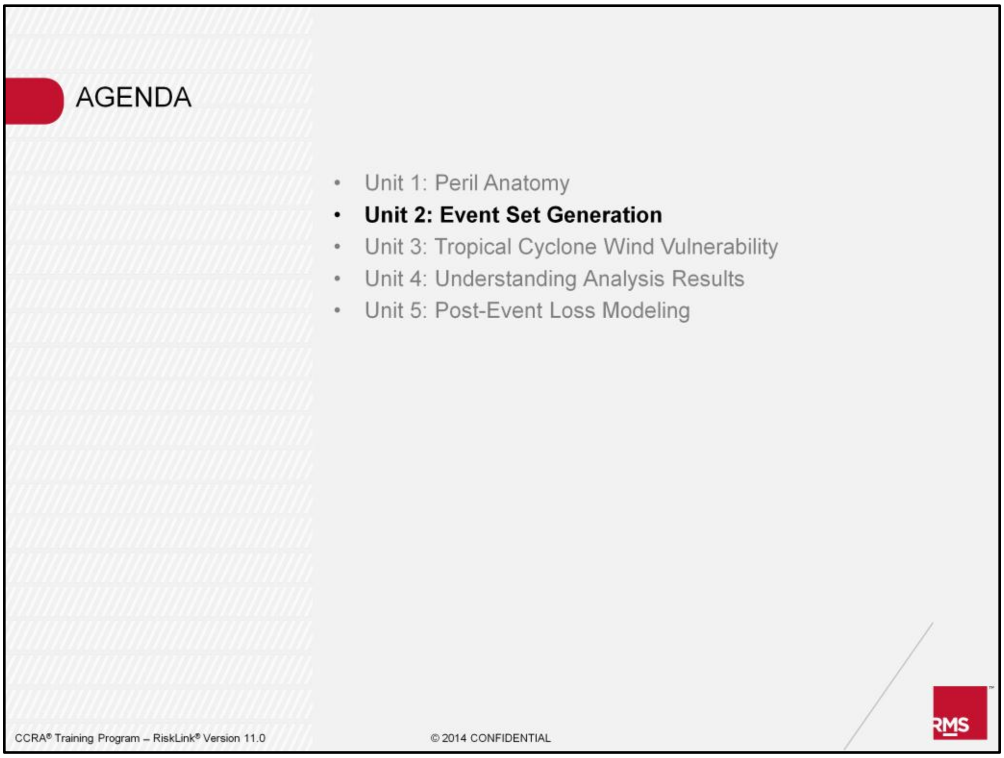
TROPICAL CYCLONE MODELING

UNIT 2

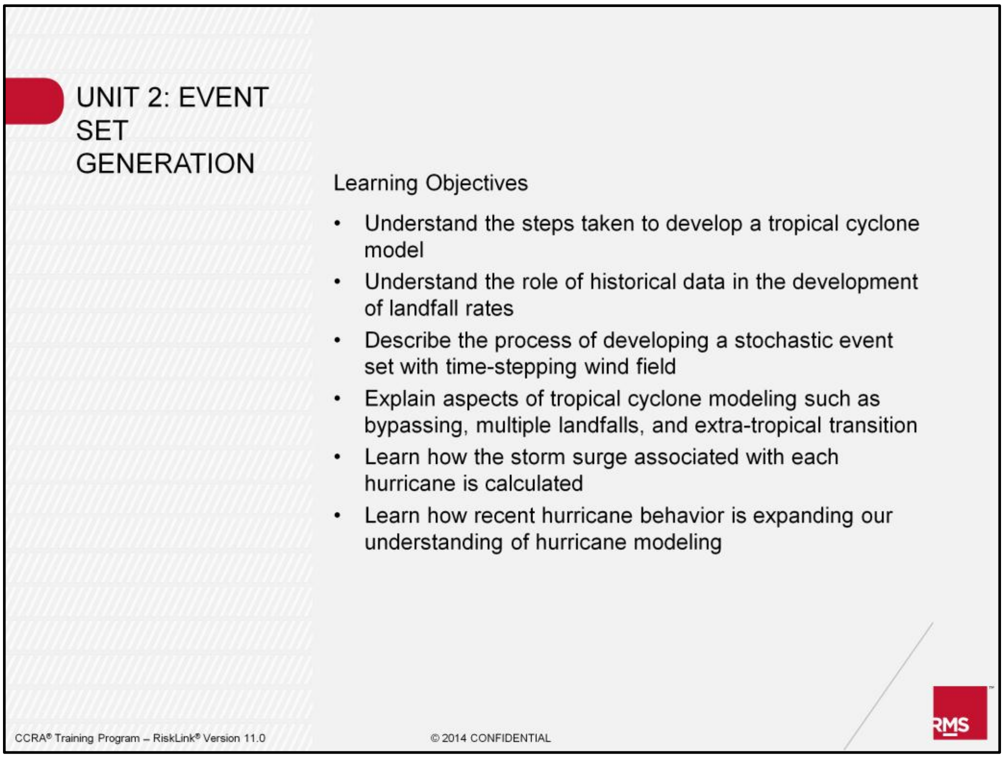
RMS® CCRA® Training Program

Certified Catastrophe Risk Analyst

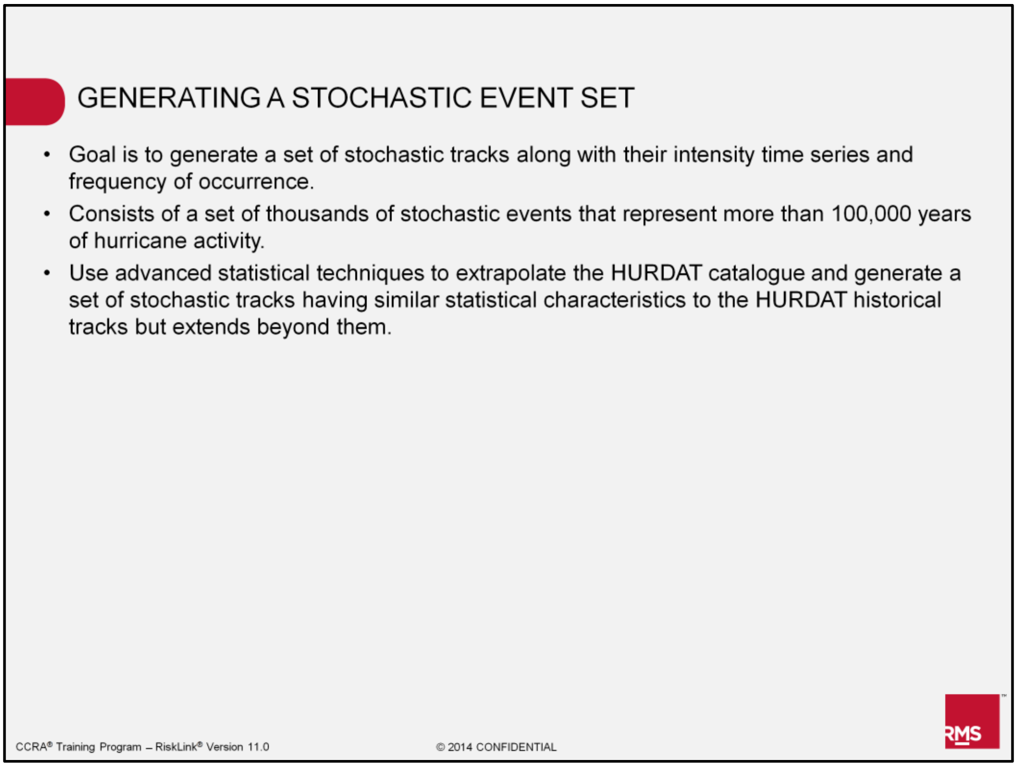


This is the agenda for the Tropical Cyclone Modeling course.The second of five presentation units in the course covers the generation of a tropical cyclone event set for modeling. This unit includes the following sections covering each part of the process:

- Storm Sampling
- Stochastic Track Creation
- Development of Landfall Rates
- Wind Field Assignment
- Surface Roughness Calculation
- Wind Field Calculation



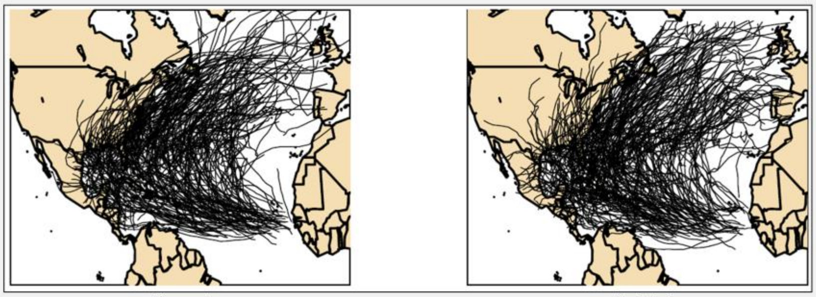
At the end of this unit you should have a good understanding of each of the six learning objectives listed on this slide.



