attempting a landing, a pilot should always reset the altimeter to the correct altimeter setting of the destination. The pilot contacting the weather facility via the Pilot to Metro Service (PMSV) or phone patch is usually the way the altimeter is updated. Only then does the altimeter read field elevation on touchdown.

5.2.2. Altimeter Setting Forecasting Methods

QNH is the altimeter setting Air Force Weather forecasters work with the most. QNH altimeter setting can be obtained by measuring the surface pressure and reducing it to sea level. When ALSTG is set, the altimeter indicates height above mean sea level. Follow the steps below to forecast the QNH.

- **Step 1.** Obtain the current ALSTG setting in inches of mercury (Hg) for the desired location.
- **Step 2.** Obtain the corresponding sea-level pressure in mb.
- **Step 3.** Forecast the sea-level pressure for the desired station.
- **Step 4.** Determine the difference between current and forecast sea-level pressure.
- **Step 5.** Multiply the sea-level difference by 0.03 (1 mb is approximately 0.03 inches Hg).
- **Step 6.** Add or subtract (add when forecast sea-level pressure is higher than current reading) the value obtained in Step 5 to the current altimeter setting in Step 1.

Below is an example of how to determine a forecast altimeter setting.

- **Step 1.** Current altimeter setting is 29.98 inches.
- **Step 2.** Current sea-level pressure is 1015.5 mb.
- **Step 3.** Forecast sea-level pressure is 1020.5 mb.
- **Step 4.** 1020.5 - 1015.5 = 5.0
- **Step 5.** 5.0 x 0.03 = 0.15
- **Step 6.** 29.98 + 0.15 = 30.14

30.14 (inches of Hg) is the new forecast altimeter setting you’ll pass along. Note: The aircraft commander will subtract 0.01 from this setting for the final value to compensate for the height of the aircraft altimeter above the ground surface.
Remember to consider diurnal effects, upstream observations, and the synoptic situation with every pressure forecast.

1. Why is it that as we increase in elevation, the pressure decreases?

2. What is the standard mean sea level (MSL) pressure used for?

3. What is an altimeter?

4. Determine the forecast altimeter setting (QNH) for a station in 5 hours if given a current ALSTG of 30.11, a current SLP of 1020.3, and a forecast SLP of 1022.5.

5.3. D-Values

The D-value is the difference between the true altitude of a pressure surface and the standard atmosphere altitude of this pressure surface. D-values are used mostly by bombers, fighter-bombers, and helicopters. You might encounter other aircraft that require you to compute D-values; thus, it’s important to know how to compute them.

\[ D = \text{true altitude} - \text{standard altitude} \]

Suppose a flight is proposed at 11,000 feet MSL. By using the closest constant pressure product to the proposed altitude (here, 700 mb), you can determine the D-value. The standard height of the 700 mb level is 9,780 feet above sea level. In our case, assume that the upper-air data indicates that the 700 mb level is at 9,200 feet. Therefore, the D-value is 9,200 – 9,780 or –580 feet. The aircraft, then, would be flying 580 feet below the indicated altitude if its altimeter had been set at 29.92 on takeoff.

To make it even easier, a D-value computation chart has been developed so that you can graphically figure out the D-value. The methods listed below uses a graph (Figure 5-1) to compute estimates of the D-value at any altitude by interpolating between heights of standard pressure surfaces, or between surface altimeter setting and the height of a standard surface. Caution: The D-value change is assumed to be linear with height; the error with this assumption should not cause the estimated D-value to be off by more than 50 feet. There are other inherent errors in forecasting pressure heights and altimeter settings that could affect the estimate.

- **Step 1.** Determine the altitude of interest (aircraft flight level, for example).
- **Step 2.** Determine the observed or forecast heights (in meters) of standard pressure levels bounding the altitude of interest (a helicopter at 7,000 feet would be bound by the 700 mb and 850 mb surfaces, for example).
• **Step 3.** If the altitude of interest is below the 850 mb level, determine the observed or forecast height of the 850 mb level (meters) and the observed or forecast surface (not reduced to sea level) altimeter setting in inches of Hg.

• **Step 4.** Plot the heights of the pressure surfaces and/or the altimeter setting on the graph in Figure 1-58. Connect them with a straight line.

• **Step 5.** Locate the point at which the line drawn crosses the altitude of interest, then read straight up the graph to get the D-value in feet.

**Example:** Compute a D-value for 3,000 feet, given an 850 mb height of 1,640 meters and a surface altimeter of 30.15 inches of Hg. Be sure to plot the altimeter setting point on the zero altitude line, and connecting that point with the 850 mb point gives a D-value of +430 meters. First, you draw a line from the surface altimeter setting to the height of the 850 mb height (remember you need to use the pressure that correlates best with the flight level). Then, draw a line along the flight level until it intersects the line from the earlier step. Finally, from the intersection, draw a line straight up and read the D-value.

![D-Value Computation Chart](image-url)
5.4. Pressure Altitude (PA)

The PA is the elevation in the standard atmosphere at which a given pressure occurs. Most aircrews require PA to calculate takeoff and landing performance. The formula for calculating PA, using a given altimeter and the field elevation (FE), in feet, is:

\[ PA = FE + [1000 \times (29.92 - QNH)] \]

In the formula, QNH is the forecast or observed altimeter setting. For example, let’s say that the PA for your airfield is +3,000 feet. This means that any aircraft landing or departing performs as though it is at 3,000 feet of elevation, no matter whether the field elevation is 3,000 feet or not.

The PA is easily computed. All you need is the field elevation and the altimeter setting. Use the step-by-step procedures below for computing the PA. Use a field elevation of +750 feet and an altimeter setting of 30.02 as an example:

- **Step 1:** Subtract the altimeter setting from 29.92.
  \[ 29.92 - 30.02 = -0.10 \]

- **Step 2:** Multiply the answer in Step 1 by 1,000.
  \[ -0.10 \times 1,000 = -100 \]

- **Step 3:** Add the answer in Step 2 with the field evaluation.
  \[ -100 + 750 = 650 \]

Therefore, the pressure altitude is +650 feet.

This method can be used to compute the PA for an airfield since you know the field elevation and the altimeter setting for the time of concern. Suppose you want to compute the PA for an airfield with a field elevation of +330 feet and an altimeter setting of 29.76. The same procedures are applied.

- **Step 1:** \[ 29.92 - 29.76 = 0.16 \]
- **Step 2:** \[ 0.16 \times 1,000 = 160 \]
- **Step 3:** \[ 160 + 330 = +490 \text{ feet} \]

5.5. Density Altitude (DA)

Density altitude is the altitude at which a given density is found in the standard atmosphere. The effects of air density on heavy airlift operations can limit its payload. For example, if the pressure altitude at a 6,000-foot mountain location is equal to the standard-atmosphere pressure for 6,000 feet, but the air temperature is 100°F (over 60°F warmer than the standard-atmosphere at that height) the density of the air would equate to the density normally found at 10,000 feet. Under these conditions, runway length requirements for some fixed-wing aircraft could increase by 50% or more, and hover-lift capabilities of some rotary-wing aircraft could be exceeded.

Density altitude cannot be measured directly, but must be computed from pressure and virtual temperature (temperature at which dry air would have the same density as a moist
air sample) at the altitude or location under consideration. The easiest way of computing
density altitude is to use a Skew-T product that has an overprinted density altitude
nomogram or by using the nomogram (Figure 5-2) below.

![Density Altitude Nomogram](image)

**Figure 5-2. Density Altitude Nomogram**

- **Step 1**: Find the temperature, and draw a line straight up
- **Step 2**: At the pressure altitude (See Section 5-3 on how to compute PA), draw a line
  from the intersection of Step 1 straight left
- **Step 3**: Read the density altitude in thousands of feet. The example in Figure 5-2 shows a DA of 1,000 feet.

5.6. **Sea-Level Pressure (SLP)**

SLP is the atmospheric pressure at mean sea level. In other words, what the pressure be
if the column of air was adjusted to sea level. It can be measured directly at sea level or
determined from the observed station pressure at other locations. SLP is normally
reported in mb and the standard is 1013.25 mb (29.92 inches of mercury).5.6.1. Computing SLP
Use the following steps to obtain sea-level pressure:

- **Step 1:** Obtain height of 1000 mb surface using the following formula.
  \[ \text{1000 mb height} = \text{500 mb height} - (\text{1000-500 mb thickness}) \]
  Note: The number is negative if the 1000 mb surface is below ground level.
- **Step 2:** Divide 1000 mb height by 7.5 meters/mb
- **Step 3:** Add value of Step 2 to 1000 mb

**Example:** Using the upper air charts, the 500 mb height is 5500 meters, and the 1000-500 mb thickness is 5300 meters, here we see this computation in a real world situation.

- **Step 1:** 5540 meters - 5370 meters = 170 meters. The 1000 mb height is 170 meters.
- **Step 2:** 170 meters divided by 7.5 meters/mb = 22.67 mb
- **Step 3:** Add 22.67 mb to 1000 mb = 1022.67 mb

5. If the field elevation is 875 feet and the altimeter setting is 30.08, what is the station’s PA?

6. Explain the effects of air density on heavy airlift?

7. Compute the SLP based on the following criteria: the 500 mb height is 5520 meters, and the 1000-500 mb thickness is 5300.

