SEVERE CONVECTIVE STORM MODELING

UNIT 1

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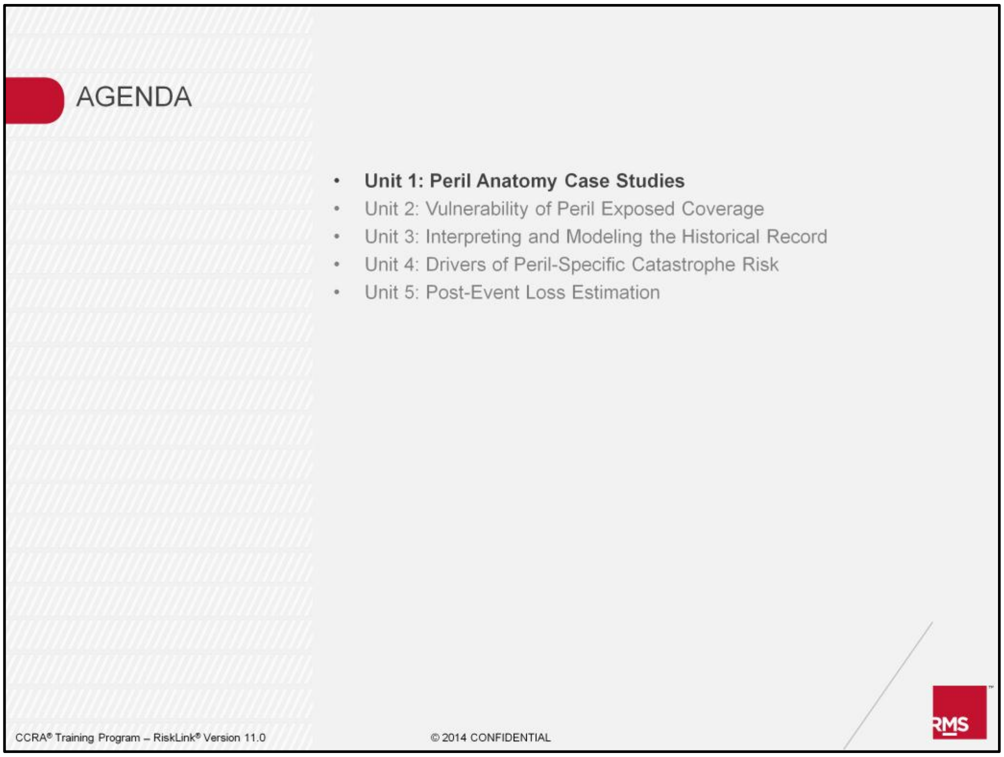
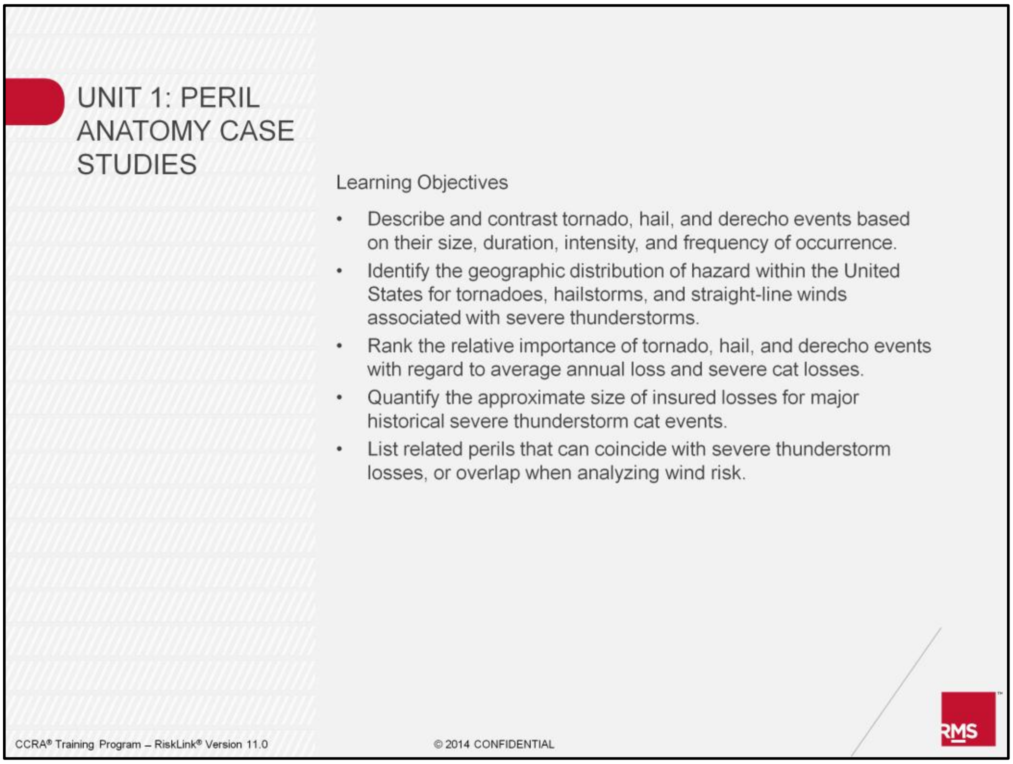
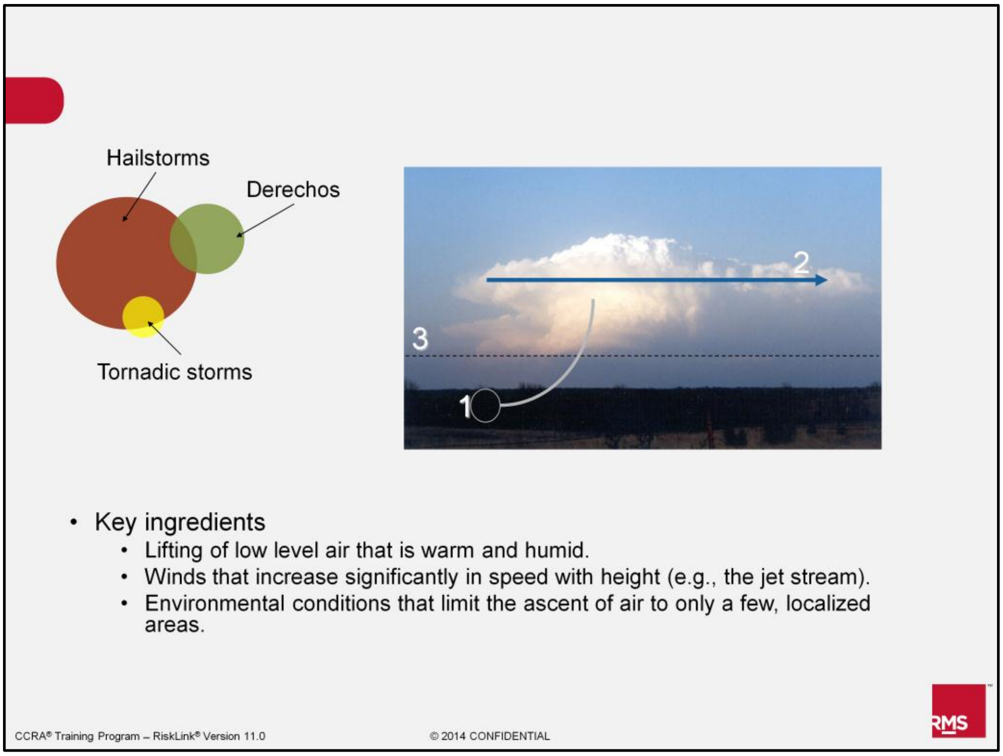


This unit discusses the peril anatomy of the severe convective storm model.



At the end of this unit you should have a good understanding of each of the five learning objectives listed on this slide.



We will begin with a physical description of the severe convective storm. All of the hazards listed on this slide — tornadoes, hailstorms, and derechos — are formed by severe thunderstorms.

For a conventional or common thunderstorm to develop, air in the atmosphere is forced upward to the point of saturation and a cloud is formed. The process of forming a cloud has a warming effect which can enhance the air's ability to ascend. Under the right conditions, that ascent can be very aggressive or very dramatic, which can result in a towering thunderstorm. This basic process is very common in the summer months and can produce a thunderstorm that can have very localized straight-line wind effects or very small hail., However, often a conventional thunderstorm is not one that produces catastrophic loss.

There are some key ingredients in the atmosphere that relate to how a storm becomes more severe. The first is that the storm is located in an environment with high vertical wind sheer. This means that the wind speed increases dramatically with height, so it is occurring near the jet-stream. This helps the thunderstorm be sustained for a long period of time. It also develops a rotational component which is very important in order for it to produce large hail, have the potential for tornadoes and to be maintained for six or eight hours.

Often times, there are environmental conditions that limit the ability for these severe thunderstorms to develop which makes them very localized. It is not very common that we would have an entire state covered with severe thunderstorms at one time. There are often only several, maybe four or five, severe thunderstorms in any one state at a time. This is related to the environmental conditions that suppress or limit the development of widespread severe thunderstorms. Those conditions are technically a thermal inversion that occurs in the atmosphere or a cap that limits the ascent of air, which therefore limits the production of thunderstorms to only a few very intense areas.

