Advanced Spotter Training 2009

Lesson 7: Tornadoes

From Last Time

- We discussed the nature and origin of wind.
- We explored how wind causes damage.
- We discussed the nature of gust fronts and downbursts.
- We explored the evolution of derechos.

This Time

- This time we are going to discuss the most severe weather event that can happen, the tornado.
- We will first discuss what a tornado is.
- Then we will discuss ideas about how tornadoes form.
- Finally, we will go over where you are likely to find tornadoes.

Homework Review

Go over the homework problems from last time:

- Describe how a downdraft produces wind at the surface.
- Describe the effect of evaporative cooling.
- Explain how structures fail under the action of wind.
- Speculate on the risks of flying debris posed to spotters in the field. How would you avoid such risks?

Homework Review *(continued)*

- Speculate on the severe potential from a gust front.
- Speculate on the severe potential from dry microbursts.
- Explain how a derecho happens.

What is a tornado?

- As stated in Lesson 2 a tornado is a violently rotating column of air pendant from a thunderstorm and in contact with the surface.
- The first aspect of this definition is the part about violently rotating air.
- What does it mean for air to rotate? How does it rotate?
- First off, every updraft rotates.

What is a tornado? *(continued)*

- Take your right hand and make a fist so that your thumb lays across the top of your fist and your fingers are aligned vertically as if you were holding a mug.
- Extend your thumb upward.
- Extend your pointing finger forward.
- Extend your middle finger so that it is pointing straight to your left.
- This is a representation of what we call, in physics, the *right-hand rule*.

What is a tornado? *(continued)*

- Assume the thumb represents the direction of the updraft.
- Assume the pointing finger represents inflow leading into the updraft.
- The middle finger points in the direction of the resulting force; in the case we have a tendency for rising air with forward velocity to rotate to the left (counterclockwise).

What is a tornado? *(continued)*

- This is what causes the updraft to rotate.
- What constitutes violent rotation?
- The current standard is the Enhanced Fujita scale, but this relies on wind estimates based only on the damage done.
- Last time we examined how winds damage structures.
- It takes time for winds to penetrate a structure.

What is a tornado? *(continued)*

- If you have a very fast moving EF5 tornado it might not have time to do EF5 damage along its path.
- Similarly, a very slow-moving EF1 scale tornado may do extensive damage since potential targets are under the action of the wind for longer periods.
- So, we need to settle on a definition for what violent means in this context.

What is a tornado? *(continued)*

- I propose using the severe wind limit as the start of the tornado scale.
- Weak Tornado: 50 knots - 100 knots.
- Strong Tornado: 101 knots - 200 knots.
- Violent Tornado: 201 knots +.
- While these are arbitrary, so are all of the other scales. This has the advantage of being simple.

What is a tornado? *(continued)*

- The idea that tornadoes are pendent from a thunderstorm is likely wrong in the face of current data.
- It seems that many tornadoes (perhaps even most of them) form from the ground up (see tornadogenesis below).
- If this is true, then the tornado is not pendant from the thunderstorm.
- This is a problem.

What is a tornado? *(continued)*

- The thing that connects the tornado to the thunderstorm is the updraft of the thunderstorm, or some other vertical forcing mechanism.
- Perhaps a better definition would be something like this: "A tornado is a violently rotating column of air in contact with the ground and driven by vertical forcing."

Vertical Component of the Wind

- The vertical forcing of the updraft gives the tornado a vertical component to its winds.
- This is one reason why vehicles are unsafe in strong or violent tornadoes.
- Since the air is driven upwards it exerts a force on the underside of any object.
- After some critical value is reached, the object will become weightless.

Vertical Component of the Wind *(continued)*

- After that the object becomes debris, whether it is a playing card, a truck, or a building.
- A human being becomes weightless when vertical winds reach around 90 knots.
- A vertical wind speed of 100 knots will make most cars weightless.
- A vertical wind speed of 110 knots will make most minivans weightless.