8. Given an 850 mb height of 1,700 meters and an altimeter setting of 30.00 inches of Hg, use the D-value chart below to compute the D-value for 4,000 feet.
At this point, your trainer and/or certifier should answer any questions you, the trainee, have or to clarify any points you are still unclear on. Your trainer and/or certifier should also review local/regional rules-of-thumb and techniques developed in your AOR(s) with you.
MODULE 6 - TURBULENCE AND LOW-LEVEL WIND SHEAR

TRAINEE’S NAME______________________________

CFETP REFERENCE: 14.3.

MODULE OVERVIEW:
This module discusses turbulence, both low-level and upper-level, and low-level wind shear (LLWS) concepts and general rules. Then, the module makes the trainee apply this knowledge towards making a turbulence or LLWS forecast.

TRAINING OBJECTIVES:

• OBJECTIVE 1: Demonstrate your knowledge of the different categories of turbulence, the causes for turbulence and the effects of turbulence on aircraft operations, answer questions with at least 80% accuracy.
• OBJECTIVE 2: Answer questions on the general rules, techniques, rules of thumb, and principles and procedures of forecasting turbulence with at least 80% accuracy.
• OBJECTIVE 3: Demonstrate your knowledge of the causes of low-level wind shear and its effects of turbulence on aircraft operations by answering questions with at least 80% accuracy.
• OBJECTIVE 4: Show that you comprehend low-level wind shear forecasting by answering questions on the general rules, techniques, rules of thumb, and principles and procedures with at least 80% accuracy.
• OBJECTIVE 5: Using either real-time weather data or canned scenarios, provide answers to questions concerning turbulence and low-level wind shear with at least 80% accuracy.

EQUIPMENT AND TRAINING REFERENCES:

• AFWA/TN-98/002, Meteorological Techniques
• AFWA/TN-98/002, Meteorological Codes
• AFH 11-203, Volume 1, Weather for Aircrews
• METOC 50-1P-0002, Volume 5, Introduction to Forecasting: Forecast Charts and Forecasting Weather Elements
• Meteorology Today: An Introduction to Weather, Climate and the Environment
• SC 01W01A, Volume 3, Weather Element Forecasting, Flight Hazards, and Limited Data
- AWS/TR-79/006 (Revised), *The Use of the Skew-T, Log P Diagram in Analysis and Forecasting*
- Aerographer’s Mate 1 & C

**PREREQUISITES AND SAFETY CONSIDERATIONS:**
- Completion of the MetSat and Analysis and Prognosis QTPs
- Familiarity with the TAF code found in Chapter 1, AFMAN 15-124, *Meteorological Codes*

**ESTIMATED MODULE TRAINING TIME:** 2.5 Hours
CORE TRAINING MATERIAL AND REVIEW QUESTIONS

6.1. Turbulence Discussion
Turbulence is an irregular movement of air in the atmosphere that creates wind gusts and sharp, quick updrafts and/or downdrafts that can occur in combinations and, can quickly and unexpectedly change the flight characteristics of the aircraft. This unexpected air movement can cause serious damage to aircraft and potentially injure aircrew members and passengers. It is important to understand the causes of turbulence to be able to forecast the phenomena correctly.

6.2. Turbulence Categories
There are four categories of turbulence severity (see Table 6-1). Keep in mind that the severity of turbulence is dependent on the aircraft in question.

- **Light** - Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw). Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little or no difficulty is encountered in walking.

- **Moderate** - Turbulence that causes rapid bumps or jolts without appreciable changes in aircraft altitude or attitude. Occupants feel definite strain against seat belts or shoulder straps. Unsecured objects are dislodged. Food service and walking are difficult.

- **Severe** - Turbulence that causes large, abrupt changes in altitude and/or attitude. It usually causes large variations in indicated airspeed. Aircraft may be momentarily out of control. Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food service and walking are impossible.

- **Extreme** - Turbulence in which the aircraft is violently tossed about and is practically impossible to control. It may cause structural damage.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (LGT)</td>
<td>&lt;25 knots/90 nm</td>
<td>3-5 knots/1,000 feet</td>
</tr>
<tr>
<td>Moderate (MDT)</td>
<td>25 – 49 knots/90 nm</td>
<td>6-9 knots/1,000 feet</td>
</tr>
<tr>
<td>Severe (SVR)</td>
<td>50-89 knots/90 nm</td>
<td>10-15 knots/1,000 feet</td>
</tr>
<tr>
<td>Extreme (EXTRM)</td>
<td>≥ 90 knots/90 nm</td>
<td>&gt; 15 knots/1,000 feet</td>
</tr>
</tbody>
</table>

Table 6-1. Turbulence Categories Based on Horizontal and Vertical Shear
6.3. Turbulence Effects

Turbulence affects aircraft performance in several different ways. For better customer support, you need to understand the effects of turbulence on airframes.

- Turbulence is directly proportional to the speed of the aircraft. This means that the faster the aircraft flies in a turbulent area, the more turbulence it experiences.
- Turbulence is inversely proportional to the weight of the aircraft; i.e., the heavier the aircraft, the less turbulence it experiences.
- Turbulence is directly proportional to the wing area (or arc of the rotor blade for helicopters) of the aircraft. The greater the distance between the leading edge of the aircraft wing or rotor blade and the trailing edge, the greater the turbulence experienced.
- Turbulence is inversely proportional to the lift velocities of a rotary wing aircraft. This means that helicopters with slower lift velocities are associated with greater turbulence, and faster lift velocity helicopters are associated with less turbulence.

6.4. Turbulence Types

Turbulence, for our purpose, can be divided into three different types based on how the turbulence forms. They are thermal/convective turbulence, frontal turbulence, and mechanical turbulence.

6.4.1. Thermal/Convective Turbulence

Thermal/convective turbulence is often associated with surface heating. As the surface is heated by solar radiation, the air above it is warmed through contact. The warm air rise in uneven and irregular motions, creating eddies and gusts. These eddies and gusts lead to the “rough” air. Most thermal turbulence is usually classified as light turbulence. However, some locations may experience moderate turbulence, especially hot, arid regions where strong irregular currents result from large amounts of heating.

The most intense version of convective turbulence is thunderstorm activity. Whenever thunderstorms (or even towering cumulus) are forecast in a region, you should anticipate turbulence along with it. Thunderstorms, in everyday forecasting practice, imply turbulence.

6.4.2. Frontal Turbulence

Fronts can produce moderate or greater turbulence, depending on a number of factors including the strength of front, the speed of the front, and the wind shear along the front. Fronts moving 30 knots or more and fronts moving through rough terrain generally produce at least moderate or greater low-level turbulence due to the strong updrafts associated with the frontal zone. Fronts that have significant wind shifts or wind shear are frequently accompanied by convective activity making them hazardous to aircraft. Use the graph in Table 6-2 to determine turbulence based on wind shear.
6.4.3. Mechanical Turbulence

Mechanical turbulence is caused by horizontal and vertical wind shear and is the result of pressure gradient differences, terrain obstructions, or frontal zone shear. The three types of mechanical turbulence discussed in this module are clear air turbulence (CAT), mountain wave (MW) turbulence, and wake turbulence.

6.4.3.1. Clear Air Turbulence (CAT)

CAT includes turbulence not associated with visible convective activity. It includes high-level frontal and jet stream turbulence. It may also occur in high-level, non-convective clouds. CAT significantly impacts aviation and will be discussed in greater detail later in the module.

6.4.3.2. Mountain Wave Turbulence

Mountain wave turbulence is the most severe type of terrain-induced turbulence. If the dynamics are favorable for the formation of mountain wave turbulence, the wind flowing over the hills and mountains is set into smooth oscillation. This oscillation can become so vigorous (in terms of intensity) it frequently produces severe to extreme turbulence. For this reason, it is critical to accurately diagnose the initial onset phase of mountain wave turbulence, so those aviators can have an adequate warning as to the potential development of this highly hazardous condition.
6.4.3.3. Wake Turbulence

The last sub-type of mechanical turbulence that we will discuss is wake turbulence. Wake turbulence is becoming a more common problem with the increased use of heavy aircraft. Wake vortices are primarily a product of lift. They roll off the wingtips and trail behind the aircraft. Heavy, slow, and aerodynamic aircraft produce the strongest vortices. Although both neither forecast nor recorded in a TAF, wake turbulence is a problem and you should be aware how wake turbulence forms as well as its effects (see Figure 6-1).

Figure 6-1. Wake Turbulence

1. The effect of turbulence is _______ (directly/inversely) proportional to the speed of the aircraft, _______ (directly/inversely) proportional to the weight of the aircraft, and _______ (directly/inversely) proportional to the wing area (or arc of the rotor blade for helicopters) of the aircraft.

2. Turbulence is divided into three types based on how it forms. What are these three types?

3. Which of the following types of mechanically-induced turbulence is the most severe?
   a. CAT
   b. MW
   c. Wake
   d. None of the above

6.5. Clear Air Turbulence (CAT)

Turbulence is a mesoscale phenomenon, which is not readily identifiable on a synoptic scale, although, specific synoptic patterns in the atmosphere are associated with the potential turbulent areas. We will start our discussion with the synoptic patterns of clear air turbulence (CAT).

Although CAT generally occurs in clear air, it is not limited to the cloud-free atmosphere. CAT may occur in the vicinity of jet streams, upper air closed lows, sharp troughs, areas
of strong thermal advection, or an advancing cirrus shield. Turbulence is a transitory atmospheric condition that has varying effects on aircraft operations.

Studies show that CAT usually forms in association with specific synoptic patterns. To accurately forecast the location and intensity of turbulence, you need to be able to recognize the development and weakening of these patterns. Here are some of the most common patterns and parameters associated with CAT.