OVERVIEW OF HAILSTORMS

- Hailstorms
  - Size of hailshaft: 10 to 20 miles wide (15 to 30 km)
  - Duration: 45 min to 6+ hrs
  - Fall speed: 40-100 mph (70-180 kph)
  - U.S. frequency: about 100,000 per year

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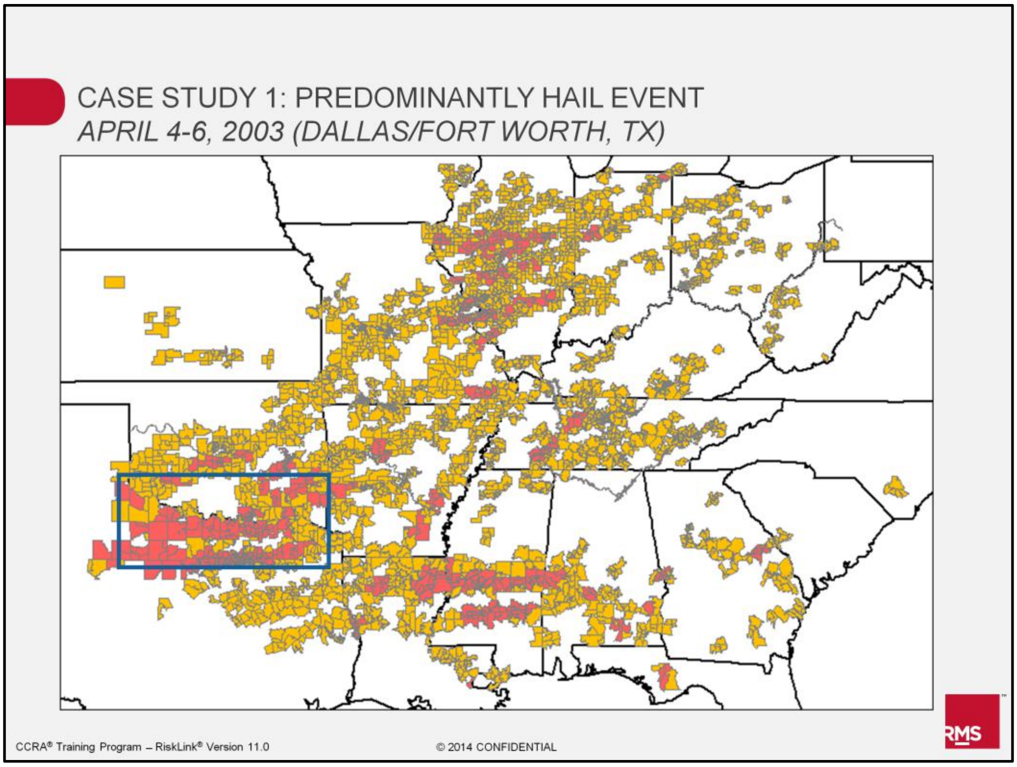
When we look at a severe thunderstorm from a distance, like the image on the slide, hail can look like a white column descending from the base of the cloud. That column is called a hail shaft and it can be up to 20 miles wide. As the parent thunderstorm evolves and moves, often from west to east or from southwest to northeast, it sweeps out a swath of hail. In many severe cases, when the thunderstorm is in the right environment, it can sustain itself for many hours. The swath of hail that is produced can be hundreds of miles long; it can span one or more states very easily before that storm goes on to decay.

Individual hailstones fall at their terminal velocity, so the only limit to their speed is the wind resistance they experience as they fall out of a cloud. That terminal velocity can be between 40 and 100 miles per hour. Ultimately, when those hailstones make an impact on the roof, windows, or cladding of a building, they can have a significant effect. The hailstones can also be accelerated by the winds. Straight-line winds and hail come hand in hand in many cases. In fact, they often come together in most catastrophic events.

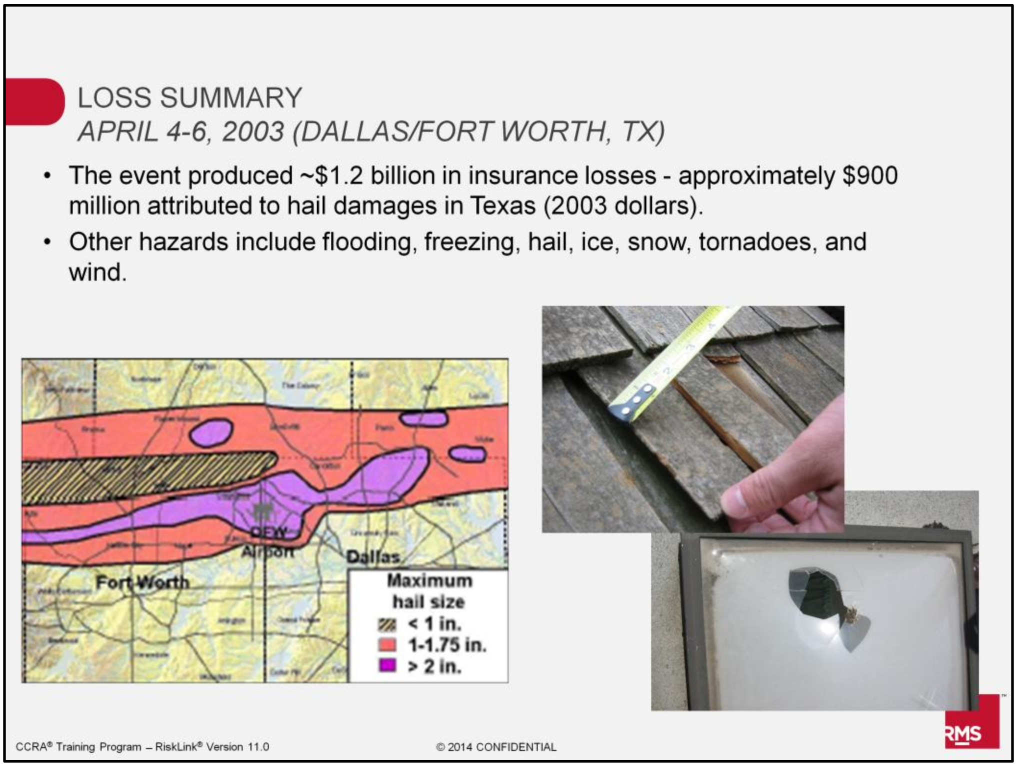
The other thing that is very important to know when we talk about these three sub-perils for severe thunderstorms is that hail is the most frequent of the three. There are about 100,000 hailstorms that occur each year in the U.S. While not all of these are severe, those that are severe are also very common. When we refer to severe, we are referring to a threshold of having a hailstone three-quarters of an inch or greater in diameter.



Here is an example of a hail-dominant catastrophic event. This image shows an event that occurred in the first week of April in 2003 in the U.S. There were a large number of severe thunderstorms that occurred over parts of the South and the Midwest. This map shows each of the ZIP Codes that were impacted by hail produced by those thunderstorms, which is categorized in two size thresholds. Those that are severe (above ¾ of an inch diameter) are shown in yellow. Those in red are highlighting thunderstorms that produced hail in excess of 1½ inches in diameter.

The outlined box is in north Texas. There was a series of very severe hailstorms that moved across north Texas and affected the cities of Dallas and north Fort Worth, which drove much of the catastrophic loss from this one event.

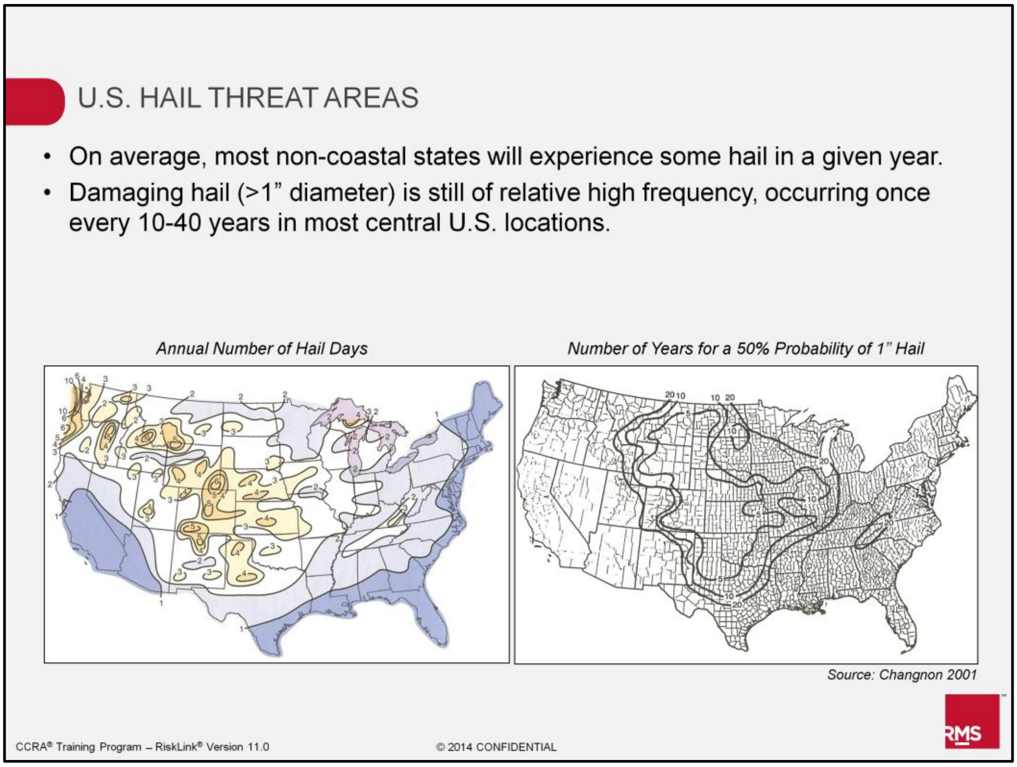
When we trace these ZIP Codes, we begin to see the hail swaths that were caused by each of these events. In the case of north Dallas, we are looking at hailstorms that spanned much of the state, across parts of western Texas on through northeast Texas, crossing over Dallas/Fort Worth. We can also see that some of these hail swaths are oriented from west to east and others are oriented more from southwest to northeast. That is reflective of the different severity characteristics of storms. Those that are most severe tend to be oriented more to the west-to-east direction, while the weaker ones are more oriented from the southwest to northeast.