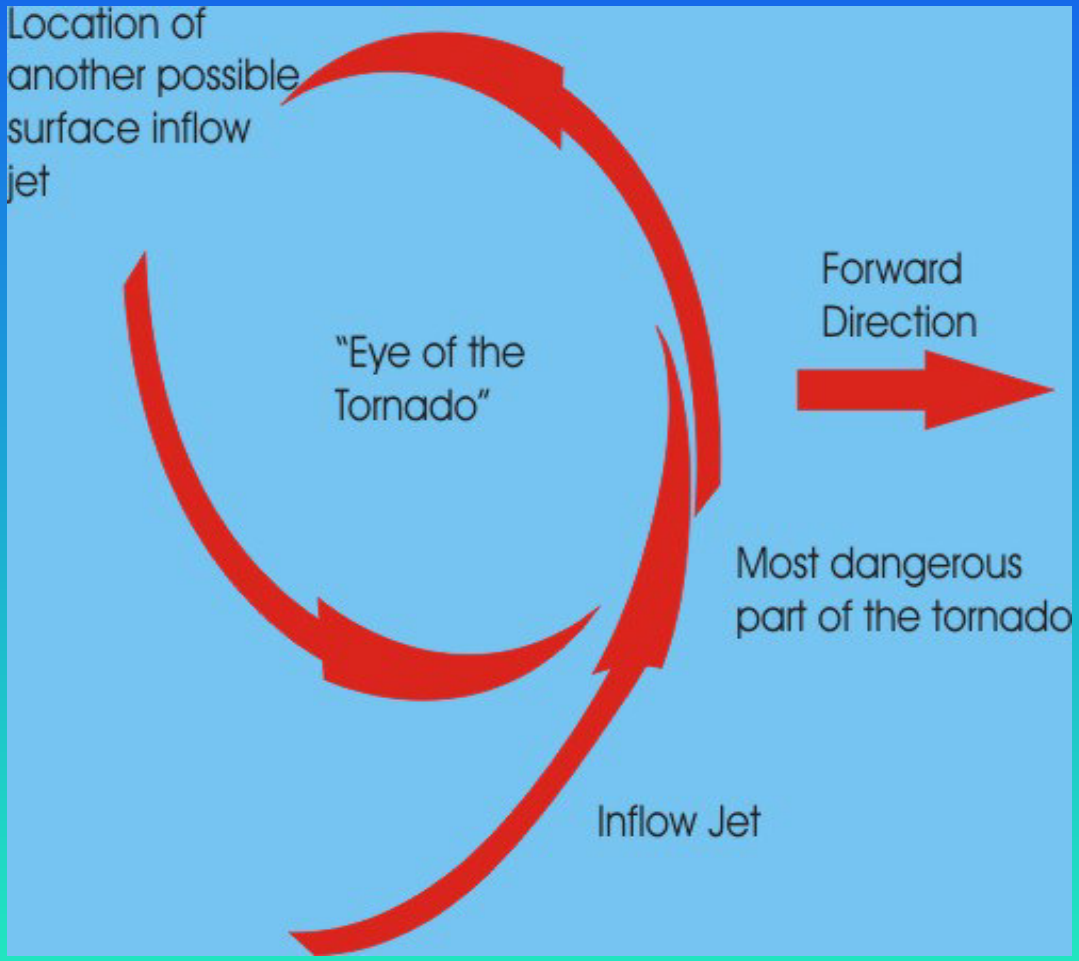
Vertical Component of the Wind *(continued)*

- In 1999 on 3 May the town of Moore in Oklahoma was hit hard by a nearly mile-wide violent tornado.
- In a damage photograph taken a mile from the tornado damage path, a metal folding chair can be seen neatly driven through a 4x4.
- This 4x4 was twelve feet from where it had been located.

Vertical Component of the Wind *(continued)*

- It had been one of two vertical supports holding up a balcony.
- The folding chair was thrown a mile from the tornado with enough force to knock a 4x4 vertical support out from under a balcony and drive the leg of the chair all the way through it!
- Thus is the power of a violent tornado...

Structure of a Tornado



- To the left we look down from above on a tornado.

