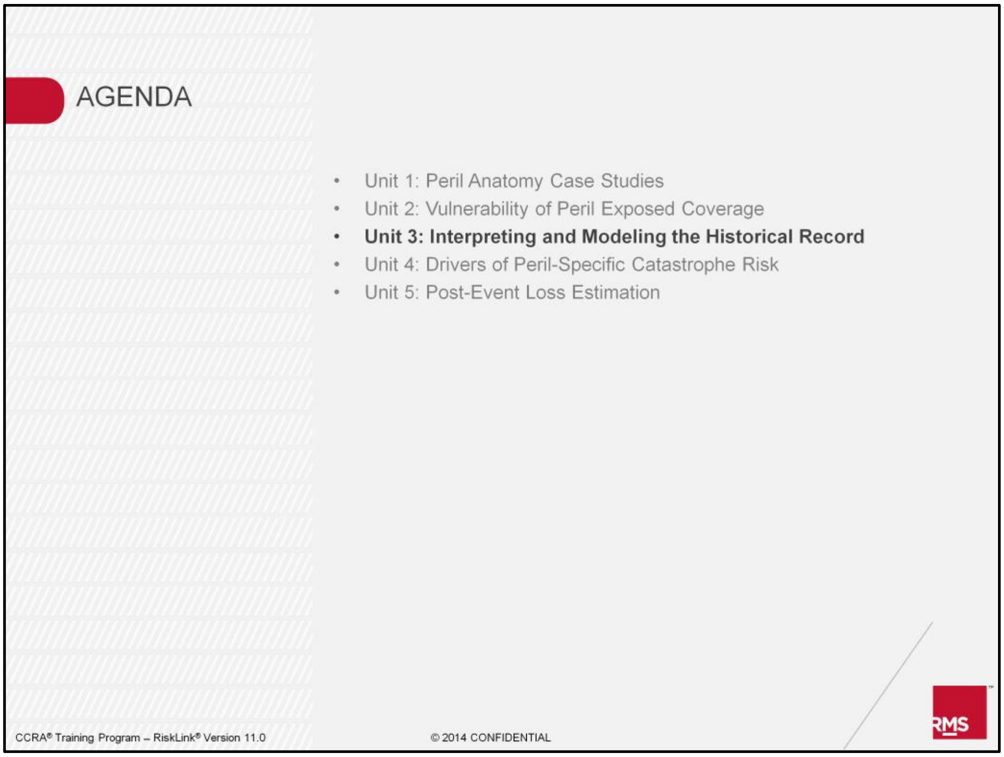
SEVERE CONVECTIVE STORM MODELING

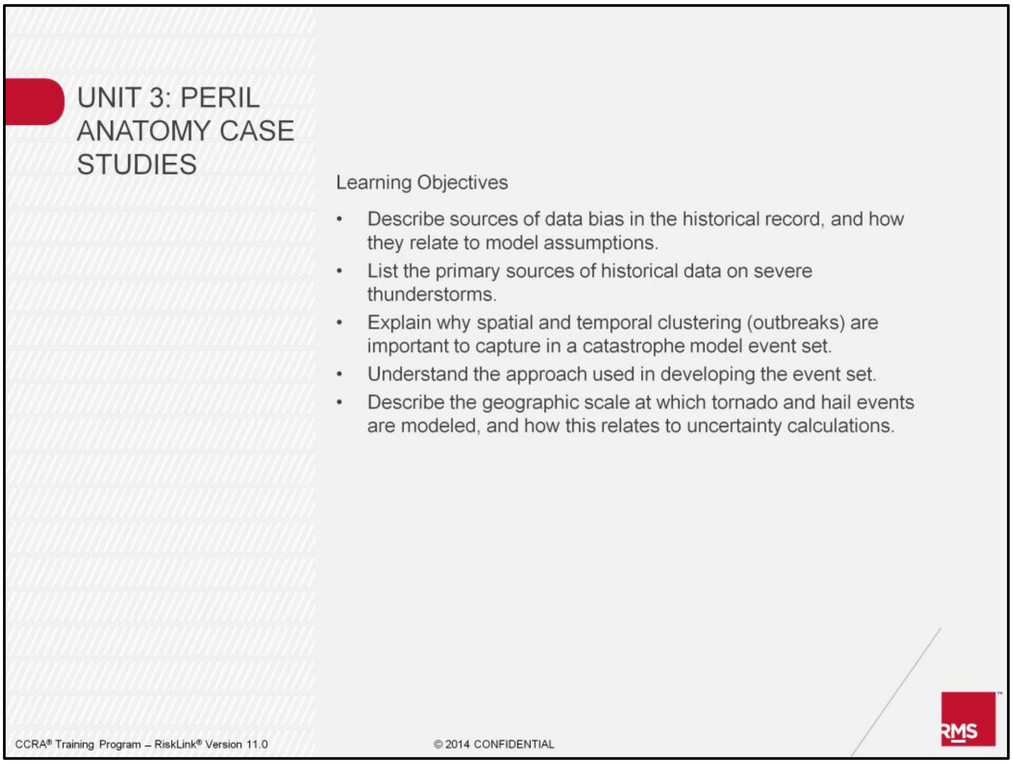
UNIT 3

RMS® CCRA® Training Program

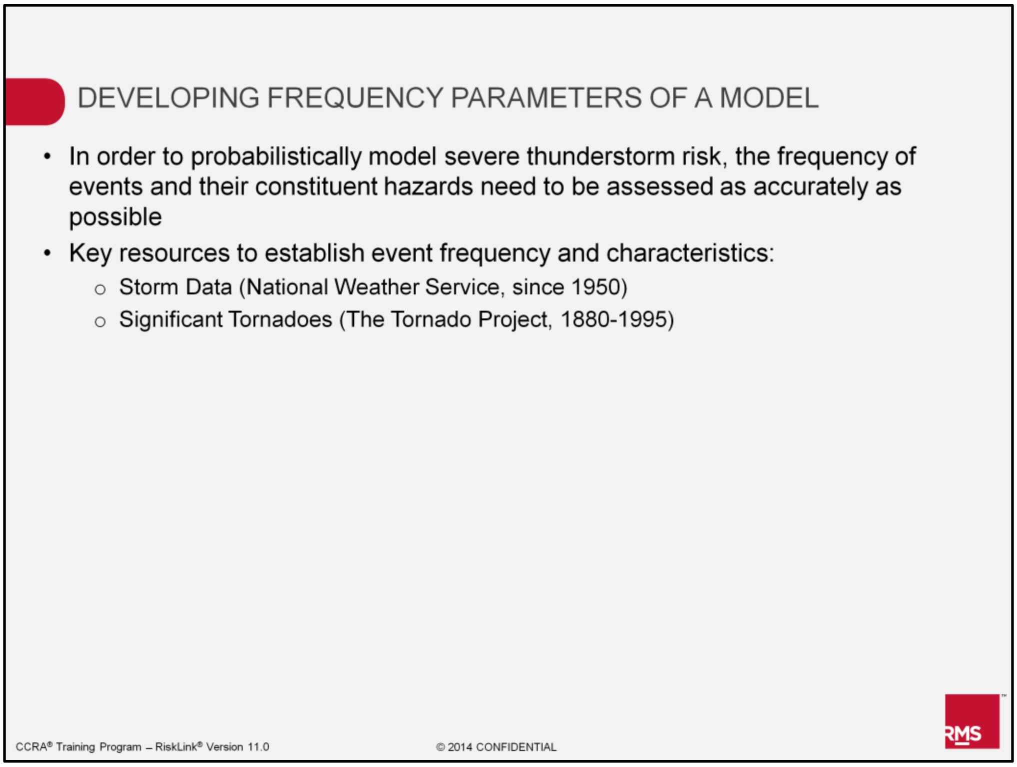
Certified Catastrophe Risk Analyst



This unit discusses the vulnerability module of the severe convective storm model.



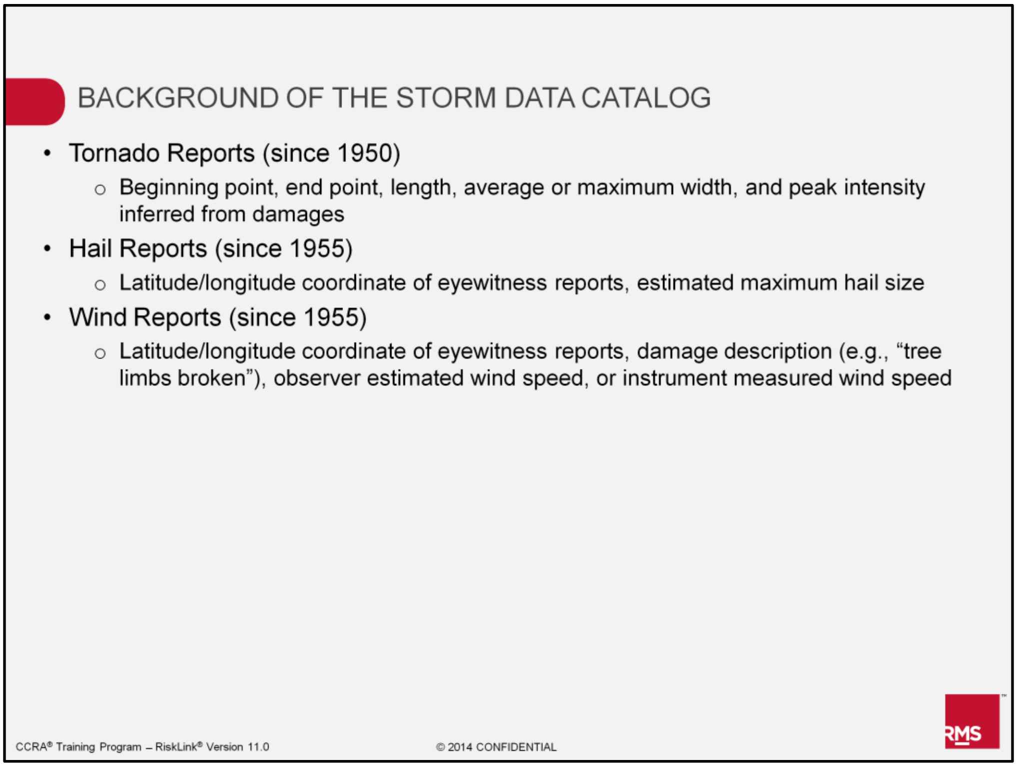
At the end of this unit you should have a good understanding of each of the five learning objectives listed on this slide.