Although the event outbreak spanned multiple states and had a very large footprint, the losses were driven by those few hailstorms that were very severe and directly impacted the major urban area of north Dallas and Fort Worth.

The map on the left comes from a roof-to-roof survey where an engineer estimated the hail size produced by that event in those regions. We can see that there was a broad area of hail that exceeded one inch in diameter. In the northern suburbs of Dallas where there are a number of upscale residential communities, the hail size was greater than two inches in many locations. The end result was an insurance loss for the event of approximately $1.2 billion, and $900 million (2003 dollars) of that was driven by the hail damages in the state of Texas.

When we look at these examples there are other hazards that occur with these events. The remaining $300 million of loss in this event was driven by hail outside of this region, as well as other perils like flooding, freezing-cold temperatures, ice, snow, and in some cases, tornadoes and straight-line winds. These events do have a number of different hazards associated with them, but often one of the individual hazards becomes the dominant driver of loss in a given event.



Before we look at each of the other hazards, let’s look at the geographic distribution of hail frequency across the U.S.

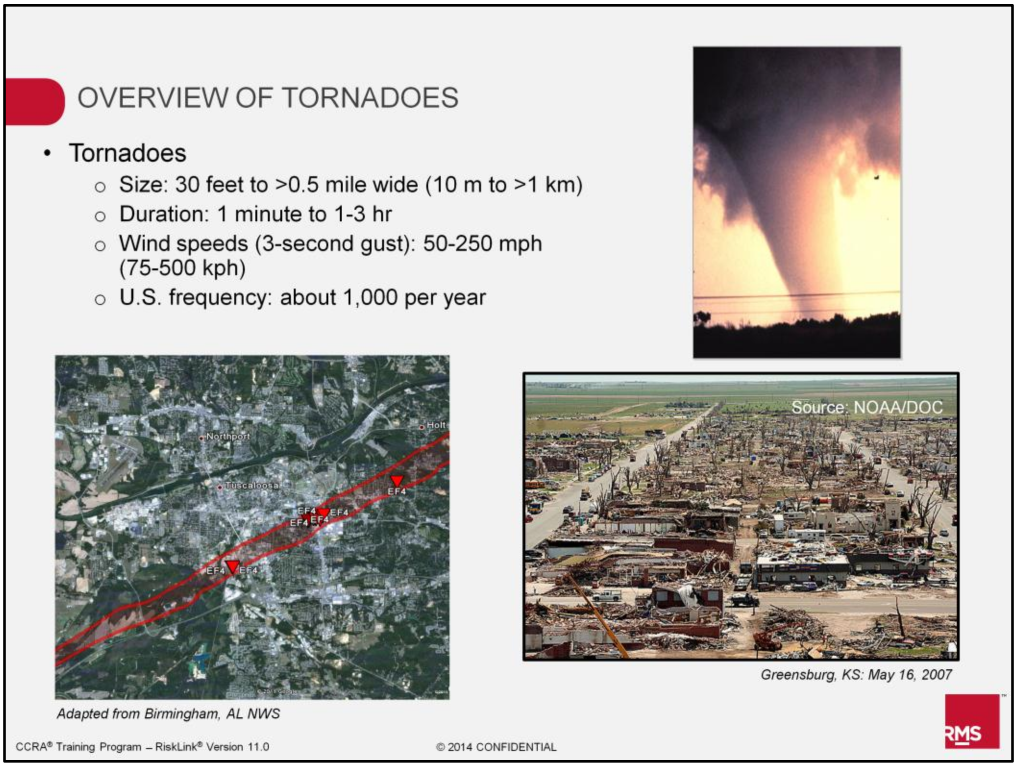
When the historic catalog of hail occurrence is assessed, it can give us a sense of where that geographic variation is. Those analyses are typically done from two points of view.

One point of view is to describe the frequency of hail in terms of hail phase, which is an account of whether or not hail occurred on any given day at a location irrespective of the size of that hail. The image on the left represents this point of view. The image on the right shows the frequency for a specific hailstone size. In this case, we are focusing only on hail that is greater than one inch in diameter.

In the image on the left we are looking at the annual number of days we would expect to experience hail. Interestingly, almost all of the U.S. (excluding southern California, parts of Arizona, the Atlantic coast, and the Gulf coast) experiences, on average, at least one day with hail in a given year. Much of this hail is very small, so much of it has no relevance to property risk. For example, San Francisco often gets hail each year, but because it is pea sized, it is not large enough to cause significant loss.

To get a geographical sense of where the hail frequency is highest, it is important to focus in on the map on the right. These contours illustrate the number of years where there is a 50% probability of having a one inch hailstone occurring at a point. We can roughly double these numbers to get a return period of having one inch hail. It is also very important to understand that the high occurrence of large hail is focused on those states from Montana and North Dakota in the north, southward through Nebraska and Kansas and down into Oklahoma and Texas.

Also notice that this is a very high frequency peril. It is likely for hail to happen every ten to 20 years in this region. Hail at this one inch threshold can produce damage to roofs or automobiles. Often a home will experience hail damage before weathering and other effects will cause its roof to deteriorate and need to be replaced.

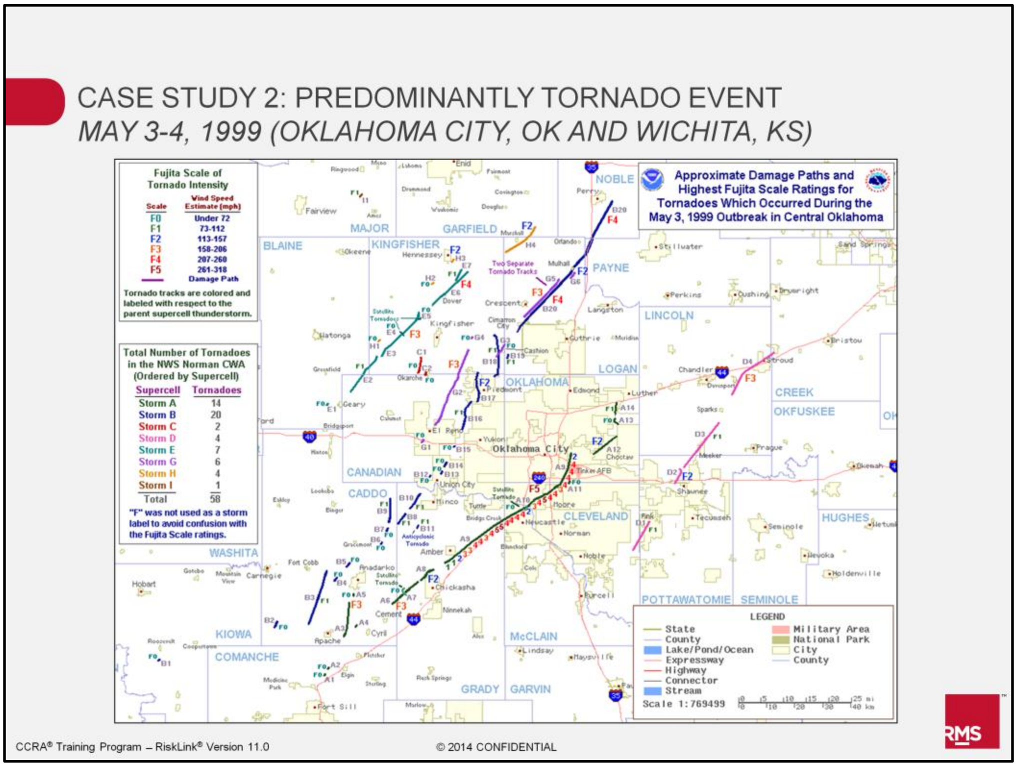


Tornadoes are probably the most familiar of the three hazards. Their intensity, their localized impacts, and even their sudden development tend to make them very dramatic, so this is one element of the severe thunderstorm hazard that is most covered in the media.

