Air Force Weather Qualification Training Package
Convective Weather Trainee Workbook

Providing Standardized Training to
“Exploit the Weather for Battle”

AIR FORCE WEATHER AGENCY
TRAINING DIVISION
106 Peacekeeper Dr., Ste 2N3
Offutt Air Force Base NE 68113-4039
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Trainee Workbook Instructions

- This QTP Trainee workbook standardizes on-the-job training (OJT) for Air Force Weather (AFW) personnel. The intent is to breakdown subject matter by modules into teachable elements called task objectives. Use the Table of Contents for quick reference to find the module you need.

- Workbook materials give a module overview plus 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 questions confirmation key.

- As a trainee, before you start completing this workbook, you need to understand the QTP process. You need to know that each QTP has three components. Part one is this Trainee Workbook (TW) that contains all subject matter material. Part two is the Trainer’s Guide (TG) explaining how each module and task objective is taught. Part three is the Evaluation Package (EP) containing all task certifier written exams, performance applications, and confirmation keys to grade your comprehension.

- Be sure the 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 Evaluation Package. The task certifier will grade all responses. If a written score or performance application is less than what is required, you will need to restudy the module material and your trainer will provide additional OJT in those weak areas. Once the material has been restudied you will be require to retake the evaluation.

- After you successfully complete the Evaluation Package for each module, inform your trainer. Your trainer will get a task certifier who will perform a final certification checkride on the module. Upon completion of a module, your supervisor will ensure all documentation is completed in your training records.

- 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 feel you are not getting adequate training on a topic, discuss this situation with your supervisor and/or unit-training manager. Additional material or a different trainer may be assigned.

- Routine corrections and minor updates to this document will be done via disseminated 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 – Characteristics of Thunderstorms

TRAINEE’S NAME ____________________________

CFETP REFERENCE: 12.12.1

MODULE OVERVIEW:

This module covers the basic characteristics of thunderstorms; the structure, conditions and types of convection.

TRAINING OBJECTIVE:

• After completing the module, the student will be able to identify the structure of thunderstorms, conditions favorable for thunderstorm formation, and types of thunderstorms. The student will demonstrate this ability by answering questions with at least 80% accuracy.

EQUIPMENT AND TRAINING REFERENCES:

• Technical Report 200 (Rev), (Notes on Analysis and Severe-Storm Forecasting Procedures of the Air Force Global Weather Central)
• AFGWC/TN 79/002 (Training Guide for Severe Weather Forecasters)
• AFWA/TN-98/002, (Meteorological Techniques)
• AFCCC/TN 96/003 (Lightning Climatology for Low-level Flying Routes in the United States)
• Meteorology Today (Sixth Edition)
• Meteorology (Fifth Edition)
• Cooperative Program for Operational Meteorology, Education and Training (COMET)

PREREQUISITES AND SAFETY CONSIDERATIONS:

• Completion of the Analysis and Prognosis QTP
• Completion of the Weather Elements QTP
• Completion of the Basic MetSat QTP
Completion of the Radar QTP

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

1.1. General Information Concerning Convection

Forecasting convective weather conditions and providing the necessary warnings for the protection of both personnel and resources is one of the greatest responsibilities of the weather forecaster.

Thunderstorms represent one of the most challenging weather conditions that you may face. High winds, hail, lightning; heavy rain, turbulence, and tornadoes are a definite threat to the safety of all resources on the base or in the field. This includes equipment and personnel.

**DID YOU KNOW?**

- At any given moment, nearly 1,800 thunderstorms are in progress over the surface of the earth.
- On average, the United States gets 100,000 thunderstorms each year. Approximately 1,000 tornadoes develop from these storms.
- Large hail results in nearly $1 billion in damage to property and crops annually.
- The power of lightning’s electrical charge and intense heat can electrocute on contact, split trees, ignite fires and cause electrical failures.
- More deaths from lightning occur on the East Coast of the U.S. than anywhere else on earth.
- More forest fires are started in the West U.S. as the lightning season coincides with the dry season there.
- Approximately 10,000 forest fires are started each year by lightning.
- Approximately $100 million in annual losses result from forest and building fires caused by lightning.
- Straight-line winds exceeding 100 mph are responsible for most thunderstorm damage.

Thunderstorm activity is very serious business. This module covers the conditions, structure, and types of convection.
1.1.1. Thunderstorm Conditions

What is a thunderstorm? A thunderstorm is formed from a combination of warm moist air and a force capable of lifting the air such as a warm and cold front, a sea breeze, or a mountain. Since lightning causes thunder, all thunderstorms contain lightning. Thunderstorms may occur singularly, in clusters or in lines. Thus, it is possible for several different thunderstorms to affect one location in the course of a few hours. This does not imply that you should ignore isolated thunderstorms; in fact some of the most severe weather occurs when a single thunderstorm affects one location for an extended time.

For thunderstorms to occur, three basic requirements must be met:

- The airmass must be unstable.
- Relatively warm, moist, low-level air must be available
- There must be some type of low level lifting mechanism (trigger). The trigger is needed to start moving air upward. This trigger may be unequal heating of the surface, the effect of terrain, or the lifting of warm air along a frontal boundary.

Several of these mechanisms usually work together to generate thunderstorms.

Note: in this module we use the word convection to mean thunderstorm.

1.1.1.1 Lift and Forcing Mechanisms

There are two types of lift and forcing mechanisms, synoptic and mesoscale.
Synoptic scale lift, by itself, will not generate or trigger convection, but does produce an environment favorable for the development of deep, moist convection. It does this by:

- Increasing the lapse rate
- Reducing the negative area below the level of free convection (LFC). The LFC is the level in the atmosphere where the rising air becomes warmer than the surrounding air.
- Making it easier for near-surface air to be pushed upward to the LFC by creating an exhaust mechanism aloft.

Some synoptic scale lift systems are:

- Mid and upper-tropospheric short wave troughs
- Upper level divergence associated with jet stream maxima
- Warm air advection

Mesoscale lift is identified through numerous studies as the mechanism that starts and focuses the forcing in the boundary layer. These studies suggest that mesoscale boundary layer convergence lines play a major role in determining where and when storms form. Thus it is extremely important that the forecaster be able to identify any boundary layer convergence zones in his or her area of interest.

Three factors produce mesoscale convergence zones at or near the surface. These are boundaries, topography, and differential heating. Let's look at each one in more detail.

Boundaries refer to any low-level discontinuity characterized by cyclonic shear and convergence. Some boundaries that you should be familiar with are:

- Troughs
- Convectively-produced outflows or gust fronts (discussed in more detail later)
- Moist discontinuities or dry lines (discussed in more detail later)
- Colliding convergence lines. These lines initiate storms or intensify existing thunderstorms

Topography is usually a less obvious and often subtle lifting mechanism; the convergence produced by near-surface wind flow interacting with the terrain is what produces the lift. Knowledge of the local or forecast area topography is vital to a good forecast. Some topography features you should be aware of are:

- Mountains
- Hills
- Coastlines
- Valleys

The final mesoscale lift that we will discuss is differential heating. Differential heating can be defined as a strong temperature difference over a relatively short distance. This difference can create mesoscale circulation that has a potential for upward motion.
sufficient to carry boundary layer air to the LFC. Some sources of differential heating are:

- Sea / land breeze
- Land / lake breeze
- Mountain / valley breeze
- Clear sky – cloud boundaries
- Urban heat island effects

1.1.1.2 Divergence Aloft

The divergence of upper level winds can also provide favorable regions of thunderstorm development. Divergence aloft is a required upper-level exhaust mechanism; however, by itself, it is not enough to produce thunderstorms. To produce convection, divergence aloft needs to be coupled with low-level convergence. Some upper level features that infer divergence are:

- Short waves – produce divergence downstream
- Jet maxima – divergence can be found in the left front and the right rear quadrant of the jet max

1.1.1.3 Shear

Shear enables a storm to live longer and become more severe. There are two components to wind shear: speed and direction. Increasing wind speed with height, and veering of the winds with height is usually more favorable for development of deep convection or supercells. Supercells are severe thunderstorms with usually one rotating mesocyclone. Supercells are discussed in much greater detail later. Figure 1-2 depicts examples of vertical wind profiles for different types of thunderstorms.

![Figure 1-2 Idealized Vertical Wind Profiles](image)

Wind shear is important in thunderstorm development for two reasons:
• Air parcel trajectories are tilted (figure 1-3) so that precipitation does not fall back through the updraft. Without this shear, the cells would collapse upon themselves as the precipitation and the downdraft fall back through the updraft. The shear coupled by strong winds aloft allows the storm’s updraft and downdraft to coexist for an extended period of time.

**Figure 1-3 Tilted Updraft**

• Vertical shear creates horizontal vorticity (local spin about a horizontal axis). This horizontal vorticity is a vital ingredient in the development of a rotating updraft and subsequent severe thunderstorm development.

Figure 1-4 depicts the correlation between the updraft strength and the amount of shear. The stronger the updraft and shear, the more likely the supercell event.

**Figure 1-4 Correlation between Shear and Updraft**
1. What are the three ingredients necessary for thunderstorm development?

2. Synoptic scale lift, by itself, will / will not generate or trigger convection. (Circle the correct response)

3. What needs to be coupled with upper level divergence to produce convection?

4. What are the two components of wind shear?

1.2 Types of Convection

There are two types of convection, forced convection and free convection. Forced convection is caused by some type of lifting mechanism that forces the air aloft. The forced air continues to rise until either it becomes negatively buoyant and the lifting mechanism is no longer strong enough to keep the air parcel aloft or an external force influences it (for example: convergence aloft). Some examples of forced convection are air lifted by a frontal boundary, air forced aloft by mountains, or some type of low-level convergence.

The second type of convection is free convection. Free convection is caused by warm air rising without any external influences (i.e. fronts, terrain, convergence, etc.). The heating of the surface by the sun’s short wave radiation and the subsequent release of long wave radiation from the earth’s surface warms the air in the low levels and causes it to rise. The warmer air will continue to rise until it is cooled (through the adiabatic process) to the temperature of the surrounding air or an external force influences it. Free convection and forced convection sometimes work together. As the warm air rises, it is replaced by air at the surface creating low-level convergence that enhances the upward vertical motion of the air parcels.

5. What is the difference between free convection and forced convection?

1.3 Single Cell Thunderstorm

Scattered thunderstorms that form in warm, maritime tropical air masses far from frontal boundaries are often referred to as single cell thunderstorms, or pulse storms. These storms are usually short-lived and rarely produce severe weather. Thunderstorms however, don’t just appear; they must go through stages of development. This is often referred to as the thunderstorm life cycle or pattern. This pattern can be broken down into three stages, the cumulus stage, mature stage, and the dissipating stage.
1.3.1 Cumulus Stage

The first stage is the cumulus stage (figure 1-5). In this stage the cloud is composed primarily of updrafts. No precipitation falls from this type of cloud because all the precipitation is held aloft by the updraft. To an observer watching the development of thunderstorms, the cumulus stage will appear like a puff of cotton.

If you have ever watched a thunderstorm develop, you may have noticed at first the cumulus clouds grow upward only a short distance, then dissipates. This is because the cloud droplets evaporate as the drier air surrounding the cloud mixes with it. However, after the water droplet evaporates, the air is moister than before. The rising air is now able to condense at higher levels, and the cumulus cloud grows taller. As this process continues the cumulus cloud will begin to grow into rising towers or domes.

![Figure 1-5 Cumulus Stage](image)

1.3.2 Mature Stage

As the cumulus cloud continues to build, the cloud droplets also grow larger. The cloud droplets will continue to grow and rise until the updraft is no longer able to keep them suspended.

While this phenomenon is taking place, drier air from around the cloud is being drawn into the cloud. This is called entrainment. The entrainment of drier air evaporates some of the droplets, cooling the air through the process of evaporative cooling. The air, now cooler and heavier than the air around it, begins to descend. The downdraft may be enhanced as falling precipitation drags some of the air along with it. This point signifies the beginning of the mature stage (figure 1-6).

During the mature stage, the thunderstorm is considered to have the most potential for destruction. The top of the cloud, having reached the stratosphere, begins to take on the familiar anvil shape. Strong upper level winds spread the cloud’s ice crystals horizontally. The cloud may extend upward to over 60,000 feet. Updrafts and downdrafts reach their greatest strength in the middle of the cloud, creating severe turbulence.

The mature stage is also when hail begins to form. Hail is formed in the vicinity of the updrafts near the freezing level. As liquid precipitation is carried above the freezing level, it freezes into a frozen droplet, and then falls back below the freezing level only to be lifted again by another updraft. Each time the hail descends below the freezing level it
is coated with another layer of water. This water-coated hail is then once again lifted above the freezing level. This causes the hail to continue to grow until it becomes too heavy for the updraft to support it and it falls toward the earth. The size of the hail reaching the surface depends on two factors:

- The strength of the updraft. The stronger the updraft, the larger the hail it can support.
- The height of the freezing level. The freezing level must be close enough to the surface so the hail doesn’t melt during descent.

1.3.3 Dissipating Stage

Individual thunderstorms are not long-lived phenomena. About 15 minutes to an hour after the storm enters the mature stage, it begins to dissipate (figure 1-7). The dissipating stage occurs when downdrafts form throughout the cloud. The downdrafts deprive the storm of its rich supply of warm, moist air and cloud droplets are no longer able to form. The once mighty storm now contains primarily weak downdrafts accompanied by light precipitation. As the storm dies, the lower level cloud particles evaporate rapidly, sometimes leaving only the cirrus anvil.

As these cold downdrafts reach the surface, they may once again force warm, moist air upward. The rising air then condenses and gradually builds into a new thunderstorm. This may cause a series of thunderstorms to grow into a line, one next to the other, each in a different stage of development. Thunderstorms that develop in this fashion are termed “multicell” storms.
6  In which stage is hail most likely to occur?

1.4 Multicell Thunderstorms

A multicell cluster consists of a group of cells moving as a single unit, with each cell in a different stage of the thunderstorm life cycle. As the multicell cluster evolves, individual cells take turns being the most dominant. New cells tend to form along the upwind (typically western or southwestern) edge of the cluster, with mature cells located at the center and dissipating cells found along the downwind (east or northeast) portion of the cluster.

In figure 1-8, a group of multicell storms can be seen over Texas. These storm clusters are labeled A through C, with A being the oldest storm cluster. Notice new cell development in the southwestern quadrant of each cluster (noted by arrow). This is the convergent inflow area where surface moisture and heat aid in further convective development. Dissipating cells can be seen in the northeastern quadrant of each storm cluster.
Figure 1-8 GOES East Image

Multicell cluster storms frequently look similar to the one pictured in Figure 1-9. Looking north from about 10 miles, note the three distinct updraft towers at the left (west) portion of the storm (3,4,5). The heaviest precipitation likely falls beneath the highest cloud top (3). The right (east) side of the complex is dominated by anvil outflow, moving with the storm from left to right (1,2).

Figure 1-9 Multicell Thunderstorm

Multicell severe weather can be of any variety (winds, hail, weak tornadoes, etc), and generally these storms are more potent than single cell storms. Organized multicell storms have a higher severe weather potential, although unorganized multicells, which are simply conglomerates of single cells, can produce sporadic severe events.

The multicell storm’s survival is dependent on an unimpeded warm, moist inflow. As moisture accumulates in the mid and upper portions of the storm, the mass of the accumulated water weakens the updraft if not carried away. Strong mid and upper level winds are necessary to carry the accumulated precipitation downstream to prevent it from
falling back into the updraft. These winds carry the precipitation away from the updraft allowing the updraft and downdraft to coexist. The strong mid and upper level winds draw mass away from the updraft further intensifying it. This is the same principle as the “chimney effect”. The stronger the wind above the chimney, the stronger the updraft created in the chimney.

At low levels, the inflow is cut off from entering the forward portion of the storm by the precipitation and the associated downdraft. Southerly winds will allow the cell to continue to draw in warm, moist air along its right rear flank. The images to the right and below illustrate this.

**Figure 1-10 Multicell Development and Propagation**

The image on the left is an idealized radar view of the regeneration of new cells in the multicell complex. New cells form on the right flank and move through the complex to die on the left flank. This gives the impression that the complex is moving to the right of the actual direction that the line is moving.

The close proximity of updrafts within the multicell cluster storm results in updraft competition for the warm, moist low-level air. Thus, updrafts never attain extremely strong vertical velocities and each has a short life span when compared to a supercell updraft. Naturally, multicell severe weather usually is less intense than supercells but still can be quite potent. It is possible to have marble to golf ball size hail and 50 to 70 knot winds.
7. What is a multicell thunderstorm?

8. Explain why a strong mid and upper level jet is important to multicell development.

9. Why do multicell complexes sometimes give the impression that they are moving right of the actual storm motion?

1.5 Supercell Thunderstorms

The supercell is the most awesome and potentially dangerous of convective storm types. Although supercells are rare, they pose a very high threat to life and property. The supercell has been defined as a thunderstorm consisting of one quasi-stationary rotating updraft (in relation to the storm) which may exist for several hours. The updraft is extremely strong, reaching estimated speeds of 150-175 miles per hour. This rotating updraft is what separates supercells from regular thunderstorms. Supercells form under a combination of the following conditions:

- Moist and very unstable low levels of the atmosphere
- Dry air in the mid to upper levels of the atmosphere
- Strong vertical wind shear
- Winds change direction by roughly ninety degrees in the lowest four kilometers

Supercells can produce devastating weather conditions. Hail greater than two inches, strong downbursts of 80 miles per hour or more, torrential rain, and deadly tornadoes have accompanied supercells.

1.5.1 Mesocyclone

The rotation inside a supercell is called a mesocyclone. A strong jet in the upper levels of the atmosphere accompanied by veering winds closer to the surface causes this rotation (Figure 1-11).
The strong vertical wind shear creates horizontal anticyclonic vortices, which, when entrained into the updraft, become tilted vertically. When winds veer with height, the horizontal vortex is tilted in such a way that cyclonic rotation in the midlevel is induced in the updraft (A rarer case occurs when the winds back with height and an anticyclonic rotation is induced in the updraft).

**Figure 1-12 Horizontal Vortices Tilted into Updraft**
Figure 1-13 Early Stage of Supercell Evolution and Accompanying Shear

Strong easterly-induced shear can also produce cyclonic rotation if entrained into the updraft (Figure 1-14)

Figure 1-14 Upward Tilting in Easterly Shear

The center of the mesocyclone marks the position of the mesolow. Large amounts of mass are carried aloft and strong upper level divergence (exhaust) takes this mass out of the thunderstorm column. Conditions aloft that promote upper level divergence are necessary ingredients in the formation of thunderstorms, both severe and non-severe. The divergence causes the anvil to grow rapidly in all directions, including upstream against the upper level winds. This creates a sharp upwind anvil edge (Figure 1-15).
Figure 1-15 Cirrus Anvil on the Back Edge of Thunderstorm
To compensate for the mass being forced aloft, subsidence takes place outside the cloud. This downward motion suppresses convective activity around the supercell. This suppression along with the supercell’s strong updraft cuts off the low-level moisture supply to any other cells. This combination starves any potential storms of their fuel supply. This leaves the supercell free to absorb all the moist, unstable, low-level flow.

10. What differentiates a supercell from other thunderstorms?

11. Explain what occurs when strong vertical wind shear interacts with horizontal anticyclonic vortices.

12. Where is the mesolow located?

13. Why is other convective activity usually suppressed around a supercell?

1.5.2 Forward Flank Downdraft
As mid level winds divert around the updraft, the wind carries precipitation downstream. As this precipitation begins to fall, a downdraft begins to develop downwind of the updraft core. This is known as a forward flank downdraft (FFD). The falling precipitation drags mid level winds toward the surface, enhancing the FFD (Figure 1-16).
14. Why does falling precipitation enhance the forward flank downdraft?

1.5.3 Rear Flank Downdraft

The rear flank downdraft (RFD) forms when mid and upper level winds pass beneath the upwind anvil and collides with the updraft causing a buildup of mass. As mass builds, some evaporation begins to take place on the back edge of the updraft. Due to the evaporative process (entrainment), the air on the back edge of the updraft begins to cool and sink. This sinking, cool air, along with precipitation drag, enhances the RFD (Figure 1-17).
15. How does the Rear Flank Downdraft develop?