As with all of the peril models, the review of historic data for severe thunderstorms is very important to accurately assess the frequency of tornadoes, hailstorms, and straight-line winds in a given region.

One of the key resources that is used is the Storm Data Catalog. This database has been maintained by the National Weather Service since 1950 for tornadoes, and since 1955 for hail and straight-line wind occurrences.

Another key resource, *The Significant Tornadoes* by Tom Grazulis, is leveraged by RMS in the development of frequency assumptions for tornadoes. This large book, published in 1993, looks at tornado frequency since the 1600s. The most reliable estimates of strong tornado frequency or significant tornadoes, which we would refer to as F2 or greater intensity, are found in the book from 1880 to the 1990s, which is when the project ended.



Next we will talk about the types of information captured in the Storm Data Catalog. This will be helpful later in this unit when we discuss the assumptions that need to be made to supplement that catalog.

Tornado reports in the database go back to 1950. Each report is logged with a beginning point or a beginning coordinate and its end point, creating a tornado line path of a specified length. For some years, there is also information in the database on either an average or a maximum width of the tornado over the length of that path.

In addition, there is a peak intensity that has been inferred from the damages that are assigned to each of the individual tornadoes. Depending on the year, that peak intensity might have been inferred at the time of the event through the damage survey afterward or through a retroactive investigation of media reports and photographs for events that occurred prior to 1971.

Each hail report is based on the location, or the latitude and longitude coordinates, where the eyewitness observed hail and the estimation of the maximum hail size in terms of its diameter. Just as the Fujita Scale for tornadoes is subjective and concerns around the consistency of tornado rankings are evident, there is currently not a consistent and objective means for measuring the full extent of hail that occurs from a thunderstorm.

While the database, which goes back to 1955 for hail, contains a single location where hail was observed, it does not characterize the entire swath or the entire region. Association between that point observation and the area it represents is one of the assumptions that needs to be addressed in a catastrophe model.

Wind reports are very similar to hail in that they are based on eyewitness reports rather than actual measurements throughout the affected area. The observing stations across the U.S. that have wind sensors are far too sparse or are spaced out too greatly to monitor and archive information on straight-line winds reasonably well. The phenomena is small so individual microbursts or downbursts that occur in these systems of straight-line winds are localized enough that it is essentially luck if they happen to pass over a standard observing system. So as with tornado and hail, most wind reports come from eyewitnesses.

It is much easier for an eyewitness to estimate hail size at a location by comparing it to an object he/she might be familiar with, such as a golf ball, a coin, or a softball, than it is to estimate wind speed. Estimating actual wind speed while experiencing it is very difficult. Most of the wind reports either have an estimate that defaults to a round number, such as 55 miles an hour, or damage descriptions rather than any wind speed information. For example, perhaps tree limbs were broken or minor roof damage was observed, and this was noted in the database. Occasionally, there is an instrument-measured wind speed but this applies to only a minority of reports in that database.

CONSTRAINING HAZARD UNCERTAINTIES

- Least uncertain aspects of frequency for these hazards are:
  - Frequency and bounding area of a damaging tornado
  - Point frequency of any hail (hail days) and hail of one inch or greater in diameter (property damage threshold)
  - Frequency and bounding area of a derecho (i.e., catastrophic straight-line wind event)

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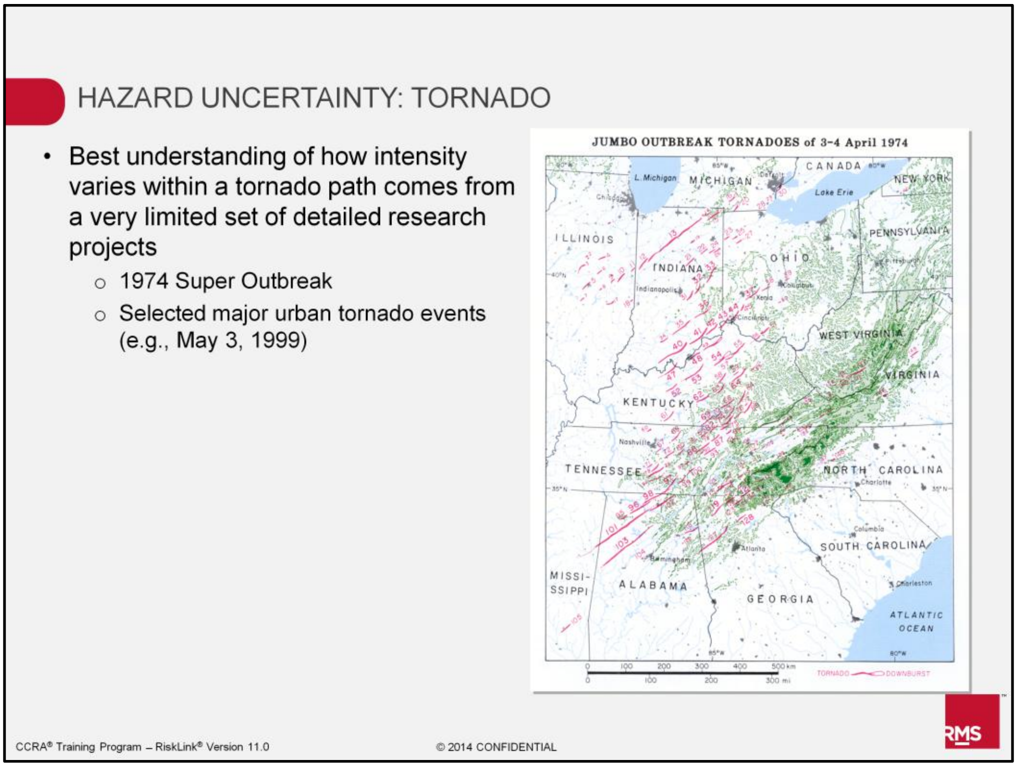
In Unit 1 we discussed examples of certain aspects of tornado, hail, and straight-line win frequency. For tornadoes, we looked at the return period for an F2 or greater intensity tornado affecting a point. This is reasonably well-established based on the database that is available. What is less certain is the frequency of the 200 mile per hour wind speed from a tornado.

For hail, the least uncertain information is the point frequency of any hail occurring at a point. Information that supplements the Storm Data Catalog includes cooperative observers, or individuals who have recorded hail occurrence over time. Most of these were on farms and were related to the ability to make a crop hail loss claim for the farm and the frequency of 1-inch or greater hail on the properties may have been archived fairly consistently. So the frequency of 1-inch hail or greater occurring at that location is fairly reliable.

For straight-line winds, it is the frequency of the bounding area of one of these very intense straight-line wind events, called derechos, that are the least uncertain.

When we look beyond understanding the return period for a given wind speed and the damage it can cause, or the return period for a given hail size, we see that additional research and additional modeling assumptions need to be made that are important for catastrophe risk assessment.



As we proceed, consider how these uncertainties would potentially relate to differences from one model to another and how you would want to understand how those judgments or parameterizations of a model were made before adopting the model.

For any one tornado, the historic database has information on its length, width, and the peak intensity across any point along that rectangle. When we looked at the May 3, 1999, case example in Oklahoma City in Unit 1, the map we showed indicated several intensity contours within the path. So there was significant variation both along and across the tornado path in terms of its intensity.

From a catastrophe modeling standpoint, we need to represent that variation of intensity both along and across a path. Much of that information comes from somewhat limited data sets but there are a large number of reports from those limited data sets that can give reasonable confidence in the assumptions that go into a model. Most of those assumptions come from the 1974 Super Outbreak.

The most widespread and most comprehensive aerial survey of any outbreak was done after that event in 1974 by Dr. Fujita and a large number of his collaborators. It is from that event we derive most of the assumptions on how intensity varies along and across a path of a tornado.

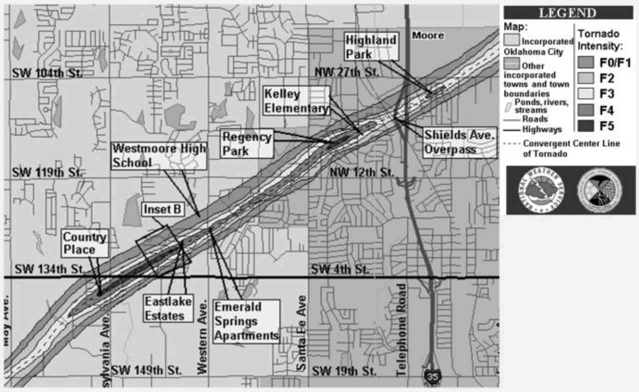
There were also selected major urban tornado events like the Oklahoma City event. On a very selective basis there have been surveys that have mapped the variation intensity within a tornado path like was done in Oklahoma City. Those can also be used to help understand how that variation intensity exists within individual tornado paths.

SPATIAL VARIATION OF TORNADO INTENSITY

- The most intense areas of damage account for a very small portion of the tornado path.