By definition, a tornado is an intense vortex that develops on the ground. It is a very intense area of winds in a cyclonic nature, and it is focused in a very small scale. Most of these tornadoes are small in scale and very short-lived, where the diameter of its vortex can be measured in feet (e.g., 30 feet) and it might last for only a few minutes. Those tornadoes are typically classified as EF0 in their peak intensity, and therefore, are not a big factor for insurance risk assessment.

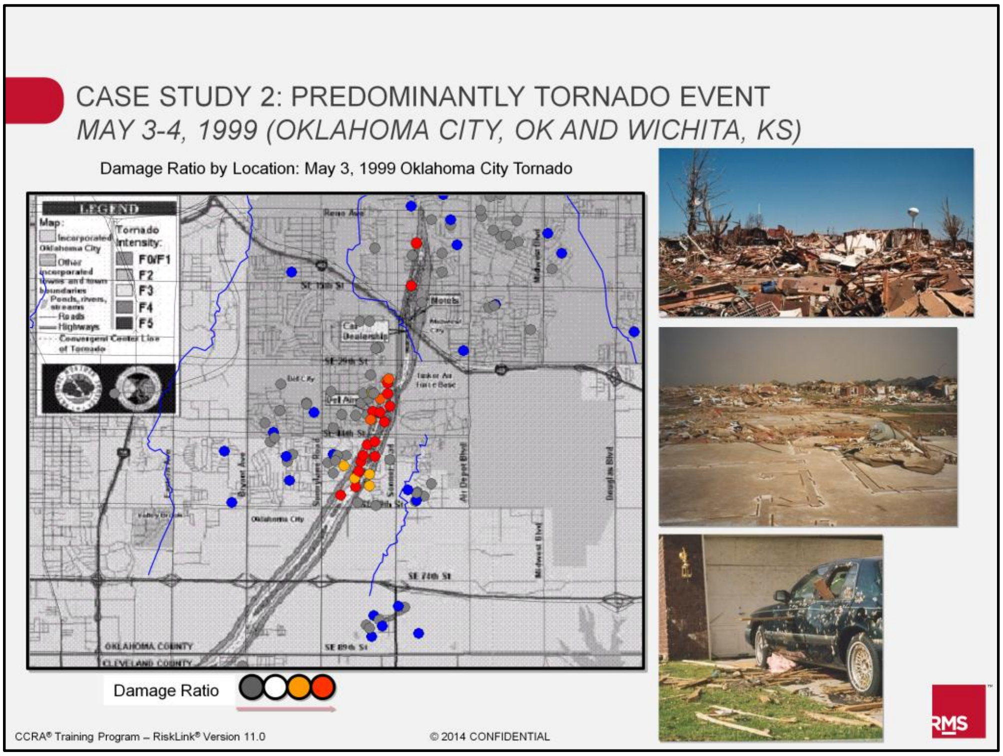
But there are tornadoes that can be very damaging, where the wind speeds can begin to approach 200 to 250 miles per hour. These tornadoes can be very wide. As they become more severe, they are often more likely to be wider and longer lived. Their width can be up to a half mile or more, and they can last for several hours. Their path length can be 50 or 100 miles in total.

The frequency of tornadoes seems very high with approximately 1,000 per year in the U.S., but most of those are these short-lived and weak tornadoes. There are only about ten to 20 tornadoes in a year that actually reach strong and violent wind levels that can produce the types of property damage you see illustrated in the lower right.



On May 3, 1999 there was a major outbreak of these supercell or intense severe thunderstorms across Oklahoma and southern Kansas in the U.S. Many of these storms produced multiple tornadoes throughout their lifetimes. You can see some examples of that as we look at this line of tornadoes that were produced sequentially as the storm moved from southwest to northeast, making its way into Oklahoma City. You can see other examples of that as well, where one severe thunderstorm produced a series of tornadoes throughout its existence.

The most damaging tornado in this outbreak crossed south Oklahoma City and produced up to F5 level damage, which is the peak level of damage that is measured using the Fujita Scale. We will talk about this scale later in the course. The key thing to note at this point is that it was an extremely intense tornado that went directly through suburban and urban areas and produced considerable insurance loss.



On the left is a close-up of the tornado path as it moved through the areas of south Oklahoma City. The severity of this type of a tornado produced many total insurance losses within the core part of its path.

The map shows damage ratios from actual insurance claims that were paid. Those in red are 100%, or very near 100%, loss ratios. Further out from the tornado damage ratios are considerably less; more on the magnitude of a 5-10% damage ratio.

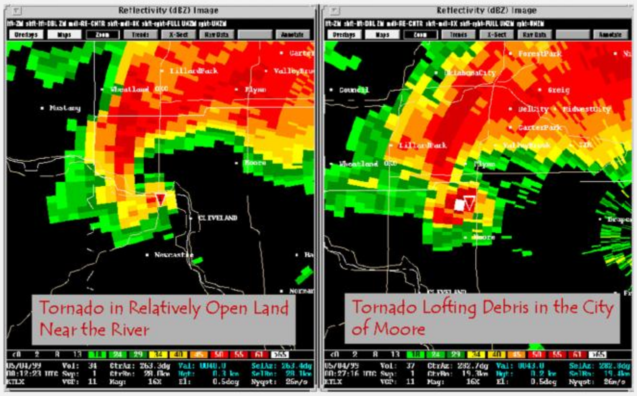
What we want to highlight while looking at this map are the different contours in the path of the tornado. These contours show the intensity of damage that was produced as assessed by the National Weather Service and other surveyors who looked at this event. Typically the intensity decays from the center of the tornado outward. On the outer edges, or the fringe of the tornado, the wind speeds can be fairly low, with 50 to 60 mile per hour peak gusts. So the damage ratios will also typically decay as we go outward from the center of the tornado.

But, again, the tornado itself is being produced by a severe thunderstorm, and that severe thunderstorm can include hail and straight-line winds. When we see these lower-scale damage ratios off to the north of the tornado path, a lot of them are not due to the wind effects from the tornado but rather straight-line winds that might occur with the same thunderstorm. In particular, these areas in the north are losses from hail that occurred to residential roofs on the north side of the tornado.

LOSS SUMMARY

MAY 3-4, 1999 (OKLAHOMA CITY, OK AND WICHITA, KS)

- The event produced ~$1.9 billion in insurance loss –with over $1 billion attributed to tornado damages in Oklahoma (2008 dollars).
- Other hazards include flooding, hail, and wind.



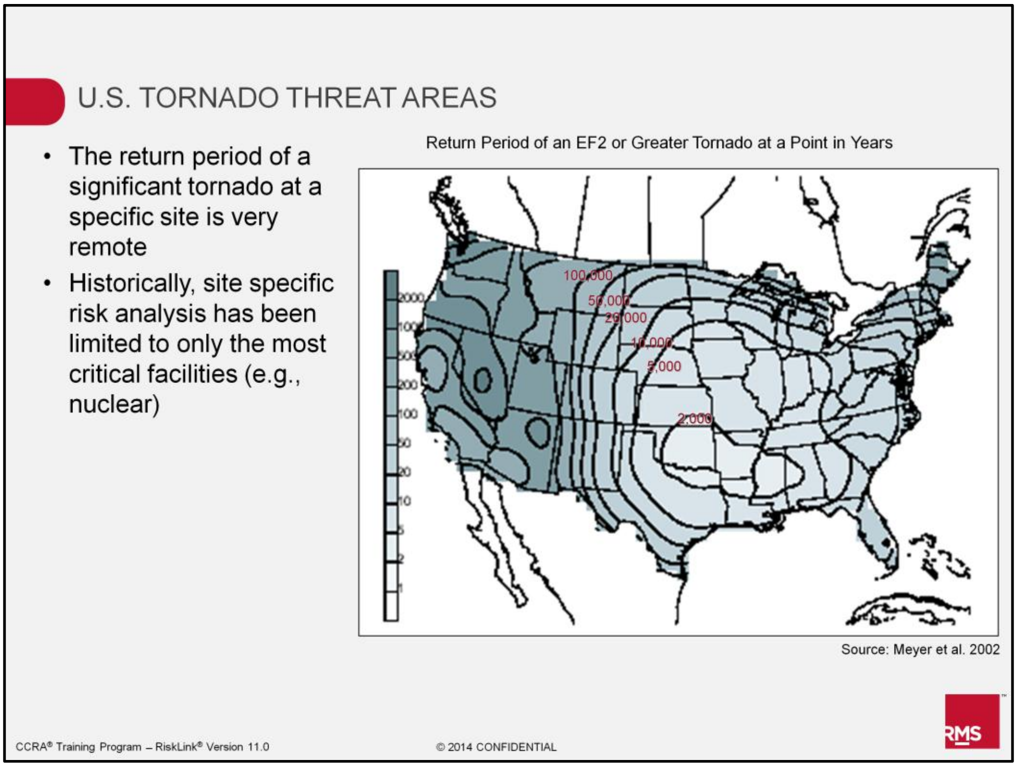
Source: NSSL

To summarize this example, the event spanned a couple of days producing severe thunderstorms throughout the South and Midwest resulting in an event loss total of approximately $1.9 billion in insurance loss. In this case, over $1 billion of that loss was attributed solely to the one major tornado that affected the Oklahoma City metropolitan area directly.