16. How does the evaporation process enhance the Rear Flank Downdraft?

1.5.4 Weak and Bounded Weak Echo Region

The strong, rotating updraft pushes low level moisture high into the storm. This causes an area of precipitation free air to develop. This area or “vault” as it is commonly referred to, is known as the weak echo region (WER). If the updraft is strong enough that precipitation is wrapped back around the updraft core, a bounded weak echo region (BWER) will form. The BWER is located on the right rear flank of the storm. Typically the vault decreases in width with height, extending to a height one-half to two-thirds of the cell’s depth. The horizontal dimensions of the BWER are normally 5 to 12 kilometers. The storm top is located directly over the vault (Figure 1-18).

Figure 1-18 Bounded Weak Echo Region (BWER)

17. What causes the BWER?

18. Where is the storm top located in relation to the BWER?

1.5.5 Two Cell Mesocyclone

As the RFD intensifies and descends, interaction with the updraft creates a divided or two-celled mesocyclone as seen in Figure 1-19. The two-celled structure has strong cyclonically curved updrafs to the east in the “warm inflow sector” and strong cyclonically curved downdrafs to the west in the “cool outflow sector”. An intense shear zone forms at the interface between the two cells.

As the RFD descends and entrainment with the updraft occurs, the updraft weakens and the BWER begins to collapse as evidenced by lowering of the storm’s cloud top (evident both visually and on radar). The mesocyclone descends with the BWER and its
circulation center (the mesolow) shifts to the zone of high vertical velocity gradient between the updraft and the RFD. When the RFD reaches the surface, a rear flank gust front is created. This greatly increases the amount of low level shear present beneath the storm.

**Figure 1-19 Two-Cell Mesocyclone**

When the mesolow shifts to the area separating the RFD and the updraft, a subvortex may also form in this region. The subvortex is an intense circulation center that may rotate around the mesolow or may be coincident with it.

On the surface, the RFD overtakes the FFD and forms an occlusion (much like a frontal occlusion). This weakens the updraft and the BWER begins to collapse. This causes the mesocyclone and the subvortex to descend toward the surface. The mesolow and subvortex are above the surface occlusion and this is the most likely place for strong tornadic activity to occur. The interaction of the subvortex and the low-level shear associated with the gust fronts and inflow can produce strong tornadic activity.

As the mesoscale system continues to occlude, the inflow is greatly reduced, the updraft weakens and the tornado dissipates. The updraft can redevelop along the line of convergence associated with the gust fronts and the process can start over.

19. What might the lowering of the storm’s cloud top signal?

20. What greatly enhances the amount of low level shear that is present beneath a storm?

21. Name the interactions that can produce strong tornadic activity.

**1.5.6 Supercell Visual Clues**

Visual characteristics can be used to determine supercells. In the upper-levels, the presence of an anvil and an overshooting top are good indicators of severe storms,
particularly supercells. Anvils can indicate where the storm is moving and possibly the strength of the updraft. The direction the cirrus is being blown off is the general direction of movement.

Overshooting tops can also indicate the updraft strength (figure 1-21a). If the top is small, chances are the storm will be short-lived. If the overshooting top appears dome-like and lasts for a fairly long period of time, the supercell is more than likely severe.

In the midlevel of the storm, recognition of a strong updraft can be noticed by the distinction in the clouds (figure 1-21b). A well-defined, sharp-edged appearance is a sign of a strong updraft. If the clouds at the midlevel are clumped together, with no separation, the updraft is weaker.

Since supercells have a rotating updraft, striations in the cloud wall of the cumulus cloud will give it a spinning or rotating appearance. Another sign of a rotating updraft is a ring of clouds encircling the updraft tower in the mid-level region.
In the low-levels, many visual distinctions can be made. The first is the rain-free cloud base, which is normally located in the rear section of the storm, where inflow is occurring (Figure 1-22).

![Figure 1-22 Rain Free Cloud Base under Supercell](image)

Another indication at the low-levels is the presence of a wall cloud (Figure 1-23a) under the rain-free cloud base. This inflow into the cloud may show rapid vertical motion. (Note: Not all wall clouds rotate, and not all wall clouds are associated with tornadoes). A cloud with the appearance of a wall cloud, but with outflowing winds associated with it, is considered a shelf cloud (figure 1-23b).

![Figure 1-23 Left to Right: Wall Cloud, Shelf Cloud](image)
22. Name three visual indicators of a strong updraft in a supercell.

23. Where is the rain-free cloud base located?

24. What is the difference between a wall cloud and a shelf cloud?

1.5.7 Types of Supercells

We have just finished discussing the “classic” supercell. However, there are two other types of supercells that need to be discussed further. A supercell that produces heavy precipitation and large hail is called a High Precipitation supercell (HP). A supercell characterized by little precipitation is referred to as a Low Precipitation supercell (LP). Both of these storms produce extremely violent weather including tornadic activity.

1.5.7.1 High Precipitation Supercell

High Precipitation supercells are storms containing copious amounts of precipitation (Figure 1-24). They can occur in any part of the U.S. and are easy to detect on radar. They usually have a large radar echo with evidence of rotation within the storm. The heavy precipitation may obscure some (or all) of the "rain-free" base area and important cloud features.

![Figure 1-24 High Precipitation Supercell](image)

1.5.7.1 Low Precipitation Supercell

Low-precipitation supercells are most commonly found on the High Plains of the U.S., near the dryline. The High Plains are generally referred to as the region west of 100° longitude to the foot of the Rocky Mountains. Sometimes called "dryline storms", LP supercells have been documented in the Upper Midwest as well. LP supercells are difficult to detect on radar, because the radar echoes are usually small and weak (low reflectivity values) and the radar may not detect rotation within the storm. LP storms are fairly easy to identify visually, however. The typical low-precipitation supercell has a translucent main precipitation area. The main storm tower is usually thin, bell-shaped (flared out close to the cloud base), and has corkscrew-type striations on the sides of the tower.
25. Which one of the supercells, HP or LP, produces violent weather including tornadic activity?

26. Explain why LP storms are difficult to detect on radar.

1.6 Storm Motion

The motion of supercell storms deviate from the mean winds. Usually, supercells move to the right and slower than the mean winds. Such storms are called severe right moving supercells (SR). Occasionally, severe left (SL) moving supercells are observed (this phenomena occurs only about 2% of the time). A single storm on rare occasions may split into SR and SL supercells.

A cyclonic rotating updraft is associated with winds that veer strongly with height. This environmental condition produces the SR supercell. The SR supercell is associated with all forms of severe weather. Anti-cyclonic rotation of the updraft is associated with winds that “back” with height. This environmental condition produces the SL supercell. The SL supercell is a notorious hailier, but tornadoes are rare.

The Magnus principle is useful in explaining the movement of SR and SL storms. Remember, as the mid and upper-level winds flow into the back of the updraft core, mass begins to build up. Some of this mass is diverted around the updraft in the direction of the rotation, and some is forced against the flow of rotation (Figure 1-26). Pressure imbalances form affecting the movement of the storm. The storm will move towards the direction of the pressure deficit.
Figure 1-26 Magnus Effect as Related to Supercell Movement

1.6.1 Supercell Movement

The Following are Supercell Motion Rules of Thumb:

- Move 30 to 60° to right of mid level flow.
- Follow old discontinuity lines.
- May follow low level moisture source (moist axis).
- May split into cyclonic/anticyclonic couplets.
27. How do supercells usually move in relation to the mean winds?

28. What phenomena usually produce severe left moving supercells, and what kind of severe weather are they noted for?

1.7 Lightning

Figure 1-27 Lightning over Australia

As mentioned earlier, there are approximately 1,800 thunderstorms occurring simultaneously around the earth at any given moment. These thunderstorms produce about 100 cloud-to-ground lightning strikes every second. Lightning is a very powerful force that can kill people and animals, destroy trees and buildings, initiate forest fires and disrupt power for hundreds and thousands of people each year.

During the past 30 years in the United States, lightning has ranked second only to flash floods in weather-related deaths with an average of 85 people killed annually by direct lightning strikes. Approximately the same number die as a result of lightning related fires and accidents. Lightning usually takes its victims one at a time, so it is not given the
same media attention as tornadoes and hurricanes which often result in multiple deaths and massive destruction of property. Additionally, injuries from lightning average more than 2.5 times the amount of deaths from lightning, so the number of people affected by lightning every year is large.

Let’s begin with how lightning forms. Both the earth and the atmosphere are electronically charged. The net charge of the earth is negative and the upper atmosphere (ionosphere) is positive. The atmosphere, between these two layers is a poor conductor with a weak continuous positive (+) to negative (-) current. There is distinct diurnal variation, which correlates well with global thunderstorm activity.

Why charge separation in clouds? There are many theories on how different charge zones form in thunderstorms. Two of the theories are freezing effects involving impurities and charge transfer during particle collision.

- **Freezing Effects.** The general theory is that, as the updraft becomes established in the cloud and water droplets freeze into ice, the frozen pieces of ice grow and fall toward the ground, crashing into the smaller particles of ice. During these collisions, ions or bits of charged ice are probably transferred, giving the hail a - charge. The ice slivers with a net + charge are carried high into the cloud. The net result is + charges in the top part of the cloud and - charges near the lower part. The electrons in the bottom of the cloud are attracted to the + atoms in the top of the cloud, in other clouds and on the ground.

  In general, it has been found that clouds containing large ice particles and small supercooled water drops have the capacity to promote charge separation, thus, producing electric fields sufficient for lightning to occur.

- **Charge Transfer.** As particles interact, oppositely charged particles move apart in the updraft to form the observed charge centers. The charge separation rate depends therefore on the liquid water content (LWC), the number and sizes of ice crystals and hail particles in the charging zone (CZ). These variables are influenced by several factors such as the strength and duration of the updraft below the charging zone, the number and size of supercooled drops. The electric field strength at any time depends on the charge separation rate and the duration of charging.

The electrical charges in a thunderstorm begin to polarize late in the growth stage of towering cumulus as significant updrafts develop. Electrical activity can occur in as little as 5-10 min after cloud growth begins. During this time, a negative charge center develops in the CZ. As the potential gradient increases between the earth and the base of the cloud, + ions begin to stream into higher points of the ground below (trees, towers, etc. as seen in figure 1-28.). The first strikes likely occur between pockets of less charge within the cloud mass, resulting in in-cloud and cloud-to-cloud lightning.
Figure 1-28 Polarization of Thunderstorm and Surrounding Region

The Lightning Discharge.

The attraction between the + and - atoms may eventually become so large (technical term is called the potential gradient) that there is a sudden rush of these atoms toward each other resulting in the lightning discharge.

Most of the total energy expended in a lightning discharge goes into light and heat. Thunder is produced when air immediately around the lightning channel is superheated to 15,000-60,000 F (8,000-33,000 C) in less than a second. When the air is heated this quickly, its density is much less than the surrounding environment and the surrounding air rushes in and collides, causing the thunder noise. When lightning strikes nearby, the sound may be a loud bang, crack, or snap often followed by a rumbling or growling sound caused by sounds from different heights along the channel at farther distances. The sound reaches our ears at varying times and may last for several seconds. Thunder can be heard up to an average of 10 miles (15 km) away (50 seconds from the visible flash to the bang sound). One can estimate how many miles away a lightning strike is located by counting the number of seconds between the observed lightning and the sound of thunder and dividing by 5. In a quiet location, under favorable atmospheric conditions, thunder can be heard farther than 10 miles away. Figure 1-28 shows examples of polarization and several types of lightning discharges.
1.7.1 CONUS Lightning Climatology

In this section we will look at some different types of lightning climatology available. The best use of lightning climatology is to provide an estimate of thunderstorms frequency.

Air Force Combat Climatology Center (AFCCC) has lightning climatology that depicts the seasonal average lightning strikes per hour. Figure 1-29 shows the different averages throughout CONUS during the March to October time frame.

**Figure 1-29 Hourly Average Lightning Strikes for Mar – Oct**

Monthly climatology is a more refined span of time and will indicate the average hourly lightning strikes for CONUS per month. Just to get an idea of how the thunderstorm situation across CONUS changes throughout the year, let’s look at the month of March and the month of August. In figure 1-30, notice the concentration of lightning strikes centered in the central Oklahoma area, an average of 70+ an hour.
In August, (see Figure 1-31), central Florida is the hot spot, averaging 450+ lightning strikes per hour, and Kansas has 250+ per hour. Based on this information, you would expect to forecast more thunderstorms in these 2 locations than in other places.

1.7.2 Other Types of Thunderstorm (Lightning) Climatology

AFCCC also has climatology that shows the number of thunderstorm days a forecaster can expect in any given year. Since we know that thunderstorms produce lightning, we
can use thunderstorm climatology as an indication of lightning potential. Figures 1-32 and 1-33 indicate annual thunderstorm days for the Western Pacific and Europe.

Figure 1-32 Annual Thunderstorm Days in the Western Pacific
Figure 1-33 Annual Thunderstorm Days in Europe

Forecasting lightning potential is done for a number of reasons. Safety of ground personnel, protection of equipment, and protection of aircraft with their multitudes of electronics on board are all good reasons to issue lightning watches and warnings. Even though Figure 1-34 is a great picture to look at, it is a very uncomfortable feeling for those in the aircraft.

Figure 1-34 B2 Flying Near a Thunderstorm
1.7.3 Lightning and Severe Weather

Many studies have analyzed cloud to ground (CG) data to determine if a relationship exists between CG flash rates, polarity, and severe events (tornadoes, wind and hail). The purpose of these studies has been to determine if these relationships could be used as a severe weather forecasting tool.

1.7.3.1 Time of Occurrence

There is evidence CG lightning is most frequent prior to the occurrence of severe weather, when the inflow to the cell is greater than the outflow. If updrafts dominate the storm, it is difficult for hail to fall and reach the ground. When the outflow increases, as in the case of a microburst or extremely heavy rain, or the inflow decreases (thus allowing large hail to fall), there appears to be a corresponding decrease in the CG lightning strike count. A study of severe storms in the northeastern United States supports this premise. The study found that tornadoes and hail occurred about 10-15 minutes after a pronounced peak in the 5-min CG lightning rate. In a downburst event, very destructive winds occurred just after the 5-min rate peaked.

1.7.3.2 Positive (+) and Negative (-) CG Flashes and Severe Events

One of the more significant results in a study by Reap and MacGorman (1989) was the relationship between the strike density of + and - flashes per hour in 48 km grid boxes and the relative frequency of severe thunderstorms. They showed a significant correlation between the occurrence of severe weather and elevated rates of 30 or more + flashes per hour.

A study conducted in 1993 noted that tornadic storms and hailstorms comprise an overwhelming majority of storms dominated by frequent + flashes. Although there was considerable variability in the details, there are tendencies toward some patterns.

In 1982, Goodman studied the relationships between lightning and storm structure in a severe, non-tornadic, supercell thunderstorm in central Oklahoma. He found lightning strikes were concentrated near the mesocyclone and zone of high reflectivity. The lightning activity began to decrease as soon as the mesocyclone began to decay.

These studies have opened considerable debate on the causes of variations in observed + and - CG strikes, implied thunderstorm dynamics, and the use of the + and - CG strike information to determine severe thunderstorm potential, particularly tornadic storms.

1.7.3.3 Lightning and Mesoscale Convective Complex

Mesoscale Convective Complexes (MCCs) sometimes produce as many as 40,000 or more CG flashes during their lifetime. They often have higher ratios of positive to negative flashes than smaller convective weather systems. A study done by Goodman and MacGorman (1986) found 10 MCCs, CG flash rates in excess of 1,000 per hour can be sustained on average more than nine consecutive hours with peak rates of nearly 2,700 per hour. Peak rates, averaged over 5 min intervals, of 60 per min were not uncommon and averaged 42 per min.

Lightning damage occurred with half of the MCCs and was the most frequent between the development and mature phases (the most electrically active period) of the MCC life cycle. The lightning activity appears to be independent of the size of the total cloud
shield at maximum extent and MCC life-cycle duration. The lightning strikes tended to occur in regions near cold cloud tops as depicted in IR satellite imagery.

1.7.3.4 Lightning and Squall Lines

Keighton et al. (1991) described Doppler radar-observed storm structure and CG lightning activity through the entire life cycle of a squall line. Only CG strikes were utilized, since these are the majority of the total number of CG flashes in most thunderstorms. They showed that the CG flash rate in the convective region is related to the apparent strength of the updraft. The following is a summary of their findings regarding the location of lightning at the various stages of a squall line life cycle.

- Before the storm became a supercell, the lightning strikes, which were relatively infrequent, emanated from the anvil west of the core.
- When the supercell was producing its first tornado, most lightning strikes occurred around the edge of the most intense core and under the anvil south of the core.
- As the supercell weakened, ground strikes clustered closer to the core.
- During the squall line stage, most of the CG lightning strikes were found to the rear of the core in the remnants of the supercell, and in the core of the cells, which were less mature, to the southwest.

The overall CG strike rate peaked during the middle portion of the squall-line phase. The area of the mid-level radar echo associated with the most intense reflectivity core was well correlated with the ground strike rate. It was also found that the majority of negative lightning was with or near the high reflectivity cores (>35 dBZ).

1.7.3.5 Lightning Related to Hail

Studies have shown lightning activity closely associated with hail streaks. Lightning seldom occurred where the hail fell, but, generally formed and moved forward in a 6-10 square mile area on either side of the hail streaks. The centers of CG lightning closely associated with the hail, typically developed 9 minutes before the hail at a point 3 miles (5 km) upstream of the storm with the first hail. This suggests that the CG flashes began as the hailstones were developing aloft. The centers then grew in areal coverage and flash frequency until hail began and then diminished shortly after the hail ended. The duration was about 26 min. The CG centers often developed in a cell core, and most often occurred 5 minutes after the low-level echo core (>45 dBZ) had developed. In most cases, the lightning centers with hail ended 10 minutes or more before the echo core responsible for the hail and associated lightning had ended.

There was a rapid increase in flashes just before the hail, with a peak just after hail began, and a uniform number of flashes during the minutes when hail was occurring. The hailstorm's severity was well correlated to the rate of flash during the hail fall. However, more than 75% of all lightning centers on the studied hail days were not associated with damaging hail, indicating that lightning activity was not a good predictor of hail. Hailstorms associated with cold fronts had more lightning activity and less complexity than those associated with stationary frontal storms.
Another study noted that all storms with frequent + CG regions and a high confidence of hail, produced large hail during the period when + CG flashes dominated. If the polarity switched to negative, the diameter and frequency of large hail reports usually decreased. The study noted that + CG flashes occur at high rates and high densities near the beginning of active CG lightning periods of hail-producing thunderstorms. These flashes are beneath large storms with radar echoes as tall as 18 km (58,000 ft), with reflectivities in excess of 50 dBZ, and with large hail at the ground. These findings provide additional evidence of a direct relationship between + CG flash frequency and storm severity.

In Summary

- Indications are that CG flashes began as the hailstones develop aloft.
- There appears to be a direct correlation between a hailstorm's severity and the rate of flashing during the hail fall.
- Since more than 75% of all lightning centers in the storms on the studied hail days were not associated with damaging hail; lightning activity may not be a good predictor of hail.
- Hailstorms occurring with cold fronts had more lightning activity and less complexity than those associated with stationary frontal storms.

### 1.7.3.6 Lightning Related to Tornadoes

Knapp studied the dominate polarity of CG lightning in 264 tornadic thunderstorms which occurred east of the Continental Divide during the Spring 1991 severe weather season. Time series comparison found a well-defined peak-lull-peak pulsing flash rate with the most significant peak occurring during the 20 min period prior touchdown. There were also indications of some lightning decrease during the tornado and flash polarity tended to shift toward - CG strikes at the time of initial tornado report.

MacGorman and Burgess (1994) noted that in all cases observed by Doppler radar, storms dominated by + CG flashes had at least some rotation, and in most cases they were low precipitation (LP) or classic supercell storms. Storms often switched from LP supercell to classic supercell or from classic supercell to high precipitation (HP) supercell at roughly the same time as the dominant ground flash polarity switched. The majority of storms dominated by + CG flashes produced tornadoes.

An investigation of CG lightning characteristics associated with violent-tornado producing supercells found numerous variations in CG patterns. However, evidence suggest the following characteristics may have substance:

- A peak CG flash rate preceding tornado formation appeared in over 70% of the storms.
- There appeared to be a decrease in flash frequency coincident with tornado touchdown.
- The eleven + type supercells were associated with long-track tornadoes, F5 damage or severe weather outbreak conditions.
• The distribution of the maximum CG activity with respect to stages of
tornadogenesis occurs during all three tornadic phases (30-min prior, during
and 30-min after the tornado).

• There was no apparent correlation between the relative number of CG flashes
and tornadic intensity.

