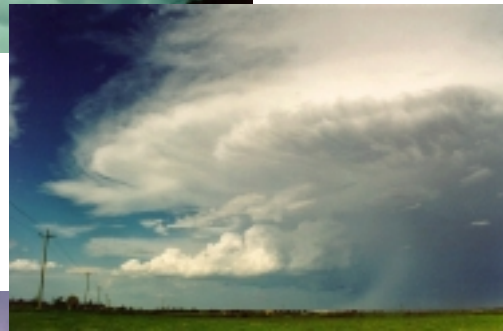
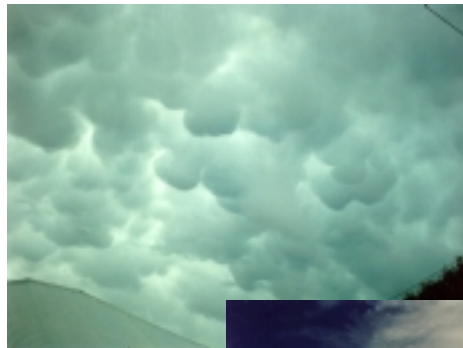


# THUNDERSTORM ANATOMY AND DYNAMICS

## An Overview



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# 1. Introduction

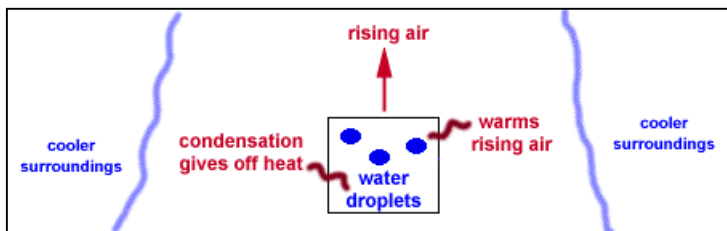
*The purpose of this paper is to present a broad overview of the various cloud structures displayed during the life cycle of a thunderstorm and the atmospheric dynamics associated with each. Knowledge of atmospheric dynamics provides for a keener understanding of the physical processes related to the “why and how” certain cloud features form. Accordingly, observation of cloud features presents visual queuing of changes in the atmosphere.*

## 2. Thunderstorm Formation and Stages of Development

**Thunderstorm development is dependent on three basic components: moisture, instability, and some form of lifting mechanism.**

- 2.1 Moisture** – As air near the surface is lifted higher in the atmosphere and cooled, available water vapor condenses into small water droplets which form clouds. As condensation of water vapor occurs, latent heat is released making the rising air warmer and less dense than its surroundings (figure 1). The added heat allows the air (parcel) to continue to rise and form an updraft within the developing cloud structure.

- 2.1.1 In general<sup>1</sup>, low level moisture increases instability simply by making more latent heat available to the lower atmosphere. Increasing mid level moisture can decrease instability in the atmosphere because moist air is less dense than dry air and therefore is unable to evaporate precipitation and cloud droplets as effectively as drier air.

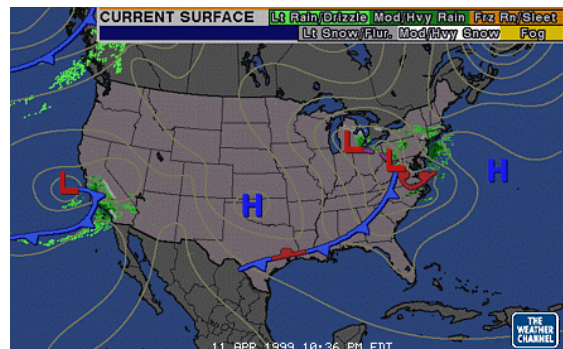


• Figure 1 – Positive buoyancy / instability as a result of condensation and release of latent heat. (fm WW2010)

Evaporation of precipitation at or below cloud level cools the air within precipitation downdrafts. This makes the air more dense and increases downdraft velocity and instability.

### 2.1.2 Sources of Moisture.

- ♦ Air masses – Maritime polar air masses originating over the Northern Pacific Ocean bring large quantities of moisture to the northwestern U.S., while dry continental polar air from Canada frequently interacts with moist sub-tropical air from the Gulf of Mexico (figures 2 and 3).
- ♦ Advection – Low level convergence as a result of differential heating produces much of the thunderstorm activity along the Gulf Coast and Florida while mid level advection of tropical moisture associated with low level jet streams decreases stability aloft (figure 3).