F Rating	% Area
F0/F1	36%
F2	25%
F3	26%
F4	11%
F5	1.8%

Oklahoma City, May 3, 1999



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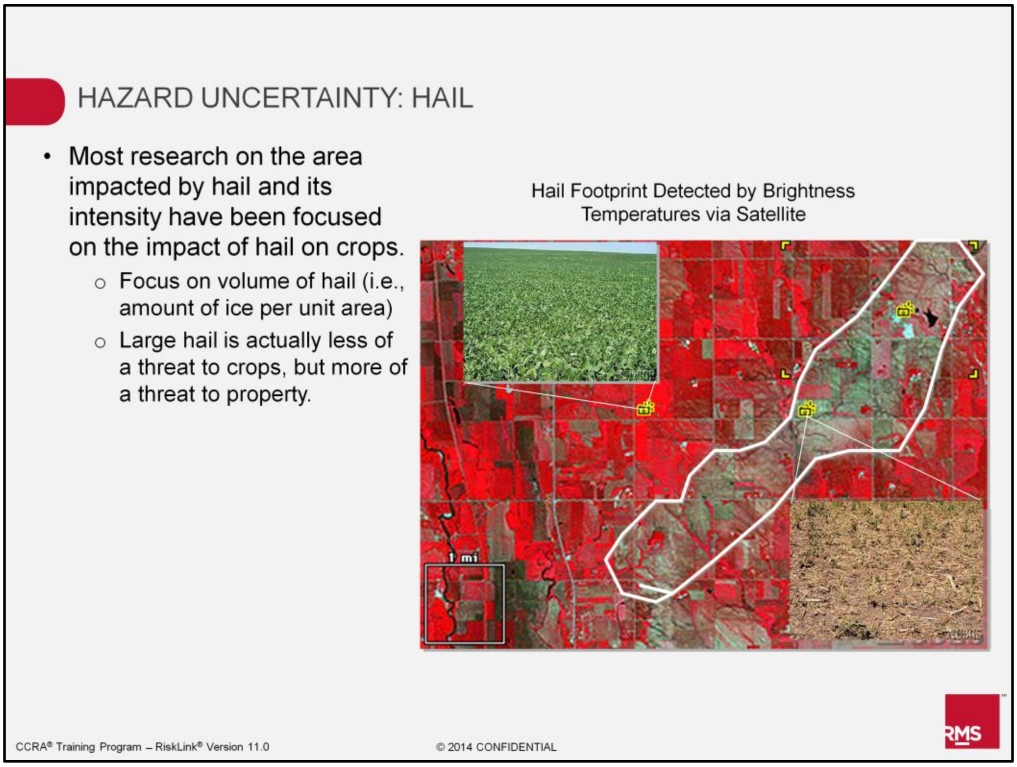
This is another example from that May 3, 1999 tornado, which illustrates how the intensity within this path varies. You can see that there is a dark area of the tornado path in the lower left corner of the image. As you go up toward the right, there is another dark area where there was F5 level damage. Those are very small areas. The vast majority of the tornado path actually consists of F0 or F1 damage and some F2 or F3 damage. Less than 13% of the entire path, which was tens of miles long, had F4 to F5 intensity.

For most applications, it is critical to differentiate between the F0 and F1 portion of a tornado path and the F2 or greater portion of a tornado path. That distinction is a bit more reasonable and more certain when we look at the limited amount of data that can be used to establish these assumptions.

You also need to be aware that there is a significant variation in wind speed and damage across a tornado path. When we look at real-time event situations in Unit 5, keep in mind that many assume every location within an F5 tornado path is a total loss even though there is a significant part of the tornado path that is F0 or F1 intensity. For that reason, assuming a location is a tornado loss if it is hit by a tornado is a conservative assumption.



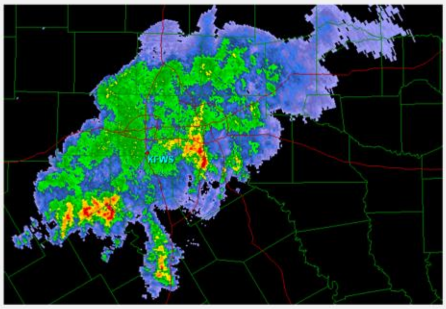
Hail and wind observations are at a location point and so an assumption needs to be made to associate an area with that point. A common approach is to associate or assign an area to a hail report based on the crop damage produced by a hailstorm rather than the property damage.

The image on the right illustrates the differences in damage to vegetation that can exist after a major hailstorm. The white bounding area on this satellite image is the area in which the hailstorm occurred. You can see the different reflectivity, or brightness, relative to its surroundings where there is exposed dirt because the crops have been stripped compared to the neighboring regions. Damage to crops can be assessed either by an individual observer or using satellite imagery.

When making modeling assumptions we must consider the fact that crops are damaged in a slightly different way than property. A crop is more vulnerable to the volume of ice, or the amount of hail. The vulnerability of property is driven by the maximum diameter of hail and the density and fall speed of hail stones; for crops it is driven more by the volume of hail irrespective of hail size. That requires investigation into exactly what we are measuring in terms of an area and whether or not hail damage to crops in that area is representative of the area of hail that is relevant to the property risk assessment.

USE OF RADAR TO STUDY HAIL HAZARD

- Radar emits a signal and measures the intensity of the reflection.
  - Reflected by particles: rain drops, hail stones
  - Hail is visible, and the anvil cloud associated with a thunderstorm leading to a tornado is visible. Wind (tornado or downdrafts/derechos) is not visible.



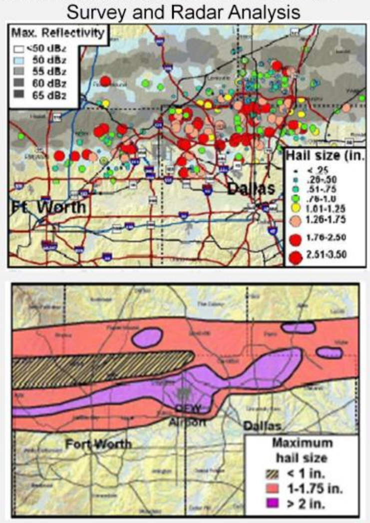
The radar image shows reflected signal intensities. It requires complex post processing and signal analysis before it can be analysed in terms of individual perils.

Additional observing systems, such as weather radar, are becoming available for use as a proxy for a measure of the hail intensity at its breadth. Some approaches that are currently being used to correlate between the detailed land-based or roof-based surveys and insurance claims correlate that physical loss or physical damage information with what we infer about a thunderstorm from radar data. All of those approaches provide a more reliable assessment of the spatial impact of a hailstorm compared to the crop damage estimates mentioned earlier.

HAIL AREA AND HAZARD DISTRIBUTION

- Possible to trace the hail storm on the radar
- The intensity of the radar signal reflection is correlated with the density and size of the hail stones. Therefore, the signal is a measure for kinetic energy of the storm. In itself, it is not reliable to derive hail stone sizes from the radar.
- Interpretation of the signal in terms of distribution of hail stone size and numbers can be calibrated against information from roof damage assessments and review of insurance claims.

Hail Footprint Based on Roof Damage Survey and Radar Analysis



Marshall et al., 2004

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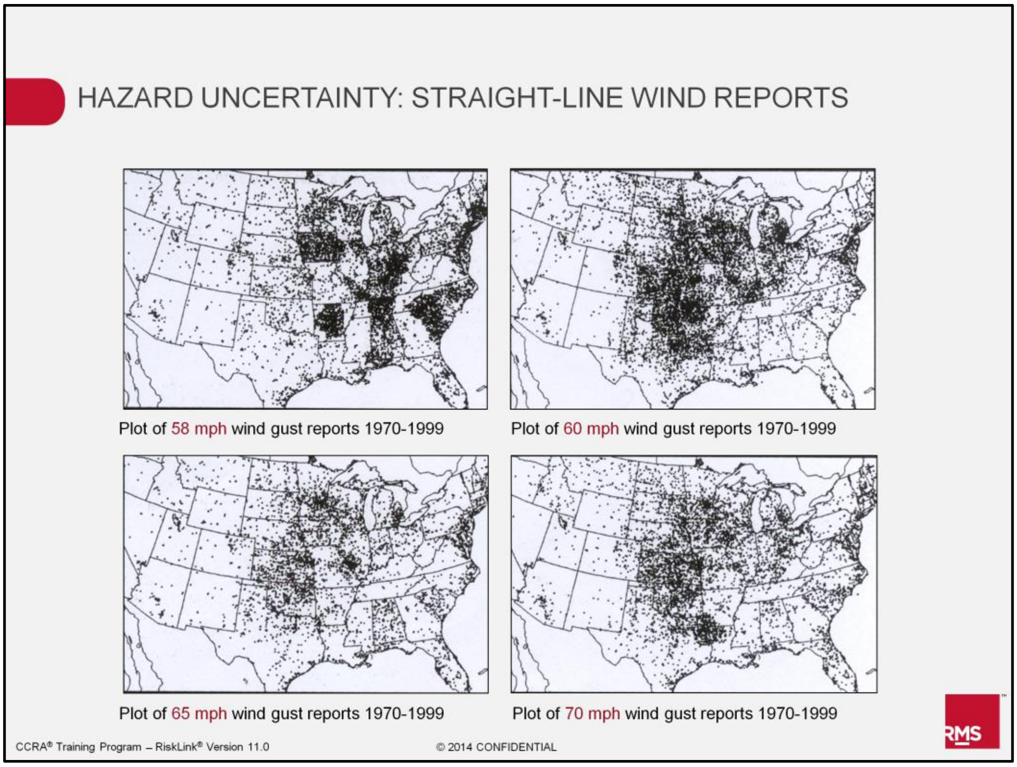
The radar data allows us to delineate the hail storm as it develops and moves. We can build up a picture of the storm over time, and see where hail fell. The signal indicates the presence of hail aloft, so we have to factor in a small shift where the hail is driven by wind before it hits the ground. This is clearly visible when comparing radar reconstructions of a hail storm with damage observations (e.g., from claims).

The intensity of the radar signal reflection is driven by both the size of the hail stones and their density. This means that radar data is not sufficient in itself to indicate the hail stone size of a storm. However, the combination of stone size and density is a good indicator for the kinetic energy of a hail storm, which is highly correlated with the damage. By combining damage surveys with radar images, we can build up expertise in the prediction of damage from kinetic energy. Since the spread of hail stone sizes within a storm is very large, the uncertainty bands on classification of energy from a radar signal is also large. This is a reflection of the natural variability of hazard within a hail storm, and this will be directly reflected by the hazard.



Next we will talk about straight-line winds. You may have observed that there is some variability in how different models handle straight-line wind reports and the modeling of those straight-line winds. Some reasons for why that variation exists and some understanding around what some of the challenges are in modeling straight-line winds will be discussed next.