Curran and Rust studied + CG flashes produced by two low-Precipitation (LP)
thunderstorms in west Oklahoma. These thunderstorms, which initially were positive,
split with the right-moving one evolving into a tornadic supercell. CG flashes produced
by this supercell were predominately negative. The highest rate of + ground flashes
occurred during LP splitting and merging, when about 84% of the ground flashes were
positive. The maximum total ground strike rate occurred during the tornadic supercell
phase and when all but one of the CG flashes were negative.
Module 2 – Mesoscale Convective Systems

TRAINEE'S NAME ____________________________

CFETP REFERENCE: 12.12.1

MODULE OVERVIEW:

This module covers the basic characteristics of squall lines Bow echoes and Mesoscale Convective Complexes and microbursts. It will include the structure’s, conditions needed for formation and types of convection.

TRAINING OBJECTIVES:

• OBJECTIVE: After completing the module, the student will be able to identify the structure of mesoscale convective systems, conditions needed for formation, and types of weather associated with these systems. The student will demonstrate this ability by answering questions with at least 80% accuracy.

EQUIPMENT AND TRAINING REFERENCES:

• Technical Report 200 (Rev), (Notes on Analysis and Severe-Storm Forecasting Procedures of the Air Force Global Weather Central)

• AFGWC/TN 79/002 (Training Guide for Severe Weather Forecasters)

• AFWA/TN-98/002, (Meteorological Techniques)


• Chris Cappella, USA TODAY, Oklahoma “Heat Burst” Sends Temperatures Soaring.

• Fernando Caracena, NOAA/Forecast Systems Laboratory, Forecasting Microburst & Downburst, 1995.


• AWS/FM-83/004 (Mesoscale Convective Complexes and General Aviation)
• NWS CR-08 (*North Central Great Plains Derecho Producing Mesoscale Convective Systems (DMCSs): a forecasting Primer*)

• NWS CR-10 (*A comprehensive Severe Weather Forecasting Checklist and Reference Guide*)

• Cooperative Program for Operational Meteorology, Education and Training (COMET)

**PREREQUISITES AND SAFETY CONSIDERATIONS**

• Complete module 1

**ESTIMATED MODULE TRAINING TIME:** 3 hours
2.0 Squall Lines and Bow Echoes

The Glossary of Meteorology defines squall lines as: “any non-frontal line or narrow band of active thunderstorms.” Traditionally, Air Force Weather has described squall lines as narrow bands of thunderstorms that form in the vicinity of inactive cold fronts. They form when air flowing down the steep slope of the inactive cold front collides with the synoptic scale winds ahead of the front inducing low-level convergence. While this definition remains valid, a revised definition might describe squall lines as a band of linearly oriented clouds containing a region of strong cumulonimbus regardless of where they form.

Once a squall line form, it may move faster than the cold front behind it, thus, it travels far from the originating front. On other occasions, the two merge as the front travels faster than the squall line.

Squall lines frequently produce severe weather near the updraft/downdraft interface at the storm's leading edge. Downburst winds are the primary threat, although “golf-ball” size hail and gustnadoes (Weak tornadoes that form along the gust front, not associated with a mesocyclone.) can occur. Flash floods occasionally occur when the squall line decelerates or becomes stationary, with thunderstorms moving parallel to the line repeatedly across the same area.

Bow Echoes or “bowing line segment” is an arched/bowed out line of thunderstorms embedded within a squall line. Bow echoes, most common in the spring and summer, are usually associated with an axis of enhanced winds that often create straight-line wind damage at the surface. In fact, bow echo-induced winds/downbursts account for a large majority of the structural damage resulting from convective, non-tornadic winds.

Note: Straight-line winds are any surface wind that is not associated with rotation. For example, the first gust from a thunderstorm, as opposed to tornadic winds.

Figure 2-1 Squall line and Bow Echo Propagation
2.1 Typical Properties of a Squall Line

Numerous observations have shown squall line’s have the following characteristics:

- A squall line is much longer than it is wide. The typical length is about 300 miles (500km). The width of a squall line is typically about 60 miles (100km).
- There is a narrow line of strong echoes along the front side of the squall line. Severe weather, if any, appears with these echoes.
- A wide area of continuous, stratiform precipitation exists in the central and western portion of squall lines.
- The lifetime of a squall line is on the order of 10 hours. Some form and dissipate within 2 hours, but others have lasted as long as 4 days.

Figure 2-2 Cross Section and Radar image of a Squall Line

1. Where is severe weather frequently found in relation to a squall line?

2. What type of weather is the primary threat from squall lines?

3. Bow echoes, most common in the spring and summer, are usually associated with what type of weather?

4. What is the typical length and width of a squall line?
2.2 Structure of a Squall Line

The cloud system of the squall line consists mainly of cumulonimbus (CB) on its leading edge and altostratus and nimbostratus on its rear side (figure 2-3). The CB location relative to the updraft and downdraft is similar to other convective storms.

![Figure 2-3 Vertical Structure of Squall Line](image)

2.3 Environments Associated with Squall Line/Bow Echo

Squall lines produce a variety of severe weather with strong winds being the primary threat. Some general parameters for formation are:

- Strong directional shear from the surface to 700mb with little to no shear aloft.
- 500mb winds > 50 knots.
- Well defined westerly jet stream.
- Great range of instability, from marginally unstable to extremely unstable.
- Active southeast low-level jet transporting deep low-level moisture into the threat area.
- Warm moist air overrunning cooler air.
- Evaporative cooling in the upper levels.
- Cold air advection at 500mb and a layer of dry potentially cold air 3-7 km AGL (9800-23,000 ft).
- Low-level wind shear, which encounters the circulation induced by the cold thunderstorm outflow, sustaining low-level convergence.

The following guidelines apply to using the 850/500mb thickness chart:

- Squall lines often develop about 100 miles upstream of the 850/500 thickness ridge.
- Squall lines often develop in the area of the maximum horizontal anti-cyclonic shear zone of the thickness ridge.

The following areas are conducive to initial squall line outbreak:

- Along and just ahead of a cold front or along an advancing dry line.
• Along a low-level trough, within or just above the moist layer.
• Bounded by a 700mb cold front eastward to a point where the air is too stable to produce severe weather.
• Where dry air at 700mb meets overrunning warm moist air.

Steering and Timing:

• Steering of squall lines is generally the 500mb wind direction at 40% of the wind speed.
• Maximum threat time is from peak of afternoon heating to shortly after sunset.

Squall lines are common across the United States east of the Rocky Mountains, especially during the spring when the atmosphere is most “dynamic”. The following is a list of seasonal parameters and features associated with squall lines.

2.3.1 Summer (Weak Synoptic Pattern)

Surface Patterns:

• General east-west frontal boundary (formation area frequently north of front).
• Strong surface convergence (near formation area)
• High dew points pooled near front with maximum values just south of front.
• Very high surface equivalent potential temperatures (theta-e) values along track.

Upper-Level Patterns

• Straight or anti-cyclonically curved mid/upper-level flow near ridge axis.
• Weak shortwave trough located near/upstream from genesis region.
• Moderate/strong warm advection at 850 and 700mb present near genesis area with weaker advection downwind. Neutral or weak cold advection noted in mid/upper level over and downwind of genesis area.
• 850mb moisture very high and pooled just south of bow echo track; drier air can be present at 700 and 500mb enhancing damaging wind potential.
• The bow echo moves generally along 850 and 700mb thermal gradient (along or north of thermal/theta-e ridge axis)
• The bow echo often moves parallel to front with slight component towards warm sector.

Thermodynamic and Vertical Wind Shear Profile

Thermodynamics are processes involving the transformation of heat, or the flow of heat, from a hotter body to a colder body.
• Average maximum convective available potential energy (CAPE) values in genesis area roughly 2400 J/kg with even greater instability downwind where average maximum CAPE is about 3500-4000 J/kg (range of 2500-6000 J/kg). **Note:** J/kg stands for Jules per kilogram.

• Extreme instability due to gathering of moisture near front; surrounding upper-air soundings may be unrepresentative of true local instability.

• Winds at 850 and 700mb show good directional shear (veering) near genesis area and speed shear are primarily parallel to storm track downwind.

### 2.3.2 Late Winter/Spring (Strong Dynamic Forcing)

#### Surface Patterns

- Strong, progressive low pressure system and associated warm/ cold fronts.
- Squall line with embedded bowing line segment often located along or north of warm front.

#### Upper-Level Features

- Moderate/strong wind fields throughout atmosphere; 850mb wind speeds 30-60 kts are common with upper-level jet stream axis aloft nearby (often north and or west of squall line.)
- Wind fields stronger than in warm season.
- Significant divergence/convergence fields and dynamic forcing (to produce strong lift) associated with convective development, which overcomes possible limited moisture and instability.
- Environmental wind momentum aloft may transfer downward causing damaging surface winds, especially if no low-level inversion is present.

#### Thermodynamic and Vertical Wind Shear Profile

- Cool season squall lines/bow echoes are often associated with less instability than warm season events.
- The degree of instability varies widely. CAPE values may vary from less than 500 J/kg to over 2000 J/kg. Strong, forcing/vertical shear can overcome even limited instability.
- Layer of dry, potentially cold air (or cold advection/backing winds) often present in mid-level downdraft entrainment area (3-7 km layer) which collides with squall lines from upstream side, thereby enhancing damaging wind potential.
- Cool season squall lines/bow echoes associated with moderate/strong wind shear within the lowest 2.5km layer (surface to 850 or 700mb).
- Optimal conditions for bow echo development is a linear shear profile with strong speed (limited directional) shear of ≥ 50kts within lowest 2.5 km of atmosphere with minimal shear aloft.
5. What is the primary cloud system associated with squall lines?

6. Average maximum CAPE values in genesis area are roughly ______ J/kg with even greater instability downwind where average maximum CAPE is about ______ to ______ J/kg with a range of ______ to ______ J/kg.

2.4 Formation of Squall Lines

There are several ways for squall lines to form (figure 2-4). Squall lines can be categorized as follows:

- **Broken line.** Individual cells develop separately along a line and later join into a more continuous configuration.
  - Forms along cold front.
  - Relatively weak wind shear.
  - High CAPE.

- **Back building.** Similar to the development of multicell storms.
  - Can occur with or along a number of different types of surface boundaries.
  - High CAPE
  - Usually unidirectional flow through a deep layer with minimal shear.

- **Broken areal.** Seemingly random distributed cells enter a line formation.
  - Formation appears to result from the interaction of outflow boundaries
  - Low CAPE.

- **Embedded areal.** Stratiform precipitation gradually changes shape into a squall line.
  - Convective line appears within a larger area of weaker stratiform precipitation.
7. Which of the four squall line formations mentioned is categorized by individual cells that start developing separately along a line and later join into a more continuous configuration?

8. Which of the four squall line formations mentioned is categorized by stratiform precipitation that gradually changes shape into a squall line?

2.5 Derechos

Derecho (Deh-RAY-cho), Spanish for “straight ahead”, was coined by Iowa weather forecaster Gustavus Hinrichs in 1886. They had previously been called "Great Blows of the Prairie". In meteorology, the term derecho is used to define widespread, rapid moving, convective induced winds, which produce significant damage and casualties. Derechos are the result of squall lines creating numerous downbursts. They are common from the central and northern Plains to the Ohio Valley during the late spring and summer. In order for a convective event to be classified as a derecho, it must have winds greater than 50 knots and the damage area must be at least 250 nautical miles long. The damage reports can be in a single path or a series of paths.

Derechos have been classified as either progressive or serial (figure 2-5). Progressive derechos are usually characterized by a single bow-shaped system that moves north of, but parallel to a weak east-west oriented stationary boundary. Serial derechos are composed of a series of bow-echo features along a squall line, usually located within the warm sector of a synoptic scale system.

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Classification of Squall Line Development

<table>
<thead>
<tr>
<th>Broken Line</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Back Building</td>
<td></td>
</tr>
<tr>
<td>Broken Areal</td>
<td></td>
</tr>
<tr>
<td>Embedded Areal</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2-4 Squall Line Development
Figure 2-5 Progressive and Serial Derecho

Four types of echo structures associated with derecho events have been identified.

**Type 1 Derecho Echo Patterns**

The overall radar reflectivity pattern of “Type 1” is characterized by two or more bowing segments. Each of the individual segments may be as long as 100 km in length and may be associated with a meso-circulation near the northern end of the segment. Strong low-level reflectivity gradients are frequently observed along the segment’s forward flank, signifying the location of the system’s updraft region. The location of rear inflow notches (RIN) (Figure 2-6), strong low-level reflectivity gradients along the leading edge, and the greatest degree of bowing mark the location where swaths of damaging downburst winds are most likely to occur.

Figure 2-6 Type 1 Derecho Echo Pattern. (The channels of weak echoes are also known as Rear Inflow Notches.)
Type 2 Derecho Echo Patterns

Reflectivity structures associated with this echo pattern include a short, but solid bowing segment 80 to 100 km in length orthogonal (at a right angle) to the shear vector. Strong low-level reflectivity gradients mark the leading edge of the bowing structure while one, and sometimes two, RINs are depicted along the trailing edge of the leading convective line. The strongest winds can be expected in the vicinity of the intense low-level reflectivity gradient.

![Type 2 Derecho Echo Pattern](image)

Figure 2-7 Type 2 Derecho Echo Pattern

Type 3 Derecho Echo Patterns

The mature stage of this reflectivity pattern is often marked by a bow echo, 40 to 120 km in length, having strong low-level reflectivity gradients along the leading edge of the bow and a single pronounced RIN along the system's trailing flank. Swaths of damaging downburst often accompany the bowing structure. The overall convective system may increase in size during the evolution of the bow echo. One or several storms exhibiting supercellular reflectivity structures are often found along the southern (upwind) flank of the bow echo.
**Figure 2-8 Type 3 Derecho Echo Pattern**

**Type 4 Derecho Echo Patterns**

Type 4 patterns are characterized by the evolution of a “High-precipitation” (HP) supercell evolving into a bow echo. During the HP storm evolution, new convective cells rapidly form along the leading edge of the storm's rear flank downdraft (RFD). This new convective growth may extend as far as 60 to 120 km south or southwest of the HP storm. Damaging winds have been documented along the leading edge of the storm's rear flank downdraft and locations southwest of the leading line. Hail (1 to 4 cm in diameter) and brief tornadoes have been recorded near the northern edge of the leading RFD and storm's updraft center. The HP storm's inflow region is marked by a downwind weak reflectivity notch surrounded by strong low-level reflectivity gradients and capped by high radar reflectivity aloft. Strong low-level reflectivity gradients are also observed along the leading edge of the HP storm's RFD/outflow region.
Figure 2-9 Type 4 Derecho Echo Pattern

Use the worksheet on the following page to help determine if the potential for a derecho exists.
Johns and Hirt Derecho Checklist

A. If all of the following conditions are present in the area of interest proceed to Part B. Otherwise derecho development is not likely.
   1. 500 mb flow direction is 240°-360° Y or N
   2. Quasi-stationary boundary nearly parallel to 500 mb flow? Y or N
   3. 850 mb warm advection within 200 nm? Y or N
   4. 700 mb warm advection within 200 nm? Y or N
   5. ELWS 25 knots or greater? Y or N

Note: ELWS is Estimated Lower Mid-troposphere Wind Speed – Average the 500 mb and 700 mb wind speeds.

B. If all of the following conditions are present in the area of interest proceed to Part D. Otherwise proceed to Part C.
   1. Maximum 500 mb, 12 hour, height falls are 60m or greater? (50m or greater at 00Z) Y or N
   2. LI is –6 or lower? Y or N
   3. ELRH <80%? Y or N

Note: ELRH is Estimated Lower Mid-troposphere Relative Humidity – Average the RH of the 500 mb and 700 mb levels. This information may be found in the FOUS bulletins. Use the R3 column for a good estimate.

C. If both of the following conditions are present in the area of interest, proceed to Part D. Otherwise, derecho development is not likely.
   1. LI is –8 or lower? Y or N
   2. ELRH <70% in storm initiation area (<80% downstream)? Y or N

D. Do the parameters satisfying the criteria for the LI and the ELWS extend downwind along the quasi-stationary front for a distance of at least 250 nm from the convective system (or where the system is expected to develop)?
   1. If yes, go to Part E.
   2. If no, potential for wind damage will probably be too localized to meet the criterion for derechos. Forecasters should still be alert for the potential development of severe weather.

E. BE ALERT FOR DERECHO DEVELOPMENT: If a convective system does develop, be particularly suspicious of any short squall line moving at a speed of 35 knots or greater in the direction of the mean flow. Closely monitor satellite loop for indications of accelerating storms, and radar for signatures suggesting damaging winds or tornadoes.
9. What is the definition of a derecho?

10. What must a convective event contain to be classified as a derecho?

11. Derechos are classified into what two categories?

12. Circle the Correct Response. Reflectivity structures associated with this pattern include a short, but solid bowing segment 80 to 100 km in length.
   a. Type 1 echo pattern   b. Type 2 echo pattern
   c. Type 3 echo pattern   d. Type 4 echo pattern

13. Circle the Correct Response. The mature stage of this reflectivity pattern is often marked by a bow echo, 40 to 120 km in length, having strong low-level reflectivity gradients along the leading edge of the bow and a single pronounced RIN along the system’s trailing flank.
   a. Type 1 echo pattern   b. Type 2 echo pattern
   c. Type 3 echo pattern   d. Type 4 echo pattern

2.6 Mesoscale Convective Complex

The Mesoscale Convective Complex (MCC) often produces significant events such as devastating floods, deadly lightning, large hail, damaging winds, and tornadoes. It is also interesting to note that up to 50% of the rainfall between the Rocky Mountains and the Mississippi River is a result of MCCs.

As with the other storms, the MCC needs the following conditions:

- A trigger
- Warm moist inflow boundary
- Warm advection below 700mb is also necessary for MCC formation.
- An exhaust mechanism (upper-level diffluence)
- Strong veering of the winds from surface to 500mb
- Less veering or slight backing of the winds from 500 to 300mb (in other words, no cold air advection or slight warm air advection)
- An area of instability (Average Total Totals =53)
A favorable environment for MCC development has potential instability and lifting. As with other convective storms, the left front or right rear quadrant of the polar front jet is a favorable place for MCC formation due to its enhancement of upper vertical motion (excessive divergence aloft).

**Figure 2-10 Examples of Mesoscale Convective Complex. Left: Enhanced IR Shot. Right IR (MB Curve)**

### 2.6.1 Physical Characteristics

The characteristics listed below are observable on satellite imagery. Realize these characteristics are not designed to uniquely describe or denote all examples of a MCC. They were designed to identify and study very large and long-lived convective systems using synoptic upper air and surface data.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>Cloud shield with IR temperatures $\leq -32^\circ C$ must have an area $\geq 100,000km^2$ and an interior cold cloud region with temperatures $\leq -52^\circ C$ must have an area $\geq 50,000km^2$</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>The size definition must be met for a period of $\geq 6$ hours</td>
</tr>
<tr>
<td><strong>Shape</strong></td>
<td>Minor axis/major axis $\geq 0.7$ at time of maximum extent. (Often described as circular in shape with the appearance of a “fried egg”).</td>
</tr>
<tr>
<td><strong>Termination of MCC</strong></td>
<td>Size definition is no longer satisfied.</td>
</tr>
</tbody>
</table>

Table 2-1 MCC Characteristics (Maddox, 1980)
14. What size characteristics are required for MCC identification?

15. The shape of an MCC is often described as having what kind of appearance?

2.6.2 MCC Tracks

MCCs tend to develop farther north as the polar front moves north and the sub-tropical high becomes more entrenched. Data gathered during a five-year study from 1978-1982 is displayed in figure 2-12.

The Gulf of Mexico provides the warm, moist air required for MCC formation. As the Polar Front moves north, the Bermuda High pumps the mT airmass from the Gulf into the Midwest US. The mT air becomes available further and further north allowing the MCC to develop more northward each month.
2.6.3 MCC Development

A typical location for MCC development is in a region of significant upper level diffluence such as the eastern side of a high-pressure ridge (figure 2-13). This difluent region provides the exhaust necessary to support strong convection. When a favorable low-level moisture boundary exists underneath an area of strong upper level diffluence, and a short wave or positive vorticity advection lobe (indicating upward vertical motion) is approaching, the necessary ingredients for MCC development exists.

