1. Conceptual Models for Origins and Evolutions of Convective Storms

Instructor Notes: The title for the instructional component is “Conceptual Models for Origins and Evolutions of Convective Storms. This is lesson 3 of the first instructional component (IC 1) in the AWOC Severe Track. Lesson 3 is on the conceptual models and important concepts regarding hail storms.

Student Notes:

Conceptual Models for Origins and Evolutions of Convective Storms

Advanced Warning Operations Course
IC Severe 1
Lesson 3: Hail Storms
Warning Decision Training Branch

2. Lesson 3 Learning Objectives

Instructor Notes: The first 4 learning objectives for this lesson on hail and hailstorms.

Student Notes:

Lesson 3 Learning Objectives

1. Determine the role of shear and midlevel rotation on updraft strength.
2. Determine the roles of buoyancy and steep lapse rates in hail growth zone.
3. Identify the effects of melting.
4. Identify favorable hail growth trajectories.

3. Lesson 3 Learning Objectives

Instructor Notes: Learning Objectives 5-7.

Student Notes:

Lesson 3 Learning Objectives

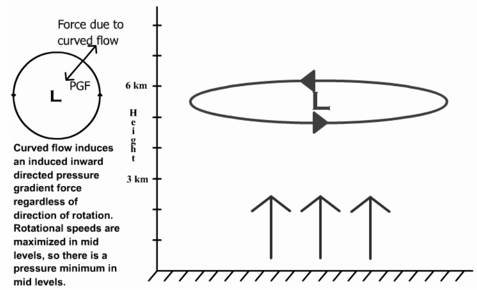
5. Identify favorable hail embryo source regions in convective storms.
6. Identify favorable soundings for surface based updraft hail and elevated updraft hail.
7. Identify characteristics of the hybrid Multicell-Supercell Hailstorm.

4. 1. Role of Shear and midlevel rotation on updraft strength

Instructor Notes: As seen in IC Severe 1 lesson 1 on supercells, wind shear produces horizontal vorticity that can tilted into the vertical within strong updrafts. Vertical vorticity is associated with mid-level rotation, and many times rotation is strongest in the mid-levels of a storm. Regardless of the direction of spin of the rotation, whether cyclonic or anti-cyclonic, there is going to be a centrifugal force associated with the rotation. The stronger the rotation, the stronger the centrifugal force. To keep the forces balanced, an opposing pressure gradient force must be present. Again, both cyclonic and anti-cyclonic rotations will have an inward directed pressure gradient force, in turn leading to a dynamically induced low pressure in the center of the circulation. Low pressure in mid-levels lead to an upward directed pressure gradient force below the circulation, and thus stronger vertical motion. It has been shown mathematically that the dynamically induced (via mid-level rotation) contribution towards total updraft velocity can be as large as the contribution due to buoyancy. With regards to hail, stronger updrafts have the ability to support larger hail stones, thus the presence of mid-level rotation can signal stronger updrafts within a storm, and thus a higher threat of severe hail with all other environmental factors being equal. Key Point: A storm exhibiting mid-level rotation is more likely to contain severe hail than one without rotation in identical environments and with all else being equal. This is because mid-level rotation can enhance updraft strength due to a dynamically induced vertical pressure gradient force.

Student Notes:

1. Role of Shear and midlevel rotation on updraft strength



5. 2. Buoyancy and steep lapse rates in hail growth zones

Instructor Notes: Steeper lapse rates aloft increases the overall instability of the atmosphere. Greater instability allows for more buoyant parcels of air if enough lift is present to overcome any cap that may be in place. Intuitively, more buoyant air (and thus lapse rates) within the –10 to –30 °C layer, corresponding to the maximum hail growth zone, would mean stronger updrafts in the growth zone. All other factors being equal, larger stones would have the ability be suspended longer in the prime growth zones, thus growing even larger. To date, no studies have been done to verify the usefulness of this concept…currently it is just a conceptual picture of an ingredient for simplified hail growth trajectories.   Key Point: Steep lapse rates in the hail growth zone (–10 and –30 °C) leading to the potential for higher instability and thus strong updrafts are favorable to support large hail.