This slide shows radar of a severe thunderstorm. Radar is a beam of radiation that is emitted toward a thunderstorm. Raindrops and hail reflect that beam back, giving a sense of where within a thunderstorm precipitation and hail are located. The intensity of the hail or rain is shown by the darker red color.

In this example of a thunderstorm, there is a large amount of rain on the north side, with hail near the radar's hook feature. We are seeing not only rain and hail returning to the radar. The image on the lower right shows a white cell which is actually the debris that was lofted by the tornado. That highlights the fact that a typical tornado environment has substantial debris. The debris can have a significant effect on property, even in cases where there are no high wind speeds, as these windborne missiles of debris are launched out of the tornado. We will discuss this more later.

Similar to the previous example, this was an event where there were additional sources of loss, including flood, hail, and winds, which contributed to the total $1.9 billion loss.



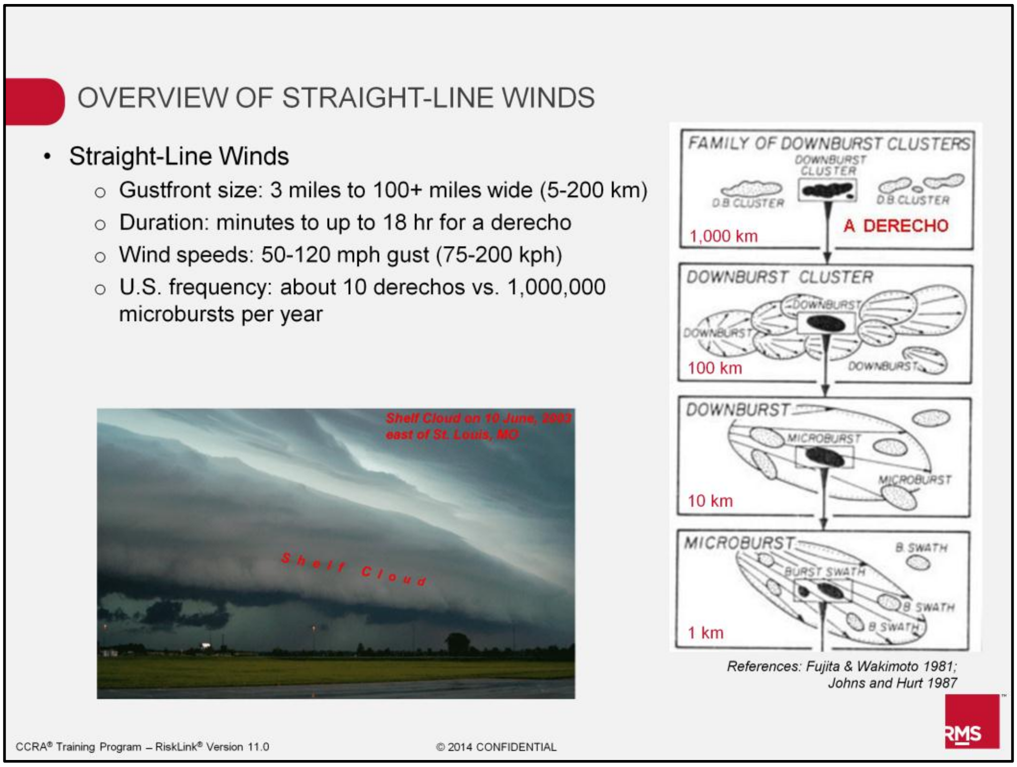
Next we will characterize the frequency of tornadoes across the U.S. and how that varies geographically. There are two key points that you should walk away with when you contrast this image with the one that was shown earlier for hail, and the image for straight-line winds which will be shown later in this presentation.

Each of the numbers shown in red represent the return period of having an F2 or greater tornado at a given point.

In the Oklahoma City example, a return period of having that tornado occur and affect any one property in Oklahoma City is in excess of 2,000 years. In most circumstances it is not that relevant to focus on site-specific tornado risk analysis because it is infrequent for a hazard to occur at one point. Historically when this type of risk assessment is done, it has been done only for the most critical facilities, such as nuclear facilities.

As you begin to look at multi-location accounts or portfolios, it can become more important to focus on tornado risk because the probability of having one of the locations in that account or portfolio affected becomes much greater.

We also want to emphasize that the areas of highest tornado frequency are not the same as the areas of highest hail frequency. For hail, the highest frequencies are often closely tied to the Rocky Mountains. For tornadoes, the highest frequencies actually extend further down toward the Southwest and the Midwest.



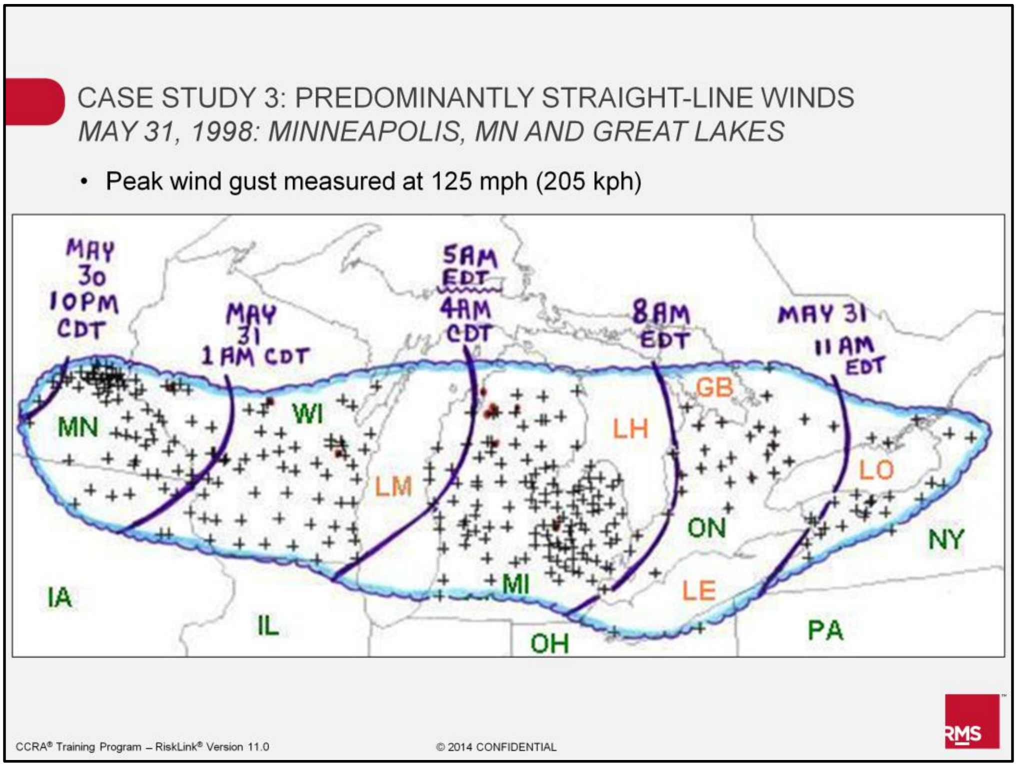
Straight-line winds are more complex because they come in many different scales. The image on the right illustrates the different scales at which these hazards can occur.

A microburst, shown in the bottom right image, is the finest scale of a straight-line wind. It can be produced by a simple thunderstorm that happens to have a burst of rain. That rain begins to evaporate and cool the air which forces it downward and produces a gust of wind at the surface. We might only see some dust blowing on the ground or trees that get blown around beneath that storm. That type of a burst is on the order of a one kilometer diameter. It is important for aviation interests, particularly when planes are trying to land, but for property risk that small-scale straight-line wind is not as relevant.

As we move up the images on the right, we are seeing larger scales of straight-line wind events. A microburst can occur in a cluster and ultimately in a family of clusters.

That family of clusters is called a derecho. It is a term that was coined back in the late 1800s to describe very widespread straight-line wind events. It is measured on the order of thousands of kilometers, where multiple states may be affected by one squall of thunderstorms producing clusters of straight-line winds as it moves across those states.