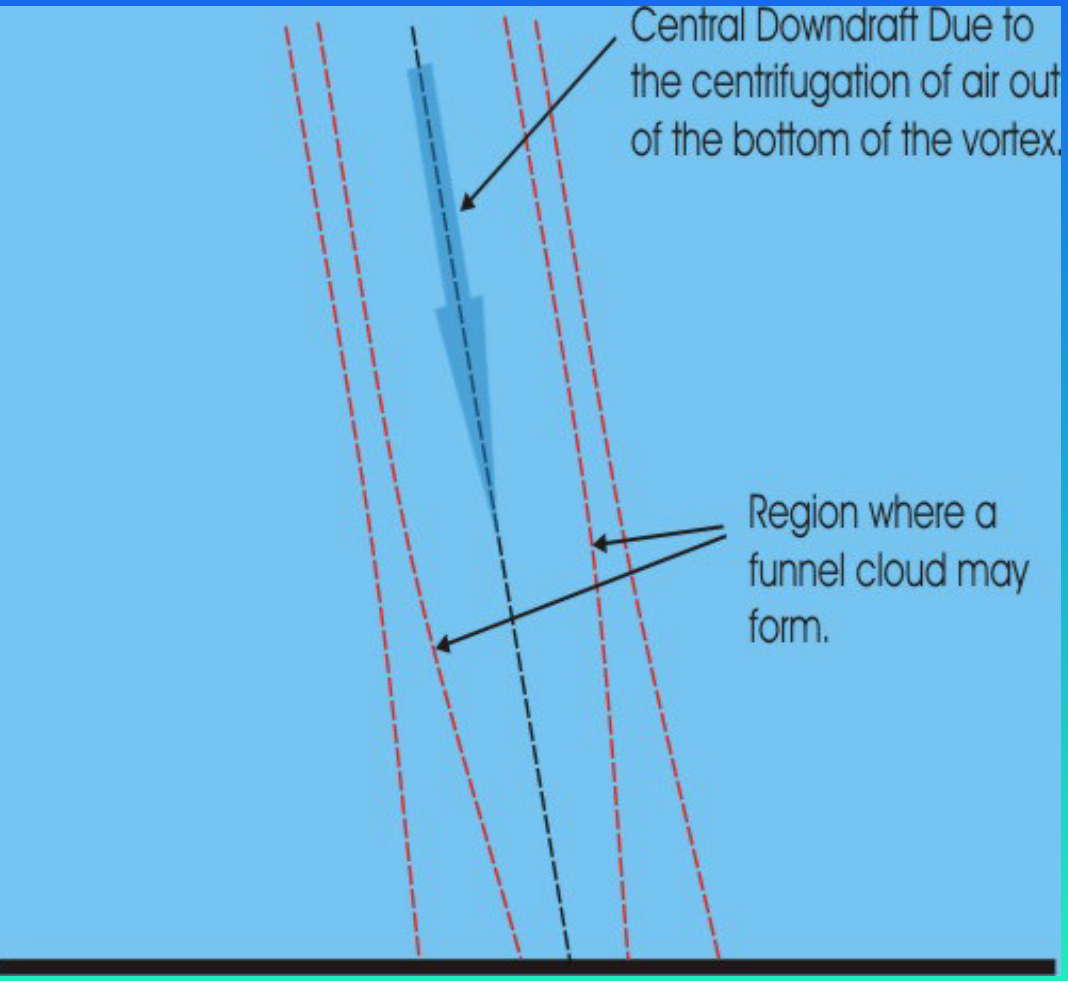
Structure of a Tornado *(continued)*

- Inflow jets are regions where the circulation of the tornado pulls the surrounding air into the vortex.
- Inflow jets are very dangerous places, winds can be sufficient to drag objects into the tornado when these jets are at ground level.

Structure of a Tornado *(continued)*

- Inflow jets are not limited to the surface, there have been some spectacular videos of tornadoes with inflow jets higher up in the vortex.

Structure of a Tornado *(continued)*



- Here is a vertical cross-section of a tornado.
- There seems to be a central downdraft, as indicated by high-resolution radar images.

Structure of a Tornado *(continued)*

- I believe this is due to air being centrifuged out of the vortex at the base of the vortex column.
- Any funnel cloud that develops forms inside the actual tornado.
- The internal downdraft lowers the pressure sufficiently to produce saturation inside the funnel.

Structure of a Tornado *(continued)*

- If there is insufficient moisture there will be no visible funnel cloud.