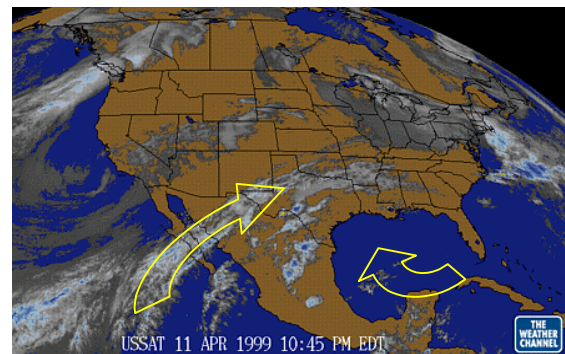
• Figure 2 – Surface Analysis VT 11/1900z APR 99

<sup>1</sup> Baker, P., <http://www.srh.noaa.gov/SJT/HTML/Preparedness/Ingredients.html>, NWS, San Angelo, 1999)

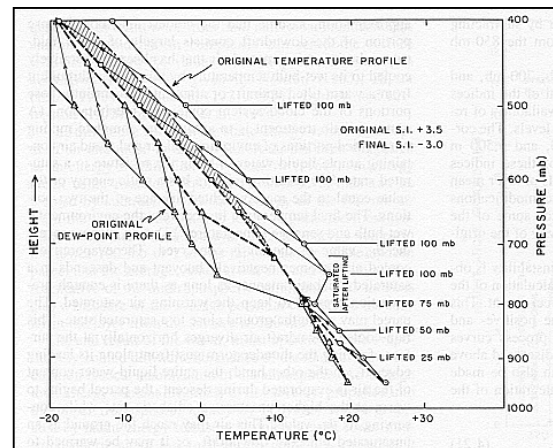
**2.2 Instability** – Defined as: “The tendency for air parcels to accelerate when they are displaced from their original position, especially the tendency to accelerate upward after being lifted. Instability is a prerequisite for severe weather - the greater the instability, the greater the potential for severe thunderstorms.<sup>2,3</sup>”

2.2.1 Sources of increased instability include:

- ◆ Warm temperatures in the lowest 5,000ft and cool temperatures in the middle and upper atmosphere (10-35 kft).
- ◆ Increased low level moisture – i.e. the high moisture content of maritime tropical air results in high wet-bulb potential temperatures which is marginally unstable and convective clouds readily form consistent with afternoon heating of near-surface layers<sup>4</sup>.
- ◆ Generally, the greater the instability, the stronger the thunderstorm updraft. Additionally, strong vertical wind shear may compensate for weak instability. Strong wind shear can lead to updraft rotation and rapid intensification and also helps direct precipitation fallout away from the thunderstorm updraft, allowing for longer duration thunderstorms.
- ◆ Surface heating and radiational cooling.
- ◆ Over land vs over water – Land heats and cools approximately 3 times faster than water. In areas near large bodies of water i.e. Florida, daytime surface heating of the land results in convective currents which sets up a sea breeze. This convergence of air from both the Gulf of Mexico to the west and Atlantic Ocean to the east results in 90-100 days with thunderstorms per year over Central Florida<sup>5</sup>. Figure 4 shows the effect of convergence and subsequent destabilization of the air column as it is forced aloft. The resulting afternoon thunderstorms persist until the solar insolation decreases enough to dissipate the thermal gradient between the land and water surfaces, causing the sea breeze to dissipate. While the land surface undergoes radiational cooling after sunset, the ocean surface retains much of the heat gained during the day and consequently, an off shore flow or land breeze often results. Off shore flow combined with synoptic or monsoonal flow sets up low level convergence at sea which frequently provides the lifting required for the formation of thunderstorms at night. Additionally, as the air above the water surface emits longwave radiation it forms a cooler layer above the warmer water. Since the air parcels nearest the ocean surface will be warmer than the layer above, an absolutely unstable situation will exist (figure 5).



• Figure 3 – GOES 9 - IR 11/1945z APR 99



• Figure 4 – Destabilization of an initially stable column due to lifting associated with horizontal convergence. (Kessler, p67)

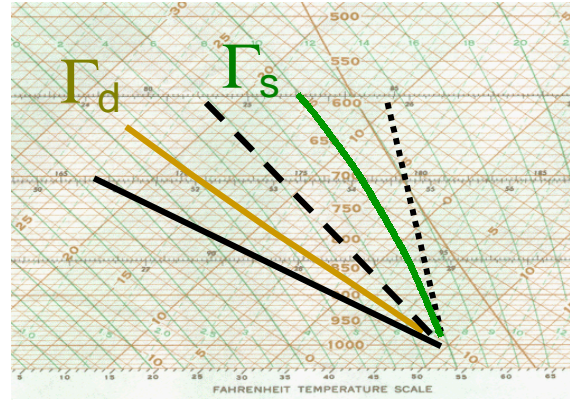
<sup>2</sup> Branick, M., [A Comprehensive Glossary of Weather Terms for Storm Spotters](#), NWS, Norman, OK

<sup>3</sup> A thunderstorm is defined as severe if it produces a tornado, 3/4 inch diameter or larger hail, and/or wind gusts 50 kts (58 mph) or higher.

<sup>4</sup> Kessler, Edwin., *Thunderstorm Morphology and Dynamics*, University of Oklahoma Press, 1983, p.79.

<sup>5</sup> Kessler, p. 15.

- ◆ At higher altitudes, radiational cooling of saturated parcels in the upper portion of clouds results in conditional instability. If this occurs in cumulus clouds (and assuming there is convection or updrafts already present), the increased instability will most likely lead to enhanced cloud development. If the upper level instability leads to the lifting of parcels beyond the level of free convection (LFC), thunderstorms are likely to occur.