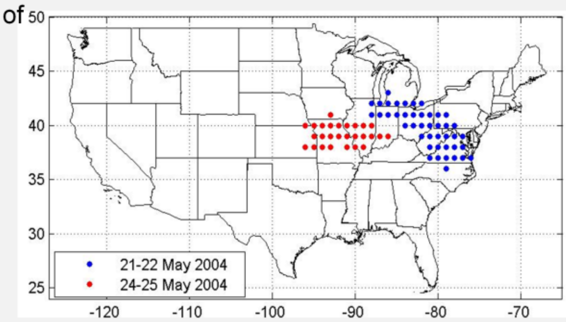
The maps on this slide are produced when the National Weather Service (NWS) reports are plotted. Each of these reflects the eyewitness reports of a wind speed that meets the threshold at a given coordinate. The only difference between each of these maps is the threshold of wind speed considered to map the reports.

The map in the upper left shows all the reports for wind gusts greater than 58 miles per hour between 1970 and 1999. What becomes immediately obvious on this map is that there are substantial biases in the way individual National Weather Service offices (which have responsibility for some counties within a state) in states like Iowa and parts of central Arkansas have cataloged reports of straight-line winds compared to their neighboring NWS office in the next county warning area.

Biases are noticeable on all of the maps on this slide. These show that there are some anomalous features in this database that make it incredibly challenging to use in a reliable way for catastrophe modeling.

WIND EVENT IDENTIFICATION CRITERIA

- Derecho: a concentrated area of convectively induced wind gusts > 26 m/s with major axis length >= 400km.
  - No check of wind speeds
  - Either N-S or E-W axis >= 400km*
- The wind reports must have chronological progression .
- No more than 2.5 hrs can elapse between successive wind reports.
- There must be at least 3 reports of either F1 damage or wind gusts > 33 m/s separated by at least 64km.
- The associated MCS must have spatial and temporal continuity.
  - Adjacent reports must be within 2º latitude and longitude of each other.



* *Indicates configurable parameter*

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This slide shows a set of criteria that can be applied to severe wind reports to detect and designate a severe wind event. A derecho would be the most extreme case, but the range of potential damage causing wind events starts from individual downbursts and ranges up to a derecho. Therefore, it is important to understand which class of events is covered by a catastrophe model. Most severe wind reports do not include exact wind speed measurements, but assumptions about the wind speed can be made based on the damage report. Where anemometer measurements are available, they improve the certainty of the scale and severity of the event and can compensate for some of the biases in the report data.

IMPLICATIONS FOR FREQUENCY DISTRIBUTION AND RISK ASSESSMENT

- Due to the inherent uncertainties in the data, interpretations of the catalogs and additional data sources used to supplement the Storm Data Catalog are critical to a model's reliability.
- In addition to the use of a wide range of available scientific resources, calibration and validation of severe thunderstorm models with insurance data is critical to ensure that judgments in hazard frequency are reasonable.

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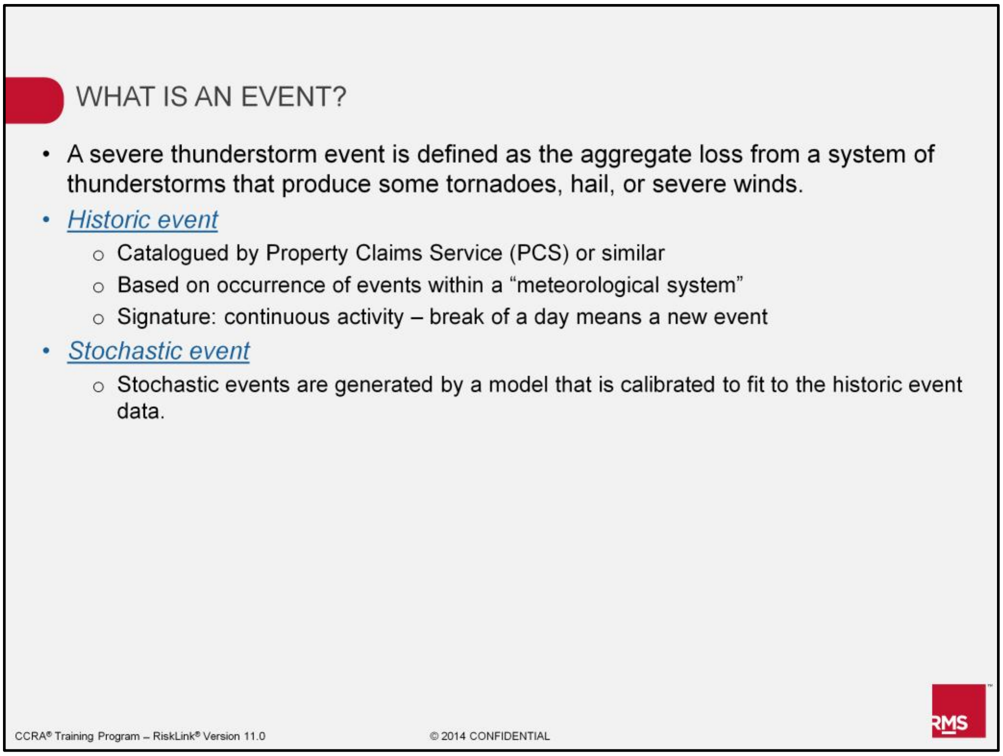
The interpretation of these catalogs and the data sources that are used to supplement the catalogs are critical to the reliability of any one model. Well-informed users of severe thunderstorm models should seek to understand how the model was developed and how these uncertainties in the historic information were addressed.

How that model has been calibrated and validated is critical. Validating against actual claims data, along with hazard information, is useful for calibrating loss amounts as well as serving to further calibrate the hazard component in areas where assumptions between an area for hail and wind are not very well known.



The remainder of this unit will focus on how events are characterized, the outbreak construct of an event, and the implications that event-based modeling approach has for how the model is applied.

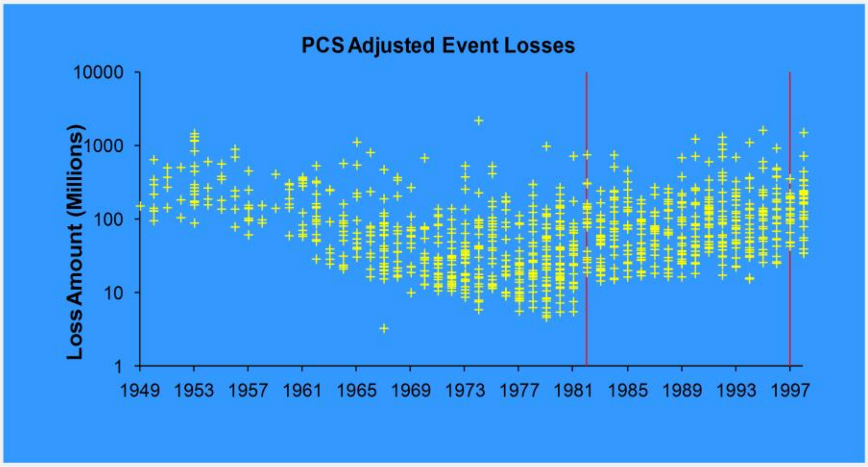
A severe thunderstorm event is defined as an aggregate series of thunderstorms that produce loss that contain some tornadoes, hail, or severe winds. That is how most catastrophe models typically will define a severe thunderstorm event, having these three hazards explicitly or implicitly captured. The RMS Severe Convective Storm model includes the risk of lightning, which accompanies severe thunderstorms.

The historic catalog, which includes reports for tornado, hail, and straight-line wind, can be segmented into a number of different "catastrophic" events. One difference that exists between severe thunderstorms compared to other wind perils like European windstorm or U.S. hurricane, is that a severe thunderstorm event is not named and the beginning and the end are not clearly defined. Because of that, there can be differences in how various business applications and catastrophe models define an event in terms of its duration.

Catastrophic events are "named" by loss bureaus, who also collect industry losses from these events. Property Claim Service (PCS) is an example of a loss bureau which is widely used in the insurance industry. PCS events are based on activity associated with distinct, large scale (continent-wide) meteorological systems. If simultaneous or continuous thunderstorm activity occurs within a synoptic scale system, this is classed as an event. Thunderstorms associated with different systems can occur simultaneously, but would be classed as different events. Looking at the catalog, this is quite rare, however. Mostly, activity occurs continuously over time, possibly over a huge geographical area, and a lapse of time (e.g., a day) would signal a break between events. From historic events, parameters are derived based on the spatial construct of the event, how that outbreak is configured geographically, and what characteristics it has to simulate stochastic events.

ANNUAL NUMBER OF CATASTROPHIC EVENTS

- There are approximately 25 severe thunderstorm catastrophes each year, once trends in the data catalog are removed.



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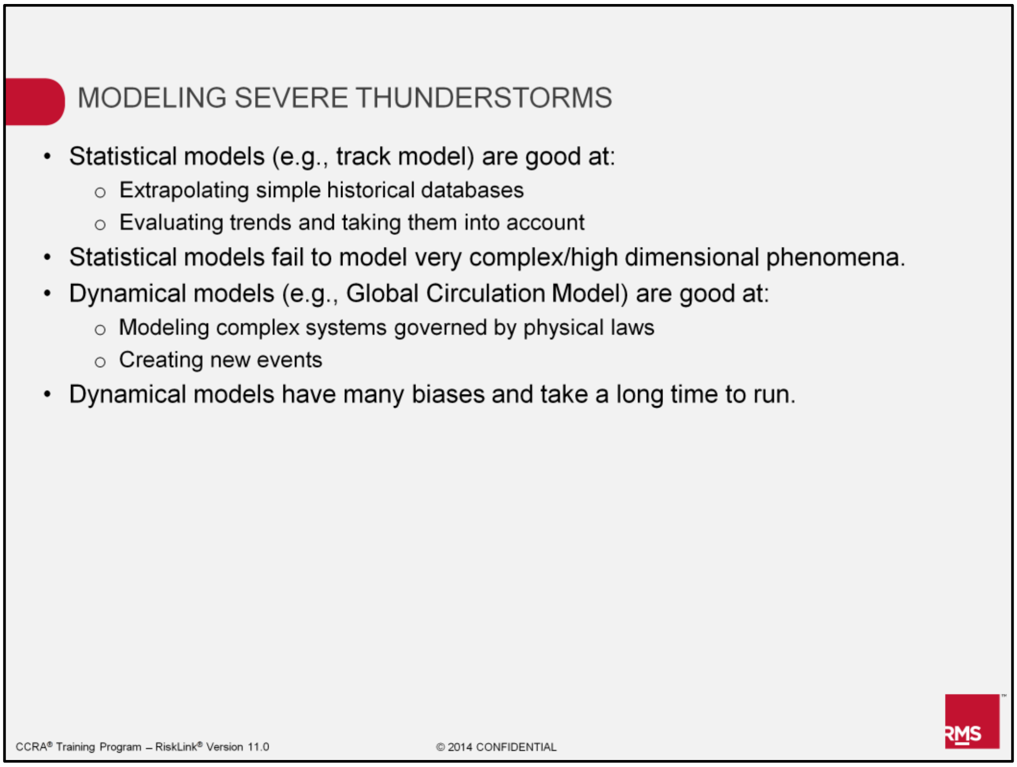
Here we are looking at estimates of loss from PCS. Going back to roughly the time period where the Storm Data Catalog begins, 1950, we adjust all of those losses for estimated changes and exposure over time, and then calculate the average number of events at a catastrophic level in a given year

The key point here is that there are approximately 25 severe thunderstorm catastrophes each year on average. These are very high frequency phenomena at a $25 million threshold in today's definition for loss on an industry level for all lines of business in the U.S.