![MCC Development Diagram](image)

**Figure 2-13 Typical Region of MCC Development in Upper Level Pattern**

16. *Where do MCCs develop in relation to the polar front?*

17. *In the upper air pattern, where is the typical location of MCC development?*
2.6.4 MCC Satellite Examples

Figure 2-14 Satellite Images of MCC Development. 13-15 Aug 1982

2.6.5 Flash Flooding

Many of the initial conditions for flash floods are similar to those for severe weather. A flood situation results when heavy rain occurs for an extended period in the same drainage basin. Fast-moving systems are not usually candidates for flash flood events. However, individual cells that move rapidly within stationary or slow moving systems can produce flash floods. The conditions necessary for such an occurrence is a fixed point for cell regeneration; such as terrain features, an outflow boundary, or frontal zone. A low-level moisture source, usually transported by a low-level jet, is a secondary ingredient.

Recognizing the transition of convection into a flash-flood-generating system is often a problem. The MCC is a major flash-flood-generating system and begins as a group of convective storms that gradually merge into one large convective area. When the system
is organized, the general mesoscale uplift sustains the steady rain and forces low-level flow into the system. Organized, merged outflows and forced steady inflow provide a fixed boundary (or regeneration point) and a steady source of moist air.

When such a organized convection forms in light wind regimes they must usually move south and east to survive as new cells form on the southern edge of the outflow while the old cells remain nearly stationary. In stronger sheared regimes the system may remain fixed as cells form on the south or southwest edge of the outflow boundary and propagate through the system along an eastbound track. The latter type is more dangerous from a flash flood standpoint; the former may be more likely to produce damaging winds.

The convective complex often begins in a strong flow regime. Owing to diabatic heating, the MCC may form a middle and upper-level thermal gradient on the west or northwest side of the system, and deflect the flow at high levels after a 6-12 hour adjustment period. Thus, the MCC may eventually become imbedded in light winds and veer sharply to the right.

Close attention must be paid to weakening severe convective systems experiencing echo broadening. Data systems must be monitored for evidence of a low-level jet flowing into the convective area. If cells on radar can be seen developing and moving away from a fixed point, flash floods are likely.

IR satellite imagery can be used to estimate rainfall. Cold cloud tops on the upwind side (or the tight upwind gradients in IR contouring) can indicate where heavy rain is occurring.

2.7 Downburst

Dr. Fujita first used the term “downburst” in 1975 when he investigated the crash of Eastern Flight 66 at JFK Airport on June 24. He found a “starburst” pattern on the ground, which he had previously seen in other collapsing thunderstorm situations. The downburst is a strong downdraft, which produces damaging winds at or near the surface. The winds are divergent due the spreading out upon surface impact (Figure 2-15). It is important to note that no definitive forecast techniques currently exist. However, Doppler radar and satellite aid in the identification of occurring or recent downbursts. Downbursts are divided into 2 categories: micro and macro burst. The surface area affected by the down rush winds determine its category

2.7.1 Microburst

A microburst has damaging winds extending out to 2.5 miles (4 km). Intense microbursts have produced winds as high as 146 knots (168 mph). The microburst may produce a starburst shaped damage field, and in many instances, trees will lay out from the center impact point.
Figure 2-15 Microburst Over Airfield

The microburst tends to form a horizontal vortex, instead of a flat wind (Figure 2-15). The vortex will spread out at a slower speed than the downrush. The microburst is broken down into 3 categories: dry, wet, and intermediate.

2.7.1.1 Dry Microburst
The dry microburst is common in areas where low-level moisture is limited, such as deserts, or steppe climates. The dry microburst is characterized by high base cumulus clouds, which produce little or no surface precipitation. At the surface a deep, dry adiabatic lapse rate exists with large dew-point depressions. Aloft, a nearly saturated
layer exists above 9800 feet. The dry microburst is often identified when dust is blown upwards and away from the collapsing cell.

Notice in figures 2-17 and 2-18, the dryness of the air in the low-levels and the moisture aloft. Keep in mind, the dry microburst occurs in high-based thunderstorms and showers, and typically have little to no moisture associated with them.

Figure 2-17 Example of sounding in dry microburst environment (also know as an Inverted V Sounding)
Figure 2-18 Example of sounding in dry microburst environment
2.7.1.2 Wet Microburst

The wet microburst occurs in moisture abundant areas such as the southern U.S. Storms producing moderate to heavy rain are good storms to suspect for wet microburst potential. The wet microburst may appear as a darkened mass of heavy rain falling through lighter rain (Figure 2-20). The equivalent potential temperature may be used to identify wet microburst potential when the difference between the surface and moisture aloft is 20°C.

Figure 2-21 is an example of a wet microburst sounding. Notice the moist environment commonly found in the SE U.S.
Figure 2-21  Example of a sounding in a wet microburst environment

2.7.1.3 Intermediate Microburst

The intermediate microburst is common in Texas and along the coast of the Gulf of Mexico. These areas generally do not meet the dry or wet microburst criteria but fall somewhere in-between. The intermediate microburst environment is characterized by little or no inversion, a dry adiabatic lapse rate at least 5,000 feet deep below the CCL, a moist 5,000 – 15,000 foot thick, mid-tropospheric region between, and a dry layer above 15,000 feet.

Refer to figure 2-22. Notice the large positive energy area and little to no capping inversion. Dry and moist air plays roles with this scenario also. The dry adiabatic lapse rate layer, at least 5,000 ft deep is below the CCL and a moist mid-tropospheric layer exists between 5,000 ft and 15,000 ft. Also notice the elevated dry layer above 4600 m (15,000 ft).
2.7.2 Macroburst

The macroburst is a downburst with winds spreading out greater than 2.5 miles (4 km). Damage from an intense macroburst may appear “tornado like” and result in false tornado reports. The damaging winds may last from 5 to 30 minutes and have attained speeds as high as 116 knots (134 mph). Because the macroburst is not as compact and affects a larger area than a microburst, the wind will be less. Macroburst often form in groups that occur in succession. When this happens, cold air piles on top of cold air and a “gust front” may form.

2.7.3 Heat Burst

A heat burst is an unusually large and potentially damaging area of winds that increase surface temperatures by significant amounts. In contrast to a cooling downburst from thunderstorms, the heat burst is a very warm downburst. For example, at an Oklahoma station, a heat burst increased the temperatures from 88°F to 101°F in a few minutes. As with cooling winds from thunderstorms, the temperature will return to the environmental temperature in a short time. In the example, the temperature had fallen back to 92°F after 50 minutes.

The difference in the cooling downburst and the heat burst is the origin of the parcels of air. In the cooling downburst, the air parcels begin their descent from relatively low
levels, but in a heat burst the air parcels originate from very high altitudes. When the moist inflow into a thunderstorm is cut off, the storm collapses. Cool rain falls from high altitudes, and as the cool rain descends, it evaporates in dry air and cools further. This process causes the air to become heavy and pick up speed. As the heavier air descends, it undergoes adiabatic warming before it reaches the surface.

No one knows how common this event is, up to this time, the heat burst has only been recorded a few times.

2.7.4 Radar and Visual Indicators

There are no current techniques to forecast the downburst. However, you may use the radar and other visual indicators to identify a downburst.

2.7.4.1 Using Radar

The radar may provide indicators that a downburst is occurring or about to occur. The following is a refresher on information covered in the Radar QTP.

- VIL values at the center of the storm rapidly decrease.
- Echo tops fall over the area of the storm collapse.
- Low-level velocities increase dramatically.
- Reflectivities at the center of a storm decrease in value and height.
- High spectrum width values around the base of the storm.

Observing

Different types of microbursts have different appearances. For dry microbursts, look for a dust curl forming at the leading edge of the advancing wind blowing dust away from the storm (as seen in figure 2-19). In Figures 2-23a through 2-23e, (wet downburst) notice the development of the downburst, over time around the main rain shaft.
Figure 2-23a  Initiation of Wet Burst. Rain shaft is moving downward.

Figure 2-23b. Wet Burst Continued. Notice the well-established rain shaft. The “foot” or curl will develop to the left of the rain shaft.
Figure 2-23c. Wet Microburst Continued. Notice “Foot” Developing

Figure 2-23d. Wet Microburst Continued. Curl still developing
18. Damaging winds from a downburst extend to 2.3 miles and with maximum recorded winds of 95 knots. This is a description of a ________.
   
a. derecho  
b. rain burst  
c. microburst  
d. macroburst

19. The wet microburst has an equivalent potential temperature difference of ________.
   
a. 18° C  
b. 20° C  
c. 22° C  
d. 25° C

20. What process causes a heat burst?
a. adiabatic warming
b. adiabatic cooling
c. convective warming
d. convective cooling

At this point, your trainer and/or certifier should answer any questions you have or to clarify any unclear points. Your trainer and/or certifier should also review local/regional rules-of-thumb and techniques developed in your AOR(s) with you.
Module 3 – Airmass Types and Thunderstorms

TRAINEE’S NAME ____________________________

CFETP REFERENCE: 12.12.1, 13.13.1

MODULE OVERVIEW:
This module we cover different airmass types and thunderstorms associated with them. This module primarily covers CONUS airmass types but other regions of the world will be added as we acquire the information.

TRAINING OBJECTIVES:

• OBJECTIVE 1: Identify facts concerning airmasses and the type of thunderstorms expected from those airmass types with at least 80% accuracy.

• OBJECTIVE 2: Given vertical and horizontal products, demonstrate an understanding of airmasses and the type of thunderstorms expected with those airmasses to the satisfaction of the trainer/certifier.

EQUIPMENT AND TRAINING REFERENCES:

• TR 200 (Revised), Notes on Analysis and Severe-Storm Forecasting Procedures of the Air Force Global Weather Central

• AFWA TN-98/002, Meteorological Techniques

PREREQUISITES AND SAFETY CONSIDERATIONS:

• Completion of the Analysis and Prognosis, METSAT, Weather Elements, and Radar QTMs.

ESTIMATED MODULE TRAINING TIME: 3 Hours
CORE TRAINING MATERIAL AND REVIEW QUESTIONS

3.0 Severe Synoptic Patterns

Identifying severe synoptic patterns is essential to identifying areas of potentially severe thunderstorms. TR200 (Rev), states, “successful tornado and severe-thunderstorm forecasting is largely dependent upon the forecaster’s ability to carefully analyze, coordinate, and assess the relative values of a multitude of meteorological variables and mentally integrate and project these variables three-dimensionally in space and time.” The ability to correctly identify severe synoptic patterns saves time and allows energy to be focused on the threat area.

Note: In the following severe weather patterns, the parameters are 12Z depictions, while the outbreak areas are depicted at the time of occurrence, which may not be 12Z. Hence, the advection of severe weather parameters must be taken into account.

3.1. Type A Synoptic Pattern (Dryline)

With the Type A Pattern, thunderstorms initially form on the edges of dry air. Storms tend to form rapidly in widespread, isolated clusters. This type pattern is noted for severe thunderstorms from west Texas to southern Iowa.

3.1.1 Characteristics

The following features that must be present for thunderstorm formation characterize the Type A Pattern:

• A well-established southwesterly 500 mb jet.
• A distinct surface to 700 mb warm dry-air intrusion from the southwest.
• Low-level confluence along the dry line.
• Low-level moisture advection from the south, ahead of the dry air.

3.1.2 Severe Weather

As stated earlier, severe weather may occur from Eastern Texas to Southwest Iowa and is characterized by unusual rapid growth, with almost immediate formation of hail, damaging winds, and tornadoes.
3.1.2.1 Severe Weather Area

Severe weather may extend up to 200 miles to the right of the 500 mb jet and from the area of maximum low-level convergence to the point where the moisture decreases to less than needed to support convection. The most violent storms usually form where the jet meets the moist/dry air convergence area.

A secondary outbreak area may be along and 150 miles to the right of the 500 mb horizontal speed shear zone. It will extend from the maximum low-level convergence area to the point where low-level moisture reaches a point to no longer support severe weather.

3.1.2.2 Trigger Mechanisms

- Diurnal heating.
- Passage of an upper-level jet max.
- Low-level intrusion of warm, moist air.
- Mid-level dry air moving into a moist region.
3.1.2.3 Timing

Look for thunderstorms to develop at the time of maximum heating or up to 6 hours afterwards. Under normal circumstances, convection is usually capped by an inversion until the convective temperature is reached. Once convective activity has started, watch for it to continue for 6 to 8 hours or longer. The convective activity may last until the moist and dry air mixes, changing the airmass structure.

1. What is the primary synoptic feature of the Type A pattern?
   a. Cold Front
   b. Warm Front
   c. Surface Trough
   d. Dryline

2. Which of the following is NOT associated with the Type A Synoptic Pattern?
   a. A well-established southwesterly 500 mb jet.
   b. A distinct warm dry-air intrusion from the southwest, surface to 700 mb.
   c. Streamline diffuence along the dry line.
   d. Low-level moisture advection from the south, ahead of dry air.

3. __________ (TRUE/FALSE) Once convection begins, expect it to last for 6 to 8 hours. (If false, correct the statement.)

3.2 Type B Synoptic Pattern (Frontal)

The Type B Pattern is characterized by prefrontal squall lines with one or more mesoscale lows. These squall lines form at the intersection of the low-level jet and the upper-level jet. The lows often form in the area of the intersection of the low-level jet and the warm front and are frequently accompanied by tornadic outbreaks.

3.2.1 Characteristics

The Type B Pattern is characterized by the following features:

- A well-defined 500 mb jet.
- A well-defined dry air intrusion between the surface and 700mb.
- A strong unstable wave with associated cold and warm fronts.
- Almost always have frontal and prefrontal squall lines.
- Strong cold-air advection behind the cold front.
- Low-level jet, instrumental in transporting warm, moist air from the south.
• Cool, moist air associated with 500 mb and 700 mb trough axes. The axes will lie to the immediate west of the threat area.

• Low and mid-level confluence between low-level warm air and mid level cooler air.

![Type B Tornado-producing Synoptic Pattern](image)

**Figure 3-2 Type “B” Synoptic Pattern**

### 3.2.2.1 Severe Weather

The severe weather with the Type “B” pattern is associated with strong cold air advection and strong cold fronts. This type of system can occur at anytime but severe weather usually occurs in the spring. As cold air moves down into the lower 48 states, it collides with warm, moist air moving up from the south. This collision of contrasting air masses leads to strong thunderstorms.

### 3.2.2.2 Severe Weather Areas

A number of events occur in the initial severe weather area beginning with the development of mesoscale lows at the intersection of the low-level jet and the warm front. As a result upward vertical motion in the area is increased. The location of severe weather depends a great deal on the speed of the cold front, coupled with the speed of the dry intrusion area. Severe thunderstorms occur along or just ahead of a surface cold front where strong cold air advection aloft and dry air advection at the 850 mb and 700 mb levels interact. A key place to look is up to approximately 200 miles to the right of the upper-level jet to the dry intrusion area. Another key area is from 150-200 miles north of the jet, extending south to the leading edge of the dry air intrusion.

A secondary area of concern is associated with squall lines that form 150 to 200 miles north of the upper-level jet. The area could extend down to the leading edge of the dry
air intrusion. The threat area does not extend far into the dry air because the absence of moisture decreases the chance of thunderstorm development. Evaluate the potential for severe weather along and 150 miles to the right of the horizontal speed zone of the upper-level jet.

3.2.2.3 Triggers

- The speed of movement of the approaching cold front coupled with the dry air intrusion, is the key factor. In this type, it is the cold front that provides lift and the dry air decreases stability.

- Intersecting lines of discontinuity. Watch for intersecting squall lines, intersecting upper and lower-level jet streams, and the intersection of a low-level jet and warm front. Another key is the speed of movement of the approaching cold front coupled with the dry intrusion.

3.2.2.4 Timing

In this pattern, thunderstorms can occur anytime and may last all day and night. These thunderstorms do not require diurnal heating, and as long as the airmass stays absolutely unstable, thunderstorms in a squall line can persist.

4. What is the primary synoptic feature of the Type B pattern?
   a. Cold Front
   b. Warm Front
   c. Squall Line
   d. Dryline

5. Which of the following is NOT a feature of the Type B Synoptic Pattern?
   a. A well defined 500 mb jet.
   b. A well defined dry air intrusion from the surface to 700 mb.
   c. A strong unstable wave, with associated cold and warm front.
   d. Rarely has frontal and prefrontal squall lines.
   e. Strong cold-air advection behind the cold front.

6. __________ (TRUE/FALSE) With this air mass pattern time of day is critical to the start of convective activity. (If false, correct the statement.)

3.3 Type C Synoptic Pattern (Overrunning)

As a review, overrunning is warm, moist air overrunning cold, dense air below. You may think this is a stable situation; but it all depends on the stability of the warm air. If the warm air is unstable, the lift over the cold air may actually encourage the development of thunderstorms.
3.3.1 Characteristics
The type C pattern is characterized by the following features:

- An east to west oriented stationary front with warm, moist overrunning tropical air.
- A west-southwest to west-northwest upper-level jet or a strong 500 mb westerly horizontal wind speed shear zone.
- A 700 mb dry intrusion advecting from the southwest.
- Tornadoes may occur when surface dew points are 50°F (10°C). Fuel comes from the release of latent heat.

![Type C Tornado-producing Synoptic Pattern](image)

Figure 3-3 Type “C” Synoptic Pattern

3.3.2. Severe Weather
Tornadoes, large hail, and damaging winds are all possible in the Type C Pattern. Strong overrunning and the presence of a stationary front are warning signs to the potential for severe weather.
3.3.2.1. Severe Weather Areas
Scattered thunderstorms develop on and north of the stationary front due to overrunning (figure 3-3). In the overrunning region, a squall line may form along the leading edge of the dry air intrusion and thunderstorms may reach severe levels. The severe threat area extends approximately 50 miles west of the axis of maximum overrunning to the eastern edge of the overrunning.

3.3.2.2. Triggers
Overrunning, maximum diurnal heating, and a dry air intrusion where active thunderstorms already exist combine to trigger severe convective weather.

3.3.2.3. Timing
Severe thunderstorm occurrence and duration depends on the onset time of dry air intrusion and maximum heating. Severe weather continues until the dry air intrusion decreases or moves out. Activity can last 6 hours after maximum heating.

7. _________ (TRUE/FALSE) Severe weather is confined to an area 50 miles to the south of a stationary front. (If false, correct the statement.)

8. What dew point temperature is generally the lowest value needed for tornado development?
   a. 50°F (10°C)
   b. 60°F (16°C)
   c. 65°F (18°C)
   d. 67°F (19°C)

9. _________ (TRUE/FALSE) A Type C pattern does not require a dry air intrusion for severe thunderstorms. (If false, correct the statement.)

3.4 Type D Synoptic Pattern (Cold Core)
The Type D pattern is noted for hail producing storms and funnel clouds. Single tornadoes are rare but they do occur. The key to this pattern is the cold core system.

3.4.1. Features:
   • A deep southerly upper-level jet
   • A deepening surface low
   • A 500 mb cold core low
   • Cool, dry air advection at all levels
• A low-level jet advecting warm, moist air from the south-southeast, under the cold air aloft

Figure 3-4 Type “D” Synoptic Pattern

3.4.2. Severe Weather
Funnel clouds in the Type D Pattern are often referred to as “cold air” funnels. The reason for instability is warm air moving under cold air aloft, which is associated with a cold core low at 500 mb.

3.4.2.1. Severe Weather Area
Thunderstorms will form in the area between the upper-level jet and the closed isotherm center at 500 mb (figure 3-4).
Severe weather may occur in the area bounded by approximately 150 miles right of the upper-level jet, back to the cold core low, and to the front edge of the dry air intrusion, and to the east and northeast limit of the underrunning warm air (Figure 3-5).

3.4.2.2. Triggers
• Intense low-level confluence. Lift is generated when confluence is present in the low levels, and diffluence is occurring aloft.
- Decreasing stability due to the upper level cold air moving over warm, moist air.

![Barotropic Low Diagram]

**Figure 3-5 Barotropic Low**

### 3.4.2.3 Timing

Violent storms typically occur during max heating with a rapid decrease in intensity after sunset.

10. **A Type D Synoptic Pattern typically has a cold core at what level?**
   a. Surface
   b. 850 mb
   c. 700 mb
   d. 500 mb

11. **What type of tornadic activity is often seen in a Type D Pattern?**
   a. Waterspout
   b. Tornado
   c. Funnel Cloud
   d. No specific type of tornadic activity.

12. **Thunderstorms will form in an area between the _______ and the _______.**
   a. low-level jet, cold front
   b. low-level jet, first closed isotherm at 850 mb.
   c. upper-level jet, closed isotherm at 500 mb.
   d. upper-level jet, upper cold front.
3.5 Type E Synoptic Pattern (Squall Line)

With the Type E Synoptic Pattern, frontal or prefrontal squall lines are usually well defined. The squall lines may be fast or slow moving. In either case, severe storms develop rapidly.