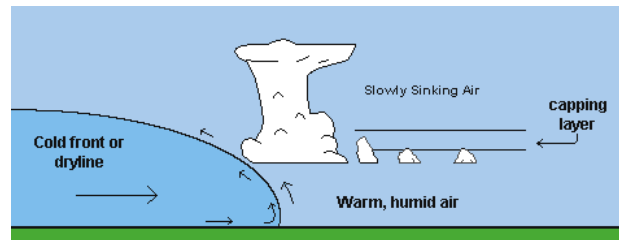
• Figure 5 – Environmental (air parcel) stability relative to dry and saturation adiabatic lapse rates.

## 2.3 Lifting mechanisms.

2.3.1 Lift is needed to overcome convective inhibition, sometimes referred to as a "cap." The cap is a layer of relatively warm air usually 10-15 kft aloft and forms under a large upper level ridge where the air gradually sinks and warms from compression. When the air sinks to roughly 10-15 kft, it is warmer than the air just below it (a stable condition), forming a "capping inversion." Lift is needed to push developing updrafts through the inversion if thunderstorm development is to occur. The weaker the capping inversion, the less amount of lift is needed to overcome it.

2.3.2 Primary sources of lift:

- ◆ drylines and cold fronts (figure 6)
- ◆ terrain features
- ◆ differential heating – which often occurs when morning low clouds erode over a particular area, with low clouds persisting nearby. A thermal gradient, or boundary, develops at sunrise and differentially heats the earth's surface.



• Figure 6 – Lifting associated with a cold frontal boundary or dryline. (fm NOAA)

- ◆ Sea breeze / Land breeze – also a form of differential heating and described above.

2.3.3 Vertical shear

- ◆ Low vs high shear.
  - The amount of vertical wind shear present is critical in determining what type of storm will form. Multicellular storms with short-lived updrafts tend to form in areas of minimal vertical shear. Low shear results in weak inflow to a storm. Consequently, the outflow reaching the ground in the form a precipitation downdraft pushes the colder air of the downdraft out and away from the storm as a gust front. This, in turn, cuts off the storm's source of warm, moist air, resulting in a storm with short-lived updrafts. Weak updrafts also allow precipitation to fall within it, which can eventually eliminate the updraft in its entirety.
  - As the vertical wind shear increases, storms with persistent updrafts will be favored. Stronger vertical wind shear results in stronger inflow to the storm. The gust front will be "held" close to the storm, and the storm will have access to the source of warm, moist air for a much longer time. Therefore, the storm's updraft will tend to last longer when the environment has strong vertical wind shear. Precipitation will tend to fall down-wind from the



updraft rather than through the updraft, which enables the updraft to continue for a relatively longer period of time<sup>6</sup>.

◆ Low level jet streams<sup>7</sup>

- Nocturnal (non-frontal) thunderstorms in the Midwest are typically associated with a low level jetstream oriented N-S or NE-SW.
- Boundary layer low-level jets are frequently observed at night along the western portions of the Great Plains with maximum winds often exceeding 25 m/s within 500m of the ground. A strong west to east horizontal pressure gradient along the lee of the Rocky Mountains with a sustained flow of air northward from the Gulf of Mexico generally occurs with this phenomena. While the presence of a low-level jet is not required for thunderstorms to occur, the downstream convergence associated with the jet core explains the increased potential for nocturnal thunderstorm development. This low-level jetstream has been described as an atmospheric analog to the Gulf Stream current and its diurnal variation is not well understood.

## 2.4 Stages of Development<sup>8</sup> (figure 7)

- 2.4.1 Cumulus Stage – Characterized by an updraft throughout most of the cell, which causes the cloud to grow. Drier air flows in through the sides and the top, and mixes with the updraft. With continued upward motion a large amount of water condenses and eventually falls as precipitation. The cumulus stage typically lasts 10-15 min.
- 2.4.2 Mature Stage – Characterized by the presence of downdrafts and updrafts, as water droplet size exceeds the capacity for the updraft to suspend the droplets, the droplets begin to fall. Precipitation then initiates the downdraft due to viscous drag (of the water on the air) and evaporative cooling of the air. This is the start of the mature stage of development. The downdraft reaches the ground as a cold core in the rain area and spreads over the surface as a gust front, and modifies the surface wind pattern. The mature stage lasts 15-30 minutes on average.
- 2.4.3 Dissipating Stage – Characterized by weak downdrafts throughout most of the cell, the downdraft interferes with the updraft at low levels in the cloud, and eventually cuts off the updraft from its source region. Since warm moist air can no longer rise to make cloud droplets, the cell enters its dissipating stage. With the decay of the updraft and consequent elimination of the source of rainfall, the downdraft weakens and finally dies out completely, leaving a residue of cloudy air. The dissipating stage lasts about 30 minutes.