Student Notes:

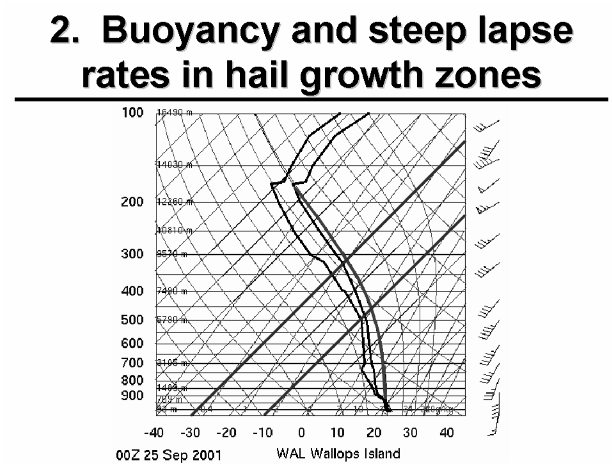
2. Buoyancy and steep lapse rates in hail growth zones

- Most studies have found that the most significant hail growth occurs in the -10 to -30°C layer
- Higher CAPE in the -10 to -30°C layer could mean larger hail
- Important to have steep lapse rates in the hail growth zone

6. 2. Buoyancy and steep lapse rates in hail growth zones

Instructor Notes: This is a sounding from Wallop's Island, VA. Thin CAPE profile from a tropical environment. Lapse rates in the -10 to -30 layer are weak. Surface based CAPE is over 1000 J/kg but stretched through a large depth. Consequently, even with great shear and CAPE, there was absolutely no hail to report on this day with weak lapse rates and CAPE in the hail growth zone.

Student Notes:

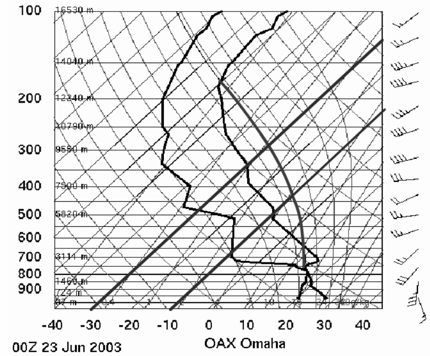


7. 2. Buoyancy and steep lapse rates in hail growth zones

Instructor Notes: This is a sounding from Omaha, NE. This CAPE profile is thick. There quite a bit of surface based CAPE, and much of it is in the -10 to -30C layer. The lapse rates, thus CAPE, are significant in the hail growth zone. Supercells containing baseball to american football sized hail pounded southern Nebraska. One storm produces the world record for hail diameter, over 7 inches.

Student Notes:

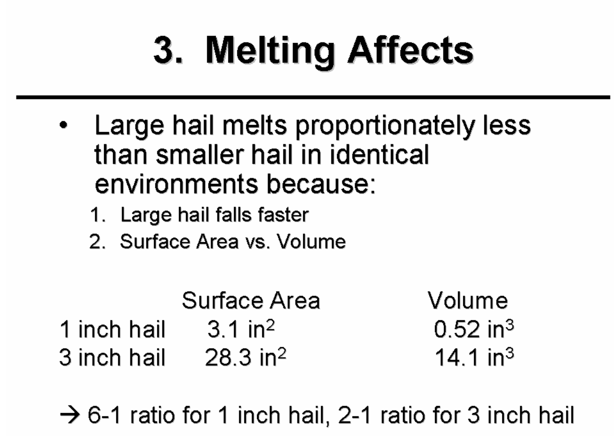
2. Buoyancy and steep lapse rates in hail growth zones