First Discussion!

- Discuss the multivortex tornado, and how this might come about.

Section 2

Tornadogenesis and Dissipation

Tornadogenesis

- The process of tornado formation is called *tornadogenesis*.
- The way a tornado forms is still a matter of both intense debate and research.

Tornadogenesis *(continued)*

- This process seems to involve the following elements:
  - A source of vertical forcing. This can be an updraft, convergence, or even the vertical motion caused by rotating winds. Whenever you have counterclockwise winds, the right-hand rule requires vertical motion.

Tornadogenesis *(continued)*

- A source of rotation: This can be caused by veering winds with height, or by turbulence caused by convergence, or by some other mechanism that is not currently known.

Tornadogenesis *(continued)*

- There are some other factors that may play a part:
  - Strong inflow into the region where the tornado will form. This may carry eddies formed from convergence into the updraft region.
  - A warm RFD has been linked to increased vortex production at the surface.
  - Vortex lines are produced whenever the atmosphere spins around.

Tornadogenesis *(continued)*

- By collecting large numbers of vortex lines you get a stronger vortex (so long as they are all pointing the same way).
- The RFD can bring mid-level vortex lines (produced by a mesocyclone, for example) to the ground, thus increasing the number of vortex lines at the surface.
- Any RFD can intersect the inflow winds at a sharp angle, producing eddies which can be drawn into the updraft region of the thunderstorm.

Tornadogenesis *(continued)*

- There seems to be a critical ratio between the strength of the updraft and the strength of the inflow, called the *swirl ratio*. Within this ratio a tornado will form, otherwise it will not.

- A tornado will continue so long as there is a source of vertical motion and inflow. If strong winds undercut the vortex, the tornado will dissipate.

Tornadogenesis *(continued)*

- If the thunderstorm updraft weakens, or the convergence ceases, the tornado will dissipate.
- If cold air is ingested into the updraft, causing the updraft to weaken, the tornado will dissipate.

Tornadogenesis *(continued)*

- It is possible for the conditions that produced the tornado to move away from the tornado.
- This may result in the development of another tornado further away. This is called *cyclic tornadogenesis*.
- The first tornado may still exist as other tornadoes form nearby.

Tornadogenesis *(continued)*

- It is also possible for multiple tornadoes to develop around a very strong tornado.
- This is not the same a multiple-vortex tornado.
- This effect is sometimes called a *tornado cyclone*, and a large region of the air under the thunderstorm will be seen to be rotating.