There are a lot of events that may not reach a catastrophic level in between those catastrophes that contribute to the aggregate loss. When you look at individual catastrophe model output and look at the number of events in a given simulation year, it would be a number that is quite a bit higher than this because many events that are not catastrophic in their intensity, but are significant for the consideration of the aggregate annual loss, are included.

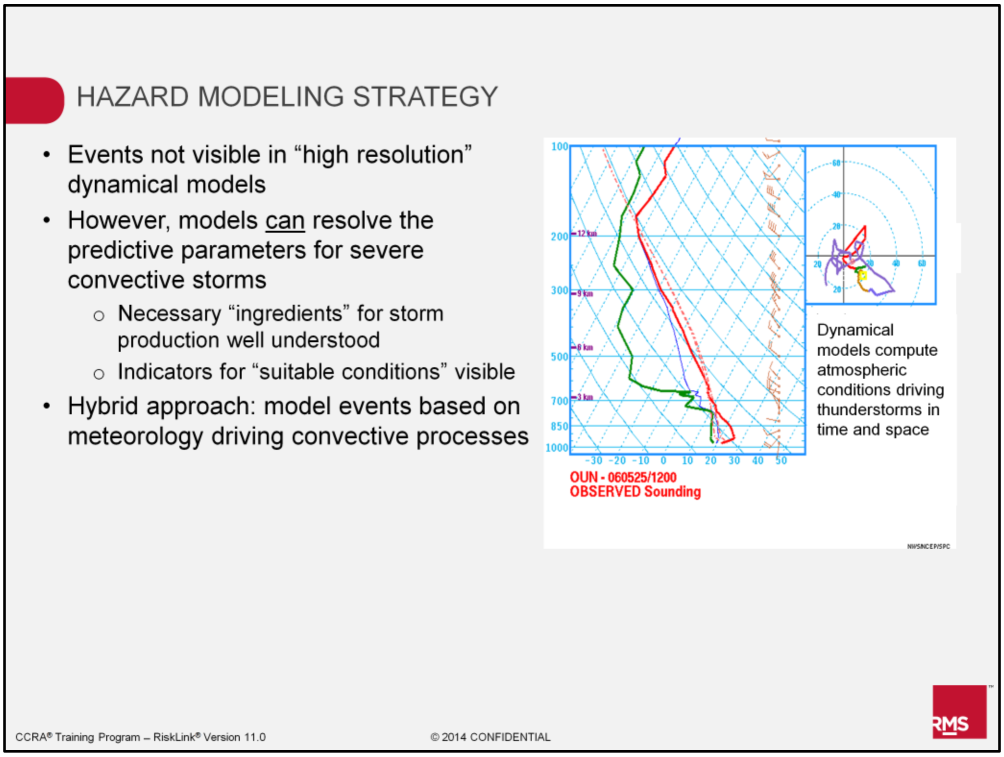


Now that we have seen what kind of data is available, we will look at ways to model severe thunderstorms. Generally, two types of models are used to model these kind of processes. It is important to understand the advantages and disadvantages of each type.

Statistical models have historically been used to model processes and trends in all sorts of disciplines, including risk modeling. For instance, the RMS hurricane track model is a statistical model, and so was the Tornado/Hail model (up until RiskLink 7.0). Statistical models are very powerful tools for analyzing observations, and are good at evaluating trends and extrapolating historical data. However, they can be less good at capturing very complex processes.

In recent years, risk modeling has increasingly made use of dynamical models, which are developed in meteorology for weather forecasting and climate modeling. Dynamical models are highly complex mathematical models that simulate the laws of physics in the natural system. Natural phenomena such as hurricanes, winter storms, and thunderstorms are governed by these physics. Therefore, these models can be very good at capturing the complexity of such events. For instance, the RMS winter storm model relies on a dynamical model to ensure the highly complex footprints are realistic. However, despite the advance in the science, dynamical models still have significant biases, and their results need to be interpreted carefully. Moreover, they are computationally very expensive to run.

Now that we have seen the types of models used in risk modeling, we will look at the RMS thunderstorm model.



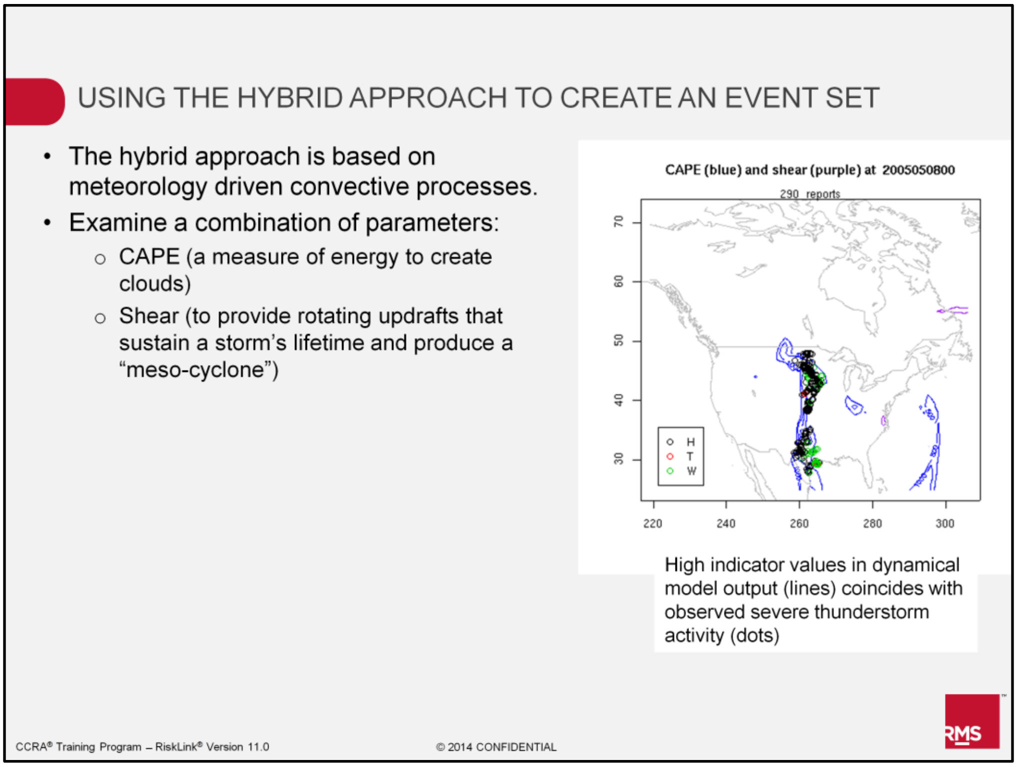
Next we will look at why it is important for a severe thunderstorm catastrophe model to physically look at individual events and to simulate the physical event. We have seen that historical events consist of continuous activity of individual tornadoes, hail, wind, and lightning over a series of one to several days. These events can occur over large areas. We need to be accurate in how we model these events over time, and equally be accurate in how we model their spatial pattern.

It is important to understand the correlation of risk between two individual locations or two cities. Outbreaks of tornadoes, particularly multi-day occurrences, can affect more than one metropolitan area at the same time. Users have to apply catastrophe models not only with an understanding of the portfolio risk but also to determine the correlation of risk between different areas within that portfolio. The complexity of thunderstorm outbreaks would seem to make it a prime candidate for a dynamical modeling approach.

However, due to the nature of the convective process, these events are not visible in most dynamical models. It requires a model with a resolution of about a meter or less to capture these events accurately. The development of dynamical convective event models is still very much an advancing field of science. It is not feasible at this stage in their development to use these models to generate stochastic events on a continental scale. Apart from the need to understand their biases, it would simply be too computationally intensive and expensive to run these models.

Still, convective event modeling presents a challenge for a purely statistical approach. First, the development and occurrence of convective events is highly complex. We saw earlier in this unit that available data is heavily biased and contains many errors. Therefore, RMS has taken a hybrid approach for the most recently released convective storms model. This hybrid approach relies on the following. The physics of convective processes driving the thunderstorms are well understood. While convective processes themselves are very localized and operate on a small scale, there are indicators for these convective processes that are modeled accurately by larger scale dynamical models. Therefore, the hybrid approach uses the indicators of convection as a proxy. This way, we can capture the complexity of the process, and also overcome the biases in the observations. We use statistical models to forge the link between the proxy, from output from a dynamical model, to small scale, high resolution thunderstorm footprints. We will look at that process in more detail in the next few slides.