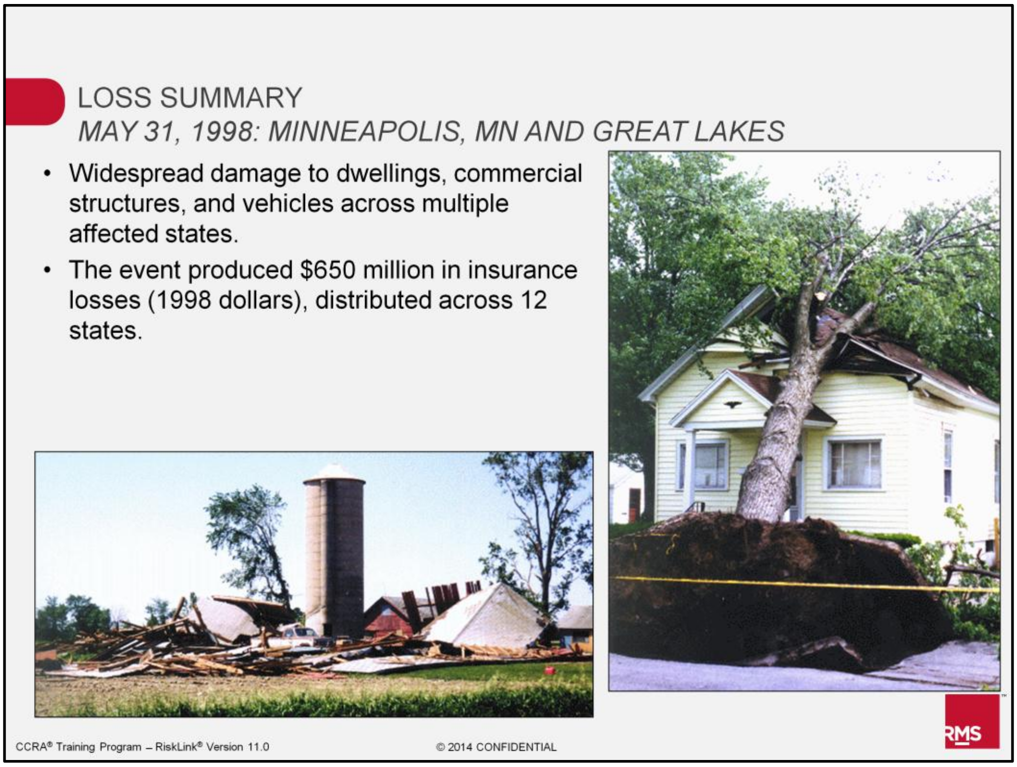
The wind gusts within these events, can be up to 120 mile per hour. This is similar to the type of peak winds that might be seen in a low to moderate hurricane. They can also be rather frequent. About ten of these derechos, or families of downbursts, occur each year in the U.S. That sounds like a fairly low frequency, particularly when we consider there are about a thousand tornadoes a year, but derechos are extremely large relative to a tornado. While a tornado is about half mile wide or maybe up to 100 miles in length, derechos may affect entire states. It is the larger size of a derecho that makes the frequency at any one location much higher than would be for a tornado.



This case study is for one of the highest loss-causing derecho events that has occurred historically. It progressed from Minneapolis, Minnesota, shown in the upper left of the image, to Buffalo, New York over the span of half of a day.

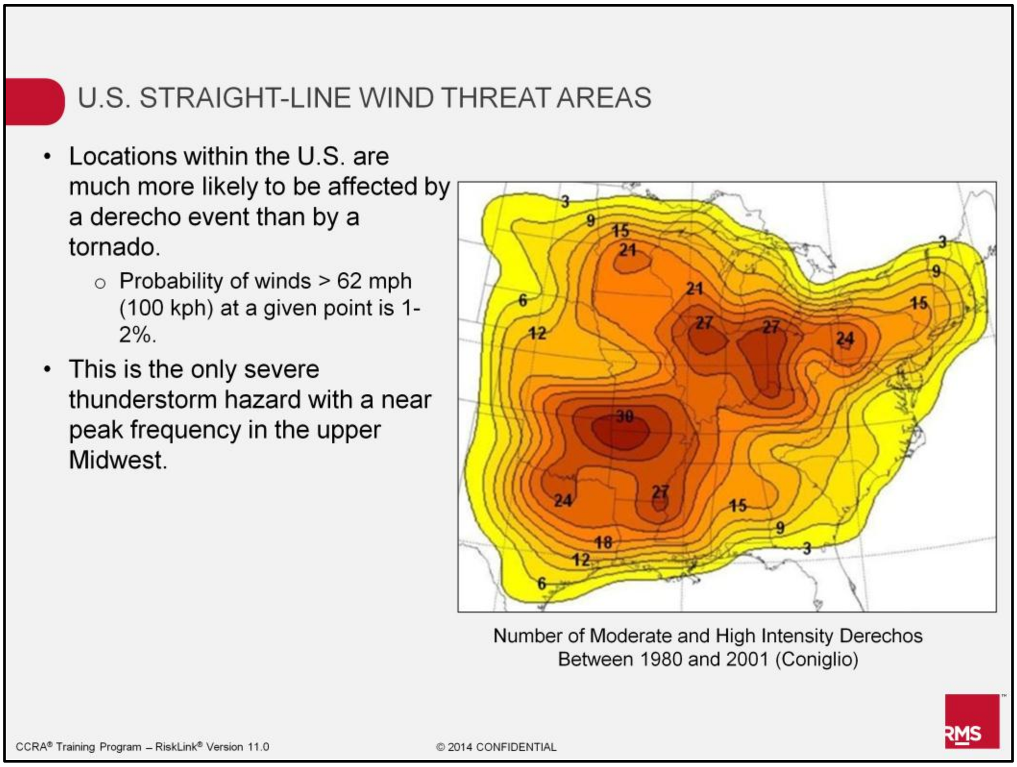
This map shows the advancement of the thunderstorm squall. The arced purple lines are illustrations of the leading edge of that thunderstorm squall as it progressed from west to east. Each of the plus signs within that scalloped region reflect a report by the public of damaging winds indicating trees were downed or there was structural damage to a building. The peak measured wind gust in this event was 125 miles an hour in Wisconsin.

Keep in mind that this is not a continuous area of strong winds like we might see more characteristic in a hurricane. This is a region that is characterized by extremely fine-scale downbursts that occur in a cluster. So there are many pockets of damage that occur over this broad region rather than a continuous area.



The widespread but intermittent damages that occurred to property from this event totaled about $650 million in insurance loss (1998 dollars). There were seven states affected directly by the derecho. When we look at the overall severe thunderstorm event (i.e., reports outside the immediate derecho area) over several days surrounding the May 31st event, there were a total of five other states that were affected by some aspects of this severe weather event.

What you see in these two photos are the types of damage that might be typical of a very severe straight-line wind event. The effects are significant on trees, and those trees can have effects on infrastructure, such as power. Weaker constructed buildings, such as barns or outbuildings, can be very severely damaged. When we look at better constructed or even engineered buildings, there is often fairly low-end damage to roofs and building components Again, we are focusing on types of winds that might be in a Cat 1 to Cat 2 hurricane intensity.



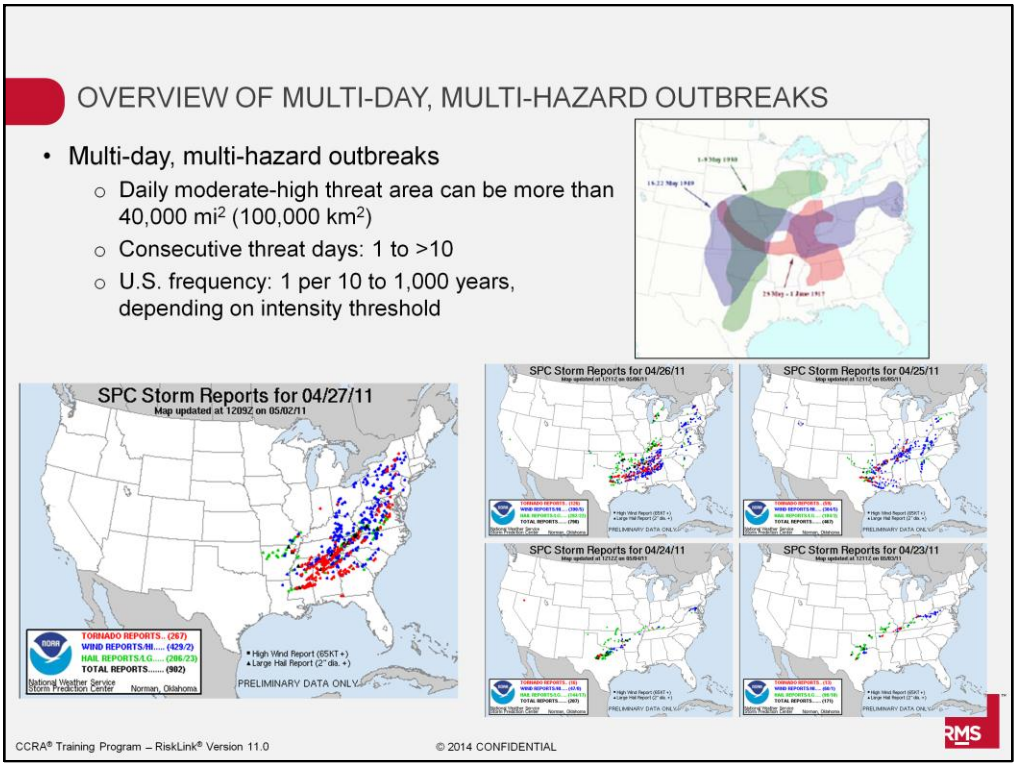
Geographically, the location of peak frequency of straight-line winds relative to tornadoes or hail peak frequency is an important point.