• Figure 7 – Stages of thunderstorm development: cumulus stage, mature stage, dissipating stage. (fm Burroughs, p. 49)

<sup>6</sup> NOAA, *Advanced Spotters Field Guide* at <http://www.crh.noaa.gov/lmk/sguide.htm>

<sup>7</sup> Kessler, p. 114.

<sup>8</sup> Rogers, R.R and M.K. Yau, *A Short Course in Cloud Physics*, McGill University, Canada, 1989, p. 222.

- 2.4.4 Thunderstorm animations at <http://www.public.iastate.edu/~mt206/stations/nsf/index.html> are located at Iowa State University. Movies and animations at this site were taken from the Forecaster's Multimedia Library [A Convective Storm Matrix: Buoyancy (Shear Dependencies)] with the permission of COMET (Cooperative Program for Operational Meteorology, Education and Training), Boulder, Colorado.

### 3. Types of Thunderstorms

***Once the instability in a cumulus cloud is sufficient for an updraft to form, the development, and type of thunderstorm that forms, is dependent on the strength of the updraft<sup>9</sup> (figure 8).***

- 3.1 Single Cell – typically last 20-30 minutes and are quite rare since the gust front from one storm often triggers the formation of another cell some distance away<sup>10</sup>. Although most single cell storms are not regarded as severe, they can produce severe weather elements such as downbursts, hail, heavy rainfall, and occasionally weak tornadoes.

#### 3.2 Multicell

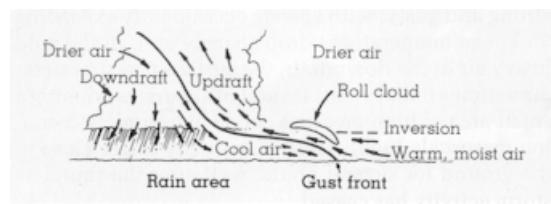
- 3.2.1 Multicell line – Multicell or “squall” line storms consist of a line of storms with a continuous, well developed gust front at the leading edge of the line (figure 9). The gust front acts to force warm, moist air ahead of the storm line into the updraft column. These storms can produce small to moderate size hail, occasional flash floods, and weak tornadoes.

- 3.2.2 Multicell cluster – this is the most common type of thunderstorm and consists as a group of cells moving as a single unit, with each cell in a different stage of the thunderstorm life cycle (figure 10). Although individual cells tend to last only 20-30 minutes, the cluster itself may last for several hours. Multicell storms can produce moderate size hail, flash floods, and weak tornadoes.

- 3.2.3 Supercell – The supercell is a highly organized thunderstorm. Although supercells are rare, they pose an exceptionally high threat to life and property. Like the single cell storm, the supercell consists of one main updraft. However, the updraft in a supercell is extremely strong, reaching estimated speeds of 150-175 miles an hour. The rotating updraft of a supercell, called a mesocyclone, helps produce extreme severe weather events, such as giant hail (more than 2 inches in diameter), strong downbursts of 80 miles an hour or more, and strong to violent tornadoes<sup>11</sup>.



• Figure 8 – Thunderstorm intensity based on type and updraft strength. (fm NOAA)

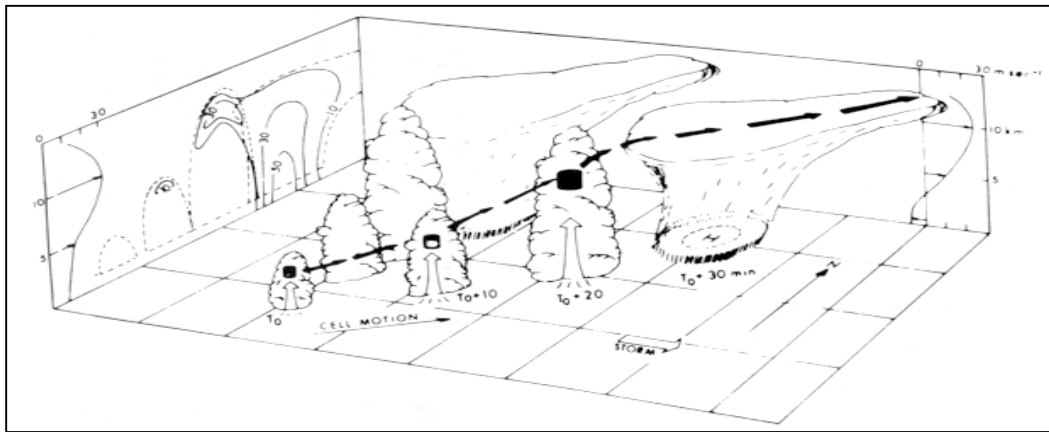


• Figure 9 – Common features seen in multicell or squall line thunderstorms. (fm Ahrens, p. 412)

<sup>9</sup> UIUC WW2020

<sup>10</sup> Advanced Spotters Field Guide, p. 9.