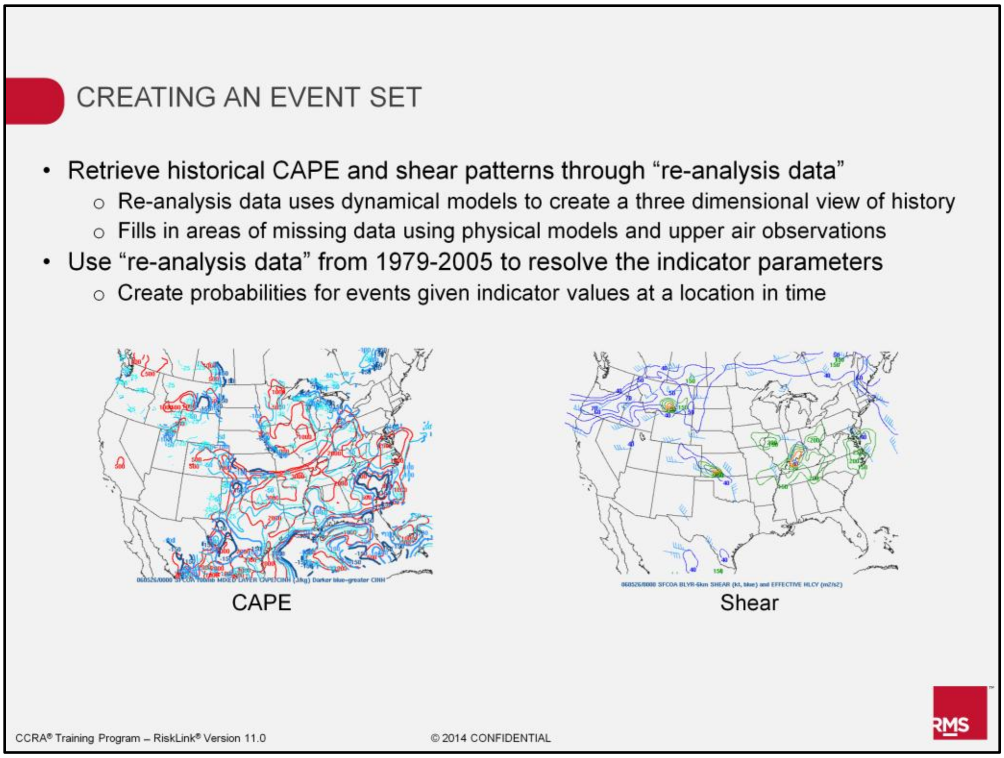
In summary, there are many advantages of using a hybrid approach. We can capture highly complex patterns occurring in nature in convective storms, and we can model events where no observations have been made, or the observational record is flawed, such as in less densely populated areas. Finally, the model is less susceptible to population biases in the historical record. This hybrid approach implements recent advances in science to simulate more realistic event footprints.



Next we will focus on how a hybrid approach uses dynamical model output to model thunderstorm events.

First, let us quickly recap a few facts about thunderstorm development that were already discussed in Unit 1. For a severe thunderstorm to develop, there has to be sufficient warm, moist, rising air, and a moderate to high wind shear (that is, wind speeds that increase substantially with increasing height). This process is captured by two quantitative parameters: the convective available potential energy (CAPE) and the shear. We use these parameters as a convective indicator, as jointly high CAPE and shear values make it more likely that a thunderstorm will occur. However, thunderstorm activity is not a certainty under those circumstances. This is also why severe weather forecasts only give warnings. Based on extensive analysis of observations and atmospheric conditions, we can model the probability that any combination of CAPE and shear leads to a thunderstorm. This (statistical) model takes into account seasonality and location, since high indicator values in the south of the U.S. in winter have a different probability of an event actually occurring than in summer.

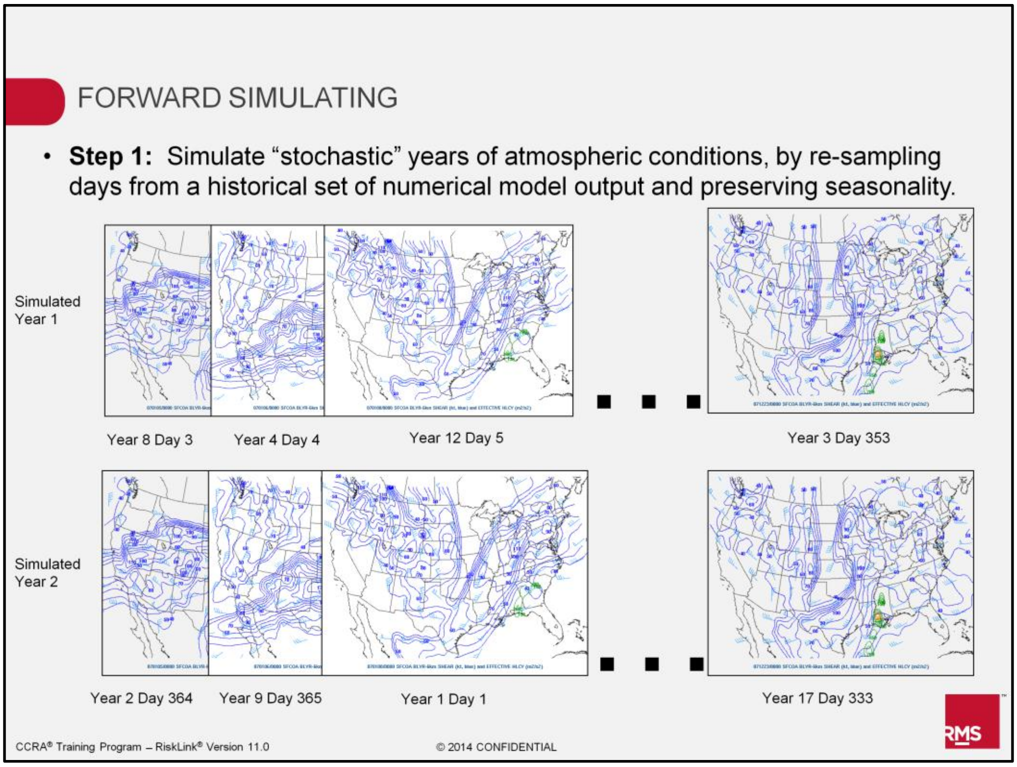
We now look at the use of dynamical models in the hybrid approach. A dynamical model representation of the atmosphere will evaluate the CAPE and shear value at a location at a given time. We can therefore use the convective indicator values in the output from a dynamical model to model the probability of thunderstorm activity across the North American continent in time.



RMS uses dynamical model output in the form of re-analysis data. Re-analysis data is produced when state of the art dynamical models are used to analyze the atmosphere, continually assimilating all observations available. The model output creates a four dimensional reconstruction (in space and time) of the state of the atmosphere going back into history. The continual assimilation of observation in this process minimizes bias and model error.

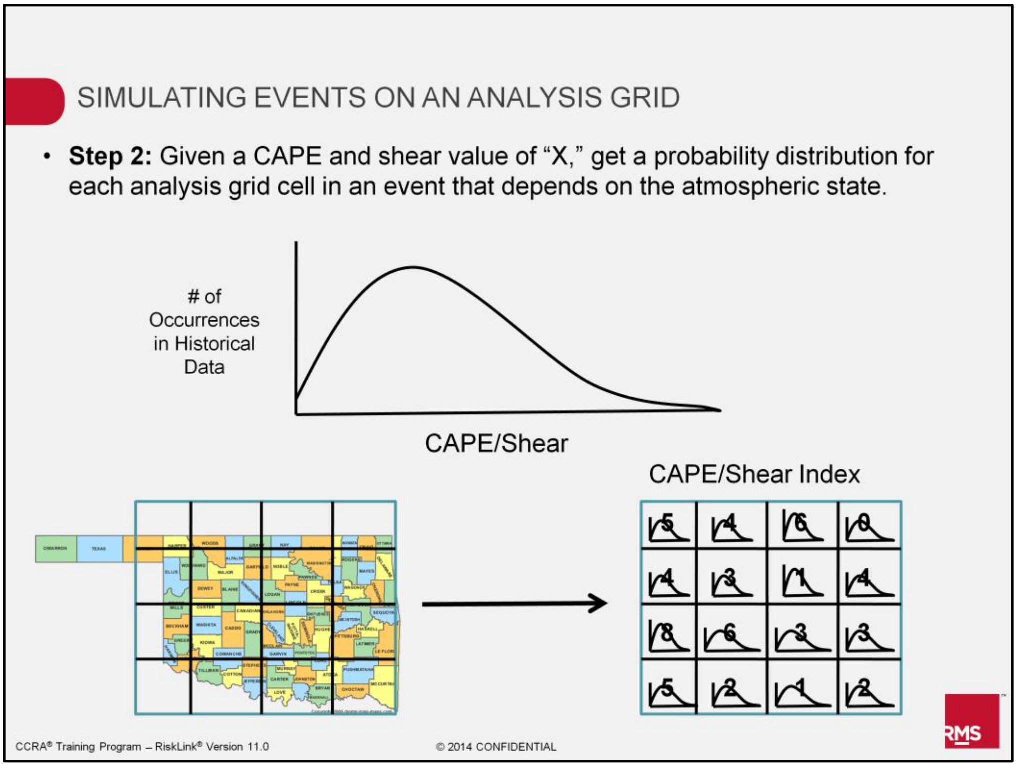
The RMS Severe Convective Storm model uses re-analysis data from the period of 1975-2005, from a model focused on the North American continent. We use this data to calibrate the RMS model for the probabilities of events at locations throughout time. This data is then used to simulate stochastic events.

The indicator values give a high-dimensional view of the structure and complexity of thunderstorm events. They do not tell us exactly where individual tornadoes occur, but we know that the final pattern of events has followed the areas with high indicator values. Therefore, monitoring the indicator values allows us to see the continental scale and pattern of the event, and its development over time. The pattern of these events is highly complex, but when analyzed through the indicator values it becomes more predictable. Since this large scale also drives the correlation of these events, the modeled events will be realistic.