8. 3. Melting Effects

Instructor Notes: Melting affects hail most significantly affects smaller hail sizes as they fall through the 0°C level. All other factors being equal, small hail will melt proportionately more than large hail for 2 reasons: 1. larger hail has a higher terminal velocity and spends much less time in the melting layer before reaching the surface and 2. surface area is related to the radius of the hailstone, squared, while volume of rainwater loss is related to the cube of the radius. Thus, smaller hailstones will have a proportionately larger surface area exposed to melting conditions than larger stones, and thus proportionately melt faster than larger stones as well. Certain atmospheric conditions favor more rapid melting as well, with the amount of melting always dependent on the initial size of the hailstone. Conditions within the melting layer that favor melting are relative humidity (higher RH promotes greater melting and/or the presence of liquid drops falling with the hail), temperature profile (higher freezing level and warmer temps favor greater melting). Low relative humidity allows for a delay in the onset of melting by providing favorable conditions for the hailstone surface to remain dry. In melting layers with 50% or less relative humidity, melting has been found to proceed when the stone reaches air with +5 °C, obviously diminishing the amount of time the hail falls through the melting layer. Additionally, low RH hinders melting even if the stone is coated in water, since the layer of water is more likely to evaporate off the surface, cooling both the hail stone and the surrounding environment, further slowing the melting process. Having a warmer temperature profile intuitively results in more rapid melting, as heat transfer from the atmosphere to the hailstone is larger in a warmer environment. Another factor not mentioned above deals with hailstone ice density. Low density hail (common on the high plains), typically with graupel cores, melts much more effectively than high density hail. It is also strongly size dependent, but it is very important to note that low density hail is easily the most important factor when dealing with melting. The problem is that we currently have absolutely no way of knowing if low density hail exists in a storm, nor what proportion of the total hailfall consists of low-density stones. Finally, microphysical differences between the makeup of all the stones in a hailfall can also influence melting, although these differences have not been studied nor can they be measured at this time. Some of these differences are shape of the hailstone, hailstone size spectrum within a particular hailfall, and direct influences of surface hailstone heat transfer, among others. Key Point: Smaller hail melts proportionately more than larger hail because of differences in surface area and terminal falls speeds. Thus, hail that is large in-cloud will remain large at the surface. Relative humidity, temperature profile, and hailstone density all play important roles in the amount of melting a stone undergoes falling through the melting layer.

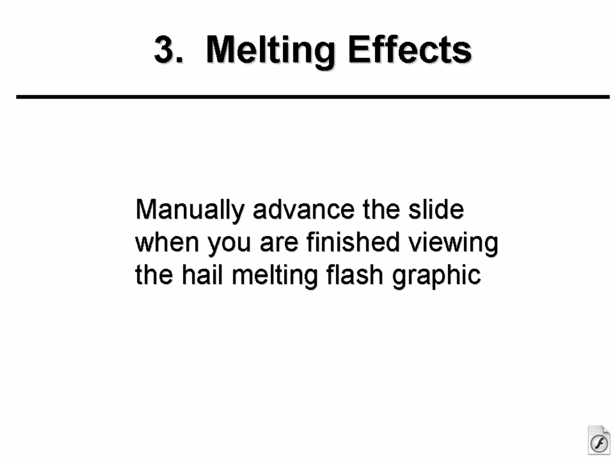
Student Notes:



9. 3. Melting Effects

Instructor Notes:

Student Notes:



10. 4. Hail Trajectories

Instructor Notes: Hail trajectories have been found to be extremely diverse within convective storms. The diversity of the trajectories becomes even more complicated when the size of the storm and the strength of the updraft/wind shear increases. A single trip up an updraft in a pulse storm can grow a hailstone up to about golfball size (Knight and Knight 2001), and the updraft necessarily has to have an ideal vertical velocity profile such that the hail stone spends as much time as possible in the updraft. An updraft too weak won't allow a sizable stone to grow, and an updraft too strong will eject the hail embryo too quickly before significant growth can occur. Hail larger than about golfball in size can be produced with some form of recycling trajectories within a storm or complex of storms. Recycling can occur with multicelled convection where an older updraft produces hail that falls into or near the base of a newer updraft. Supercell convection allows for numerous recycling trajectories, but the bulk of the trajectory studies to date have found relatively simple paths through or around the main updraft, and nearly all of the growth occurs within a fairly narrow altitude and temperature range (-10 to -30°C). The largest hail tends to originate from embryos that find themselves on the southwest side of the large updraft. Upon entering the updraft these particles are then able to experience the longest growth time by traversing the full length of the updraft's long dimension (Foote 1984). The importance of any hailstone trajectory lies in the amount of time the hailstone resides in an updraft, and this time period is referred to as "residence time". As residence time increases, so does the possibility for growth of large hail within a convective updraft. Residence time is increased when: The hailstone's terminal velocity is nearly balanced by an updraft, the updraft width is substantial, and storm relative flow across and through the updraft isn't too strong.   Key Point: A wide variety of trajectories exist that can produce large hail. The important concept is residence time within the updraft, the longer the residence time, the larger the hail. Wide updrafts and larger embryos lead to the largest hail sizes.