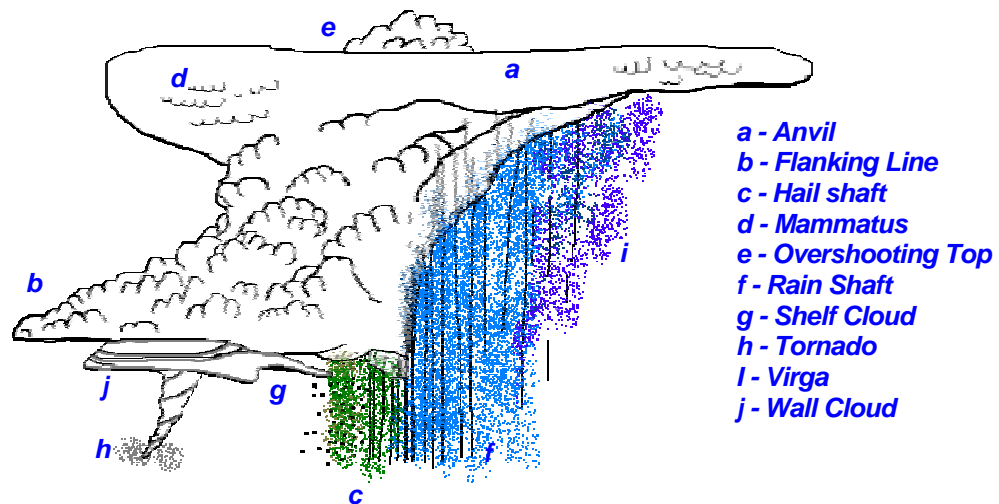
<sup>11</sup> Advanced Spotters Field Guide, p. 10.



• Figure 10 – Schematic view of a multicell storm showing four separate cells at different stages of development. The heavy dashed line is the trajectory of the youngest cell. (fm Rogers, p. 231)

## 4. Visual Components of Thunderstorms

*“... a number of visual clues (which) can be used to gain an idea of a thunderstorm's potential strength and organization, and the environment in which the storm is developing<sup>12</sup> (figure 11).”*



• Figure 11 – Thunderstorm anatomy. (fm NOAA)  
<http://www-mfl.nhc.noaa.gov/tstmmap.html>

### 4.1 Upper level features.

4.1.1 Anvil Characteristics – The anvil is a flat cloud formation at the top of the storm. Air and internal cloud material rising in the updraft reaches the equilibrium level where it begins to slow down. As the upward momentum of the updraft diminishes, upper level winds “shear off” the top of the thunderstorm cloud and force it downwind where it spreads out to form the anvil shape.

<sup>12</sup> Advanced Spotters Field Guide, p. 10.

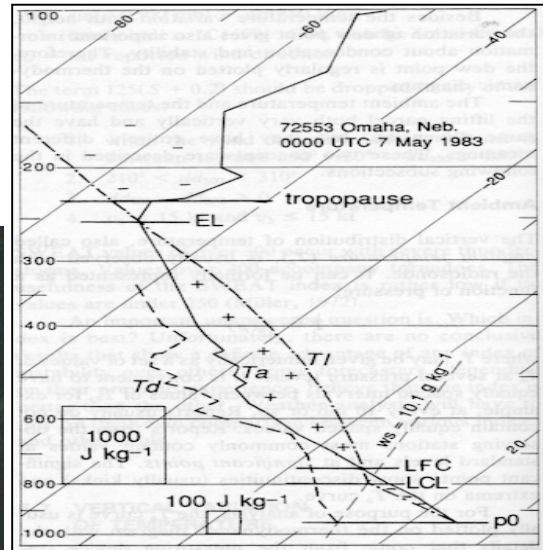
### ◆ **Indications**

- A thick, smooth-edged anvil indicates a strong updraft and potential severe weather.
- A thin, fuzzy anvil indicates a less intense updraft and the storm is less likely to produce severe weather.
- A large elongated anvil streaming in one particular direction, reflects strong upper-level winds and precipitation will fall downstream well ahead of the updraft channel.

4.1.2 Overshooting tops<sup>13</sup> (figure 12) – When air parcels within a storm are lifted beyond the level of free convection (LFC), they become positively buoyant and continue to rise. This gain in momentum allows a storm updraft to overshoot the equilibrium level (EL) and form a “bubble-like” cloud top in the stratosphere (figure 13). Above the equilibrium level, the air parcels are now colder than the surrounding environment, become negatively buoyant and sink back toward the surface, before spreading out into the anvil.



• Figure 12 – The small “bubble-like” cloud formation at the top of a thunderstorm is an overshooting top caused by strong updrafts. (fm UIUC, WW2010)

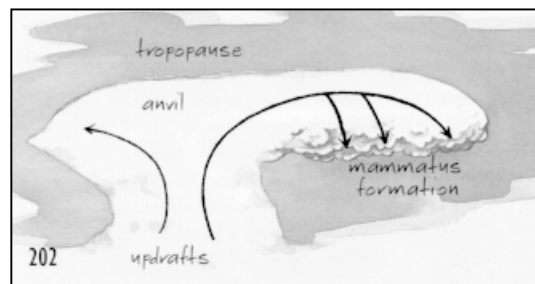


• Figure 13 – Skew-T analysis showing areas of positive (+) and negative (-) buoyancy areas for an air parcel continuing to ascend beyond its initial condensation level. (fm Djuric, p. 82)

### ◆ **Indications**

- Although overshooting tops are a transient feature and usually short lived, the presence of an overshooting top is highly indicative of very intense updrafts and potentially severe weather.
- Storm over-flights have shown that intense tornadoes occur after the top has collapsed though this feature is not directly associated with tornado formation itself<sup>14</sup>.