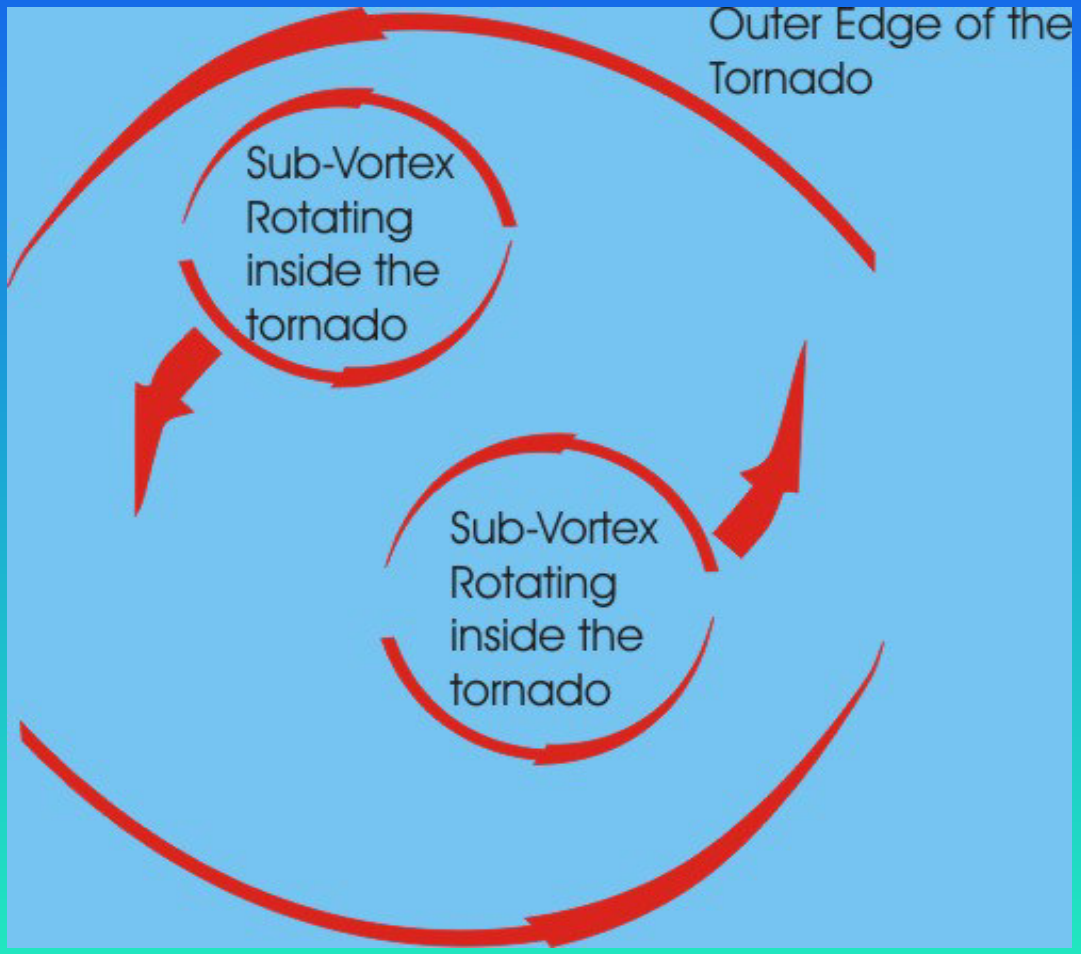
Tornadogenesis *(continued)*

- This can become coupled with (or even produce) a mesocyclone.
- Large tornadoes undergo a process where the flow inside the tornado becomes disrupted, but does not dissipate.
- The result is a turbulent vortex where smaller sub-vortices are produced and rapidly dissipate within the larger tornado.

Tornadogenesis *(continued)*

- This process is called *vortex breakdown*.

Tornadogenesis *(continued)*



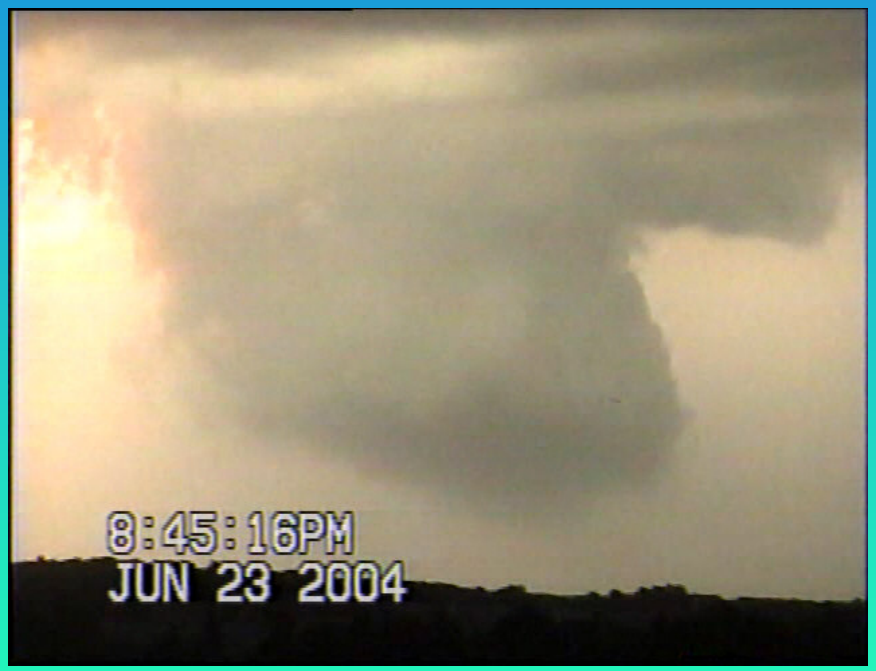
- Such a tornado is called a multivortex tornado (or a multiple vortex tornado) and might look like this from the top down.