Student Notes:

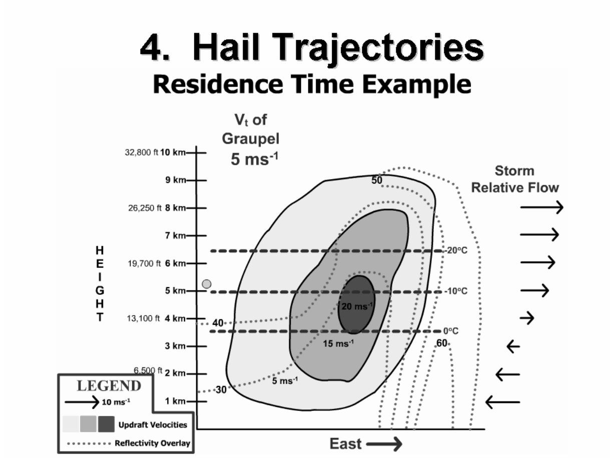
4. Hail Trajectories

- Very diverse trajectories in hailstorms
- The longer the residence time, the greater the resulting hail size from a given storm

11. 4. Hail Trajectories

Instructor Notes:

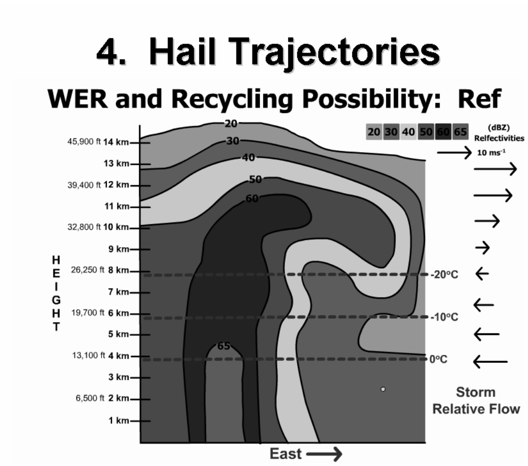
Student Notes:



12. 4. Hail Trajectories

Instructor Notes:

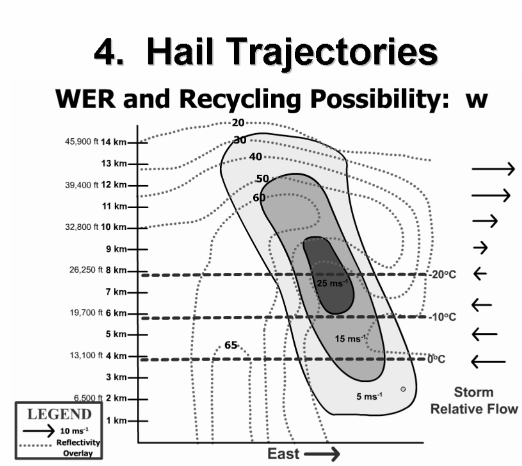
Student Notes:



13. 4. Hail Trajectories

Instructor Notes:

Student Notes:



14. 5. Favorable Embryo Source Regions

Instructor Notes: The main issue about hail embryo origins is how embryos arrive within the updraft (Knight and Knight 2001). There is no real distinction between an embryo and small hailstone, thus some of the principles involved in transport are covered in other objectives. A remarkable finding regarding hailstone embryos is that many analyses of hailstone collections from significant hailstorms from all over the world reveal mixtures of types of embryos. The importance of this is that either embryo delivery into strong updrafts straddles the freezing level or embryo sources are typically diverse: or both could be true. If embryos sources straddled the freezing level then frozen drops and graupel particles would equally be likely as embryos. Though embryo sources are very diverse, there are 3 important sources of hail embryos within convective storms. The first is within developing cumulus towers on the flanks of parent storms or within newer updrafts within multi-celled convection. The embryos grow within the developing updraft early in the lifecycle when updraft velocities are ideally not so strong that all liquid water is advected too quickly vertically before significant growth can occur. Of course this mechanism works in single celled "pulse storms", where embryos grow in a developing updraft, then as they are advected vertically, they grow such that their Vt increases at about the same rate that the updraft velocities increase, thereby significantly increasing residence time in the updraft growth zone. These storms, given the right environmental conditions and ideal updraft velocities, can produce over 1.00 inch diameter hail from the initial embryo. The second favorable source of hail embryos is near stagnation points in the mid-levels of a convective storm with an intense updraft. The updraft is necessarily intense so that mid-level storm relative flow does not significantly penetrate the updraft nor significantly tilt the updraft. A stagnation point arises when the strong updraft is an obstacle to the mid-level flow, resulting in a dynamically induced high pressure on the upwind side of the updraft and a region of little to no horizontal flow where the mid-level flow splits and is diverted around the updraft. Realize that the updraft is porous, i.e. it isn't a "rigid" obstacle to the low, it diverts a certain percentage of the mid-level flow, but some of the flow enters and mixes with the updraft. This region is important for embryo growth because it is on the edges of the main updraft in which the embryos can stay with the storm long enough to grow. A third favorable source of hail embryos is from drops shed from growing or melting hail above or below the 0°C level. This source assumes hail is already present in the storm. Hailstones that are greater than 9 mm in diameter have been found to shed liquid drops during either melting or wet growth processes. These shed drops then can become hail embryos if they are lofted above freezing in an updraft. The majority of hailstones within a severe thunderstorm that contain frozen drop embryos are likely to be formed through this process. Key Point: Understand that where embryos come from is relatively unimportant, but what is important is where (and if) they are input into the updraft. Know three important areas for embryo growth: stagnation points in the mid-levels of an updraft, within growing cumulus towers on the flanks of the parent storm or within multi-celled convection, and from drop shedding. Additionally, all 3 sources may be working within a given convective storm at the same time.