3.5.1 Features

- Well defined upper-level westerly jet
- Well-defined dry air bounded by a 700 mb warm sector
- Low-level convergence
- Moderate to strong southerly low-level flow advecting warm, moist air over cooler drier air

3.5.2 Severe Weather

In addition to developing ahead of cold fronts, squall lines associated with the Type E pattern also develop ahead of warm and occluded fronts.

Figure 3-6 Type “E” Synoptic Pattern
3.5.2.1 Severe Weather Areas

Severe weather may develop along and south of the upper-level jet but north of the 850 mb warm front. The west-east boundary is from the 700 mb cold front to the area of increasing stability (figure 3-6).

Thunderstorms form in the overrunning warm air between the 850 mb warm front and the upper-level jet axis; where the 700 mb dry air intrusion meets the frontal lifting of the warm, moist air in the low-levels, and the strong 500 mb cold air advection.

A secondary threat area exists where the 700 mb dry air intrusion extends south of the 850 mb warm front. Thunderstorms can develop along the 500 mb horizontal speed shear zone and along transitory, active squall lines.

3.5.1.2 Triggers

- Frontal lifting of warm, moist, unstable air
- A 700 mb dry air intrusion
- Diurnal heating
- Cold air advection at 500mb

3.5.1.3 Timing

Thunderstorms will develop with the onset of 500 mb cold air advection into the severe outbreak area. Maximum severe activity occurs from the time of maximum heating to a few hours after sunset. At times, severe storms may continue until midnight, or until the airmass becomes more stable.

13. The western boundary of the primary severe weather threat area is the

a. Surface cold front
b. 850 mb cold front
c. 700 mb cold front
d. 500 mb shortwave trough

14. Thunderstorms may develop along the 500 mb

a. Trough
b. Vorticity Maximum
c. Horizontal Speed Shear Zone
d. Ridge axis at the point of NVA
15. At times severe storms may continue __________ or until the __________.
   a. Until sunset, vorticity lobe moves away.
   b. Until sunrise, air mass becomes stagnant.
   c. Until midnight, air mass becomes more stable.
   d. Until maximum heating, air mass advects away.

Figure 3-7 US Regions and Air Mass Types

3.6 Type I Great Plains Air Mass Pattern

Up to this point the discussion has focused on synoptic patterns known to produce wide scale severe thunderstorms. The focus now switches to specific air mass characteristics required for development of severe thunderstorms, beginning with the Type I Great Plains Air Mass.

3.6.1 Area

The Great Plains (figure 3-7) lies between the Missouri River and the Rocky Mountains. The region gradually increases in elevation from the river valley to the mountains.

3.6.2 Temperature/Humidity

The temperature lapse rate is conditionally unstable in the strata above and below the inversion or stable layer. The relative humidity (RH) below the inversion is normally over 65% and the surface dew point is usually above 55°F (13°C). Rapid drying of the air
is evident on upper air soundings through the inversion (Figure 3-8). RH increases slightly directly above the inversion and increases slightly more rapidly with height.

3.6.3 Winds Aloft
Winds increase with height above the inversion.

3.6.4 Stability Indices
The air mass is conditionally unstable from the surface to 400 mb. The following indices are values associated with the Great Plains Airmass.

- Showalter Stability Index (SSI): Negative.
- Lifted Index (LI): -6
- Vertical Totals (VT): 28
- Cross Totals (CT): 26
- Total Totals (TT): 54

![Figure 3-8 Example of Great Plains (Type I) Air Mass Sounding](image)

3.6.5 Severe Weather
Tornadoes have wide, long paths that occur in the Great Plains airmass. The tornadoes are usually more numerous in the late afternoon but may occur at any time of day. Widespread wind damage and large hail usually accompany storms.

3.6.6 Associated Weather
The following precedes or occurs with thunderstorms:

- Morning stratus, then temporary clearing with mid-clouds.
• Unseasonably high surface temperatures. With thunderstorms, temperatures will drop rapidly, then return to previous readings unless the thunderstorms are associated with a cold front
• Rapid dew point rises 1 to 4 hours prior to the onset of thunderstorms
• Light to moderate winds prior to thunderstorm onset
• Slow hourly pressure falls, followed by a brief rise just prior to thunderstorm onset. Once the storms begin, pressure will fall quickly, followed by a sharp rise, then a return to the normal trend following passage or dissipation of thunderstorm
• Mammatus is usually reported with tornado-producing thunderstorms.

16. In a Great Plains air mass, the relative humidity below an inversion is usually over ______ %.
   a. 50
   b. 55
   c. 60
   d. 65

17. The air mass from the surface to 400 mb is ______ ______ ________.
   a. unconditionally unstable
   b. conditionally unstable
   c. unconditionally stable
   d. conditionally stable

18. Prior to thunderstorm commencement, the surface winds will usually be _____.
   a. Light to strong
   b. Light to moderate
   c. Moderate to strong
   d. Calm

3.7 Type II, Gulf Coast Air Mass
The Gulf Coast Air Mass is generally warm and moist. This airmass is of tropical origin and characterized by deep moisture content with relative humidity of over 65% up to 20,000 feet. This very warm airmass (temperatures commonly over 80°F) is also
characterized by a lapse rate that is conditionally unstable with no stable layer or significant inversion.

3.7.1 Area

The Gulf Coast air mass can be found in the northern Mississippi, Alabama, Georgia, eastern Texas, and Louisiana region of the U.S.

3.7.2 Temperature/Humidity

The lapse rate is conditionally unstable with no significant inversion or stable layer (figure 3-9). Surface temperatures are normally ≥ 80°F (27°C). The RH is usually over 65% from the surface to 20,000 feet.

3.7.3 Winds Aloft

Normally, winds decrease with height. Though strong winds are not required, a correlation exists between the occurrence of tornadic activity and wind shear.

3.7.4 Stability Indices

The LI (-6) and TT (54) values are the same for this air mass as they are for the Great Plains air mass we discussed earlier.

![Figure 3-9 Example of a Type II Air Mass Sounding](image)

3.7.5 Severe Weather

Tornadic activity is restricted to storms separated by 30 – 50 miles. The tornado or waterspout is short lived, with narrow and short paths. Strong downburst winds may occur but hail is not a major concern as the Wet Bulb Zero (WBZ) height is generally above 11,000 feet.

3.7.6 Associated Weather

The following precedes or is associated with thunderstorms:
Cloudy with scattered rainshowers
- Little temperature or dew point change prior to or after thunderstorms
- Pressure falls just prior to tornado or waterspout
- Slow weather changes.

19. Surface temperatures are typically __________.
   a. ≥70°F (21°C)
   b. ≥75°F (24°C)
   c. ≥80°F (27°C)
   d. ≥85°F (29°C)

20. Normally, winds __________ with height.
    a. increase
    b. decrease
    c. does not change

21. (TRUE/FALSE) Since the WBZ is usually above 11,000 feet, hail is highly probable. (If false, correct the statement.)

3.8 Type III, Pacific Coast Air Mass

The Pacific Coast Air Mass is responsible for waterspouts along the West Coast of the U.S. Cold air at all levels is the key feature of this air mass.

3.8.1 Area

The air mass is does not extend far inland due to the Cascade, Sierra Nevada, and Coastal Mountain Ranges, which act as a wall, keeping the cool, moist air on the immediate coast.

3.8.2 Temperature/Humidity

The temperature lapse rate is conditionally unstable and does not have significant inversions or stable layers (Figure 3-10). Surface temperatures range from 50°F (10°C) to 68°F (20°C). The RH routinely exceeds 70% at all levels from the surface to 500 mb.

3.8.3 Winds Aloft

Winds increase and veer with height. Average speeds are 15 knots at 850 mb and 50 knots at 500 mb.
3.8.4 Stability Indices

The instability in the air mass is not as great as the Great Plains and Gulf Coast air masses. The LI is usually around –3 and the TT is in the vicinity of 54.

![Temperature curve, Dew Point curve, Wet-bulb curve](image)

Figure 3-10 Example of Type III Air Mass Sounding

3.8.5 Severe Weather

Tornadic activity usually occurs alone, has a short life span, and a short, narrow path. The tornadic activity is often found in extensive areas of cloudiness with rain showers and isolated thunderstorms. The WBZ height is usually low and only small hail occurs. Wind gusts are usually not much stronger than the strong gradient winds already blowing. Thunderstorms may have virga, mammatus, and funnel clouds associated with them. Often virga will look like a funnel cloud and generate public reports of tornadic activity.

3.8.6 Associated Air Mass Weather

Expect cloudy skies and rainshowers. Winds may be strong due to a tight gradient. There is no abrupt or unusual weather present except pressure changes associated with tornadic activity.

22. This is a _____ air mass and surface temperatures will range from ________.
   a. warm, 65°F (18°C) to 80°F (27°C)
   b. cool, 50°F (10°C) to 68°F (20°C)
   c. cool, 55°F (13°C) to 72°F (22°C)
   d. warm, 60°F (16°C) to 77°F (25°C)
23. Winds _______ and _______ with height.
   a. increase, veer
   b. decrease, veer
   c. increase, back
   d. decrease, back

24. The LI is usually around ________.
   a. –2
   b. –3
   c. –4
   d. –5

25. Hail is small because the WBZ is ________.
   a. low
   b. high

3.9 Type IV, Inverted “V” Air Mass Type

With the Inverted “V” Airmass, maritime polar air outruns continental tropical air between 5,000 and 8,000 feet above the surface. Thus the look of the inverted “V”, or dry air near the surface and moist air above (Figure 3-11).

3.9.1 Area

This situation is seen in the High Plains, or the lee side of the Rocky Mountains. The lee side consists of the area bordered on the east by western Nebraska, south into Texas, and west into the southwest desert regions.

3.9.2 Temperature/Humidity

The sounding for an Inverted “V” airmass has a dry lower layer below a cool, moist layer. Figure 3-11 shows a conditionally unstable situation. The WBZ height is approximately 8,000 feet.

3.9.3 Winds Aloft

The winds in the vertical show an increase in speed and a veering with height.

3.9.4 Stability Indices

The LI for this situation is not considered representative because the low levels are dry. The normal TT for this situation is 53.
3.9.5 Severe Weather

This air mass produces violent straight-line windstorms. Tornadic activity is usually confined to funnel clouds. When tornadoes occur, they are usually narrow and rope-like, causing damage in a small area. Tornadoes tend to be isolated, rapid-moving, and short-lived with short and narrow paths. Tornadoes are usually associated with a mid-level trough triggering the thunderstorm activity.

On the other hand, these storms are major hail producers due to the dry air and the 8,000 foot WBZ height.
26. Briefly explain what causes the “Inverted V” appearance on an upper air sounding.

27. What is the primary concern with this air mass?
   a. Strong tornadoes
   b. Tornado families
   c. Large hail
   d. Strong straight line winds

28. The WBZ height is usually ________.  
   a. 7,000 feet
   b. 8,000 feet
   c. 9,000 feet
   d. 10,000 feet
Module 4 – Severe Thunderstorm Parameters

TRAINEE’S NAME ____________________________

CFETP REFERENCE: 12.12.1, 13.13.1

MODULE OVERVIEW:
This module will cover severe thunderstorm. Parameters found on vertical as well as horizontal products will be discussed.

TRAINING OBJECTIVES:
• OBJECTIVE 1: Identify facts concerning the parameters for convective severe weather and how they apply to a forecast with at least 80% accuracy.

• OBJECTIVE 2: Given vertical and horizontal products, demonstrate an understanding of the indices and how they apply to forecasting severe convective weather to the satisfaction of the trainer/certifier.

EQUIPMENT AND TRAINING REFERENCES:
• TR 200 (Revised), Notes on Analysis and Severe-Storm Forecasting Procedures of the Air Force Global Weather Central

• AFWA TN-98/002, Meteorological Techniques

• AWS/TR-79/006 The Use of The Skew-T, LOG P Diagram in Analysis and Forecasting

• AWS/TN-83/001 Operational Meteorology of Convective Weather

PREREQUISITES AND SAFETY CONSIDERATIONS:
• Completion of the Analysis and Prognosis, METSAT, Weather Elements, and Radar QTPs.

ESTIMATED MODULE TRAINING TIME: 3 Hours
CORE TRAINING MATERIAL AND REVIEW QUESTIONS

4.1. Severe Thunderstorm Features

This section will discuss features associated with the development of severe thunderstorms such as winds, wind shear, fronts and boundaries, and significant severe weather parameters.

4.1.1 Winds

Winds play a significant role in the development and sustainment of severe thunderstorms. Some winds are beneficial to the development and some are not.

1.1.1.1. Strong Mid-Level Winds

In order for a mid-latitude thunderstorm to become severe, strong mid-level winds are required. The mid-level winds help establish a separate updraft and downdraft. The winds will help push the precipitation away from the updraft, allowing the updraft to continue to grow and sustain. These mid-level winds may be a reflection of a strong upper-level jet. The strongest storms have winds of 50 knot or greater.

Note: Mid-level winds > 35 knots are considered “jet” winds.

4.1.1.2 Vertical Wind Shear

Vertical wind shear is important for the development of severe thunderstorms. It has the effect of tilting the storm, in essence, blowing the rain shaft away from the updraft. A strong low-level wind, under a light upper-level wind, can have the effect of pushing the thunderstorm base away from the tower, thus tilting the storm.

Vertical shear is usually considered a change in wind direction of 30° or more from the low-levels to the mid-levels. If the vertical shear is less than 30°, the upper wind speeds should be 30% or greater than the lower winds.

In very high wind speeds, the difference in speed from the top to the base may destroy all but the strongest storms. Very strong vertical wind shear is deadly for weak storms but will actually help the strongest storms develop further.

4.1.1.3 Intersection of Max Low-Level Winds and Boundaries

A frequent area of severe thunderstorm development is where maximum low-level winds intersect with a boundary (e.g. a warm front, old squall line, etc.).

4.1.1.4. Intersecting Mid and Low-Level Jets

An area conducive to severe thunderstorm development is the area at and northwest of a mid and low-level jet intersection (Figure 4-1)
4.1.1.5. Horizontal Shear

The presence of horizontal speed shear associated with the upper level jet may help decrease stability. The shear enhances the upward vertical motion by increasing lift over a given area. Shear strength is depicted in Table 4-1.

<table>
<thead>
<tr>
<th>Shear Strength</th>
<th>Change in Wind Speed</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEAK</td>
<td>&lt; 15</td>
<td>90 NM</td>
</tr>
<tr>
<td>MODERATE</td>
<td>≥ 15 ≤ 30</td>
<td>90 NM</td>
</tr>
<tr>
<td>STRONG</td>
<td>&gt; 30</td>
<td>90 NM</td>
</tr>
</tbody>
</table>

Table 4-1 Shear Strength
1. Strong mid-level winds help establish __________.
   a. a strong gust front and intense lightning.
   b. an updraft and downdraft
   c. the anvil and wall cloud
   d. hail and tornadoes

2. Vertical wind shear is defined as

3. _______ (TRUE/FALSE) The recognized wind direction change for shear is 45 degrees (If false, correct the statement).

4. Favored area for severe thunderstorm development is the __________?
   a. Area of intersection of a warm front and a low-level wind maximum.
   b. Area of intersection of an old squall line and the Polar Front Jet.
   c. Area of intersection of the sea breeze front and the Sub-Tropical Jet.
   d. None of the above.

4.1.2 Lift

As you have already learned, for convective activity to exist, lift must be present. In order for a thunderstorm to become severe, there must be an abundance of lift. Lift can come from a multitude of sources ranging from heating of the surface to an approaching cold front.

4.1.2.1 Cold Fronts

Probably the most recognized lifting mechanism is the cold front. Thunderstorms may develop ahead of the front (Figure 4-2) and if the conditions are right, severe thunderstorms may occur. It is important to note the cold front alone is not the only cause of severe thunderstorms, but many of the features that exist with cold fronts add to the list of features required for severe storm development.
4.1.2.2 Pre-Frontal Squall Line.

Inactive cold fronts may have a squall line up to 150 miles ahead of the front (figure 4-3). This is an ideal area for severe thunderstorm development. The lifting of the air at the squall line gives thunderstorms the lift needed to become severe. When the 700mb wind is perpendicular to the cold front, the air will be pushed down the frontal boundary and away from the front. As the air meets an opposing flow, it is pushed up and lift is supplied.

Figure 4-2. Cold Front and Lift

Figure 4-3 Pre-Frontal Squall Line
4.1.2.3 Warm Front

Even though severe weather is not usually associated with warm fronts, it does occur. The stability of the warm air is the key to severe thunderstorm development. Unstable air riding up the warm front supplies the lift needed to enhance thunderstorm development. Thunderstorms associated with the warm fronts have the potential to collapse and generate high winds.

4.1.2.4 Other Boundaries

The following boundaries may also provide the lift necessary for severe thunderstorm development.

- Upper Cold Fronts
- Sea breeze fronts
- Outflow boundaries from earlier thunderstorms
- Dry lines

4.1.2.5 Intersecting Boundaries

Intersecting boundaries have the potential for severe thunderstorm development, if other needed elements are present. Outflow boundaries, sea breeze fronts, cold fronts and dry lines, are just a few examples of boundaries that may intersect (Figure 4-4). The intersection of small boundaries may be enough to develop severe thunderstorms.
5. A squall line may develop up to _________ miles ahead of an inactive cold front.
   a. 50
   b. 125
   c. 150
   d. 300

6. _________ (TRUE/FALSE) In order for pre-frontal squall line formation, the 700 mb winds must be parallel to the associated cold front.

7. _________ (TRUE/FALSE) Since a sea breeze front is not supported by upper level features, it cannot supply the lift needed for severe thunderstorm develop.
4.1.3 Vorticity

Recall from the Analysis QTP that vorticity is the spin of an air parcel. This spin can be created by wind shear and/or by curvature. In the case of positive vorticity, the spin is cyclonic. In the case of negative vorticity, the spin is anticyclonic. The spin air parcels acquire or loose as they move through the atmosphere is indirectly related to vertical motion.

4.1.3.1 Strong PVA

Positive (cyclonic) vorticity advection (PVA) occurs when air parcels move from a region of cyclonic vorticity into a region of less cyclonic vorticity or higher anticyclonic vorticity. Negative (anticyclonic) vorticity advection (NVA) occurs when air parcels move from a region of anticyclonic or neutral vorticity into a region of less anticyclonic vorticity or higher cyclonic vorticity. Figure 4-5 shows a cyclonic vorticity maxima embedded in a 500mb trough in the Northern Hemisphere.

![Figure 4-5 Vorticity Maxima Embedded in Trough (modified from Doswell)](image1)

Let's assume air parcels are moving through the trough from the west. Figure 4-6 illustrates the path of the parcel through the vorticity pattern.

![Figure 4-6 Air Parcel Movement Through the Vorticity Pattern (modified from Doswell)](image2)
As the parcel approaches the vort maxima, the parcels are moving from an area of anticyclonic or neutral vorticity into a region of increasing cyclonic vorticity. They must spin faster cyclonically. In order to do this, the parcel contracts (recall the conservation of angular momentum - the ice skater). This contraction is convergence. As the parcel contracts at 500 mb, and if the negative vorticity advection is greater above 500mb and less below 500mb, air is forced downward. This is a consequence of the conservation of mass and is illustrated in figure 4-7a and 4-7b.

![Figure 4-7 Convergence Aloft](image)

Notice the surface parcel expands in response to the convergence aloft. This expansion is called "divergence". As the parcel exits the trough, the situation is reversed. Now the parcel is moving into an area of decreasing cyclonic vorticity, so PVA is occurring. The parcel must decrease its cyclonic spin, so it expands and spins slower. This expansion (divergence aloft) is accompanied by a compensating convergence near the surface and upward vertical motion (figure 4-8).

![Figure 4-8 Divergence Aloft](image)

PVA is an indicator of upward vertical motion; convergence in the low-levels and divergence in the upper-levels. In this context, the lower and upper-levels are in relation to the Level of Non-Divergence (LND), usually around 600mb.

4.1.3.2 PVA and Thunderstorms

Research has determined that in most severe weather outbreaks, moderate to strong PVA was present.