6.5.1. Surface Cyclogenesis

CAT frequently forms near the jet stream core N-NE of the surface low development during cyclogenesis (see Figure 6-2). Sometimes the surface low redevelops north of the main jet, with a formation of a secondary jet (Figure 6-2). Numerical models may not forecast the formation of this new jet.

CAT intensity is directly related to the strength of cyclogenesis, the proximity of mountains, the intensity of the jet core, and to the amplification and curvature of the downstream ridge. For cyclogenesis less than 1 mb/hour, expect moderate CAT. For cyclogenesis greater than or equal to 1 mb/hour, expect moderate-to-severe CAT.

![Figure 6-2. CAT and Surface Cyclogenesis](image)

6.5.2. Upper-Level Lows

Moderate CAT is often found in the vicinity of deep upper-level troughs and closed lows. The examples in Figure 6-3 shows CAT development in various stages during the formation of a cutoff low. CAT usually forms in the areas of confluent and difluent flow. Once the low is cutoff, CAT will diminish to light in the vicinity of the low.
Figure 6-3. CAT and Upper-Level Lows

6.5.3. 500 mb CAT Patterns

The 500 mb product is useful for forecasting CAT. However, do not use it exclusively. Consider data at all available levels. The following 500 mb patterns may be indicative of CAT:

- Shortwave troughs near one another (double troughs).
- A well-defined thermal trough.
- A narrow band of strong winds with strong horizontal wind shears.
- Closed isotherm cold pocket moving through an open flow pattern (i.e., height field with no closed contours).
- 500 mb winds greater than 75 knots in areas with wind shifts greater than or equal to 20°, and tight thermal gradients.
- Troughs associated with a surface frontal wave (often indicated by sharply curved isotherms around the northern edge of a warm tongue).
6.5.4. Shear Lines In Upper-Level Lows

Forecast moderate CAT when the jet stream is greater than or equal to 50 knots around a closed upper-level low, and a very narrow neck occurs with a shear line separating the prevailing flow around the low. Forecast moderate to severe CAT if the jet reaches 115 knots. The potential for CAT is greatest between the two anticyclonically curved portions of the jet (see Figure 6-4).

![Figure 6-4. CAT With Shear Line In Upper-Level Low](image)

6.5.5. Difluent Wind Patterns

Most CAT is observed during formation of difluent upper-level wind patterns (usually above 500 mb). After the difluent pattern establishes, CAT may weaken in the difluent zone. However, when a surface front is present (or forming), the potential for CAT increases in the areas of difluent flow near the surface system (see Figure 6-5).

![Figure 6-5. CAT and Difluent Winds](image)
6.5.6. CAT and Strong Upper Winds

CAT can exist in areas of strong winds when isotherms and contours are nearly parallel and only minor variations exist in wind direction (about 20° of temperature per 4° of latitude) with exceptionally tight thermal gradients. Figure 6-6 illustrates a situation in which 500 mb winds exceeded 100 knots in the vicinity of a very high thermal gradient. CAT was observed between flight level of FL180 and FL330. Additionally, CAT often occurs along and above a narrow band of strong 500 mb winds when horizontal wind shears are strong on either side of the band, especially if the winds have a geostrophic tendency.

![Figure 6-6. Likely Areas of Turbulence in the Jet Stream](image)

6.5.7. Confluent Jet

When two jet stream cores converge to within 250 nm, the potential for CAT increases. Figure 6-7 shows the potential CAT area where two jets come within a distance of 5° latitude. Since the poleward jet is usually associated with colder temperatures and is lower than the second jet, the poleward jet will often undercut the other and produce strong vertical wind shears. The potential for CAT ends where the jets diverge to a distance of greater than 5° latitude.

![Figure 6-7. CAT with Confluent Jet](image)
6.6. CAT Associated with Upper Thermal Patterns

This section will discuss CAT associated with thermal patterns such as thermal ridges and troughs. CAT frequently occurs in regions of increasing thermal gradients, as best described by cold air advection in long and short wave troughs. At 300 mb, there is normally an absence of cold air advection, so a careful analysis of 200 mb height and temperature fields is necessary. The 500 mb height and vorticity fields can be used to identify short waves that are indirectly related to this advection. CAT is forecast in the area of strongest isotherm packing just ahead of the temperature trough. Normally, moderate turbulence should be forecast from the height where sufficient vertical shear associated with the cold advection is found to 2,000 feet above the tropopause in cyclone-scale waves.

6.6.1. Temperature Gradients At and Above 300 mb

Analyze both the thermal and wind patterns to assess the potential for CAT. Strong cold-air advection is one significant clue to CAT potential. Expect CAT when a temperature gradient of greater than or equal to 5° C/120 nm exists or is forecast to occur and at least one of the following is observed:

- Trough movement greater than or equal to 20 knots.
- Wind shift greater than or equal to 75° in the region of cold advection.
- Horizontal wind shear greater than or equal to 35 knots/110 nm (~200 km).
- Wind component normal to the cold advection is greater than or equal to 55 knots.

6.6.2. Open Isotherm Troughs

This situation encompasses the majority of the CAT patterns. The noticeable bulging of a cold-air tongue in a relatively tight thermal gradient may occur at or near the bottom of the trough. In either case, the isotherms curve more sharply than the contours (see Figures 6-8). In both cases, moderate turbulence was reported between FL250 and FL350.

![Figure 6-8. Two-Basic Cold-Air Patterns Conducive to CAT](Image Link)
6.6.3. CAT in Cold-Tongue Troughs

Cold tongues commonly develop and move in from the northwest behind a pressure trough. Wind direction changes only gradually in this area. These troughs often move into the western states from the Pacific (see Figure 6-9). Once the thermal configuration shown becomes apparent, check for development at higher levels. The left half of Figure 6-9 shows a trough and tongue of cold air at 300 mb extended across the indicated turbulence zone on a northwest-southeast line and was instrumental in creating the turbulence. The right half of Figure 6-9 shows a thermal gradient in combination with a smooth, strong wind flow pattern and a high isotherm amplitude. This pattern indicates a strong probability of CAT. The tight thermal gradient produced an average of 8 knots/1,000 feet of wind shear between 24,000 and 26,000 feet in Northern Utah. CAT began with a tightening thermal gradient. Strong winds, an abnormally tight thermal gradient, and higher amplitude isotherms than contours at 500 mb were strong indicators.

![Figure 6-9. CAT in Cold-Tongue Troughs](image)

6.6.4. Closed Isothermal Patterns

CAT is often found in a moving, closed cold-air isotherm pattern at 500 mb when the height contours are not closed (see Figure 6-10). CAT incidents between FL240 and FL370 were numerous in this rapidly moving pattern. The shear zone in the east region of the jet streak over the northern US Rockies contributes to the CAT.

![Figure 6-10. CAT in Closed Isothermal Pattern](image)
6.7. CAT Associated with Troughs and Ridges
Upper-level troughs and ridges can offer provide us with clues for possible CAT.

6.7.1. Shearing Troughs
Rapidly moving troughs north of a jet may produce CAT in the confluent flow at the base of the trough (see Figure 6-11). The main area of CAT is north of the jet core.

![Figure 6-11. CAT in Shearing Trough](image)

6.7.2. Strong Wind Maximum to the Rear of the Upper Trough
CAT potential is high when a strong north-south jet is located along the backside of an upper trough. CAT usually occurs in the area of decreasing winds between the base of the trough and the maximum wind upstream. The change of wind speed should be greater than or equal to 40 knots within 10° of latitude for CAT to occur. If the difference between the jet core and the minimum wind speed is greater than or equal to 60 knots, CAT is most likely to occur between the jet core and the base of the trough, centered on the warm-air side of the jet (Figure 6-12).

![Figure 6-12. CAT Associated with Strong Wind Maximum to Rear of Upper Trough](image)
6.7.3. 500 mb Deep Pressure Trough

A common configuration is a relatively deep pressure trough at 500 mb. CAT is often found in a sharply anticyclonic, persistent isotherm pattern downwind of the trough. In the example shown in Figure 6-13, the isotherms are sharply curved anticyclonically through eastern Mississippi and Alabama, and the amplitude of the isotherms exceeds that of the contours. CAT was found downwind from the sharp curvature in the isotherms lee of the trough between FL180 and FL260.

![Figure 6-13. CAT in Deep 500 mb Trough](image)

4. _________ (TRUE/FALSE) CAT seldom occurs in regions of increasing thermal gradients, as best described by cold air advection in long and short wave troughs.

5. CAT often occurs _________ and _________ a narrow band of strong 500 mb winds when horizontal wind shears are strong on either side of the band, especially if the winds have a geostrophic tendency.
   a. South and above
   b. South and below
   c. Along and above
   d. Along and below
6. When two jet stream cores converge to within _______ nm, the potential for CAT increases.
   a. 100
   b. 250
   c. 500
   d. None of the above

7. When assessing the potential for CAT, you need to look at both the thermal pattern and ________ pattern.
   a. Wind
   b. Thickness
   c. Orographic
   d. None of the above

8. When a strong wind maximum is in the rear of the upper trough, the change in wind speed should be greater than or equal to __________ kts within __________ of latitude for CAT to occur.