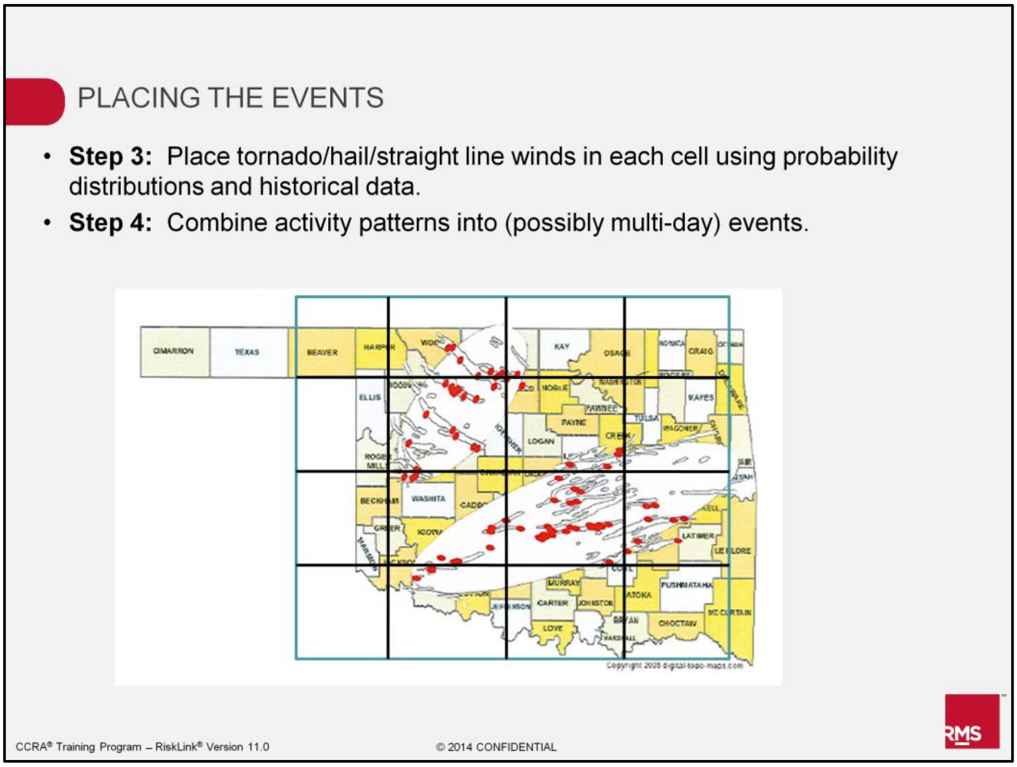


When simulating an event set, a series of simulated years is generated. Each simulated year consists of 365 days of re-sampled data. We re-sample each simulated day from all years available from the re-analysis data. However, we do sample from a restricted set of days centered on the target date, since the indicator values show strong seasonal variation. For instance, when sampling a January 1 day, we can pick any day from December and January throughout all years observed. However, we cannot pick a July day. And the beginning of December and end of January would be more unlikely to occur in the sample than the days immediately on and around January 1.

In order to preserve spatial and temporal correlations in the events, blocks of days, rather than individual days, are sampled. There is no guarantee that subsequent blocks come from the same year or month. This means that the final simulated year is an entirely unique sample of the convective indicator values over the year. It may be an extreme year, with continuous high levels of activity starting early on in the year; or conversely, it may be a quiet year, with not much activity except for high summer.

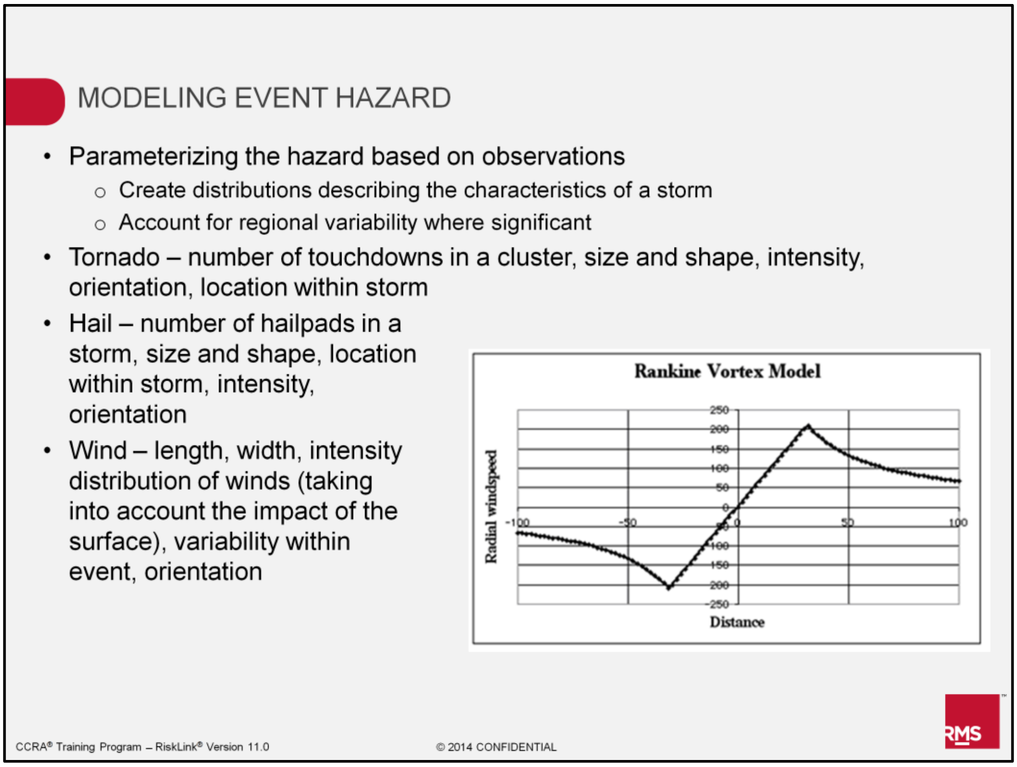


After creating a time-series that consists of re-sampled days, the probability model is applied to this simulated time-series. For each location, we have values of the convective indicators CAPE and shear throughout each simulated day. This joint indicator value determines the probability of an event occurring at that location. We sample a set of locations where events will be simulated, and we sample these from all locations, weighted by their probability. The most active regions will have the largest weight, and therefore are most likely to be sampled, i.e., "hit", by an event. In contrast, regions with low activity will get a low weight, but still stand a small chance of having an event. As long as events are simulated for a sufficiently long time-series, we can be sure that all regions that have a chance of convective events will eventually see one. This is important because it ensures the model has a fair representation of convective storms in all areas in the U.S.



Having sampled events throughout the simulated time-series, the next step is to fill in the high-resolution picture of what these events look like. This is done using parameterizations of high-resolution observations, where available. The hazard is put on a grid, which is much higher resolution than the re-analysis data. More about grids and event scale will be discussed later in this course.

It is important to note that this method does not place events where they have been observed. Although the simulated day is based on re-analysis data from an actual day in history, the event observations from that historical day are not used to allocate stochastic events. The stochastic events can be in different locations and this allows for the fact that convective events are not a certainty given high indicator values. They can be in locations with high indicator values where no events have been observed before, perhaps because there was not sufficient population density to observe events in the past. However, they *could* be in the locations where events have been observed before. Because many such locations are sampled to create one stochastic event, the final event is almost certainly “new”. The final step is to designate events.

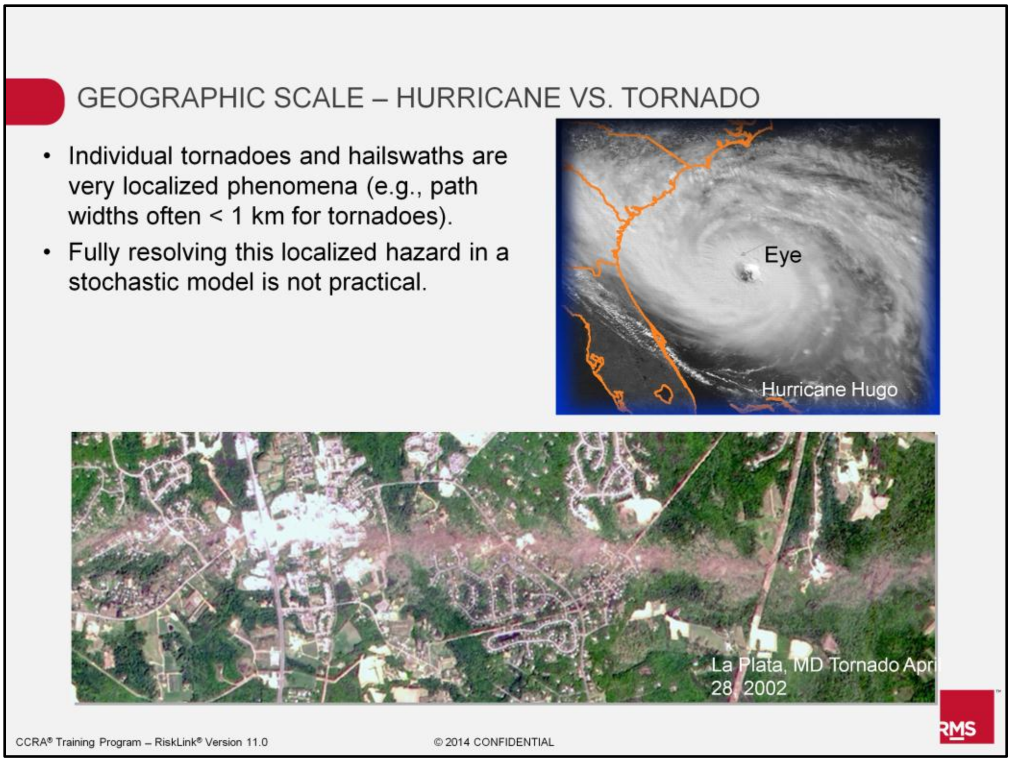


The observations on which the high resolution hazard is parameterized use all available information as detailed in the first part of this unit. Where significant regional variation exists, this has to be incorporated in the model.

A storm is modeled in an "idealized" form, but this does not mean that the model is unrealistic. The complexity of the parameterization determines how accurately the events will resemble reality. By sampling from distributions, we include the natural variability into the sampling process. This means that the resulting storms are not all shifted reproductions of a few observed storms, but reflect the range of events that will occur in reality, given a long enough observational period.

The modeling of tornado clusters is based on the strongest tornado in the cluster. This is sampled first, and this then determines the number of touchdowns. After that, there are statistical models for the size distribution of each intensity class, as well as their orientation and placement within the storm. We use a physical parameterization for vorticinal wind speed to allocate the intensity of wind within the touchdown.

When parameterizing winds, we have to take into account the impact of the surface roughness on the wind. Where surface roughness is high, the winds tend to be lower. RMS has a high resolution model of the surface roughness all over the North American continent, which is based on satellite imagery of the land surface.