Student Notes:

5. Favorable Embryo Source Regions

- 2 primary sources, 1 secondary source

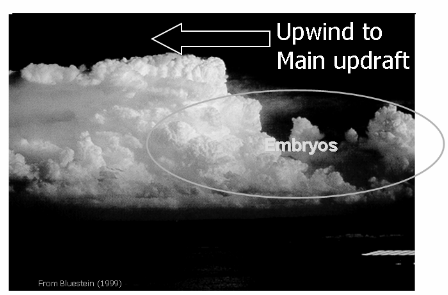
1. Nearby growing CBs, flanking lines
2. Stagnation points
3. Shed drops from growing/melting hail
   → secondary source since hail already in storm

15. 5. Favorable Embryo Source Regions

Instructor Notes: Source region #1: growing cumulus towers or flanking lines

Student Notes:

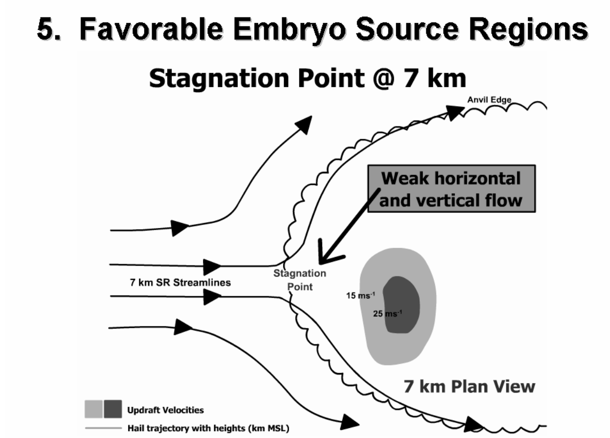
5. Favorable Embryo Source Regions



16. 5. Favorable Embryo Source Regions

Instructor Notes: Source region #2: stagnation points: very weak horizontal flow (and vertical flow), thus allowing depositional/collection growth for embryos, typically graupel

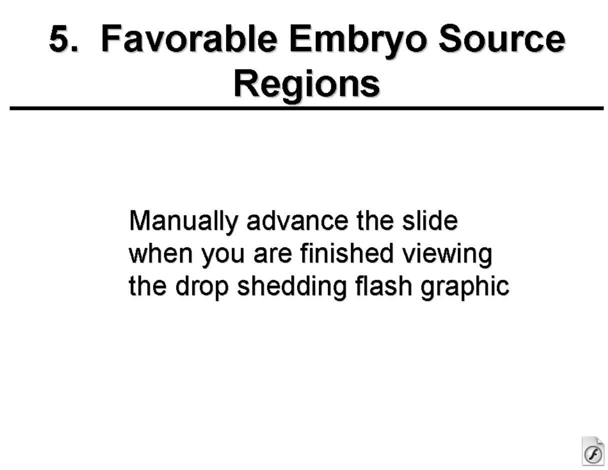
Student Notes:



17. 5. Favorable Embryo Source Regions

Instructor Notes: Source region #3: shed drops, which is a secondary source. This animation will demonstrate a hail in wet growth regime and how drops are shed from the ice core.