9. Using the pattern below, draw where you think your CAT should be located.

10. Using the pattern below, draw where you think your CAT should be.
6.8. *Jet Stream CAT Model*

In the early 1960s, the meteorology department at United Airlines developed a basic jet stream turbulence model (refer to Figure 6-14). The following applies to CAT occurrence in the model:

- Associated with converging polar and subtropical jets, mountain waves, and strong upper-level frontal zones.
- Horizontal wind shear should be greater than 40 knots/150 nm and/or vertical wind shear should be greater than 6 knots/1,000 feet.

A flight through the box would have a 50% chance of encountering CAT. Probabilities are not cumulative and are estimated.

![Figure 6-14. Jet Stream Turbulence Model for CAT](image)

6.9. *CAT Rules of Thumb*

Recent studies of turbulence outbreaks have resulted in “rules of thumb” which will assist you in determining the severity of CAT. Since CAT is usually associated with strong westerly jet streams and low tropopause heights, maximum exposure is in the middle latitudes (Northern and Southern Hemispheres) during the winter months. Due to the high tropopause heights and light winds, the equatorial regions (within 10°-15° of the equator) rarely experience CAT. Between 15° and 30° latitude, CAT can be experienced due to the penetration of strong troughs and a lowering subtropical jet stream cruise altitude. Specifically, the parameters we present here are intended as a rough discriminator for moderate turbulence. As the conditions become more extreme, consider forecasting severe turbulence. Wind speeds should be:

- 100 knots or greater poleward of 30° latitude (Polar Jet at 250 or 300 mb).
- 130 knots or greater equatorward of 30° latitude (Subtropical Jet at 200 mb).
- There is significant cyclonic or anticyclonic curvature in the flow. In general, the sharper the curve, the greater the turbulence.
- Under normal conditions, an area of CAT will likely be 20°-30° in length longitudinally (including 12-hour movement) and between 5° and 10° latitude in width.
• When the Polar and Subtropical Jets converge within 250 nm (4° latitude), the potential for moderate or greater CAT increases dramatically. The overlapping jet leaves created by this convergence amplify the vertical wind shears and the potential for moderate to severe turbulence may exist.

• Forming cutoff lows go through a transition period where the throat formed by the jet stream poleward of the low narrows rapidly. Wind speeds as low as 50 knots on either side of this throat will cause moderate turbulence especially near the anticyclonically curved portions, and winds approaching 100 knots will likely produce moderate severe turbulence.

• Studies have shown that 60% of all moderate or greater CAT occurs in anticyclonically curved portions of the Polar Front Jet (PFJ) over long wave ridges and 30% occurs in sharp, cyclonically curved portions of the PFJ.

6.10. Mountain Wave Turbulence

Investigations show that mountain wave turbulence causes more hazardous flight conditions than those encountered in any thunderstorm. Mountain waves have produced gust velocity measurements of 50 feet per seconds (fps) at 30,000 feet. Most aircraft experience structural failure when encountering gusts of 50 fps at reduced speeds or 35 fps at ordinary speeds. Calculations have shown that a high-speed jet would experience 8 to 14 times the force of gravity flying downwind through these areas of varying vertical motions.

6.10.1. Mountain Wave Turbulence Formation

Unlike normal terrain-induced turbulence, the oscillations associated with mountain wave turbulence extend from near the surface all the way to the troposphere. In order for these intense oscillations to develop, several conditions must be present.

• The component of the wind perpendicular to the mountain at mountaintop level must be at least 25 knots.

• The wind direction must be within 30° from perpendicular to the mountain range. The closer the direction to the perpendicular, the stronger the wave.

• On the leeward side of the mountain, there must be an inversion at and slightly above the ridge line. This inversion provides the bottom layer for the oscillations in the atmosphere.

• There should be a rapid increase of wind speed as altitude rises from surface to several thousand feet above the ridge line. Above this, there should be a steady strong flow up to the tropopause with speeds increasing gradually. A very rapid increase all the way to the tropopause can eliminate the wave, leaving only stagnant air trapped in the valley. The jet stream is frequently located over the mountain range when the wave is observed.
6.10.2. Distribution of Clouds and Turbulent Regions in Mountain Wave

There are specific clouds associated with the mountain wave. These are the cap (foehn wall), rotor (roll), and lenticular. Figure 6-14 illustrates the structure of a strong mountain wave and the associated cloud patterns. The lines and arrows depict the wind flow from left to right.

![Figure 6-14. Mountain Wave Cloud Structure](image)

6.10.2.1. Cap Cloud

The cap cloud hugs the tops of the mountains and flows down the leeward side with the appearance of a waterfall. This cloud is dangerous because it hides the mountain and has strong downdrafts. The downdrafts can be as strong as 5,000 feet per minute. Essentially, this means that if an aircraft were flying at 20,000 feet AGL would be at 15,000 feet AGL a minute later due to downdrafts associated with mountain-wave turbulence. You can understand how detrimental this can be when aircraft fly within close proximity to mountain peaks.

6.10.2.2. Rotor Cloud

The rotor, or roll cloud looks like a line of cumulus or altocumulus clouds parallel to the ridge line. It forms on the leeside and has its base near the height of the mountain peak with its top extending considerably above the peak. The tops may extend to twice the height of the highest peak. The rotor cloud often merges with the lenticulars above, forming a solid mass to the tropopause. The rotor cloud is dangerously turbulent. Extreme turbulence should be expected both in and below the clouds. The air in the cloud rotates around a horizontal axis parallel to the mountain range. It has updrafts up to 5,000 feet per minute on its windward edge and downdrafts of 5,000 feet per minute on its leeward edge. This cloud is stationary, constantly forming on the trailing edge (updrafts) and dissipating on the leading edge (downdrafts). The roll cloud may form immediately to the lee of the mountain or it may be a distance of ten miles downwind.
6.10.2.3. Lenticular Clouds
The lenticulars are lens-shaped clouds with bases above the roll cloud. The tops extend to the tropopause. These clouds have a tiered or stacked look that is due to the stratified nature of the moisture in the atmosphere. All lenticular clouds are associated with turbulence.

6.11. Low-Level Wind Shear
With the increase in aircraft accidents over the past few years, more emphasis is being placed on forecasting low-level wind shear (LLWS) conditions (also referred to as WSCONDS in the TAF code). Although pilots generally try to avoid LLWS, it is possible to compensate for the effects it has on aircraft if they are forewarned of its presence. To accurately provide pilots the information they need, you must first understand exactly what wind shear conditions are and what conditions are favorable for it’s development.

Wind shear is a change in wind speed and/or direction over a short distance. This wind change can occur in the vertical or the horizontal, and is most often associated with strong temperature inversions or density gradients. Under certain conditions, the atmosphere is capable of producing dramatic shears very close to the ground, where aircraft will have little room to maneuver. The four most common sources of LLWS are thunderstorms/convective activity, temperature inversions, frontal activity, and surface obstructions.

6.11.1. Conditions Favorable for LLWS
Wind shear is a common occurrence at all atmospheric levels, but there are certain meteorological phenomena that can alert us to the potential for low-level wind shear. It is important that the forecaster can identify these conditions so that the pilot can be forewarned of the possible hazard. Conditions favorable for LLWS:

- Light surface wind of less than 10 kts
- Surface-based temperature inversion
- Maximum wind of 25 to 40 kts from 600 to 1,500 feet above the top of the inversion layer

6.11.2. Thunderstorm Gust Fronts
The most dangerous LLWS occurs with the thunderstorm gust front. A cold outflow from a thunderstorm forms a mesoscale frontal-type boundary marked by temperature differences and appreciable changes in low-level wind direction and speed. This outflow occurs at the surface in all directions from the thunderstorm cell (see Figure 6-15). The major problem is predicting wind direction and speed with respect to the airfield or approach zone.
The total operational impact of the low-level wind shear produced by the thunderstorm gust front depends on the position and movement of the storm with respect to the airfield as well as the aircraft flight path. The forecaster should have a good understanding of the following gust front characteristics:

- The gust front moves faster than the generating thunderstorm and can precede the storm radar echo by as much as 10 miles.
- WSR–88D may show the gust front as a thin line echo on radar (see Figure 6-18).
- Upper portions of the gust front may precede the surface portion by up to two miles.
- A surface wind shift normally accompanies the gust front.
- Dramatic pressure rises precede the gust front. Pressure altitude changes near the surface may be 200 to 300 feet.

Thunderstorm gust fronts are often unpredictable, therefore forecasters must make aircrews aware of the shear threat they cause. Aircraft may be affected in the approach zone or on the glide slope (see Figures 6-16 and 6-17) yet airfield sensors may not indicate the gust front passage or existence. The forecaster must use sound judgment in forecasting the thunderstorm gust front.
Frontal boundaries are another common cause of potentially hazardous wind shear. The forecaster must examine the vertical structure of the front for shear as it approaches or passes an airfield.

Wind speed and direction changes across a warm frontal boundary can be especially dangerous. It is not unlikely for the shear to be on the magnitude of 90° or more (for example, 90° at 10 knots at the surface veering to 200° at 30 knots above the frontal inversion). When this shear occurs within a few hundred feet of the ground, advisories to aircrews are essential to flying safety. Warm frontal wind shear may persist for six hours or more over a particular airfield because of the small slope and slow movement of the warm front. Another important consideration of warm fronts is that low ceilings and visibilities along with the wind shear are frequently associated with passage causing poor flying conditions.

Cold frontal wind shear may be equally dramatic near the surface. However, cold fronts generally move faster than warm fronts and with accompanying steeper slopes, the duration of LLWS is usually only one to two hours.

**6.11.4. Low-Level Jet (LLJ)**

Another potential wind shear problem for aviation is the nocturnal low-level jet (LLJ). It is observed in all parts of the world, at all times of the year. In the US, it is common in the Great Plains and the central states.