Do not concentrate on the vorticity value advecting in but rather the strength of the advection (The perpendicular component of the winds to the positive vorticity advection area). Figure 4-9a. depicts contours almost parallel to the vorticity isopleths in southern Missouri and northern Arkansas. This is an indication of a weak PVA. Figure 4-9b depicts tightly packed vorticity with a perpendicular contour indicating strong PVA.
PVA is not the trigger, but rather a catalyst that “prepares the environment” for severe thunderstorm development. Thunderstorms do not require PVA to develop, but PVA does help developing thunderstorms become severe.

### 4.1.4 Jets

The jet stream is important for the transport of temperature and moisture through the atmosphere, and the development of severe thunderstorms.

#### 4.1.4.1 Upper Level Jet

Evidence has shown the strongest storms occur where the Polar Front Jet is identified in the mid-levels. A mid-level jet is an indicator of a strong upper jet.

Difluence with a supergradient condition of the jet is another parameter to consider in the development of severe thunderstorms. Air parcels reaching an area where the gradient loosens, are deflected toward higher pressure. This “spreading” leads to difluence and upward vertical motion. Figure 4-10, depicts difluence in central and eastern Texas associated with supergradient thunderstorms.

![Figure 4-10 Difluence at Front of Jet Maximum](image)

The right rear quadrant of a jet maximum is an area of PVA (indicating upward vertical motion) and is considered a prime area for severe weather. The right rear quadrant may lie in an area of abundant tropical moisture and warm temperatures and in the spring, when the PFJ is at its strongest, strong temperature contrasts may exist.
4.1.4.2 Mid-Level Jet
In order to have widespread severe convective weather, a strong mid-level jet must exist. In essence, a reflection of a strong upper-level jet must be seen in the midlevels to see widespread severe convective weather.

4.1.4.3 Low-Level Jet
If a low-level jet is present, it can often be seen in the mid-western region of the U.S. at night, and around the Great Lakes states. The low-level jet and associated severe weather can form in a relatively short period of time. Some parameters to watch in determining if a low-level jet is forming are:
- Hourly changes in surface pressure (i.e. tightening gradient).
- Hourly changes in temperature.
- Hourly changes in wind.

4.1.5 Moisture
Moisture must be present in order for thunderstorms to form. A closer look may indicate the moisture is already present or will be advected into the threat area at a later time.

4.1.5.1 Low-level Moisture
To determine low-level moisture availability, check the lower 3000 feet of a sounding. Along with or in the absence of a sounding, the 850 mb chart may be used to determine low-level moisture availability. When determining moisture amounts, use a $\leq 5^\circ C$ dewpoint depression as criteria. Once the amount of moisture is determined, the focus should shift to potential moisture changes. For example, a cold front is approaching the area of concern, and ahead of the front, the dewpoint depression is $2^\circ C$. Based solely on moisture, thunderstorms would be expected with and in the vicinity of the front. After frontal passage, the dewpoint depression becomes $10^\circ C$. Thunderstorms would be expected to move out of the area or dissipate altogether.

4.1.5.2 Changes In Low-level Moisture Field
The following may identify changes in the low-level moisture field:
- An increase or decrease in the surface dewpoint temperature.
- An increase or decrease in temperature.
- Pressure changes indicating the occurrence of upward or downward vertical motion.
- The development or advection of low clouds.

4.1.6 850 mb Temperature Ridge
A strong correlation exists between the 850 mb temperature ridge, the location of the low-level moisture ridge, and the development of severe thunderstorms. The following relationships exist between the thermal and moisture ridge at 850mb:
• If the temperature ridge is east (or downstream) of the moisture ridge, there is a weak chance of severe activity.

• If the temperature and moisture ridges are coincident, there is a moderate chance of severe activity.

• If the temperature ridge is west (or upstream) of the moisture ridge, there is a strong chance of severe activity.

4.1.6.1 Type A and B Systems
Key to severe activity with the type A or B system (figure 4-11) is the type of moisture gradient that exists. If the maximum temperature ridge is west or southwest of the moisture ridge, the chance of severe weather is high. Dry, warm air, adjacent to the moist air creates a strong moisture gradient. This gradient is generally called a “dry line” and is instrumental in the development of severe thunderstorms.

Figure 4-11 Type A and B Systems

4.1.6.2 Type C, D, and E Systems (figure 4-12)
Usually with these systems the 850 mb temperature ridge is coincident to the low-level moisture ridge. An exception to this is the Type D System where, the 850 mb temperature ridge may actually lie to the east of the moisture ridge. When we compare the amount of severe weather between these systems, the Type C and E systems tend to have fewer tornadoes than the Type A or B.

Figure 4-12 Type C, D and E Systems
8. **(TRUE/FALSE)** Evidence has shown the strongest storms occur where the Polar Front Jet is restricted to the upper levels only.

9. Expect severe thunderstorms, to include tornadoes, if the 850 mb temperature ridge is ____________.
   
   a. coincident with the low-level moisture ridge  
   b. to the east of the low-level moisture ridge  
   c. to the west of the low-level moisture ridge

**4.1.7 700 mb No Change Line**

The 700 mb No Change Line connects points of negligible temperature advection. Routinely, the line represents the separation of WAA and CAA. A quick way to find the no change line is to compare the 850 mb warm ridge with the same location on the 700 mb chart. The no change line will usually line up with the warm ridge. If the leading edge of the no change line is ahead of a mid-level trough, then a deepening of the surface low should be considered. If the surface low deepens, the chance of severe weather associated with the system is increases.

**4.1.8 700 mb Dry Air Intrusion**

A value to define dry air is a murky value at best. An important feature regarding a dry air intrusion is the relationship of the low-level winds and the 700 mb winds. The ideal relationship is winds veering with height with an increase in speed with height. The following may be used as a guide in determining “dry” air:

- 50% relative humidity  
- Dew points of less than 0°C  
- Dew point depression of >6°C

**4.1.9 Surface Pressure and Pressure Falls**

Surface pressure and pressure falls may indicate the potential location of severe weather.

**4.1.9.1 Surface Pressure**

The following surface pressure values may help to determine the potential for severe thunderstorms, particularly, tornadoes.

- If the surface pressure is above 1013 mb, the chance of tornadoes is significantly reduced.
- Most destructive tornadoes occur at 1005 mb and lower.
4.1.9.2 Pressure Falls

Surface pressure falls should be viewed as an indicator of major changes occurring on the surface and aloft. For example, a drop in surface pressure may indicate increased low-level convergence and upward vertical motion or lift.

Drops in surface pressure may also indicate changes in moisture and the low-level wind flow. For example, if a stable wave is becoming unstable, winds become cyclonic around the wave and moisture is pulled into and lifted by the system. Suppose a stable wave exists in central Mississippi and an upper-level trough approaches and deepens the wave amplitude. The flow in Alabama would become southerly and moisture would be advected from the Gulf of Mexico to the east of the low. The potential for severe weather increases as the amount of warm, moist air increases.

Minor shortwaves are often easy to identify and just as easy to miss. Short duration pressure falls may assist in the identification of these shortwaves. If the other parameters are in place for a severe weather event, the extra lift with a passing shortwave may be all that is needed for thunderstorms to produce severe winds, hail, or tornadoes.

4.1.10 500 mb Height Falls

Height falls can indicate the movement of a trough and the potential of convective severe weather.

4.1.10.1 Height Falls and the Vorticity Pattern

Height falls at 500 mb can be directly correlated to the 500 mb vorticity pattern. As positive vorticity moves over an area, the upward vertical motion or "lift" can increase. This increase in lift can trigger severe thunderstorm development.

4.1.10.2 Height Fall Areas.

500mb height falls are often found in the following areas:

- Areas of diffluence associated with a supergradient jet
- Where horizontal shear exists south of the main jet
- In the vicinity of maximum jet winds

10. Based on surface pressure alone, if the pressure is higher than 1013mb, the:
   a. Chance of strong tornadoes is significantly increased.
   b. Chance of tornadoes is significantly reduced.
   c. Chance of tornadoes is 50/50.
   d. Chance of tornadoes is 0.
11. List three general guidelines used in determining “dry” air at 700 mbs

12. __________ (TRUE/FALSE) Height falls at 500 mb CANNOT be directly correlated to the 500 mb vorticity pattern. (If false, correct the statement.)

4.1.11 Height of the Wet Bulb Zero (WBZ)

The height of the WBZ is important in determining the potential for severe convective weather, particularly hail and strong surface winds. The following rules of thumb apply to hail size in the central U.S:

- The potential for hail is greatest when the WBZ height is between 5,000 and 12,000 feet
- Large hail has been noted to fall when the WBZ height is between 7,000 to 11,000 feet with the optimal height around 9,000 feet
- Small hail ≤ ¼ inch may occur when the WBZ height is above 12,000 feet and below 5,000 feet

4.1.12 Surface Dew Points

Dew points may be used to help determine the chance of severe thunderstorms. The following dewpoint values may be used in determining severe thunderstorm potential:

- Dew points below 13°C (55°F) limit the development of severe thunderstorms.
- Weak tornadoes may occur with a Type II and III airmasses when dew points are below 13°C (55°F).

13. In the central U.S, the potential for hail is greatest when the WBZ height is:
   a. Between 3000 and 15000 feet.
   b. Between 5000 and 12000 feet.
   c. Between 5000 and 8000 feet.
   d. Between 14000 and 18000 feet.

14. Hail that is ≤¼ inch in diameter has been noted if the WBZ is lower than ________ feet and higher than __________ feet.

15. Severe thunderstorms generally occur when the surface dew point is greater than __________ °C.
4.2 Stability Indices

The overall stability or instability of an airmasses may be expressed as single index. The following indices are in general use through out AFW. Most indices can be obtained from automated soundings or other products.

Note: The indice values used in this section are for training purposes only. Actual values will vary depending on your location. Contact your trainer for values associated with your area of responsibility.

4.2.1 Showalter Stability Index (SSI)

The SSI compares low-level moisture and upper level temperatures. Use the SSI to determine the potential for thunderstorm development. Specific values have been found to identify thunderstorm possibility and intensity.

4.2.1.1 Manually Determination of the SSI (Figure 4-13)

Figure 4-13 SSI Example

- **Step 1**: Find the LCL from the 850 mb temperature and dewpoint.
- **Step 2**: From the LCL follow the saturation adiabat up to the 500 mb level, this is the parcels temperature.
- **Step 3**: Subtract this temperature from the actual 500 mb temperature.
- **Step 4**: If the parcel’s temperature is colder than the actual temperature, the SSI will be positive. If it is warmer, the SSI will be negative.
4.2.1.2 Using SSI

The SSI will give you the potential stability of the airmass and does not take into account triggers or airmass changes. If the value is negative, the atmosphere is considered unstable and if positive, the atmosphere is considered stable. The more negative the value, the more unstable the atmosphere. The following SSI values are a guide to atmospheric stability:

SSI Values

- $> +3$ Strong Stability
- $> +1$ to $\leq +3$ Moderate Stability
- $> -3$ to $\leq +1$ Weak Instability
- $> -6$ to $\leq -3$ Moderate Instability
- $\leq -6$ Strong Instability (tornadic potential)

4.2.2 Lifted Index (LI)

The LI is a modification of the SSI. It uses the average moisture in the lower 3,000 feet using the equal area method to determine the low-level moisture.

4.2.2.1 Manually Determining the LI (figure 4-14)

- Find the mean mixing ratio in the lowest 3,000 feet of the sounding.
- Find the mean potential temperature in the lowest 3,000 feet expected at the onset of convection. Use the maximum temperature from the warmest sounding or forecast the temperature at the warmest time and find the mean temperature in the lowest 3,000 feet.
- Find the LCL using these mean values.
- Follow the saturation ratio up to 500 mb. This is the assumed updraft temperature within a cloud.
- Subtract this updraft temperature from the actual 500 mb temperature.
- If the updraft’s temperature is colder than the actual temperature, the LI will be positive; if warmer, the LI will be negative.

![Figure 4-14 LI Example](image)
4.2.2.2 Using the LI

Just like the SSI, the LI is a stability value of the atmosphere and is used to determine potential thunderstorm probability and intensity. If the LI is greater than zero, the air is considered stable. The more negative the LI, the greater the instability of the atmosphere. The following LI values are a guide to atmospheric stability:

<table>
<thead>
<tr>
<th>LI Value</th>
<th>Atmospheric Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0</td>
<td>Stable atmosphere with NO thunderstorms likely</td>
</tr>
<tr>
<td>0 to −2</td>
<td>Thunderstorms possible, weak indication of severe thunderstorms</td>
</tr>
<tr>
<td>3 to −5</td>
<td>Unstable, thunderstorms probable and a moderate probability of severe thunderstorms</td>
</tr>
<tr>
<td>−6</td>
<td>Very unstable, heavy to strong thunderstorm potential</td>
</tr>
<tr>
<td>&lt; −6</td>
<td>Strong probability of severe thunderstorms and possible tornadic activity</td>
</tr>
</tbody>
</table>

Table 4-2 LI Values

4.2.3 Total Totals (TT)

The TT is the sum of the vertical totals (VT) (850 temp – 500 temp) and cross totals (CT) (850 dewpoint – 500 temp). It is used to measure the potential for thunderstorm development and thunderstorm severity.

4.2.3.1 Manually Determining Total Totals

TT are determined using the following equation:

\[
TT = (T_{850} - T_{500}) + (Td_{850} - T_{500})
\]

The following example uses the RAOB data depicted in table 4-3.

| TTAA | 52121 72201 99020 20012 06008 00169 18606 08515 92839 16409 15013 85555 12007 21012 70162 04257 24014 50581 15123 29024 40746 25116 26524 30949 40140 26054 25071 49156 25569 20215 55557 26097 15397 60558 25080 10640 74357 26552 88211 56757 25599 77210 25600 42417 51515 10164 00052 10194 14514 23014 |

Table 4-3 RAOB Information

\[
TT = (12 - 15.1) + (5 - 15.1)
\]

TT = 27.1 + 20.1

TT = 47.2

The following TT values may be used to determine potential thunderstorm development.

<table>
<thead>
<tr>
<th>TT Value</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50</td>
<td>Weak</td>
</tr>
<tr>
<td>≥ 50 to &lt; 55</td>
<td>Moderate</td>
</tr>
<tr>
<td>≥ 55</td>
<td>Strong</td>
</tr>
</tbody>
</table>

Table 4-4 TT Values
4.2.4 K Index (KI)

The KI is a measure of thunderstorm potential based on the vertical temperature lapse rate, the moisture content of the lower atmosphere, and the vertical extent of the moist layer. The index is converted to thunderstorm probability and does not give the potential for severity.

4.2.4.1 Manually Determining the KI

The following equation is used to determine the KI:

\[ KI = (T_{850} - T_{500}) + (Td_{850} - Td_{700}) \]

The following example uses RAOB data depicted in Figure 4-5.

<table>
<thead>
<tr>
<th>KI Value</th>
<th>TSTM %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 15</td>
<td>0</td>
</tr>
<tr>
<td>15 to 20</td>
<td>20%</td>
</tr>
<tr>
<td>21 to 25</td>
<td>20 to 40%</td>
</tr>
<tr>
<td>26 to 30</td>
<td>40 to 60%</td>
</tr>
<tr>
<td>31 to 35</td>
<td>60 to 80%</td>
</tr>
<tr>
<td>36 to 40</td>
<td>80 to 90%</td>
</tr>
<tr>
<td>&gt; 40</td>
<td>Near 100%</td>
</tr>
</tbody>
</table>

4.2.5 Severe Weather Threat (SWEAT) Index

The SWEAT is used to estimate the potential for severe convective weather in an airmass. The SWEAT Index takes into account low-level moisture, instability, low-level jet, upper-level jet, and warm air advection. This is the only index that applies upper-level dynamics to stability.

SWEAT is computed from five terms that contribute to severe weather potential:
- Low-level moisture (850mb dew point)
- Instability (Total Totals)
- Low-level jet (850mb wind speed)
- Upper-level jet (500mb wind speed)
- Warm advection (veering between 850mb and 500mb)

**Note:** If the reporting station is higher than 850mb, use the temperature and depression at the top of the surface layer (surface pressure minus 100mb) in place of the 850mb temperature and depression.

\[ \text{SWEAT} = 12D + 20(T-49) +2f8 + f5 + 125(S+0.2) \]

Where:
- \( D \) = 850mb dew point in degrees C (if D is negative, set the term to zero)
- \( f8 \) = 850mb wind speed in knots
- \( f5 \) = 500mb wind speed in knots
- \( S \) = Sin (500mb wind direction – 850mb wind direction)
- \( T \) = “Total Totals” in degree C (if T is less than 49, set the term 20(T-49) to zero)

Though the SWEAT value may be computed manually, for simplicity it is best derived using automated means. The following SWEAT values are used to discriminate between ordinary and severe thunderstorms:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 – 400</td>
<td>Chance of severe thunderstorms</td>
</tr>
<tr>
<td>400 – 500</td>
<td>Severe thunderstorms likely, chance of tornadoes</td>
</tr>
<tr>
<td>500 – 600</td>
<td>Severe thunderstorms and tornadoes likely</td>
</tr>
<tr>
<td>600 – 800</td>
<td>Tornadoes nearly always occur</td>
</tr>
<tr>
<td>&gt; 800</td>
<td>No severe weather – winds too strong</td>
</tr>
</tbody>
</table>

**Table 4-6 SWEAT Values**

**4.2.6 Convective Available Potential Energy (CAPE)**

CAPE is the amount of energy available to a surface parcel that has reached its Level of Free Convection (LFC). A positive CAPE value indicates upward vertical and a negative CAPE indicates downward vertical motion. Severe weather has occurred within a wide range of CAPE values. One way to use the CAPE value is to monitor the trend of the CAPE value. An increase in the CAPE value coincides with an increase in both the strength and the speed of the potential updraft core and vise versa.

Automated programs calculate the maximum updraft speed and depict the upward vertical velocity (UVV). Increasing UVV values are indicative of an increase in the strength of an updraft core, and increases in the likelihood of severe weather. The following CAPE threshold values are routinely used in the U.S:
Table 4-7 CAPE Values

<table>
<thead>
<tr>
<th>CAPE Value</th>
<th>Associated With</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1000</td>
<td>Severe thunderstorms</td>
</tr>
<tr>
<td>&gt;2500</td>
<td>Tornadic activity</td>
</tr>
</tbody>
</table>

4.2.7 Bulk-Richardson Number (BRN)

The BRN is the ratio of the buoyancy (CAPE) of a lifted air parcel to the vertical wind shear environment in which the parcel is lifted. The BRN is a complex equation best derived using automated methods.

4.2.7.1 Using BRN

High values indicate unstable and/or weakly sheared environments; low values indicate weak instability and/or strong vertical shear. The following values are used with the BRN:

<table>
<thead>
<tr>
<th>BRN Range</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>Excessive shear and severe thunderstorms are unlikely</td>
</tr>
<tr>
<td>10 to 50</td>
<td>Supercell development</td>
</tr>
<tr>
<td>≥ 50</td>
<td>Weaker, multi-cellular storms</td>
</tr>
</tbody>
</table>

Table 4-8 Bulk-Richardson Values

4.2.8 Theta-E/Equivalent Potential Temperature (EPT)

Theta-E is a measure of the temperature a parcel of air would have if lifted to saturation, all its moisture was condensed out and it was returned to the 1000 mb level. This measure is related to the density of the air, taking into account temperature and moisture. The EPT value is directly proportional to the temperature and dew point of an air parcel. High temperatures and/or high (i.e. light buoyant air) dew points will result in high EPT values and vice versa.

4.2.9 Application of Stability Indicies

Instability is a critical factor in severe weather development. Severe weather stability indices can be a useful tool when applied correctly to a given convective weather situation. However, great care should be used when applying these empirical indices because they simply cannot be applied to every weather situation and must always be applied in conjunction with other parameters. Severe weather indices only indicate the potential for convection. There must be sufficient lifting for upward motion to release the instability before thunderstorms can develop. Consider the following when using stability indices as a forecast tool:

- **Regional Analysis** - Assess stability indices for geographical regions (see Figure 4-15). Regional analysis provides the "big picture" of overall atmospheric stability and allows for quick identification of smaller areas of maximum instability.
Figure 4-15 Regional Stability Indices

- **Trend Analysis** - Track stability indice changes over time, taking into consideration past and if available, future stability trends (Figure 4-16). Trend analysis aids in recognition of airmass changes and associated stability changes.

Figure 4-16 TT Trend Analysis

- **Data Considerations** - A number of indices are tied to specific pressure levels that may (or may not) be representative of a particular convective weather situation. Sounding data must be looked at as a whole. Topography
characteristics make some indices irrelevant and local adaptations may need to be made. Also consider that the upper air soundings themselves may not be representative of the overall synoptic situation.