Student Notes:



18. 6. Hail Soundings

Instructor Notes: The link on this slide takes you to an optional website containing a wide variety of real soundings from hail cases. You can test your knowledge of favorable hail parameters based on one sounding to diagnose the threat of severe hail. In some cases, because of the unrepresentativeness of the sounding, this is difficult. The website is a good exercise to show just how diverse environments are that may produce severe hail.   Key Point: Look for strong CAPE of any kind (ML, SB, Elevated, MU, etc.), good deep layer wind shear, lapse rates aloft. Much like for supercell and tornado environmental assessment, but without any low level shear and LCL/LFC considerations.

Student Notes:

6. Hail Soundings

- 20 soundings are available for optional review, from all across the country (AK, HI included) with all types of shear/CAPE profiles:

Hail Soundings

19. The "Hail Monster"

Instructor Notes: Hybrid multicell/supercell hailstorms produce not only unusually large hail in high quantities, but the hailswaths containing the large hail cover an extraordinarily large region, leading to destruction over a large area. These storms are characterized with intense gust fronts on their rear flank, and very deep zones of convergence along the leading edge of the rear and forward flank gustfronts. These storms tend to move fast, to the right of the mean wind, and persist for several hours. They are typically non-tornadic or very weakly tornadic, both in strength and amount of time. The huge region of deep, moist convergence along the rear flank allows for a very wide region of updraft, not necessarily one single updraft, but likely many updrafts which collectively form a wide region of rising motion. Very broad updrafts have already been discussed in this lesson as allowing a high amount of residence time for hail to grow. The deep and broad convergence zone accounts for the sheer size of the hail cores. Hybrid hailstorms typically have very high Z all along south, west, and north sides of the mesocyclone.

Student Notes:

7. The “Hail Monster”

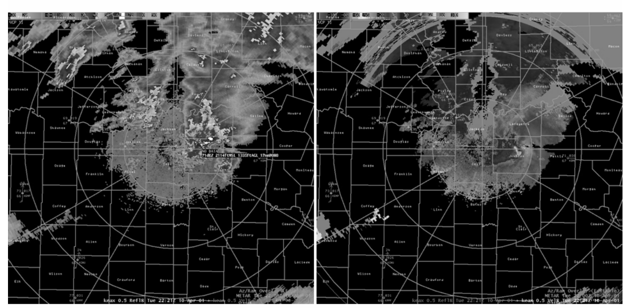
- Nelson (1987) studied hybrid multicell-supercell storms that dropped not only enormous hail, but the enormous hail covered a large area and persisted for several hours
- Characterized by a Deep Convergence Zone (Lemon & Parker 1996), huge reflectivity cores along the southern flank and forward flank, few if any tornadoes, tremendous straight line winds

20. The “Hail Monster”

Instructor Notes: April 10, 2001 Supercell that tracked all the way across Missouri, turned out to be the costliest hailstorm in US history. Notice the tremendous size of the reflectivity cores on NW of the inflow notch and to the south, typical of these hybrid multi-supercellular hailstorms. True to form, this storm produced only a few very weak, brief tornadoes, but golfball to baseball size hail across entire counties occurred, with very high amounts of this large hail.

Student Notes:

7. The “Hail Monster”

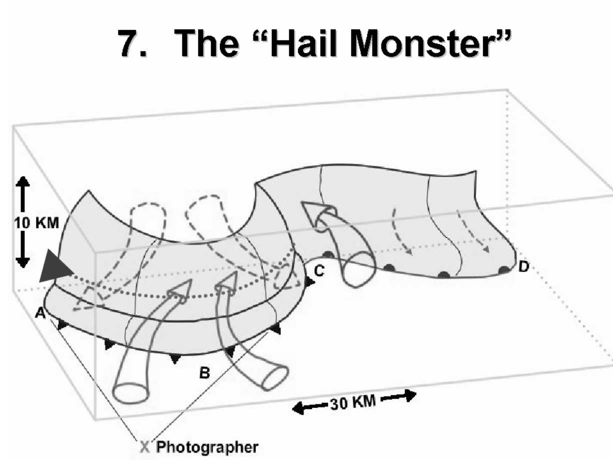


21. The “Hail Monster”

Instructor Notes: The X marks the approximate location of the photographer in the following image. This image is adapted and updated from an original image first published in Lemon and Parker (1996). The supercell updraft is located from B to C with a BWER, and the storm summit is in the vicinity of B. Arrows indicate storm relative flow; dashed arrows indicate, in perspective, flow behind the DCZ surface. Storm motion is directly at you. The most intense and deep portions of the DCZ are found nearly coincident with the strong reflectivity gradients bordering the WER and BWER. In terms of hail growth, the

DCZ has been found to shield the updraft from the destructive entrainment of environmental air. In the Lahoma Storm in August 1991, the DCZ passage signaled the greatest wind threat and within 2-5 minutes, the greatest hail threat.