The LLJ occurs above very stable air. Large changes in wind direction and speed can occur in just tens of feet. Parameters favorable for low-level jet formation are:

- Light surface wind of less than 10 knots
- Surface-based temperature inversion
- Maximum wind of 25 to 40 knots from 600 to 1,500 feet AGL
• The winds then decrease from 15 to 25 knots up to the gradient level. The core of the jet is just above the top of the inversion layer.

6.11.5. Gusty Surface Winds

Fluctuations of 10 knots or more from the mean sustained wind speed and strong winds blowing past buildings and structures near a runway produce eddies and turbulence. The resultant shear within a few hundred feet of the surface presents problems for routine aircraft operation. Gusty surface winds frequently accompany some hazards already discussed, namely thunderstorms and fronts. However, other causes must be examined. Chinook winds develop on the lee of mountains because of simultaneous warm-air advection, dynamic heating by subsidence, and rapid destruction of the shallow nighttime inversion.

These winds frequently occur along the eastern slope of the Rocky Mountains. Santa Ana winds in southern California and the foehn wind in the Alps are other examples. Forecasters must also be aware of the topography located within the vicinity of the airfield. High winds can be channeled between peaks and valleys of the nearby terrain. The result is higher wind speeds and gusts that can detrimentally affect the performance of an aircraft on takeoff and landings. This is especially true when the prevailing wind of the runway is quite different from the gusty winds produced by the nearby terrain.

6.11.6. Detecting LLWS and Turbulence Using the WSR–88D

The WSR–88D can often assist you in locating flight hazards such as frontal boundaries, low-level jets, and turbulence. In the composite reflectivity images below (Figure 6-18), you can clearly see the fine line outflow boundary to the west of the storm complex in Oklahoma spread out and expand as time goes by. These outflow boundaries will produce LLWS. For more information concerning Doppler radar interpretation techniques, refer to the Weather Radar QTP.

![Figure 6-18. WSR–88D Outflow Boundary Display](image-url)
6.11.7. LLWS Forecasting Rules of Thumb

The following rules for forecasting LLWS have been adapted by AFW. The rules may be applied to either forecast or observed conditions. The forecaster should expect LLWS when any of the following conditions are met. Assume the gradient level to be 2,000 feet AGL.

- When the sustained surface wind is 30 knots or greater.
- When the sustained surface wind is 10 knots or greater and the difference between the gradient wind speed and twice the surface wind speed is 20 knots or greater.
- When the sustained surface wind is less than 10 knots and the absolute value of the vector difference between the gradient wind and the surface wind is 30 knots or greater and an inversion or isothermal layer is present below 2,000 feet.
- When the sustained surface wind is less than 10 knots and the absolute value of the vector difference between the gradient wind and the surface wind is 35 knots or greater.
- When thunderstorms are observed or forecast within 10nm of the aerodrome.
- When there is a front approaching or passing the base with either:
  - A vector wind difference across the front with a magnitude of 20 knots or more per 50nm.
  - A temperature difference across the front of 10 °F (5°C) or more per 50nm.
  - A frontal speed of 30 knots or more.
- When a significant LLJ is suspected (25 kts or greater) or reported below 2,000 feet.
6.11.8. LLWS Checklist

Forecasting LLWS can be challenging. The use of a forecast worksheet can help you narrow the parameters needed for LLWS. The following is a general worksheet that can be used as is or modified with local rules of thumb.

![LLWS Decision Matrix](image)

Figure 6-19. LLWS Decision Matrix
11. Wind shear is a change in _______ _______ and/or _______ _______ over a _______.

12. What are the four most common sources of LLWS?

13. Why does wind shear associated with a warm front persist for up to six hours or more over a particular airfield?

14. Why does LLWS associated with a cold front last for only an hour or two?

15. ______ (TRUE/FALSE) An aircraft is scheduled to takeoff at 1000L, and your low-level inversion has not yet broke. The winds are 160° at 8 knots at the surface, but you have a low-level jet at 1,500 feet where winds are 240° at 30 knots. Is your forecast of no low-level wind shear (no WSCONDS) correct?

At this point, your trainer and/or certifier should answer any questions you, the trainee, have or to clarify any points you are still unclear on. Your trainer and/or certifier should also review local/regional rules-of-thumb and techniques developed in your AOR(s) with you.
MODULE 7 - ICING

TRAINEE’S NAME______________________________

CFETP REFERENCE:  14.3.

MODULE OVERVIEW:
This module discusses icing terminology, concepts and rules and makes the trainee apply this knowledge toward making an icing forecast.

TRAINING OBJECTIVES:

• OBJECTIVE 1: To demonstrate your knowledge of the different types of icing, the causes for icing and icing effects on aircraft operations, answer questions with at least 80% accuracy.

• OBJECTIVE 2: Be able to answer questions on the general rules, techniques, rules of thumb, and principles and procedures of forecasting icing with at least 80% accuracy to show your comprehension.

• OBJECTIVE 3: Using either real-time weather data or canned scenarios, provide answers to questions concerning forecasting icing conditions with at least 80% accuracy.

EQUIPMENT AND TRAINING REFERENCES:

• AFWA/TN-98/002, Meteorological Techniques
• AFMAN 15-124, Meteorological Codes
• AFH 11-203, Volume 1, Weather for Aircrews
• METOC 50-1P-0002, Volume 5, Introduction to Forecasting: Forecast Charts and Forecasting Weather Elements
• Meteorology Today: An Introduction to Weather, Climate and the Environment
• SC 01W01A, Volume 3, Weather Element Forecasting, Flight Hazards, and Limited Data
• AWS/TR-80/001, Forecasters’ Guide on Aircraft Icing
• AWS/TR-79/006 (Revised), The Use of the Skew-T, Log P Diagram in Analysis and Forecasting
• Aerographer’s Mate 1 & C
PREREQUISITES AND SAFETY CONSIDERATIONS:

- Completion of the Analysis and Prognosis QTP
- Familiarity with the TAF code found in Chapter 1, AFMAN 15-124, *Meteorological Codes*

ESTIMATED MODULE TRAINING TIME: 2.5 Hours
CORE TRAINING MATERIAL AND REVIEW QUESTIONS

7.1. Aircraft Icing General Information

Aircraft icing is one of the major weather hazards to aviation. Icing can be divided into two categories, external and internal. External icing is the accumulation of ice on the exposed surfaces of aircraft when flown through supercooled water drops (cloud or precipitation). Internal icing (icing of the intake, carburetor, or engine icing) literally reduces the breathing of the engine, which results in a loss of power.

7.2. Icing Effects on Aircraft

The effects of aircraft icing are serious. They include:

- Loss of aerodynamic efficiency
- Loss of engine power
- Loss of proper operation of control surfaces, brakes and landing gear.
- Loss of aircrew’s outside vision
- False flight instrument indications
- Loss of radio communication

Icing effects on helicopters are potentially more severe than fixed-wing aircraft because of their relatively slow cruising speeds and limited altitude range. Aerodynamic effects are greatly exaggerated by icing and altered aerodynamics make control unpredictable. Fixed-wing aircraft react poorly during icing conditions. Icing adds weight, increases drag and stall speed, and decreases lift (see Figure 7-1). In addition, control surfaces (i.e. flaps, ailerons, rudder and elevator) and landing gear may malfunction when coated by ice. The most significant result of ice however, is that it destroys the efficiency of the airfoil by altering its shape. This is true with either wings or propellers. When the lifting qualities of the wing are gone, the aircraft can no longer remain airborne. Ice can also accumulate on rotors and propellers resulting in extreme vibrations making the control of an aircraft very difficult, if not impossible.

![Figure 7-1. Effect of Icing on Aircraft](image-url)
In wind tunnel experiments, it has been found that an ice deposit of \( \frac{1}{2} \) inch on the leading edge of some airfoils reduces the lifting power of the airfoil as much as 50% and increasing the drag by an equal amount. Ice can form on an aircraft very rapidly, and there are recorded cases where two to three inches of ice have accumulated in a matter of minutes.

As stated above, ice adds weight to aircraft, blocks the flow of fuel in carburetors (Figure 7-2), restricts the flow of air in jet intakes and ruins engines and turbines by ingesting foreign objects (see Figure 7-3). When the relative humidity of the outside air being drawn into the carburetor is high, ice can form inside the carburetor (even in cloudless skies) when the temperature is as high as 22° C (72° F) or as low as –10° C (14° F). Carburetor icing can occur in temperatures well above 0° C, and may lead the pilot to potentially misdiagnose engine problems.

Figure 7-2. Carburetor Icing

Figure 7-3. Induction Icing
7.3. Icing Types

Aircraft icing varies considerably in density, transparency, and hardness. Temperature, drop size, and rate of accretion (accumulation or buildup) control these variations. Frost, rime ice and clear ice are the three basic forms of aircraft icing. In addition, mixtures of rime and clear ice are common—resulting in “mixed” icing.

Two basic conditions must be met for dangerous amounts of ice to form on an airframe. First, the aircraft surface temperature must be colder than 0°C. Second, supercooled water droplets (liquid water droplets at subfreezing temperatures) must be present. Water droplets in the free air, unlike standing water, do not freeze at 0°C. Instead, the freezing temperature varies from an upper limit near -10°C to a lower limit near -40°C. Therefore, the possibility of icing must be anticipated in any flight through supercooled clouds or liquid precipitation at temperatures below freezing. Figure 7-4 can be used as a basic guide of icing determination.