This image shows the country divided up into two-by-two degree cells or areas roughly the size of West Virginia. The researchers that developed this map counted every time that bounding area, or scalloped image that we showed previously (the purple arced lines), crossed one of these two-by-two degree cells. They then counted every time it crossed that cell within a 22 year period to get the numbers that you see on the image. Where you see a number, such as 20, it accounts for roughly one derecho crossing one of these 200 kilometer cells, or these two-by-two degree cells, in a given year.

The important point is that the geographic area of peak frequency is very different for straight-line winds than it is for hail or tornadoes, in particular these high intensity straight-line winds,. This is the only one of the three hazards where the peak frequency is actually located in the upper Midwest, between Minneapolis, Minnesota and northern Illinois, northern Ohio and into Pennsylvania and New York. So the example we showed is very similar in character to the types of events that can occur in the upper Midwest. Within that region, straight-line winds can be a relatively important component of the local risk as compared to, for example, Oklahoma.

The frequency, as was mentioned earlier, for hail at any one point in Oklahoma or Kansas in the Great Plains region was about a ten year return period of a one inch hailstone. For tornadoes, the frequency is on the order of about 1,000 or 10,000 years for a location to be affected.

When we look at the frequency at a point of an area in Oklahoma or in the upper Midwest, the probability of having winds that are severe or greater than 62 miles an hour at that one location is between 1-2%, or a return period of about 50 to 100 years. So straight-line wind frequency is intermediate when compared to the highest frequency hail occurrence and lowest frequency tornado occurrence.



So far we have talked about each of these hazards on an individual basis. But as was noted going through each of those case studies, multiple hazards can occur within any one event, and those events can span multiple days.

The bounding area of a multi-day event can be very large, impacting 10 to 20 states.

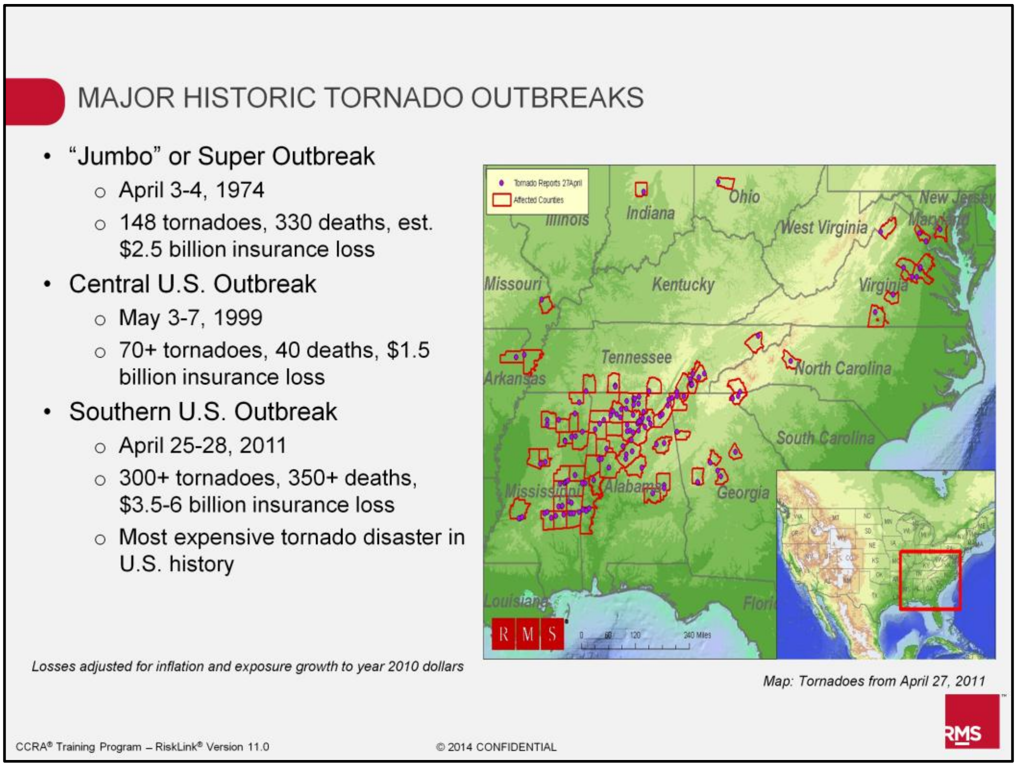
This first sub-bullet indicates 40,000 square miles might be very, very common for a multi-day outbreak. In fact, they can be even bigger than that. It might span as much as a 500 by 500 mile area in total.

The image in the upper right outlines the bounding area of a couple of major historic outbreaks that were tornado dominant. This helps to understand the scale these events can frequently be. An event like this could span a large part of the country where there are localized impacts but over a very large region.

The small multiple maps at the bottom show a slightly different view but hopefully can give you a sense of the persistence of these types of threat areas day to day. These maps show the forecasts that are issued by the Storm Prediction Center in a day-to-day assessment of the severe weather potential. They looked at a week in April 2011 where there was a five day occurrence of a very high number of tornadoes. With a preliminary estimate of 305 tornadoes, the April 25-28 outbreak more than doubles the previous worst tornado outbreak in U.S. history, breaks the previous April monthly record of 267 tornadoes set in 1974, and is nearly double the April monthly average of 161 tornadoes.

Notice that day to day, roughly the same region has a high threat for this type of hazard.

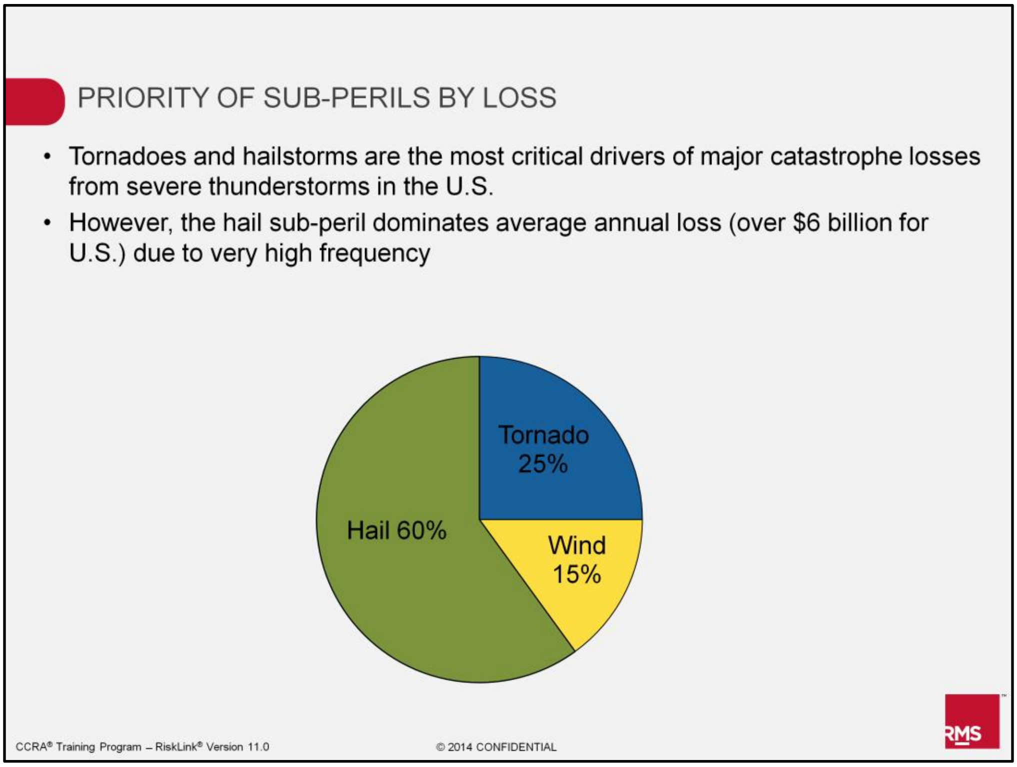
Depending on how one defines a threshold (e.g., X tornadoes in Y days or A tornadoes in B days), we can get different values on the probability of having a very intense multi-day outbreak. One example is this event in April 2011, where there were several days of tornado recurrence in a row. We will talk more about similar events later from the loss point of view. From a probability standpoint, it is not that uncommon to have multi-day outbreaks.



This slide gives some examples of major historic tornado outbreaks. To highlight one example, we will look at the first bullet on a super outbreak of tornadoes. This is an interesting contrast with what we talked about for multi-day events.