4.1.3 Mammatus<sup>15, 16</sup> – Mammatus clouds are extensions (from the bases) of pre-existing clouds and most commonly seen in cumulonimbus. Updrafts carry precipitation (ice crystals, water droplets, and cloud droplets) up to the cloud top where upward momentum is depleted at the equilibrium level. Strong upper level winds spread the updraft materials horizontally to become part of the anvil cloud (figure 14). Updraft precipitation is denser than its surrounding cloud material due to the higher



• Figure 14 – Precipitation and cloud material blown into the anvil is more dense than the surrounding cloud and it sinks, forming mammatus protruberences underneath the anvil. (fm Burroughs, p. 202)

<sup>13</sup> Kessler, p. 203.

<sup>14</sup> Kessler, p. 204.

<sup>15</sup> Whisenant

<sup>16</sup> www-mfl.nhc.noaa.gov



concentration of ice crystals and water droplets. It is also heavier than the surrounding air, and therefore it sinks back towards the earth. This evolution is enhanced by the fact that the lower surface of the anvil is adjacent to a clear air region, which is unsaturated and has a lower mixing ratio. Cloud particles descending from the anvil warm at the moist adiabatic rate but the adjacent clear air (which is unsaturated), ascends (and cools) at the dry adiabatic rate and remains warmer than the cloudy air at the same level. Since the ambient air under the anvil is positively buoyant, mammatus formations bulge downward into the less dense air. As they meet the rising air below them, pockets of clear air penetrate upwards into the cloud. The boundary between the clear and cloudy air becomes gravitationally unstable and a characteristic mammatus pattern develops (figure 15).



• Figure 15 – Mammatus cloud formations beneath a cumulonimbus anvil. (Photo by Bob Firth)

♦ **Indications**

- Mammatus are pouch-like cloud structures and a rare example of clouds in sinking air.
- Formation of mammatus below the leading portion of the anvil is a sign of a particularly vigorous storm as well as moderate to severe turbulence however, mammatus are usually seen after the worst of a thunderstorm has passed<sup>17</sup>.

## 4.2 Mid-level features.

4.2.1 Updrafts – As previously described above, moisture, instability and lift is necessary for buoyancy and upward vertical motion to occur within an air column. The degree of instability is a major factor in determining the strength of thunderstorm updrafts and downdrafts<sup>18</sup> (see figures 8 and 9).

♦ **Indications**

- Strong updraft – clouds in the main updraft area are sharply outlined with a distinct cauliflower appearance and are nearly vertical
- Weak updraft – Cloud edges are more diffuse and the updraft tower tilts in the direction of the upper level flow.
- Signs of rotation within the mid-level of the storm cell indicate the probable formation of a mesocyclone or supercell.

4.2.2 Downdrafts – “A downburst is a strong downdraft which induces an outburst of damaging winds on or near the ground<sup>19</sup>.” Downbursts are further divided into subcategories based on their horizontal scale of damaging winds. The strongest downdrafts are usually encountered within the main precipitation fallout zone<sup>20</sup>.

<sup>17</sup> UIUC WW2020

<sup>18</sup> UIUC WW2020

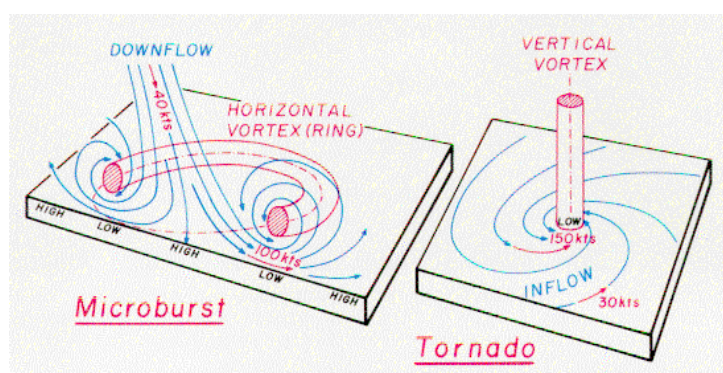
<sup>19</sup> Fujita, p. 8

<sup>20</sup> Kessler, p. 141.