As mentioned earlier, there are three basic forms of ice accumulation on aircraft: rime ice, clear ice, and frost. While in flight, an aircraft can experience any of the three. The form of icing depends primarily on the droplet size and temperature.

7.3.1. Rime

Rime ice is rough, milky, and opaque. The granular texture exists because the ice forms when very small droplets freeze almost instantly upon striking the aircraft and trap air between the spherical drops. Rime ice is most frequently associated with stratus clouds at temperatures between -8°C and -10°C, although it has been observed to form between -2°C and -30°C. In comparison to clear ice, rime ice is relatively easy to get rid of by conventional deicing methods.

7.3.2. Clear

Clear ice is glossy or translucent and is formed by the relatively slow freezing of large supercooled droplets. The large droplets spread out over the airfoil before complete freezing and form a clear sheet of ice. This ice is formed in cumuliform clouds and is the result of larger drops that are usually between 0°C and -16°C. Freezing precipitation also generates clear icing.

7.3.3. Frost

Frost is a light feathery deposit that occurs when moist air above 0°C passes over a surface that is below 0°C. An aircraft may collect frost when it is descending from cold air (below 0°C) into warmer, very moist air in lower layers. Frost may form during the night when the temperature of the aircraft skin is below freezing. Frost can cover the windshield or canopy and completely restrict outside visibility or it may form on the inner side of the canopy.
1. Aircraft icing varies considerably in density, transparency, and hardness. What three things control these variations?
   a. Drop size, rate of accumulation, and type of aircraft
   b. Temperature, drop size, and rate of accumulation
   c. Type of aircraft, temperature, and rate of accretion
   d. Rate of accretion, drop size, and type of aircraft

2. __________ (TRUE/FALSE) The most significant result of ice however, is that it destroys the efficiency of the airfoil by altering its shape.

3. What two basic conditions must be met for ice to form on an airframe?
   a. Aircraft surface temperature must be colder than 0° C and supercooled water droplets must be present
   b. Aircraft surface temperature must be colder than 0° C and outside ambient air temperature must be near -10° C to near -40° C
   c. Aircraft surface temperature near -10° C to near -40° C and supercooled water droplets must be present
   d. None of the above

4. What are the usual temperatures that rime, clear and frost icing usually form?

### 7.4. Icing Intensities

It is critical that we accurately forecast not only the type of icing, but the intensity as well. Most aircraft can handle light icing if they have deicing capabilities. However, as the icing intensity increases, more and more aircraft have problems. Let’s take a look at the different intensities of icing and how they affect an aircraft’s deicing capabilities.

- **Trace** - Trace icing is perceptible, but the rate of accretion (growth) is approximately balanced by the rate of sublimation. It is not a hazard unless
encountered for extended periods of time (over one hour). The use of deicing equipment is usually not necessary.

- **Light** - The icing rate of accretion is such as to create a hazard if the flight is prolonged in the icing zone (typically over one hour), but insufficient to make immediate diversionary action necessary. Occasional use of deicing equipment is needed.

- **Moderate** - The excessive rate of icing accretion makes even short encounters with these conditions hazardous. Diversion is necessary or continuous use of deicing equipment required.

- **Severe** - Icing conditions are such that deicing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

### 7.5. Icing Locations

Icing may occur during any season of the year, but in temperate climates, such as in most of the United States and northern Europe, it is most frequent in winter. Frontal activity is also more frequent in winter, and the resulting cloud systems are more extensive.

Generally regions at higher latitudes, such as Canada and Alaska, have the most severe icing conditions in spring and fall. In winter, polar regions are normally too cold to contain the concentration of moisture necessary for icing. The most intense icing outbreaks are usually associated with frontal systems.

#### 7.5.1. Frontal Systems

About 85% of all icing conditions occur in the vicinity of frontal systems. Refer to Figure 7-5 for a typical icing scenario with frontal systems. For significant icing to occur above the frontal surface, the warm air must be lifted and cooled to saturation at temperatures below freezing, making it contain supercooled water. If the atmosphere is unstable, icing may be sporadic; if it is stable, icing may be continuous over an extended area. Icing may form in this manner over either a warm frontal or a shallow cold frontal surface. A line of showers or thunderstorms along a surface cold front may produce icing, but the icing will be in a relatively narrow band along the front (see Figure 7-6). Icing below a frontal surface outside of the clouds will occur in freezing rain or drizzle. Precipitation forms in the relatively warm air above the frontal surface at temperatures above freezing. It falls into the cold air below the front, becomes supercooled, and then freezes on impact with the aircraft. Figure 7-7 shows the typical icing associated with a warm front. Freezing drizzle and rain occur with both warm fronts and shallow cold fronts.
Figure 7-5. Typical Icing Associated with a Frontal System

Figure 7-6. Cold Front Icing Zones
7.5.2. Cumuliform Clouds

The zone of probable icing in cumuliform clouds is smaller than in stratiform clouds. Icing is more variable in cumuliform clouds because many of the factors conducive for icing depend largely on the particular cloud’s stage of development. Icing intensities may range from generally a trace in small supercooled cumulus to moderate to severe in towering cumulus and cumulonimbus.

In a building cumulus, icing occurs at all levels where supercooled droplets exist, but is most intense in the upper half of the cloud. The most intense icing occurs in towering cumulus clouds just prior to their change to cumulonimbus. Icing is generally restricted to the updraft regions in a mature cumulonimbus and to a shallow layer near the freezing level in a dissipating thunderstorm. Icing in cumuliform clouds is usually clear or mixed.

The most significant icing in thunderstorms occurs in developing and mature thunderstorms, but little occurs in dissipating thunderstorms. This happens because the greatest icing areas are associated with strong updrafts, dissipating thunderstorms have mostly downdrafts.

7.5.3. Terrain

Icing is more likely to occur and be more intense in mountainous region than over other terrain. Mountain ranges cause upward air motions on their windward side. These vertical currents support large water droplets aloft that would normally fall as rain over level terrain. The movement of a frontal system across a mountain range combines the normal frontal lift with the mountain’s upslope effect and can create extremely hazardous icing zones.
5. About ____% of all icing takes place in the vicinity of frontal systems.

   a. 55%
   b. 65%
   c. 75%
   d. 85%

6. If warm air is unstable, icing may be __________; if it is stable, icing may be __________ over an extended area.

7. Icing below a frontal surface outside of the clouds occurs most often in __________ or ____________.

8. In a building cumulus, icing occurs at all levels where supercooled droplets exist, but is most intense where?

   a. In a shallow area just below the freezing level
   b. Only in a shallow area just above the freezing level
   c. Upper half of the building CU
   d. Lower half of the building CU
   e. None of the above

9. _________ (TRUE/FALSE) The most intense icing occurs in towering cumulus just prior to when it changes into a CB.

10. Why is icing typically more likely to occur and be more severe in mountainous terrain than over other terrain?

### 7.6. Tools and Techniques in Forecasting Icing

You can use several tools such as the WSR-88D and MetSat imagery for forecasting possible areas of icing. Skew-Ts, whether real time or forecast, are excellent sources for icing determination.

#### 7.6.1. WSR-88D

You can use radar to determine potential icing areas by looking at reflectivity-based products. As ice crystals fall through the melting level, their outer surface begins to melt.
Just below the melting level (0° C surface), large water-coated ice crystals are highly reflective. This high reflectivity produces enhanced radar signatures with a ring-like structure (refer to Figure 7-7). This feature is called the “bright band” because of its appearance on conventional weather radar. This echo is interpreted as lying just below melting level. The bright band can also be identified using a reflectivity cross-section.

**Step 1:** Find the 0° C isotherm or the freezing level by identifying the bright band.
- Seen as a ring of enhanced reflectivity (Normally found between 30-45 dBZ).
- The outer edge is the freezing level or 0° C level.
- The level can be determined by placing the cursor on the freezing level and reading the height.

**Step 2:** Use Skew-T data or PIREPs within the local area to determine the height of the -22°C isotherm. Then, use the cursor to locate this elevation on your reflectivity product.
- Returns present between the freezing level and the -22°C height have the potential of producing icing.

![Figure 7-7. Bright Bands on WSR-88D Reflectivity](image)

Note: The images in Figure 7-7 show the bright bands that correlate with the freezing level. It is evident that the freezing level has lowered in the image on the right.

Using velocity products can identify cold air advection, which typically produces cold season icing. Knowing what to look for concerning cold air advection lets you determine icing levels, whether there will be icing or not, and/or what icing intensities to forecast.

- The Base Velocity indicates cold air advection by a backward "S" pattern in the zero isodop (see Figure 7-8).
- The VAD Wind Profile (VWP) will show winds backing with height, the same pattern you see on the Skew-T (also see Figure 7-8).
7.6.2. Skew-T

Using the Skew-T is one of the most effective ways of forecasting icing. It quickly shows areas of moisture, temperature, types of advection and frontal inversions. A thorough analysis of the Skew-T is essential in understanding what is taking place in the atmosphere. We must remember that the atmosphere acts like a fluid that is always in motion. It is absolutely critical to take into account the changes to the atmosphere that will take place during your forecast period.