The super outbreak was a very extreme event. It is probably an event you have heard quite a lot about, and is often discussed when trying to understand the peak loss potential for a tornado outbreak. The reason it is often focused on is because it had the properties, in terms of the number of tornadoes that occurred and their severity or intensity on the Fujita Scale, of a record setting outbreak when we compare it to ten or 12 day periods within the historic record. The difference is that this event actually occurred in 18 hours on the afternoon of April 3rd and into the overnight hours of April 4th in 1974. There were almost 150 tornadoes total.

When we adjust up to today's dollars, we get an estimate of about $2.5 billion. We will give some more examples about how we use that event in validation later, but we wanted to highlight that we can also have very extreme outbreaks that can occur in one day rather than taking seven or ten or more days to produce that level of tornadoes.



This slide is an introduction to some of the information on losses that are associated with these severe thunderstorm perils.

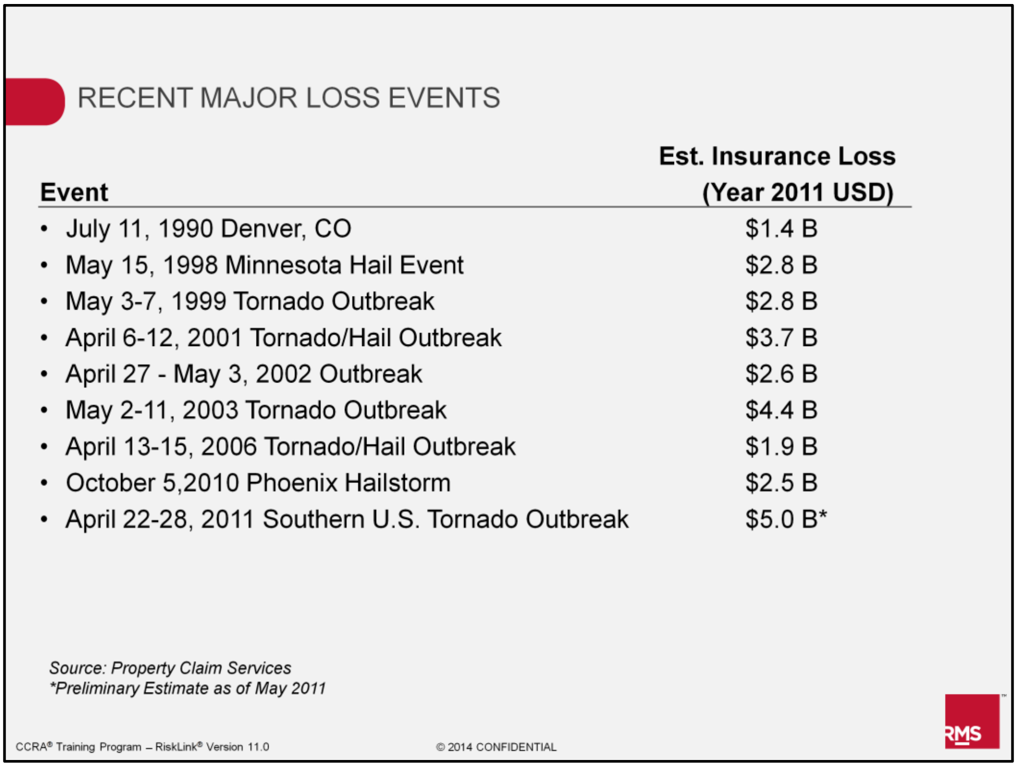
Tornado and hail hazards drive the return period of losses commonly used for reinsurance applications. In the tail of the EP curve, the critical hazards from severe thunderstorms are hail and tornadoes, whereas straight-line winds tend to be much less dominant drivers of the event loss.

To connect that with some of the case studies shown earlier, hail events often can be in the $1 to $3 billion range. Tornado events can also be within that range, and historically that has been the case. The peak catastrophe loss from a straight-line wind event is $650 million (from the event in 1998). So they tend to be lower contributors to the tail of an EP curve.

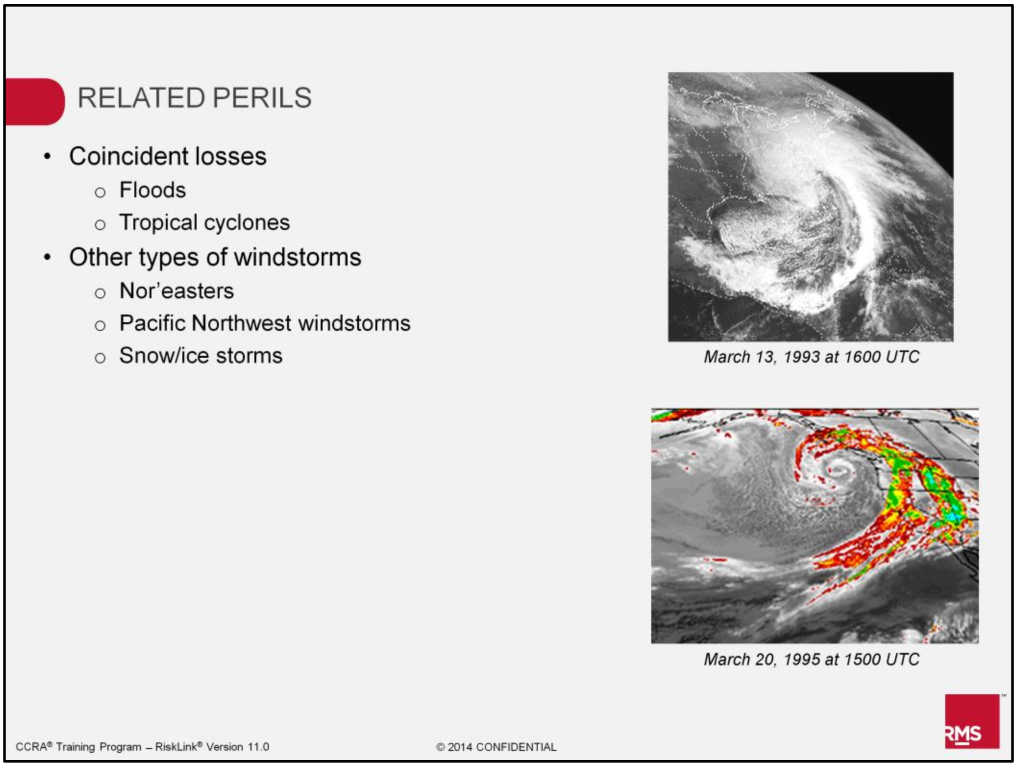
When we think about the high frequency of those straight-line winds, and in particular the high frequency of hail, those two hazards become more dominant from an annual loss point of view. For example, for rate-making applications, a higher percentage of the average annual loss is driven by straight-line winds and hail, whereas tornadoes are so uncommon, the probability of them occurring at a point is so small that they tend to contribute very little to the average annual loss.

To put the average annual loss a bit more into context, in the U.S. on average in any one year the loss that is experienced from severe thunderstorms is over $11 billion to the insurance industry. A high percentage of that is associated with hail. You can see here about $6 billion in the U.S. is due to hail on average. That is actually a number that is only slightly higher than what we would see for an average annual loss from hurricane.

The other interesting point is that these perils are very reliable sources of loss. So the variance or variability of annual loss from year to year is much less than we would see for hurricane, where the average annual loss would be driven by one major year and several years without any loss or without significant loss.



This slide reinforces points made earlier to give you a sense of the scale of catastrophic loss. These are estimates from our property claims services database on major severe thunderstorms since 1990. And these losses have been adjusted to year 2011 exposure using various economic factors, such as gross domestic product and population growth.



Although hail, tornadoes, and straight-line winds produce a substantial component of the risk inland, there are other hazards that also occur either during these events or from different events that affect the same risks in those inland regions.

As severe thunderstorms produce hail, tornadoes, or straight-line winds, they are also producing a significant amount of rain. This can cause flash flooding that may yield significant losses in some cases. We can also see tropical cyclones spawn a number of tornadoes. So there can be some coincident sources of loss between those two types of hazards.

There are also other events that can occur that are less closely related to severe thunderstorms but can also affect the same policies and can have a significant effect on catastrophic loss in some regions.

Winter storms in the Midwest, the Northeast, and the Pacific Northwest are the most key additional class of events that cause loss to inland policies for both residential and, to a lesser extent, commercial risks. We will provide more detail on the implication those other hazards have for severe thunderstorm model users later in the course. Those types of events are also expanded on in some of the other CCRA Training Program courses.

PERIL ANATOMY CASE STUDIES
KEY CONCEPTS

- Tornado, hail, and derecho events differ in size, intensity, duration, and frequency.
- The geographic distribution of hazard within the U.S. varies for tornado, hail, and derecho events, however the majority of hazard is located within non-coastal states.
- Hail events are the prominent drivers of average annual loss and severe cat losses.
- Insured losses for major historical severe thunderstorm cat events are generally less severe than losses one might see in major hurricanes. These events are much more frequent, yet less severe.
- Severe thunderstorm losses can also coincide with floods, tropical cyclones, nor'easters, Pacific Northwest wind storms, and snow/ice storms.

This slide summarizes the key points from Unit 1. If any of these points are unclear, please revisit the associated slides within the unit.