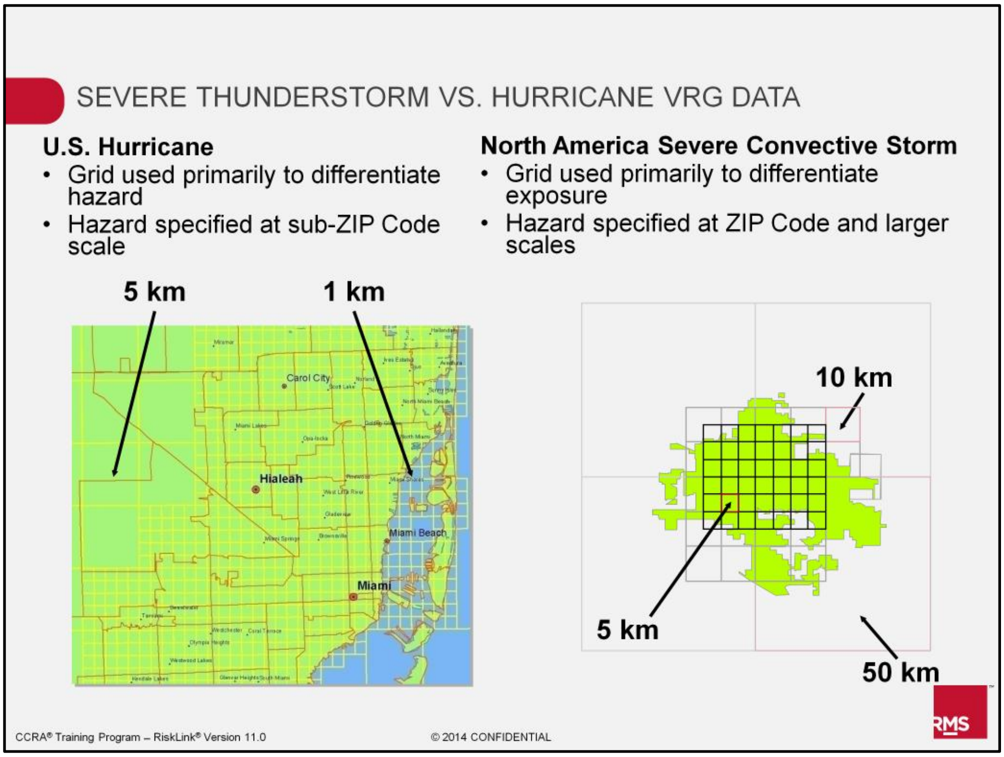
Next we will talk about how a model can be applied once an event set of 60,000 events has been created. One of the more illustrative examples is to contrast between hazards. You may be more familiar with using a hurricane model versus a tornado model. The scale of those events and how they need to be modeled puts them at opposite ends of the extremes.

The example shown in the upper right is Hurricane Hugo. The scale of its wind field footprint will be on the order of several states. As was seen in the 2004 season, one hurricane can affect half to even two-thirds of the state of Florida, as well as other states. Hugo also affected a large part of the Carolinas. So it is a very large scale event spanning hundreds of kilometers.

The image on the bottom illustrates the scale of a tornado outbreak. Here we are seeing a scale that represents neighborhoods instead of states. Some homes in one block were affected by the tornado and others in the same subdivision were not. This is a very fine-scale phenomenon.

When simulating a large number of tornado events, it would require hundreds of millions if not billions of events to represent all the possible configurations of tornadoes that could affect an individual location based on its intensity, length, width, and orientation.

Using an event-based model to resolve local hazard in a stochastic event set is not practical or feasible but the event-based modeling approach is critical in understanding the correlation of risk between different geographies.

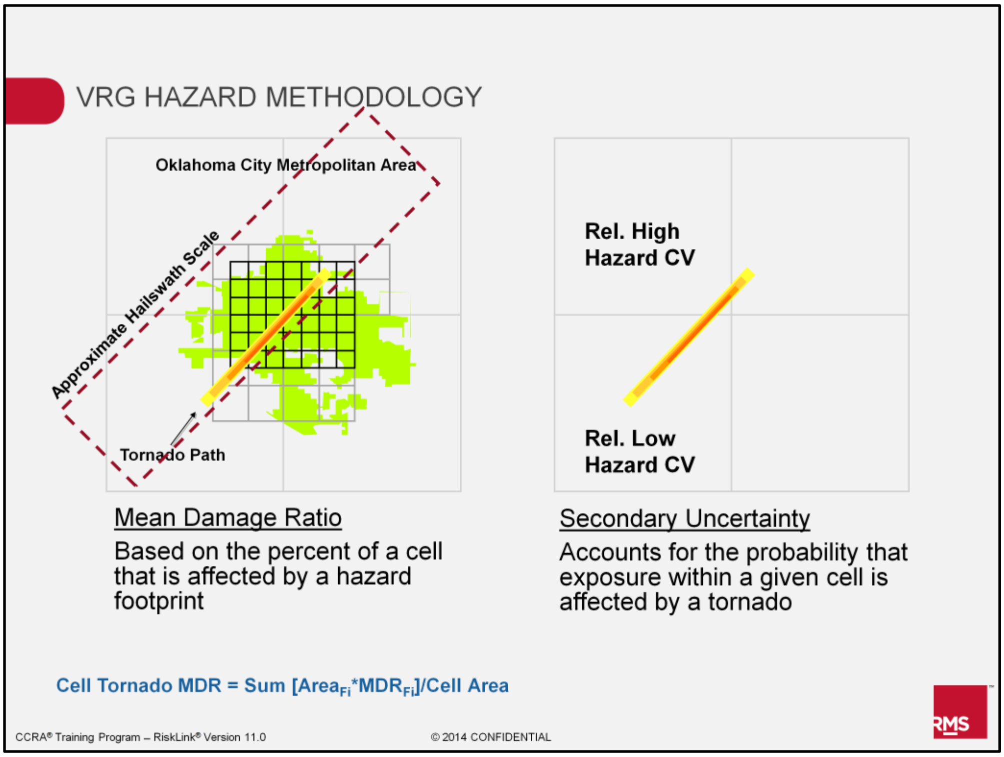


Hazard information for severe thunderstorm models is aggregated up to a higher level or to a lower resolution, which is shown on the right. We then use that information to differentiate between exposure concentrations rather than to differentiate between hazard gradients, which is common for hurricane modeling.

On the left is an example of how a cell pattern is implemented for a U.S. hurricane model around Miami. That cell pattern is used to store information on wind speed in a given hurricane, which varies between one and five kilometers in the hurricane model.

If we were to take a severe thunderstorm model down to a 1-kilometer resolution, tornado paths would only take up a small segment of that cell. To resolve the tornado hazard we would need cells that cover the entire U.S., or at least major urban areas in the U.S., and go down to a resolution of tens of meters. This would require a stochastic event set to match a high-level of modeling resolution that covers the entire U.S., which would be highly impractical.

Instead, that hazard information is aggregated up to represent the differences in exposure concentration within an urban area. The resolutions that are used are shown on the right. The green area is the Oklahoma City metropolitan area. These are the different hazard resolutions at which exposure gradients are resolved in our severe convective storm model.



The mean damage ratio is calculated based on the percent of a cell that is affected by a hazard footprint. The example on the left shows a hypothetical tornado path that passed through Oklahoma City, not unlike the May 3, 1999, event. In some of these grid cells only a portion of the cell is affected by the tornado. On average, the loss to that cell is equal to the damage ratio from the tornado, multiplied by the percentage of the area of that cell that is affected, multiplied by the total exposure in that cell.

Since not every location in that cell is going to be affected, there is uncertainty as to whether or not any one location is going to be hit by the tornado. The uncertainty in the vulnerability is specific to the severe thunderstorm model, which is different than what you would see in other models. In other words, given an impact by a tornado, there is uncertainty in how that building will perform, which we represent by a standard deviation in the mean damage ratio. We also account for uncertainty in the fact that there may not even be an impact on that location at all.

The example on the right is showing a tornado with a different type of grid cell layout. There is a very small percentage of the cell on the upper left that is affected by this tornado, so there is a very high amount of uncertainty that any one location in that cell will be affected by that tornado. This high uncertainty is accounted for in the standard deviation of the event loss. The cell on the lower left would have lower uncertainty that a location would be affected because more of the tornado affects that cell.

It is important to know that applying the severe thunderstorm model in RiskLink 11.0 requires you to focus on the output from a distributed mode analysis, or one that accounts for secondary uncertainty. Because that is a critical part of how it has been designed and constructed, it is important to use the model in an appropriate and reliable way. The expected mode option in RiskLink, which would focus only on the mean loss and not the uncertainty in that mean loss, should be ignored for this reason.

The underlying assumption in this process is that within a given cell, the distribution of exposure is uniform. So when we apply this percentage in the cell affected to the calculation, it is assuming the exposure distribution within any one cell is uniform. That is a reasonable assumption in most urban areas where a cell resolution is fairly small, but that can be reviewed before using the model to understand how reasonable that assumption is on your individual portfolio by using an accumulation analysis. That is a very valuable way to supplement the tornado risk assessment. Looking at risk not only from the point of view from an EP or exceedance probability analysis but also from an accumulation standpoint assesses this fine-scale feature that is very rare or has a very low probability.

When we look at the other hazards, hail and straight-line winds, where the footprints of events are considerably larger than tornadoes, that difference in cell resolution versus hazard area is not a concern because the hailswath area itself is much larger than that fine-scale feature for the tornado. The overlay on the left shows the approximate scale of a hailswath that might affect an urban area.

INTERPRETING AND MODELING THE HISTORICAL RECORD
KEY CONCEPTS

- Key sources of historical data on severe storms include the Storm Data Catalog and *The Significant Tornadoes* database.
- Population biases exist in the reporting of tornados .
- The main sources of hazard uncertainty include understanding how intensity varies within a tornado path, determining hail volume vs. hail size, and substantial biases in the cataloging of reported straight line winds throughout the country.
- Clustering is important to capture in order to determine the correlation of risk between different areas of the portfolio.
- Individual events are very localized; however, the hazard data is aggregated to a higher level, adding to the uncertainty of whether or not an individual location will actually be affected or not.

CCRA® Training Program – RiskLink® Version 11.0

This slide summarizes the key points from Unit 3. If any of these points are unclear, please revisit the associated slides within the unit.