7.6.2.1. The -8D Method for Forecasting Icing

One effective way to forecast icing using the Skew-T is the (–8D) Method. This method is useful in identifying areas that are favorable for icing formation. In this example (Figure 7-9), the air in the middle layers is supersaturated with respect to ice. Factors to consider when using the -8D Method:

- When the temperature and the dew point coincide in the sounding, the -8D curve must fall along the 0° C isotherm. In a subfreezing layer, the air would be saturated with respect to water and supersaturated with respect to ice. Light rime icing would occur in altostratus or nimbostratus clouds in such a region, and moderate rime icing will occur in cumulonimbus virga, cumulus virga, and stratus.

- When the temperature and dew point do not coincide but the temperature curve lies to the left of the -8D curve in the subfreezing layer, the layer is supersaturated with respect to ice and probably subsaturated with respect to cloud droplets. If the clouds in this layer are altostratus, altocumulus, stratocumulus, or altocumulus virga, only light rime icing will be encountered. If the clouds are cirrus, cirrocumulus, or cirrostratus, only light hoarfrost will be sublimated on aircraft. In cloudless regions, there will be no supercooled droplets, but hoarfrost will form on aircraft through direct sublimation of water vapor. This is critical to some aircraft and hovercraft, which cannot tolerate any form of icing.

- When the temperature curve lies to the right of the -8D curve in a subfreezing layer, the layer is subsaturated with respect to both ice and water surface. No icing will occur in this region.
Use the following steps to compute the –8D:

- Plot the upper-air data from a sounding on a Skew-T.
- Plot the temperature and dew point in degrees and tenths to the left of each plotted point.
- Determine the dew point depression for the significant levels (calculate and plot the dew point depression times -8 for all levels where the temperature falls between 0° and –22°C).
  - This is D and is always positive or zero.
- Multiply the dew point depression (D) by -8 and plot the product (in °C) opposite the temperature at the pressure level.
- Repeat Step 4 for each temperature between 0° C and –22° C.
- Connect the points plotted by step 5 with a dashed line.
- Icing layers usually occur between the intersection of the temperature curve and the (–8D) curve when it is to the right of the temperature curve. These are levels that are supersaturated with respect to ice.
- Use the cloud type, the precipitation observed at the sounding time or forecast time, the temperature, and dew point to forecast the type and intensity of icing.

Figure 7-9. Example of –8D Method
The following rules apply to the (-8D) Method

- When the temperature curve lies to the right of the (-8D) curve in a subfreezing layer, the layer is subsaturated with respect to both ice and water surface. Forecast no icing in this region.

- When the dew point depression is 0°C, the (-8D) curve must fall along the 0°C isotherm. In a subfreezing layer, the air would be saturated with respect to water and supersaturated with respect to ice. Light rime icing would occur in altostratus or nimbostratus clouds in such a region, and moderate rime icing would occur in cumulonimbus, cumulus, and stratus.

- When the temperature and dew point do not coincide but the temperature curve lies to the left of the (-8D) curve in the subfreezing layer, the layer is supersaturated with respect to ice and probably subsaturated with respect to cloud droplets.

- If the clouds in this layer are altostratus, altocumulus, or stratocumulus, only light rime icing will be encountered.

- If the clouds are cirrus, cirrocumulus, or cirrostratus, only light frost will be sublimated on aircraft.

- In cloudless regions, there will be no supercooled droplets, but frost will form on the aircraft through direct sublimation of water vapor.

7.6.3. Satellite

Satellite imagery can help you detect potential areas of icing. There are some new and exciting products that are being developed that will aid the forecasting in locating icing regions (see Figure 7-10). We will concentrate on the data that is generally available to you. For those who possess the capability to dial in geostationary satellite imagery, you can use different channel settings to detect areas of possible icing. For example, three channels (Channels 1, 2, and 4) of the five spectral channels on GOES can be useful in spotting potential aircraft icing zones. Table 7-1 shows meteorological conditions identified as important with icing in clouds and the GOES channel useful for their identification.
Figure 7-10. Experimental GOES Icing Product

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GOES Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (0° to 20° C)</td>
<td>Channel 4</td>
</tr>
<tr>
<td>High liquid water content</td>
<td>Channels 1 and 2</td>
</tr>
<tr>
<td>Large droplet size</td>
<td>Channel 2</td>
</tr>
<tr>
<td>Area coverage and thickness of clouds</td>
<td>Channel 1</td>
</tr>
<tr>
<td>Upward vertical velocity</td>
<td>Channel 1</td>
</tr>
</tbody>
</table>

Table 7-1. Icing Identification on GOES

Visible imagery obtained from Channel 1 can be useful in several respects. Primarily, it can show the horizontal extent of clouds and a relative measure of cloud thickness and water content from the observed brightness of the cloud layers. It can also be used to identify areas of embedded convection.
Cloud top temperatures are available from infrared imagery on Channel 4. Icing may be present if the cloud top temperatures are within the favorable range of 0° to -20°C and no higher cloud cover exists. During the daytime, liquid phase clouds look warmer (darker) than ice phase clouds in the shortwave infrared channel (Channel 2). Therefore, by comparing Channels 4 and 2 temperatures, you can find supercooled clouds. Larger cloud droplet sizes or slightly thicker clouds cause embedded lighter gray shades sometimes associated with more intense icing.

Finally, on any MetSat imagery, look for synoptic scale patterns such as a developing frontal systems, or baroclinic leaf. These type systems are conducive to icing. Remember to also look for barotropic systems that seem to possess some moisture such as a decaying front, or surface trough.

11. Describe the “bright band.” What does it indicate?

12. Any returns present between the ___________ and the ______ ° C height has the potential to produce icing.

13. Why is the Skew-T useful in identifying icing conditions?

14. When the temperature curve lies to the right of the (-8D) curve in a subfreezing layer, the layer is subsaturated with respect to both ice and water surface. What kind of icing will occur in this region?

15. On MetSat imagery during the daytime, how do liquid phase clouds look compared to ice phased clouds?

7.7. Icing Forecast Rules of Thumb

Here are some general rules of thumb for determining icing type and intensity. Figure 7-11 is a flow chart summary you can use.

- At 0 to -7°C, if the dew point depression is 2° or less, or at -8 to -15°C with a dew point depression of 3° or less:
  - Forecast trace or light icing in zones of neutral or weak cold-air advection.
  - Forecast light icing in zones of moderate or strong cold-air advection.
  - Forecast light icing in zones of cumulus due to surface heating.
  - Increasing cold air advection into an area raises the possibility of icing.
- Moderate icing occurs in freezing drizzle, whether below or in clouds.
- Severe icing occurs in freezing rain, whether below or in clouds.
- Forecast little or no icing in clouds not resulting from frontal or orographic lift.
• Little or no icing occurs in areas with steady non-freezing precipitation.
• Light icing occurs in areas without steady non-freezing precipitation, particularly in cumuliform clouds.
• Rime icing occurs in cumuliform clouds when the temperature is colder than $-15^\circ C$ or in stratiform clouds when the temperature is from $0$ and $-15^\circ C$.
• Clear icing occurs in cumuliform clouds when the temperature is between $0$ and $-8^\circ C$.

![Figure 7-11. Icing Flow Chart](image)

Here are some extra rules for icing type and intensity in clouds caused by frontal or orographic lift.

• Light rime icing occurs in stratiform clouds up to 300 miles ahead of a warm front when the temperatures are between $0$ and $-14^\circ C$.
• Light clear icing occurs in cumuliform clouds up to 300 miles ahead of a warm front when the temperatures are between $0$ and $-8^\circ C$.
• Light mixed icing occurs in cumuliform clouds up to 300 miles ahead of a warm front when temperatures are between $-9$ and $-15^\circ C$.
• Moderate rime icing occurs 100 miles behind a cold front or with a deep low in stratiform clouds when the temperature is between $0$ and $-14^\circ C$.
• Moderate clear icing occurs 100 miles behind a cold front or with a deep low in cumuliform clouds when the temperature is between $0$ and $-8^\circ C$. 
• Moderate mixed icing occurs 100 miles behind a cold front or with a deep low in cumuliform clouds when the temperature is between –9°C and –15°C

An easy way to determine whether favorable conditions exist for icing, you can use Table 7-2. It’s a summary of the rules shown above indicating probabilities. The higher the probability, the better chance of getting icing.

<table>
<thead>
<tr>
<th>T</th>
<th>T - Td</th>
<th>Advection</th>
<th>Icing Forecast</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C to ⊿7°C</td>
<td>≤ 2°C</td>
<td>Neutral/Weak Cold Air Strong Cold Air</td>
<td>Trace</td>
<td>75%</td>
</tr>
<tr>
<td>-8°C to –15°C</td>
<td>≤ 3°C</td>
<td>Neutral/Weak Cold Air Strong Cold Air</td>
<td>Trace</td>
<td>75%</td>
</tr>
<tr>
<td>0°C to ⊿7°C or -8°C to –15°C</td>
<td>≤ 2°C or ≤ 3°C</td>
<td>None Associated areas with vigorous Cu build-ups due to surface heating</td>
<td>Light</td>
<td>80%</td>
</tr>
</tbody>
</table>

Table 7-2. Favorable Conditions for Icing

Finally, Table 7-3 shows you a “quick and dirty” method of deciding when not to forecast icing.

- Temperatures are 0 to –7°C and the dew point depression is greater than 2°C
- Temperatures are -8 to –15°C, and the dew point depression is greater than 3°C
- Temperatures are -16 to –22°C, and the dew point depression is greater than 4°C
- Temperatures are below –22°C, regardless of the dew point depression.