<b>MACROBURST</b> – A large downburst with its outburst winds extending in excess of 4km (2.5 mi) <ul style="list-style-type: none"> <li>▪ Widespread tornado-like damage</li> <li>▪ Duration: 5-30 minutes</li> <li>▪ Max winds <math>\approx</math> 60 m/s (134 mph)</li> </ul>	<b>MICROBURST</b> – A small downburst with its outburst winds extending to less than 4 km (2.5 mi) <ul style="list-style-type: none"> <li>▪ tornado-like damage</li> <li>▪ duration less than 10 minutes</li> <li>▪ max winds <math>\approx</math> 75 m/s (168 mph)</li> </ul>
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• Table 1 – Definitions introduced by Fujita

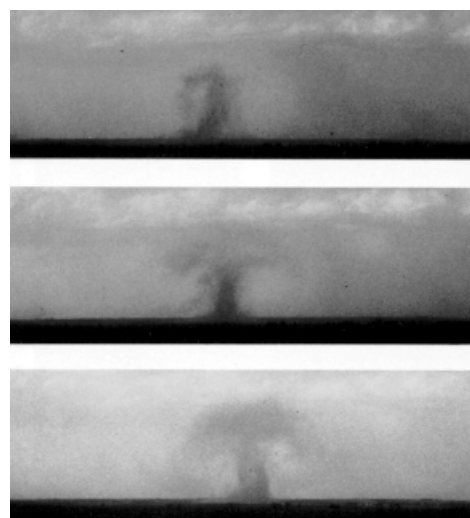
- ♦ Macrobursts are characterized by a cold dome of air built up by successive downdrafts beneath the rain shaft of a parent cloud. The pressure gradient force between the cold dome and surrounding warmer air results in a horizontal outflow creating a gust front.
- ♦ Microbursts are classified as either wet or dry. Wet events normally occur within the rain shaft of the parent cloud. Dry microbursts occur under clouds with higher bases and beneath areas of virga<sup>21</sup>. While the downdrafts of microbursts are often more intense than for macrobursts, the horizontal spreading of microburst winds is much slower due to the formation of horizontal vortices shown in figure 16 and seen in figure 17. “A microburst may be regarded as an upside-down or inverted tornado.”<sup>22</sup>



• Figure 16 – Horizontal vortex “curls” are formed as a microburst diverges at the surface producing a circulation similar to an inverted tornado.(fm Fujita, p. 14)

#### ♦ **Indications**

- Presence of a gust front – A gust front is a boundary that separates the cold downdraft of a thunderstorm from warm, humid surface air. Its passage at the surface resembles a cold front.
- Patches of virga mark microburst formation areas aloft. As the precipitation evaporates, it cools the air and starts a downdraft. If the downdraft accelerates, it may reach the ground as a microburst. Localized arcs of blowing dust (raised from the ground) usually mark the impact point of dry microbursts.



• Figure 17 – Horizontal vortices are seen in this photo of a microburst-induced dust cloud beneath a decaying anvil cloud on 18 July 1982. (Photo by Joe Golden, fm Fujita, p. 15)

4.2.3 Hail shaft – Hail is formed when either ice pellets (graupel) or large frozen rain drops grow by accreting supercooled cloud droplets<sup>23</sup> while ascending and descending within a thunderstorm updraft/downdraft (figure 18). Large quantities of supercooled water droplets exist in clouds at temperatures well below freezing, and maximum ice crystal growth occurs at  $\approx -15^\circ$ . Hail begins to fall when the mass of a hailstone exceeds the capacity of the updraft to suspend it. As it falls, the hail loses mass via melting and evaporation.

<sup>21</sup> Virga is defined as precipitation that evaporates prior to reaching the ground.

<sup>22</sup> Fujita, p. 119.

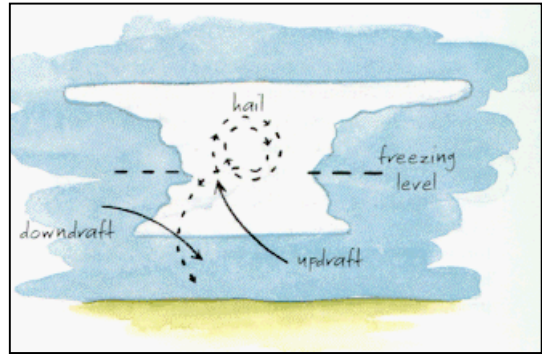
<sup>23</sup> Rogers, p.233.

### ◆ **Indications**

- “The largest hail is usually produced by the most strongly developed thunderstorm.”<sup>24</sup>
- Hail is usually accompanied by other severe weather associated with the parent storm including damaging winds, heavy precipitation, and tornadoes.