### 4.3 Hodograph

A hodograph is a graphical display of the vertical wind profile of the lowest 7,000 meters above a location. The plots are used to determine advection patterns aloft, whether a thunderstorm will rotate, and the type of thunderstorm possible.

#### 4.3.1 Reading the Hodograph

Vectors are plotted with tails at the origin pointed towards the direction the wind is blowing (Figure 4-17a). The length of the vector is proportional to the wind speed. Usually winds are plotted as a dot (tip of wind vector) to keep the hodograph from getting too messy. The dots are then connected together by a line to show changes in wind direction and speed with height. Each end is labeled with the height at which the wind was observed (Figure 4-17b).

![Figure 4-17 Hodograph](4-13a 4-13b)

The hodograph depicts wind changes with height, commonly referred to as the “vertical wind shear”. Wind shear is defined as the vector difference between winds at different levels. Figure 4-18 shows a vector difference between two points on the hodograph.
Figure 4-18 Hodograph depicting vertical wind shear

By looking at consecutive segments of a hodograph, one can see how the shear vector changes with height. When the shear vector is veering with height, the hodograph is indicating that the thunderstorm is turning clockwise and when the shear vector is backing with height, the hodograph is indicating that the thunderstorm is turning counterclockwise.

Two factors that contribute to the development of severe convective storms are convective buoyant energy and vertical wind shear. The buoyant energy strongly influences the vertical acceleration air parcels experience when forced above the LFC, while the vertical shear strongly influences convective storm type. Forecasters assess storm type by examining the hodograph structure in the lower troposphere. Specifically, three storm types, single cell, multicell, and supercell, have been identified and associated with three distinct patterns.

The unorganized hodograph (figure 4-19), which has a random appearance, is indicative of a weak wind shear environment. This type of hodograph is associated with short-lived single cell thunderstorms.
Figure 4-19 Hodograph typical of single-cell thunderstorms

The straight line or unidirectional shear profile characterizes the “straight-line” hodograph (figure 4-20). The shear profile indicates stronger directional and speed shear than found with the “unorganized” hodograph. This type of hodograph is associated with multi-cell thunderstorms. Multi-cell storms persist longer than single cell type thunderstorms due to their ability to produce new cells. Multi-cell thunderstorms can produce large hail, strong winds, and tornadoes along the gust front near the updraft center.
Figure 4-20 Hodograph typical of multi-cell storms

Directional change shear vectors in the lowest few kilometers and increases in wind speed with height characterize the “curved” hodograph. The most likely thunderstorm type associated with this hodograph is a supercell thunderstorm. The clockwise turning of the hodograph favors a cyclonic right moving supercell, while the counterclockwise turning of the hodograph favors the anti-cyclonic left moving supercell.
4.3.2 Hodographs and Storm-relative Winds

Low-level inflow is needed for thunderstorms to develop. Strong inflow, combined with moderate to strong directional shear can produce updraft rotation and storm tilt. Storm inflow appears to be the most important in the lowest 6km, with strong emphasis placed on the lowest 3km. In order to determine the storm-relative winds on a hodograph, the storm motion vectors need to be plotted (storm motion can be observed or forecasted). Using the head of the storm motion vectors as the origin, draw vectors from the head of the storm motion vectors to the vector heads (points along hodograph) of your ground-relative winds. The resulting vectors show the air inflow into the storm at the different altitudes as the storm moves through the environment. Remember, if the storm motion changes, the storm-relative winds will also change.

Figure 4-21 Hodograph typical of supercell storms
4.3.3 Hodograph Examples

The following are examples of hodographs that may represent supercell development.

- Clockwise turning in the low-levels (Figure 4-123 indicates veering winds aloft. The wider the turn, the more the winds increase with height and greater shear exists.
- This pattern favors the development of right moving storms. Right moving storms have the tendency to produce tornadoes and large hail.

Figure 4-22 Hodograph indicating storm-relative winds

Figure 4-23 Clockwise Turning in the Low-Levels
4.3.3.1 Counterclockwise Turning in the Lower Levels (Figure 4-24)

- Indicates backing winds aloft.
- Favors development of left moving storms. Left moving storms tend to only produce large hail.

![Figure 4-24 Counterclockwise Turning in Low Levels](image)

4.3.3.2 Straight (Figure 4-25)

- Winds are blowing from the same direction at all levels.
- Does not favor left or right moving storms but as mentioned earlier does suggest multicell thunderstorms

![Figure 4-25 Straight in Low Levels](image)

4.3.3.3 Supercell Indicators

- Strong speed and directional shear is needed.
- Winds veer $\geq 70^\circ$. On average, the directional shear will be about $90^\circ$ with speeds 20 – 35 knots.
- A straight trace will be evident from about 3 km to 10 km with speed shear quickly reaching over 60 knots.
16. An SSI value of –2 indicates:
   a. weak instability
   b. moderate instability
   c. strong instability

17. An LI value of –2 indicates:
   a. stable atmosphere with thunderstorms not likely
   b. Thunderstorms possible, weak indication of severe thunderstorms
   c. Unstable. Thunderstorms probable and a moderate probability of severe thunderstorms

Use the following RAOB to answer question 18 and 19.

<table>
<thead>
<tr>
<th>UJUE5 KAWN 021500 RTD100</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTAA 52141 74794 99025 12218 30003 00212 11849 00013 85567 09443</td>
</tr>
<tr>
<td>27523 70159 00803 26533 50578 15957 28051 40743 25780 27573 30945</td>
</tr>
<tr>
<td>409// 26090 25067 483// 24610 20211 545// 25618 15395 589// 26111</td>
</tr>
<tr>
<td>10641 703// 25578 88207 565// 25120 77213 25120 40705;</td>
</tr>
</tbody>
</table>

18. What is the Total Totals from the RAOB above and what does the value indicate?

19. What is the K Index from the RAOB above and what does the value indicate?

Circle the appropriate response

20. In the hodograph below, the trace is veering/backing and the storms would be right/left movers.
Module 5 – Analysis Techniques

TRAINEE’S NAME ___________________________________

CFETP REFERENCE: 12.12.1

MODULE OVERVIEW:
This module covers the basic interaction of thunderstorms and surface boundaries.

TRAINING OBJECTIVES:

• **OBJECTIVE 1:** After completing the module, the student will be able to identify surface and upper-air parameters needed for convective activity to develop. The student will demonstrate this ability by answering questions with at least 80% accuracy.

• **OBJECTIVE 2:** After completing the module the student will perform a basic analysis of severe weather parameters to the satisfaction of the trainer/certifier.

EQUIPMENT AND TRAINING REFERENCES:

• Technical Report 200 (Rev), *(Notes on Analysis and Severe-Storm Forecasting Procedures of the Air Force Global Weather Central)*

• AFGWC/TN 79/002 *(Training Guide for Severe Weather Forecasters)*

• AFWA/TN-98/002, *(Meteorological Techniques)*

• NWS CR-10 *(A Comprehensive Severe Weather Forecasting Checklist and Reference Guide)*

PREREQUISITES AND SAFETY CONSIDERATIONS

• Complete module 1-4

ESTIMATED MODULE TRAINING TIME: 4 hours
5.1 The Need for Analysis

To accurately predict weather, you must first understand the current atmospheric situation. This concept holds true especially when forecasting convective weather.

When analyzing for convective weather features, remember that all values attached to the analyzed parameters must be considered “relative” to the immediate environment. TN 79/002 states the “…analysis of any particular level incorporates the use of all available information, such as the previous analysis, additional data from radar and satellite sources and from levels above and below the level of interest. A great deal of care must be taken not to ignore, change, or smooth data that may at first appear to be in error. Meticulous attention to minor changes and transitory features in the atmosphere is imperative. A highly systematic analysis routine is required to ensure the necessary attention to small details.”

It’s not important how the data is plotted and or analyzed (i.e computers / manual method). What’s important is that you meticulously analyze the data. Don’t be fooled by “smoothing” that often results from computer analysis.

Let’s begin by looking at parameters on constant pressure charts. The analyses on these charts stress wind and temperature fields rather than the height field. Contours are drawn at small intervals to insure the identification of minor features and to avoid the tendency to smooth the analysis. Closed or detached centers are avoided and contours are drawn to imply air-mass source regions.

5.2 850mb Analysis

Some features to look for on the 850mb analysis are:

- Areas under and just west of the low-level jet (winds ≥ 25 kts).
- Thermal ridge west of a moisture axis.
- Significant warm air advection.
- Strong moisture flux convergence.
- Lifting mechanism (fronts, troughs, and dry lines).

5.2.1 850mb Streamline and Convergence Analysis

Maximum wind bands (jets) are important features since they may be associated with significant maximum moisture and thermal advection. This maximum wind band is commonly referred to as a low-level jet (LLJ). Although there is no minimum speed criterion for the LLJ, it is generally considered to be a band of winds ≥ 25kts (figure 5-1).

Accurate analysis of convergence zones will assist in locating the primary thermal ridge and axis of maximum moisture advection, near a potential severe weather threat area. Weak convergence zones are sometimes the first indication that moisture advection from a source region is occurring. If significant moisture is already present, the convergence zone may indicate deepening of the moist layer.
5.2.2 850mb Thermal Analysis

A detailed analysis of the thermal field should correctly locate the thermal ridge.

- Analyze the isotherms every 2° C
- Select an even numbered temperature that forms a continuous line across the entire chart as your first isotherm.

When analyzing isotherms, remember to look for the thermal ridge. To accentuate the thermal ridge, isotherms should parallel the streamlines wherever data permits. Do not
be reluctant to erase and adjust the pattern. A good analyst modifies his or her analysis continuously from start to finish. Note: Isotherms are sometimes depicted as dashed lines.

The thermal ridge of prime interest will lie just ahead of the strongest convergence zone. Also in most cases, cold advection will be behind and warm advection ahead of the convergence zone (figure 5-2).

Figure 5-2 850mb Thermal Analysis

5.2.3 850mb Moisture Analysis

Isodrosotherms (isopleths of equal dewpoints) are analyzed starting with a dewpoint of 6° C and in increasing values of 2° C. When drawing isodrosotherms, remember to analyze for the axis of maximum moisture advection and areas of maximum moisture. The isodrosotherms should parallel the streamlines when data permits.
Try to depict a representative moisture field. Many times subsidence will produce a moist, mixed layer just below the 850mb level. As the day progresses, boundary layer turbulence caused by low-level winds will often result in a deeper mixed layer. Twelve hours later, on the next analysis, considerable moisture may appear at the 850mb level.

Additional regions of significant moisture are associated with areas having dew point depressions of 6° C or less.

Dry lines are indicated where streamlines flow from dry air into an area of significant moisture. Primary interest lies in regions where a maximum wind band flows across a dry line to moist air (figure 5-3).
5.2.4 **Complete 850mb Analysis** (figure 5-4)

Key parameters at the 850mb level in terms of intensity are:

- **Low-level Jet**
- Values of 24 knots or less indicate weak activity
- Values 25 – 34 knots indicate moderate activity
- Values of 35 knots or more indicate strong activity

**Low-level Moisture**

- Dewpoint values of 8° C or less indicate weak activity
- Dewpoint values of 9 – 12° C indicate moderate activity
- Dewpoint values greater than 12° C indicate strong activity.

**Thermal ridge / axis of maximum moisture relationship**

- Ridge east of maximum moisture axis indicates weak activity
- Ridge coincident with maximum moisture axis indicates moderate activity
- Ridge west of maximum moisture axis indicates strong activity

*Figure 5-4 Completed 850mb Analysis*
5.3 700mb Analysis

The 700mb analysis is primarily concerned with moisture fields and dry-air tongues. Dry tongues are areas of dewpoint spreads > 6° C, or relative humidity less than 50%. Some other features to look for are:

- Wind veering ≥ 30 degrees between the surface and 700mb.
- Dry air intruding at a 40° angle with wind speeds of at least 25 knots. Look at skew-Ts, model soundings, and gridded data for significant entrainment.
- Dew point depression > 6° C. Significant dry air in mid levels may signal possibility of strong downdrafts.
- Winds cross 12-hour temperature “no change” line at > 40 degrees.
- Lifting mechanism (fronts and troughs).
- Significant upward vertical velocity (UVV).

5.3.1 700mb Streamline and Temperature Fall Analysis

Streamlines and difluent zones should be the first parameters analyzed. Maximum wind bands (jets) are important features because they produce dry intrusions. These winds may also depict areas of most rapid cold or warm air advection.

Secondary analysis parameters include temperature falls (12 or 24 hour) and the temperature no-change line.

Significant streamlines, which are not necessarily maximum winds, are drawn to help identify areas of diffluence.

Significant temperature falls (over a 12 hour period from late fall through early spring and 24 hour period from late spring through early fall) should be analyzed to indicate areas of cold advection.

The temperature no-change line (over a 12 hour period from late fall through early spring and 24 hours from late spring through early fall) will assist in forecasting the approximate location of squall-line development (figure 5-5).
Figure 5-5  700mb Streamlines and Temperature Fall Analysis

5.3.2  700mb Thermal Analysis
The 700mb chart is used primarily to find areas of dry air intrusion (entrainment), mid-level capping that can inhibit convection, and the steering flow of convective systems.
To locate thermal troughs and ridges, select an even-numbered temperature that forms a continuous line across the whole chart for the first isotherm. Analyze isotherms every 2°C.

To accentuate thermal troughs and ridges, the isotherms should parallel the streamlines so that the thermal troughs and ridges will parallel the streamlines. The thermal ridge takes on greater importance in late spring through early fall, since convective activity is normally subdued or capped at temperatures of 12°C or greater (exception in mountainous regions). Note: Isotherms are sometimes depicted as dashed lines.

Use the 500mb chart to assist in vertical stacking of the cold trough and the 700mb should be used to ensure continuity. Cold troughs help to locate the most probable areas of upward vertical motion (figure 5-6).
Figure 5-6  700mb Thermal Analysis

5.3.3  700mb Moisture Analysis

Significant moisture fields are defined by a temperature/dewpoint spread of 6° C or less. Areas of moisture detached from a primary moisture source and not solely explained by
Advection are most likely the result of upward motion associated with positive vorticity advection or moisture pockets caused by previous thunderstorms. These areas indicate a minor shortwave trough is a short distance upstream (figure 5-7).

Figure 5-7 700mb Moisture Analysis
5.3.4 Complete 700mb Analysis (figure 5-8)

Key parameters at the 700mb level in terms of intensity are:

**Intrusion of a dry line:**
- Lack of or a weak wind field indicates weak activity.
- Winds from dry to moist air at an angle of 10 to 40 degrees and a speed of 15 to 25 knots indicates moderate activity possible.
- Winds intruding at an angle of 40 to 90 degrees with wind speeds of 25 knots or greater indicate strong activity is possible.

**Wind to temperature no-change line (or significant change line) relationship**
- Winds crossing line at an angle less than 20 degrees are weak.
- Winds crossing line at 20 to 39 degrees are moderate.
- Winds crossing line at 40 to 90 degrees are strong.

![Figure 5-8 Complete 700mb Analysis](image)
5.4 500mb Analysis

The primary focus of the 500mb chart is moisture, temperature and branching in the jet structure.

The moisture field requires careful analysis because, like the 700mb chart, moist and dry regions are often related to the vertical motion fields.

The temperature analysis will help identify cold troughs and cold pools that indicate decreasing stability. Branching in the jet structure often identifies confluent and diffluent areas.

Other features to be aware of are:

- Wind speeds ≥ 50 knots
- Short waves. Especially negatively tilted, rapidly moving short waves.
- Positive Vorticity Advection (PVA) with contours crossing vorticity pattern >30 degrees.
- Significant cold pool aloft (-16°C Dec-Feb, -14°C Mar-Apr and Oct-Nov, -12°C May-Jun, -10°C Jul-Sep).
- Horizontal shear over 90 miles is ≥ 30 knots.

5.4.1 500mb Wind and Height Fall Analysis

Maximum wind bands are the most significant wind feature. Their location and forecast position help outline a severe weather area. You may recall, the wind speed and direction of flow are factors considered in calculation of the SWEAT formula index.

Any split in the flow is a possible branching of the maximum wind band (jet). Evaluate this carefully. The diffluence parameter should lie between the two branches in the maximum wind band.

Note: There are times when diffluence is present and no branching is evident. In this case, there may be a weaker flow pattern spreading away from the main jet.

A horizontal speed shear zone is indicated by a rapid decrease in the speed of flow moving in the same direction to the right of the jet. As in the previous paragraph, the weaker flow branching away from the jet may be considered a horizontal speed shear zone if the decrease in speed with distance is significant.

Note: To ease confusion, remember wind direction is depicted by streamlines and wind speed is depicted with isotachs.

Height falls at this level furnish a clue to the location and movement of long and short wave troughs. Height fall areas also approximate the area of maximum positive vorticity. Due to the seasonal variation in the frequency of migratory waves, 12-hour height falls should be used from late fall through early spring and 24-hour height falls used from late spring through early fall (figure 5-9).
Figure 5-9  500mb Streamlines and Height Fall Analysis
5.4.2 500mb Thermal Analysis

A detailed analysis of the thermal field will accurately locate thermal troughs, which is very important in identifying areas of instability. Draw the isotherms every 2° C. Select an even numbered temperature that forms a continuous line across the whole chart. The height fall field can assist in the analysis of the thermal field.

When analyzing isotherms, look for cold pools and thermal troughs. The isotherms should parallel the streamlines wherever possible so the shortwaves are enhanced. (Note: Be careful not to overdo it or the result will be thermal troughs that always coincide with streamline troughs. Avoid drawing thermal troughs coincident with streamline troughs because it will not depict warm or cold advection into or out of a streamline trough).

The thermal ridge is not used as a major parameter at this level, however it must be considered. Most convective activity is subdued or capped near its axis and/or its eastern half, especially when the thermal ridge coincides with the streamline ridge (figure 5-10).

Note: Isotherms are sometimes depicted as dashed lines.
5.4.3 500mb Moisture Analysis

Areas where the dewpoint depression is 6° C or less define a significant moisture field at 500mb. With the 700mb chart, detached areas of moisture not solely explained by advection from a primary moisture source most often result from vertical motion. These
areas, if associated with PVA, will indicate a minor shortwave is a short distance upstream (figure 5-11).

Fig 5-11  500mb Moisture Analysis

5.4.4 Complete 500mb Analysis (figure 4-12)

Summarizing the key parameters at the 500mb level in terms of intensity:

Mid-level Jet Strength

- < 35 knots is weak
- 35-49 knots is moderate
• ≥ 50 knots is strong

**Height Falls**
• < 30 meters is weak
• 30 – 60 meters is moderate
• ≥ 60 meters is strong

**Isotherm Values**
• December, January, February: -16°C
• March, April, May, October, and November: -14°C
• June, July, August, September: -10°C

![Completed 500mb Analysis](image.png)

**Figure 5-12 Completed 500mb Analysis**

### 5.5 Total Total Analysis

Total Totals (TT) is a combination of vertical totals (VT) and cross totals (CT) that can be used to provide an approximate delineation of the most unstable areas.
TT are routinely analyzed in intervals of 2 or 4 beginning at 44 (figure 5-13). **Note:** In some parts of the country and at certain times of the year, VT and or CT are more important than TT.

**Figure 5-13** Total Totals

### 5.6 Maximum Wind Analysis

The maximum wind chart is usually analyzed at the 200 or 300mb level. This analysis is very handy when the 500mb wind field is too weak to properly identify the maximum wind band (primarily in summer). Parameters to use when analyzing for maximum winds are:
• Wind speeds ≥ 50 knots.
• Diffluent areas.
  • Severe weather outbreaks often occur in the diffluent zone between the polar and subtropical jet streams.
  • Left front and right rear region of straight jet max; left front region of cyclonically curved jet max and right rear region in anticyclonic jet max.
  • Most severe weather occurs south of the polar jet and north of the subtropical jet (coupled jet), or in the left rear region of a jet max.
  • Long wave troughs and strong synoptic lift.
  • Significant height falls and/or deepening of an upper level low.

Isotachs (lines of equal wind speed) are drawn at an appropriate interval considering the overall wind field. Isotachs are drawn to locate the axis of maximum wind and to isolate maximum wind cores.

Significant streamlines, other than the maximum wind axis, are drawn to assist in identifying diffluent zones. Diffluent zones are indicated where the flow of the axis of maximum wind branches significantly.