<table>
<thead>
<tr>
<th>T</th>
<th>Td</th>
<th>Forecast</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C to ⊿7°C</td>
<td>&gt; 2°C</td>
<td>None</td>
<td>80%</td>
</tr>
<tr>
<td>-8°C to –15°C</td>
<td>&gt; 3°C</td>
<td>None</td>
<td>80%</td>
</tr>
<tr>
<td>-16°C to –22°C</td>
<td>&gt; 4°C</td>
<td>None</td>
<td>80%</td>
</tr>
<tr>
<td>Lower than –22°C</td>
<td>Any spread</td>
<td>None</td>
<td>80%</td>
</tr>
</tbody>
</table>

Table 7-3. Unfavorable Conditions for Icing

16. With a temperature of between –8°C to –15°C, the temperature dew point spread of ≤ 3°C and strong cold air advection, what intensity would you forecast the icing?
   a. Trace
   b. Light
   c. Moderate
   d. Severe
17. In freezing drizzle, whether below or in cloud, forecast _________ icing.

18. In freezing rain, whether below or in cloud, forecast _________ icing.

19. With temperatures between −8° and −15° C and the dew point spread >3° C, forecast ________ icing with a ________% probability of a correct forecast.
   a. Light; 90%
   b. Light; 80%
   c. None; 80%
   d. None; 90%

At this point, your trainer and/or certifier should answer any questions you, the trainee, have or to clarify any points you are still unclear on. Your trainer and/or certifier should also review local/regional rules-of-thumb and techniques developed in your AOR(s) with you.
MODULE REVIEW QUESTIONS CONFIRMATION KEY

Module 1 - Surface Winds

1. Poles
2. Decreases
3. TRUE
4. This is a valley breeze, so wind flow is upslope

5. c. Land breeze
6. Warm; cold
7. b. 10 KTS with gusts 16-20 KTS
8. a. 15 KTS with gusts 30 KTS
9. Initialization and verification of the model is required to effectively use its output.

10. FALSE (A decrease of pressure and density of the air, and a decrease of friction with elevation causes wind speeds, on average, to increase about 1 to 2 knots for every 2,000 feet above sea level.)
11. TRUE
Module 2 – Sky Conditions

1. Condensation nuclei, moisture, and a cooling process

2. Amount of incoming solar energy and the thickness of the cloud layers

3. Cloud bases are at the altitude of saturation, and tops are at the point where the temperature of the surrounding air is the same as, or greater than, the temperature of the parcel of air.

4. If the slope is shallow, the air may not be lifted high enough for it to reach its saturation point.

5. d. BKN-OVC at 700 feet

6. 3,600 feet (T = 27°C (81°F); Td = 18°C (65°F); DPD = 9°C)

7. A scattered deck of middle clouds is moving in (Remember, if the wind plot on the VWP is red, the RMS value is often interpreted as a scattered (SCT) deck. Notice how this deck seems to thicken over time).

8. c. Both A and B

Module 3 - Visibility, Precipitation and Obstructions to Vision

1. d. Smoke, haze, dust, sand

2. By cooling the air to its saturation point (i.e., its dew point temperature) and By evaporative cooling and mixing.

3. a. Advection fog

4. Fog does not "burn" off, but rather, the sunlight penetrates the fog and warms the ground. This causes the air temperature in contact with the ground to increase. The warm air rises and mixes with the foggy air above, which increases the temperature of the foggy air. The fog droplets evaporate, allowing more sunlight to reach the ground, and the process to continue until the fog completely dissipates.

5. FALSE (Results in widespread frontal cloudiness and precipitation at and behind the front caused by actual frontal lifting.)

6. It will be accompanied by light to moderate rain, drizzle, or snow.
7. Steady precipitation is usually common with overrunning condition and the accompanying stratified clouds. Intermittent or continuous rain/snow is common as far as 300 miles ahead of a warm front. Surface rain, drizzle and snow are associated with the nimbostratus in the warm air above the frontal surface and with stratus in the cold air. If the warm air is convectively unstable, showers and thunderstorms may occur in addition to the steady precipitation.

8. a. Active warm front

9. c. 70%

10. 2,000 feet

11. TRUE

12. Snow

13. Almost certain

14. A cloud layer or fog depth should be at least 2,000-feet thick

15. Light snow

16. TRUE (A visibility of <5/16 mile in snow equates to 1.6” of snow per hour. When the low slowed, at least another 1.6” of snow fell upstream. Thus, it would be prudent to up your original snowfall estimate of 4” to 5.6” or rounded up to 6”.)

17. Snow exposed to sunlight (SCT - BKN) for 3 days will not have a crust, and so it is subject to drift or blow.

18. Very fine dust or salt particles, which are so small that they cannot be individually seen by the naked eye.

19. c. 3

20. Haze usually dissipates, as the atmosphere becomes unstable. Heating of the atmosphere by an increase of solar radiation and/or warm air advection may cause instability. Turbulent mixing may also disturb the stable atmosphere.

21. FALSE (As far as in-flight visibility is concerned, the most critical time during air refueling is just prior to hookup when hookup must be accomplished visually.)

22. Yes (The ROT is ½ nautical mile for each degree of dew point depression. Thus, 7 C° = 3.5 nm.)

23. Most whiteouts occur when the cloud deck is relatively low and the sun angle is at about 20° above the horizon.
Module 4 – Temperatures

1. Insolation and radiation, advection, mixing, and adiabatic process

2. More daytime heating in the summer months than in the winter months, since during the summer months the sun's rays are more direct and reach the earth for a longer period of time

3. TRUE

4. FALSE (Cloud cover prevents the escape of terrestrial radiation into space and causes a “greenhouse” effect, so nighttime temperatures to be relatively warmer than if no clouds were present.)

5. 5.4° F for every 1,000 feet (for both)

6. d. 56° F

7. b. 39° F

8. 44°F

9. FALSE (Light winds allow for increased heating during the day. Wind speeds above 10 knots decrease the daily maximum temperature by 1° C (2° F) or more due to the turbulent mixing down of cooler air from aloft. For surface winds above 35 knots, the high temperature can be 3° C (5° F) lower.)

10. 47° F (Use the dew point at maximum heating.)

11. 112° F

12. -25° F

13. No (Climatology provides a look at extreme and average temperatures for that particular location with elevation and other local topography considered based on actual temperatures. Say that this location is on the windward side of a 6,000-foot mountain range. The station you based this forecast on was in the valley. Climatology may reveal the extreme temperature for that location was only 84° F.)

Module 5 – Pressure

1. As you climb in elevation, there are fewer air molecules in the air above you. Thus, atmospheric pressure decreases with increasing heights.

2. Standard mean sea level (MSL) pressure is used to ensure proper aircraft separation in the vertical.
3. An altimeter is an aneroid barometer calibrated to indicate altitude instead of pressure. When the altimeter is properly set, the altitude indicated corresponds to the equivalent pressure in the standard atmosphere.

4. 30.18 (1022.5 – 1020.3 = 2.2; 2.2 X .03 = .07; thus 30.11 + .07 = 30.18)

5. +715 feet

6. The effects of air density on heavy airlift operations can limit a heavy aircraft’s payload. Payload affects the runway length requirements (needed length could increase by 50% or more). So, you would have to decrease the payload to lift off from a higher altitude and/or hot day situation location.

7. 1029.3 mb

8. +620

**Module 6 – Turbulence and Low-Level Wind Shear**

1. Directly; inversely; directly

2. Thermal/convective turbulence, frontal turbulence, and mechanical turbulence

3. b. MW

4. FALSE (CAT frequently occurs in regions of increasing thermal gradients.)

5. c. Along and above

6. b. 250

7. a. Wind

8. 40; 10°
11. Wind speed and/or direction over a short distance

12. Thunderstorms/convective activity, temperature inversions, frontal activity, and surface obstructions

13. Warm frontal wind shear may persist for six hours or more over a particular airfield because of the small slope and slow movement of the warm front

14. Cold fronts generally move faster than warm fronts and with accompanying steeper slopes, and so, the duration of LLWS is usually only 1 to 2 to two hours.

15. FALSE (This is a case where both Steps 4-6 criteria are met. The sustained surface wind is less than 10 knots, and the absolute value of the vector difference between the gradient wind and the surface wind is 30 knots or greater and an inversion or isothermal layer is present below 2,000 feet.)

Module 7 – Icing

1. b. Temperature, drop size, and rate of accumulation.

2. TRUE

3. a. Aircraft surface temperature must be colder than 0° C and supercooled water droplets must be present

4. Rime ice is most frequently associated with stratus clouds at temperatures between -8° C and -10° C, although it has been observed to form between -2° C and -30° C; clear ice: between 0° C and -16° C; frost: when moist air above 0° C passes over a surface that is below 0° C

5. d. 85%

6. Sporadic; continuous

7. Freezing rain or freezing drizzle

8. c. Upper half of the building CU
9. TRUE

10. Vertical currents on their windward side support large water droplets aloft that would normally fall as rain over level terrain. The movement of a frontal system across a mountain range combines the normal frontal lift with the mountain’s upslope effect and can create extremely hazardous icing zones.

11. Just below the melting level (0° C surface), large water-coated ice crystals are highly reflective due to melting. This high reflectivity produces enhanced radar signatures with a ring-like structure—the bright band. The bright band echo is interpreted as lying just below melting level. The outer edge is considered the freezing level.

12. 0°; -22°

13. It quickly shows areas of moisture, temperature, types of advection and frontal inversions.

14. Forecast none

15. Liquid phase clouds look warmer (darker) than ice phase clouds in the shortwave infrared channel.

16. b. Light

17. Moderate

18. Severe

19. c. None; 80%