### • HAIL SIZE ESTIMATES IN INCHES

▪ pea .....	0.25
▪ penny .....	0.75
▪ quarter .....	1.00
▪ half dollar .....	1.25
▪ golf ball.....	1.75
▪ tennis ball.....	2.50
▪ baseball .....	2.75
▪ grapefruit.....	4.00



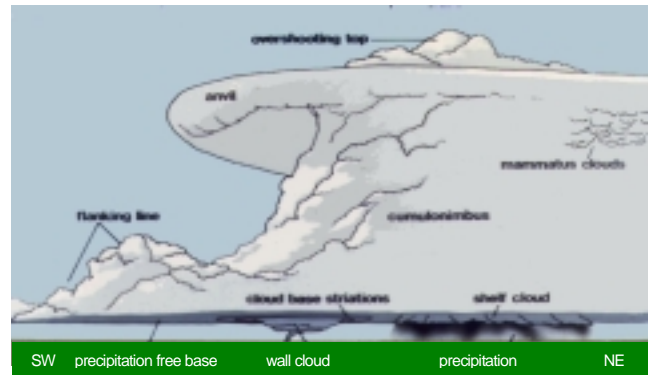
• Figure 18 – Hail growth/size is controlled by the accretion of supercooled water droplets within the updrafts and downdrafts of a thunderstorm. (fm Burroughs, p. 226)

## 4.3 Low level features (figure 19).

- 4.3.1 Wall clouds – The wall cloud is defined as an isolated cloud lowering attached to the rain-free base of a thunderstorm and usually forms to the rear (generally south or southwest) of the visible precipitation area.

### ◆ **Indications**<sup>25</sup>

- Wall clouds are usually about two miles in diameter and mark the area of strongest updraft in the storm.
- Formation of a wall cloud signifies that the storm's updraft is pulling cool, humid air from the downdraft and/or rain shaft.
- A persistent wall cloud that shows signs of rotation is indicative of possible tornado formation.



• Figure 19 – Low level thunderstorm features. (By C. Doswell and B. Dirham, fm Kessler, p. 203)

- 4.3.2 Shelf/roll clouds – Shelf clouds are long, wedge-shaped clouds associated with the gust front compared to roll clouds (see figure 9), which are tube-shaped and found near the leading edge of a gust front. Shelf clouds typically form near the leading edge of a storm or squall line.

### ◆ **Indications**

- Shelf clouds often form at the downdraft/updraft boundary.
- Roll clouds reflect the location and general movement of a storm's downdraft / gust front.

- 4.3.3 Flank line – Developed thunderstorms typically have a series of smaller cloud towers to the south or southwest of the main storm tower. These smaller towers are called a flanking line and usually have a stair-step appearance as they build toward the main storm tower.

<sup>24</sup> Kessler, p. 252.

<sup>25</sup> Spotters Guide, p.12

4.3.4 Tornadoes – Most tornadoes are associated with supercell thunderstorms (mesocyclones) which involve high velocity updrafts, downdrafts, and strong vertical shear, which induce horizontal rotation within an individual storm cell. The Fujita Scale<sup>26</sup> (table 2) describes the relative intensities of tornadoes based on wind speeds and damage.

♦ **Indications**

- Visual observations have shown that major tornadoes generally form on the right-rear flank of the storm from a convective tower close to the intersection of the flanking line and the storm's main tower<sup>27</sup>.
- Dust swirls below a wall cloud indicating a tornado has already formed.
- As a tornado develops, warm, moist air is drawn upward into the tornado's circulation and condenses rapidly. This gives the visual appearance that the tornado has not yet formed when in fact, it has most likely already reached the surface.

<b>CATEGORY F0:</b> Gale tornado (40-72 mph); light damage. Some damage to chimneys; break branches off trees; push over shallow-rooted trees; damage to sign boards.
<b>CATEGORY F1:</b> Moderate tornado (73-112 mph); moderate damage. The lower limit is the beginning of hurricane wind speed; peel surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads.
<b>CATEGORY F2:</b> Significant tornado (113-157 mph); considerable damage. roofs torn off frame houses; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted; light-object missiles generated.
<b>CATEGORY F3:</b> Severe tornado (158-206 mph); severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off ground and thrown.
<b>CATEGORY F4:</b> Devastating tornado (207-260 mph); devastating damage. Well-constructed houses leveled; structure with weak foundation blown off some distance; cars thrown and large missiles generated.
<b>CATEGORY F5:</b> Incredible tornado (261-318 mph); incredible damage. Strong frame houses lifted off foundations and carried considerable distance to disintegrate; automobile sized missiles fly through the air in excess of 100 yards; trees debarked; incredible phenomena will occur.

- Table 2 - Fujita Scale fm <http://www.outlook.noaa.gov/tornadoes/fujita.htm>

## 5. Summary

***The various cloud features associated with the formation, growth, and decay of single or multi-cell thunderstorms provide many visual clues as to the atmospheric processes necessary for cloud development, as well as the physical nature of weather production. Hence, each feature cited above is deserving of further study in order to better comprehend the physics of the atmosphere and dynamic processes related to the occurrence of those features.***

***Furthermore, knowledge of how these cloud features form or behave reveals a certain understanding of the physical changes occurring in the atmosphere resulting the ability to recognize potentially dangerous situations that require prompt action to ensure personnel and material safety.***

<sup>26</sup> Developed in 1971 by Dr. T. Theodore Fujita of the University of Chicago and Allen Pearson, then Director of the National Severe Storms Forecast Center.

<sup>27</sup> Kessler, p. 204.



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