Second Discussion!

- Speculate on how this information can tell you where a tornado is likely to occur.

Section 3

Locating Tornadoes



Locating Tornadoes

- The most likely region of a thunderstorm for tornado formation and development is in the updraft region, but only if there is a good source of warm and moist inflow.
- Tornadoes that form here are the most likely to be long-lasting and violent.

Locating Tornadoes *(continued)*

- Another place where tornadoes occur, though less frequently, are in the convergence zones where outflow boundaries are intersecting.
- This can occur in storm trains where the outflow from the dissipating lead cell encounters outflow from the maturing cell and a brief strong updraft forms between them.

Locating Tornadoes *(continued)*

- Tornadoes that form in convergence areas tend to be disorganized and weak, but they can occur in large families, and occasionally they can develop strong tornadoes.
- Another event that occurs occasionally is a weak tornado will form on the outflow and be drawn into the inflow region and will strengthen there.

Locating Tornadoes *(continued)*

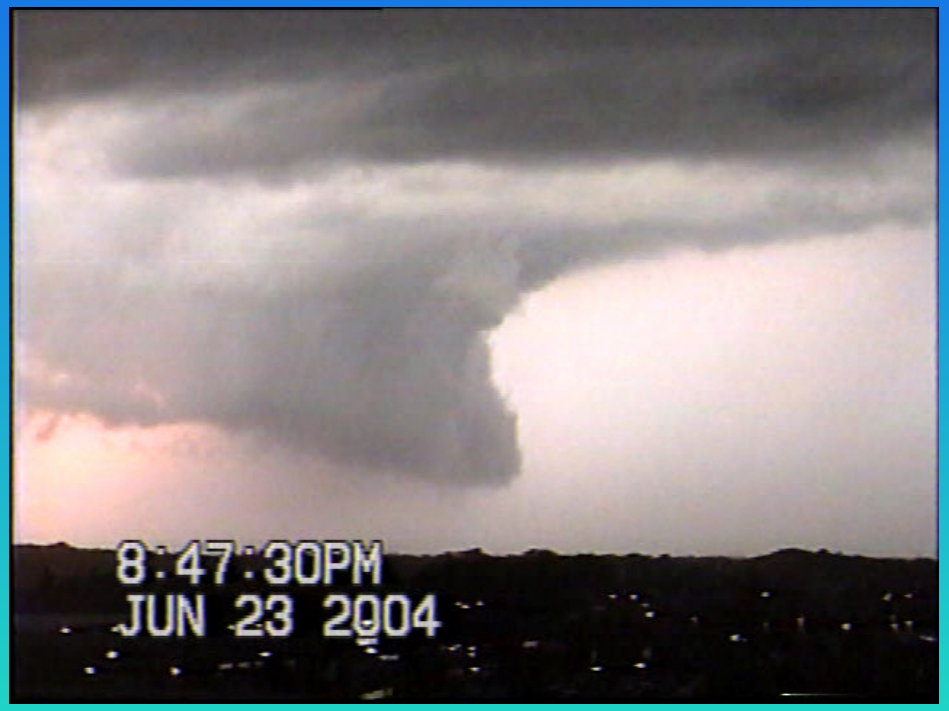
- Another type of vortex occurs on the outflow; this type fails to reach the cloud level, or so it is thought (we do not really know for sure).
- This type of vortex is called a *gustnado*.
- The only part of the gustnado that is visible is the debris cloud, so it is not really possible to tell how high up the vortex extends.

Locating Tornadoes *(continued)*

- These vortices occasionally reach the strength of a weak tornado.
- It is possible that a gustnado can be drawn into the updraft and become a true tornado.

Final Discussion!

- Discuss the destructive potential of tornadoes, and their ramifications for spotters.



Homework Due Next Week

- Describe what a tornado is.
- Determine three criteria for whether something is a tornado.
- Describe two ways that tornadoes can form.
- What is a multivortex tornado?
- How is the Enhanced Fujita scale limited?
- Draw a diagram of each type of thunderstorm that we have discussed. Speculate about where to look for tornadoes for each.

Homework Due Next Week *(continued)*

- Why is a gustnado not a tornado. Is this a realistic distinction?