Student Notes:



22. The "Hail Monster"

Instructor Notes: This is a picture of an approaching DCZ, from the Cashion, Oklahoma storm June 18, 1992.

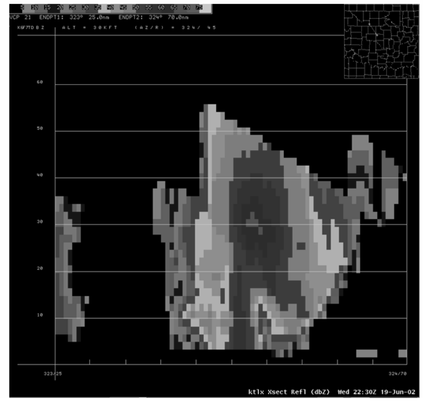
Student Notes:

23. The "Hail Monster"

Instructor Notes:

Student Notes:

7. The "Hail Monster"

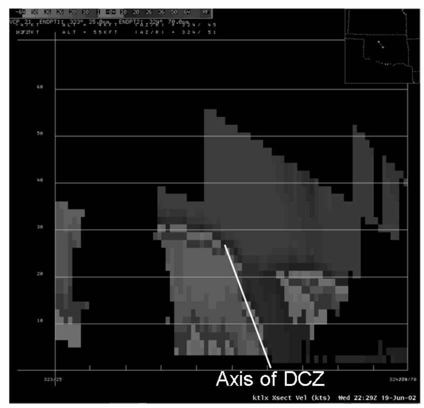


24. The "Hail Monster"

Instructor Notes:

Student Notes:

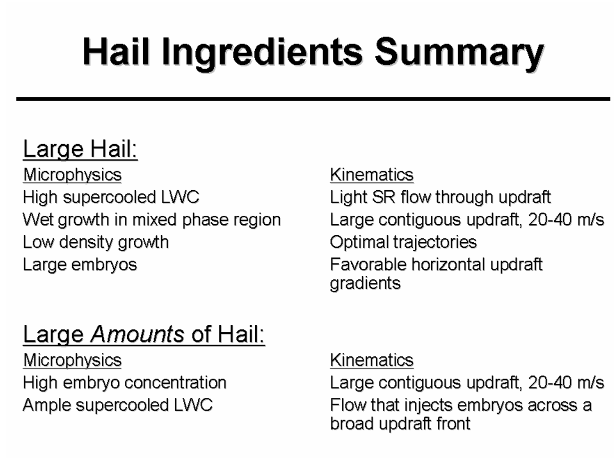
7. The "Hail Monster"



25. Hail Ingredients Summary

Instructor Notes: Summary of ingredients for large hail and large amounts of hail

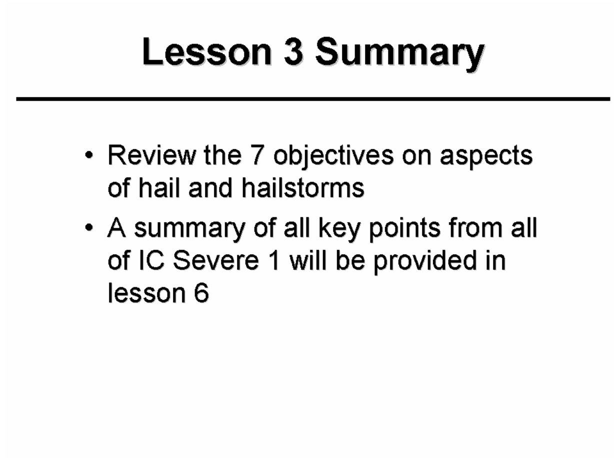
Student Notes:



26. Lesson 3 Summary

Instructor Notes:

Student Notes:



27. Lesson 3 References

Instructor Notes: Link to PDF document with all the references for IC Severe 1, Lesson 3 on hailstorms: http://www.wdtb.noaa.gov/courses/awoc/ICSvr1/lesson3refs.pdf

Student Notes:

Lesson 3 References

- Our website has a full list available:

CLICK HERE FOR HAIL REFERENCES