Horizontal speed shear zones are indicated when there is a significant decrease in speed per distance from the axis, or from the edge of the maximum wind band (figure 5-14).

Key parameters and their intensities are:

**Upper-level jet**

• Wind speed < 50 knots indicate weak activity.
• Wind speeds 50 to 85 knots indicate possible moderate activity.
• Values ≥ 85 knots indicate possible strong activity.

**Upper Level Shear (over a 90nm horizontal distance)**

• Shear values < than 15 knots are weak.
• Shear values between 15 to 29 knots are moderate.
• Shear values ≥ 30 knots are strong.
Figure 5-14 Maximum Wind Analysis

5.7 Complete Upper Air Composite

The primary purpose of the upper air composite chart is for comparison of the predominant patterns with known severe weather patterns.
The composite chart provides a structured way of combining crucial features on one map. Combining surface and upper air features in multiple colors on a single chart allows quick access to the potential location of severe weather regions. Relevant parameters may change on a daily basis, therefore the synoptic situation should, in part, dictate which parameters to use (figure 5-15).

**Figure 5-15 Complete Upper Air Composite**

### 5.8 Surface Analysis

This chart is probably the most significant tool routinely available. The dense network of reporting stations allows identification of fronts, discontinuity lines, wind shifts and other variables essential to convective development.

An hourly mesoscale surface analysis is critical to severe weather forecasting. Detailed analysis can uncover features such as boundaries, mesolows, bubble highs, strong pressure falls, and moisture pooling. The following list identifies key severe weather features:

- Dew Points > 65°F.
- Theta-E ridge and positive Theta-E advection.
• Low-level moisture flux convergence.
• Thermal ridge over or west of the moisture axis.
• Strong temperature and dew point rises.
• Areas reaching convective temperature.
• Lifting mechanism (fronts, troughs, gust fronts, dry lines, outflow boundaries etc.)
• Surface pressures ≤ 1005mb.
• Concentrated pressure falls of ≥ 5 mb over 12 hours. Pressure falls can give clues to mesolow’s formation areas. Mesolows may develop from intersections of discontinuity lines, squall line intersecting fronts or dry line, or low-level jets intersecting a warm front.

5.8.1 Isobaric Surface Analysis
Isobars are drawn every two millibars, starting with an even value. When analyzing pressure, for troughs, highs, lows, fronts, and other discontinuity lines they should be drawn coincident with pressure troughs. The strength of a discontinuity depends on the isopleth gradient ahead of or behind it (figure 5-16).

Discontinuities require close scrutiny. Parameters of particular interest are:

• **Surge Lines**: A surge line indicates wind speed convergence, that is, an area of stronger winds moving into an area of weaker winds. The leading edge of the stronger wind area is considered the discontinuity line. Such a discontinuity is commonly found along the lee slopes of mountain ranges and often accompanies an upper-air trough and cold advection aloft.

• **Convergence Zone**: The merging of winds from different directions is a convergence zone. An example is wind flow from the WSW-WNW merging with winds from the SSE-SSW. The angle at which they meet and the wind speed determines the strength of convergence.

• **Squall line**: A squall line is a pressure discontinuity line caused by thunderstorm development ahead or in the vicinity of a frontal boundary. A squall line is a combination of two or more discontinuity lines.

• **Front**: In actuality, a front is also a combination of two or more discontinuities. These discontinuities include temperature, dewpoint, pressure troughs, convergence zones, dry lines, surge lines, pressure changes, or even old squall lines. Note: Old squall lines (ones in which the thunderstorms have dissipated) are often confused with fronts.

Standard present weather symbols (in their designated colors) should be plotted. This assists in properly locating discontinuity lines.
Figure 5-16 Isobaric Surface Analysis
5.8.2 Isallobaric Surface Analysis

3-hour pressure rises and falls should be analyzed for significant values. A combination of falls and rises will assist in determining the direction of movement of lows, highs, and discontinuity lines. Falls will also assist in locating areas of moist and/or warm advection (figure 5-17).

Figure 5-17 Isallobaric Surface Analysis

5.8.3 Surface Streamline Analysis

Streamlines should be drawn to highlight the maximum convergence area and, in many cases, assist in locating the maximum wind band at lower levels (figure 5-18).
5.8.4 Surface Thermal and Moisture Analysis

The thermal and moisture analysis helps track the low-level thermal ridge, the axis of maximum moisture and associated advection. Thermal ridge is located by highlighting the isotherm that accurately depicts the warmest air.

In locating the axis of maximum moisture advection, start with the 55°F isodrosotherm (isopleth of equal dewpoints) and draw isodrosotherms at an interval that adequately defines the moist air (figure 5-19).

Note: Isotherms are sometimes depicted as dashed lines.
Figure 5-19 Surface Thermal and Moisture Analyses
5.8.5 Complete Surface Analysis

Key parameter values and their intensities on a completed surface analysis are (figure 5-20):

**Dewpoint**
- Values $\leq 55^\circ$ F indicate weak activity.
- Values between 56 and 64$^\circ$ F indicate moderate activity.
- Values $> 64^\circ$ F indicate strong activity.

**Pressure in Threat Area**
- $> 1010$mb indicates weak activity.
- Pressure between 1010 and 1005mb indicates moderate activity.
- Pressure $< 1005$mb indicates strong activity.
5.9 Determining Severity of Thunderstorms

Ample tools exist for estimating thunderstorm severity. Conventional radar identifies the height and position of tops, intensity and gradients of reflectivity, water content, echo configurations (notches, hooks, and weak echo regions), and movement. Doppler radar can show mesoscale or even tornadic circulation centers, upper divergence from cloud tops, and estimated straight-line wind speeds associated with outflow gusts. The satellite can provide positive indicators such as; observation of tails (flanking lines) south of large storms, large anvil heights, rapid anvil spreading and cloud top temperatures.

The following techniques are useful for a 0-3 hour storm severity forecast:

- On radar, watch the following indicators of potentially severe hailstorms.
  - Reflectivity >45 dBZ in middle levels;
  - At least 6km overhang outside the limits of a tight reflectivity gradient;
  - Maximum top over the overhang region or bounded weak echo region (BWER). Note: When a cell forms a BWER it has much more severe potential near the eastern side of the pendant or upstream edge of the BWER. Tornado touchdown often corresponds to the collapse of the BWER.

- Look for inflow maximizing echoes such as echoes at the southern end of lines or broken lines, echoes bulging eastward as in a Line Echo Wave Pattern (LEWP), echoes ahead of a line, and echoes developing northeast of a mesoscale low. Try to imagine how the environmental flow is entering each storm at low-levels and base an estimate of projected strength on the potential instability of the inflow air and rate of inflow. Situations in which upstream storms precipitate into, and hence stabilize the inflow air, will significantly reduce the possibility of severe weather from the cell in question.

- Be alert to clustered small echoes that merge into a large organized cell and solid or broken lines that rapidly evolve into a cellular structure. When line storms are observed on radar and satellite, watch for certain line echo configurations. Bow echoes are often indicative of mesoscale circulation, enhanced outflow, and damaging (downburst) winds. Downbursts typically occur in the reflectivity gradient region ahead of the echo. The bow echo may be part of a LEWP. Watch for rapid elongation of echoes or relative penetration of a weak reflectivity gradient on the forward edge of the storm. This may be identified in satellite imagery as warming at anvil level. The downburst activity may be very persistent and located at the nose of the advancing bow echo. The region near the up-stream side of the BWER is another favored location for downbursts. Doppler radar, if properly oriented relative to the wind direction, can aid in diagnosing strong outflow winds.

- Winds in single cells can also be significant. Some important indications in satellite visible imagery and related arc cloud propagation to maximum gust. If the speed of the arc cloud is greater than 30 knots, expect gusts of 34 – 49 knots.
• The vertically integrated liquid water (VIL) has been shown to be a useful parameter for forecasting. Values >45 kg m\(^{-2}\) imply potential for severe storms.

• Some important parameters on satellite imagery are:
  • Difference between mean anvil top temperature and minimum anvil temperature, and change in this difference. The greater the difference the stronger the chance of severe weather.
  • Spreading of isotherms at anvil level.
  • V-shaped ridges at anvil level.

5.9.1 Tornadoes

Tornadoes are one of the most visually impressive weather phenomena known. Tornadoes have occurred in every month, during every hour of the day, and in every state. The following table contains a description of the F-Scale, which was created by Dr. Ted Fujita, of the University of Chicago. The scale is as follows:

<table>
<thead>
<tr>
<th>F-Scale Number</th>
<th>Intensity Phrase</th>
<th>Wind Speed</th>
<th>Type of Damage Done</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0</td>
<td>Gale tornado</td>
<td>40-72 mph</td>
<td>Some damage to chimneys; breaks branches off trees; pushes over shallow-rooted trees; damages sign boards.</td>
</tr>
<tr>
<td>F1</td>
<td>Moderate tornado</td>
<td>73-112 mph</td>
<td>The lower limit is the beginning of hurricane wind speed; peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed.</td>
</tr>
<tr>
<td>F2</td>
<td>Significant tornado</td>
<td>113-157 mph</td>
<td>Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light object missiles generated.</td>
</tr>
<tr>
<td>F3</td>
<td>Severe tornado</td>
<td>158-206 mph</td>
<td>Roof and some walls torn off well constructed houses; walls overturned; most trees in fives uprooted.</td>
</tr>
<tr>
<td>F4</td>
<td>Devastating tornado</td>
<td>207-260 mph</td>
<td>Well-constructed houses leveled; structures with weak foundations blown off some distance; cars thrown and large missiles generated.</td>
</tr>
<tr>
<td>F5</td>
<td>Incredible tornado</td>
<td>261-318 mph</td>
<td>Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 meters; trees debarked; steel re-inforced concrete structures badly damaged.</td>
</tr>
<tr>
<td>F6</td>
<td>Inconceivable tornado</td>
<td>319-379 mph</td>
<td>These winds are very unlikely. The small area of damage they might produce would probably not be recognizable along with the mess produced by F4 and F5 wind that would surround the F6 winds. Missiles, such as cars and refrigerators would do serious secondary damage that could not be directly identified as F6 damage. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl pattern, for it may never be identifiable through engineering studies.</td>
</tr>
</tbody>
</table>

Figure 5-21 Fujita Scale
The Fujita Scale may not be a perfect system for linking damage to wind speed, but it is simple enough to use in daily practice without involving much additional expenditure of time or money. The entire premise of estimating wind speeds from damage to non-engineered structures is very subjective and is difficult to defend from various meteorological perspectives. A key point to remember is this: the size of a tornado is not necessarily an indication of its intensity.

Figure 5-22 Tornado strengths and related deaths

Tornadoes are usually associated with atmospheric instability common with supercell development. The environmental wind profile is critical. Unfortunately a storm environmental sounding is rarely available, but the forecaster can often determine winds characteristics.

Tornadic storms are typically isolated. The trajectory of existing storms should be monitored for potential changes in the wind fields. Tornadoes are possible if the storm develops or moves into a region where low-level, storm-relative shear meets these criteria:

- 90-degree veering in the wind in the lowest 4km (in other words, a deep layer of directional shear)
- At least 20 knots of inflow at 700mb and moist low-level inflow.

This type of shear is common where storms cross warm frontal boundaries. However, this criteria is valid only when cool low-level air does not inhibit the tornado circulation from reaching the ground. It has been shown that storms moving parallel to a front will have a longer tornadic potential than storms moving normal or perpendicular to a front.

An outflow boundary can serve the same purpose if it exists long enough for large scale balancing to produce favorable warm-front-like shears and for the air to regain heat. Newly generated outflow boundaries usually inhibit tornado formation in the short term by flooding the area with heavy nonbuoyant rain-cooled air, which decouples the tornado cyclone circulation from the surface.

On the individual storm scale, rotation typically begins in upper-levels over the low-level reflectivity gradient and spreads downward. The vertical stretching, evident in downdraft air on the upwind side, may be a contributor. The updraft region has significantly lower pressures, so air condenses below the convective condensation level (CCL). This rising,
negatively buoyant air forms the wall cloud. As rotation in the lower levels becomes stronger, precipitation from the rain to the north wrap around the west side of the circulation, while dry subsiding air moves in from the southwest. This intense low-level cyclonic shear may be followed by tornado formation. The wraparound rain and dry air form the hook seen on radar. The hook is generally a poor forecast indicator since it is relatively rare and the critical event may have already occurred.

A better indicator is the inflow notch. The tornado is most likely ahead of the strong reflectivity on the western edge of the notch. Eventually, rain may completely wrap around the tornado, obscuring it from observers and spotters.

The Doppler radar can monitor the existence and evolution of the mesocyclone, and on rare occurrences the tornado itself. Some important criteria for mesocyclone identification include persistent rotation and vertical continuity. After the tornado dissipates and the hook echo is no longer detected on radar, regeneration is still possible if the storm has not become outflow dominated; that is, the outflow air which had been held in check by rapid inflow, suddenly floods the flank of the storm.

Sequential development of a new wall cloud and mesocyclone occur southeast (5-10km) of the old mesocyclone, usually ahead of the rear flank downdraft in the moist inflow air. This evolution appears much like the occlusion and secondary development process that occurs at the synoptic scale. In some cases, a third or fourth wallcloud/mesocyclone/tornado event may occur. This depends on the sustained potential instability of the air south and east of the storm (the right-front quadrant relative to storm motion).

Analyze the following package. After completion, have your trainer check your work with the master analysis. Note: Data was not available to analyze for height falls.
300mb Anal 17 May 2000
500mb Anal 17 May 2000
850mb Anal 17 May 2000
Satellite Image 17 May 2000
MODULE REVIEW QUESTIONS CONFIRMATION KEY

Module 1 – Characteristics of Thunderstorms

1. Unstable airmass, available warm, moist air, some type of low level lifting mechanism.

2. will not

3. low level convergence

4. speed and direction

5. Free convection is caused by warm air rising without any external influences. Some type of lifting mechanism causes forced convection.

6. The mature stage.

7. A multicell cluster consists of a group of cells moving as a single unit.
   - Ridge east of maximum moisture axis indicates weak activity
   - Ridge coincident with maximum moisture axis indicates moderate activity

8. Ridge west of maximum moisture axis indicates strong activity. Strong mid and upper level winds are necessary to carry accumulated precipitation downstream as well as to draw mass away from the updraft, further intensifying the updraft.

9. Southerly winds allow the cell to continue to draw warm, moist air along its right rear flank causing new cell formation. As these new cells form and move through the complex and dissipate on the left flank, it gives the impression that the complex is moving to the right of the actual direction that the line is moving.

10. The rotating mesocyclone is what differentiates supercells from other severe thunderstorms.

11. As the horizontal anticyclonic vortices become entrained into the updraft, the vortices become tilted vertically. When the wind veers with height, the 1 horizontal vortex is tilted in such a way that a cyclonic rotation is induced in the updraft.

12. The center of the mesocyclone.

13. The subsidence outside the supercell, which compensates for all the mass being forced aloft, suppresses other convection around the supercell.

14. Precipitation drags mid level winds toward the surface, strengthening the FFD.
15. The RFD forms when mid and upper level winds pass beneath the upwind anvil and collides with the updraft.

16. As mass (air) begins to build, entrainment of drier air causes evaporative cooling and the cold air begins to sink. Precipitation drag will enhance this phenomenon.

17. The strong rotating updraft pushes low level moisture high into the storm leaving a vault of precipitation free air.

18. The storm top is located directly over the vault.

19. The BWER beginning to collapse.

20. When the RFD reaches the surface. This causes a rear flank gust front.

21. The interaction of the subvortex and the low-level shear associated with the gust fronts and inflows.

22. The presence of an anvil, an overshooting top, and a well defined rotating appearance in the mid-level of the storm. (A ring of clouds encircling the updraft tower, is another sign of a rotating updraft.)

23. It is normally located in the rear section of the storm, where inflow is occurring.

24. Wall clouds have in-flowing winds and shelf clouds have outflowing winds.

25. Both produce violent weather. (Did I trick anyone?)

26. The radar echoes are usually small and weak due to the relatively small amount of precipitation in these storms. This causes low reflectivity values to be depicted on radar.

27. Usually, supercells move to the right and slower than the mean winds.

28. Anticyclonic rotation of the updraft caused by winds that “back” with height cause severe left movers. SL storms are notorious hailers.

Module 2 – Mesoscale Convective Systems

1. Squall lines most frequently produce severe weather near the updraft/downdraft interface at the storm's leading edge.

2. Downburst winds are the main threat, although hail as large as golf balls and gustnadoes.

3. Bow echoes, most common in the spring and summer, usually are associated with an axis of enhanced winds that often create straight-line wind damage at the surface.
4. A squall line is much longer than it is wide. A typical length is about 300 miles (500 km). The width of a squall line is typically about 60 miles (100 km).

5. The cloud system of the squall line consists mainly of cumulonimbus (CB) on its front part and of altostratus and nimbostratus on its rear side.

6. 2400 J/kg / 3500-4000 J/kg (range of 2500-6000 J/kg).

7. Broken line

8. Embedded areal

9. In meteorology, the term derechos is defined as widespread, rapid moving, convective induced winds which produce significant damage and casualties.

10. It must have winds greater than 50 knots, the damage area must be at least 250 nautical miles long, and damage reports must be in a single path or a series of paths.

11. Serial and Progressive

12. B. Type 2 echo pattern

13. D. Type 4 echo pattern

14. Cloud Shield with IR temperatures ≤ -32°C must have an area ≥ 100,000 km².

15. MCC often have a “fried egg” appearance.

16. MCCs tend to develop farther north as the polar front jet moves north and the sub-tropical high becomes more entrenched.

17. A typical location for MCC development is in a region of significant upper level diffluence. This is often found along the eastern side of a high-pressure ridge.

18. C, a microburst must extend out to 2.5 miles and have winds up to 146 miles.

19. B, the difference in the Celsius temperature is 20°C.

20. A, An air parcel falls, compresses, and warms describes the adiabatic process.

**Module 3 – Airmass types and Thunderstorms**

1. D. Dryline

2. C. Is the characteristic that is not correct. For the statement to be correct it would have said confluence instead.

3. True. Will last 6 to 8 hours, and maybe even more.

4. A. Cold front.

5. D is the characteristic that is not correct. For the statement to be correct it would have said “Almost always”.

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6. False. Change to read, “In this air mass pattern, time of day is not important.”

7. False. Change to read, “The severe weather is found to the north of the stationary front.”

8. A. 50°F (10°C)


10. D. 500 mb

11. C. Funnel cloud

12. C. Upper-level jet, closed isotherm around a cold pocket.

13. C. 700 mb cold front.

14. C. Horizontal Speed Shear Zone

15. C. Until midnight, air mass becomes more stable.

16. D. 65

17. B. Conditionally unstable.

18. B. Light to moderate.

19. C. ≥80°F (27°C)

20. A. Increase.

21. False. Change statement to read, “The WBZ is usually above 11,000 feet, so hail is not a big concern.”

22. B. Cool, 50°F (10°C) to 68°F (20°C).

23. A. Increase, veer

24. B. –3

25. A. Low

26. Warm air is underrunning colder air aloft.

27. D. Violent straight line winds.

28. B. 8,000 feet

**Module 4 – Severe Thunderstorm Parameters**
1. B. An updraft and downdraft.
2. Vertical shear is defined as a difference of wind speeds and/or direction with height.
3. FALSE (The change in wind direction is 30°)
4. A. Area of intersection of a warm front and a low level wind maximum.
5. C. 150 miles ahead of a cold front
6. B. The 700 mb winds need to be mostly perpendicular.
7. FALSE. The sea breeze front supplies the lift and does not need upper level support.
8. FALSE. Strongest storms occur when the PFJ is reflected down into the mid levels.
9. A. The 850 mb temperature ridge is coincident with the low level moisture ridge.
10. B. Chance of thunderstorms significantly reduced due to higher pressure.
11. 50% relative humidity, dewpoints of less than 0°C and dew point depressions of >6°C
12. 13. FALSE (CANNOT should be changed to CAN)
13. B. Between 5000 and 12000 feet.
14. 5000/12000
15. 13°C
16. a.
17. b.
18. 35.3 + 21.0 = 56.3 / strong chance of strong thunderstorms
19. 35.3 + 4.6 = 39.9 / 80 – 90% chance of thunderstorms
20. Veering (clockwise turning), right moving thunderstorms

Module 5 – Analysis Techniques
200mb Anal 17 May 2000
300mb Anal 17 May 2000

500mb Anal 17 May 2000
850mb Anal 17 May 2000