The goal of creating a stochastic event set is to generate storm tracks along with their intensity time series and frequency occurrence. The RMS hurricane event set represents more than 100,000 years of hurricane activity. Advance statistical techniques are used to extrapolate the HURDAT catalogue and generate a set of stochastic tracks that have similar statistical characteristics to the HURDAT historical tracks, yet extends beyond them. The events are physically realistic and span the range of all possible storms that could occur in the coming years.

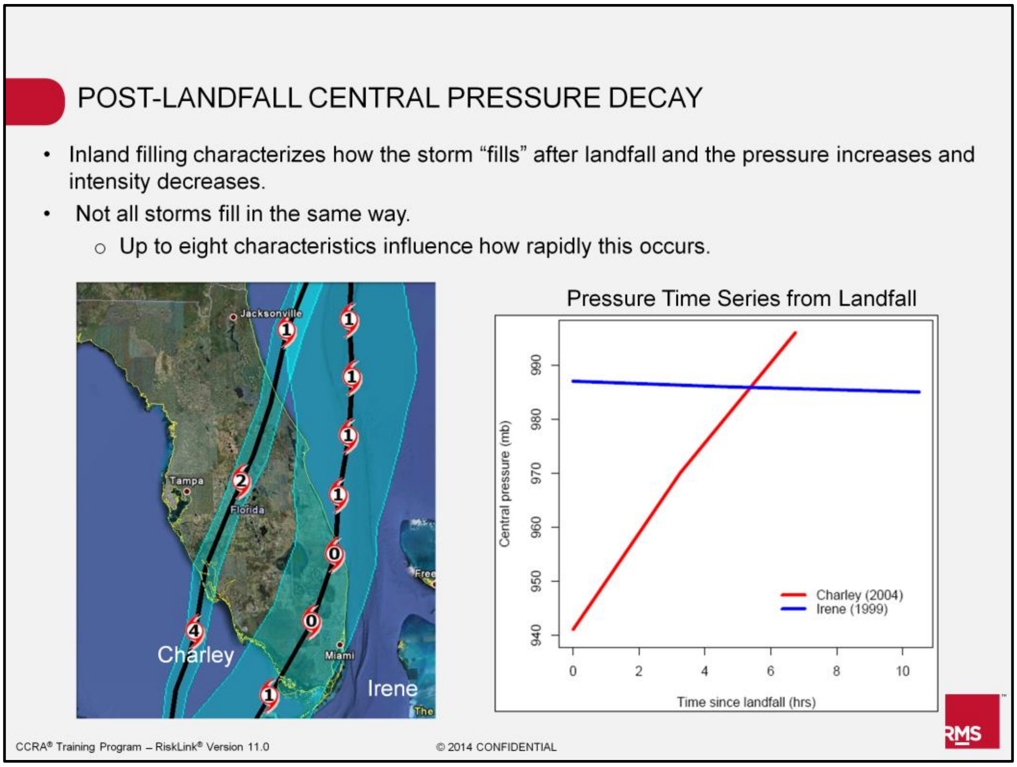
STOCHASTIC TRACKS – EXTRAPOLATING FROM HISTORY

- Track genesis location is sampled from a spatial Poisson process.
- The central pressure (used as a measure of storm intensity) is sampled from the observed distribution of genesis central pressure.
- Then the track is simulated forward in time with a six-hour increment and central pressure updated.



Comparison of Observations from 58 years of HURDAT Tracks (1950–2007) on the left, to One "58 Year" Model Realization of the RMS Statistical Track Model on the right.

Stochastic tracks are simulated from a starting point to an end point using a semi-parametric statistical track model that is based on historical data. Track genesis location is sampled from a spatial Poisson process. The intensity field is derived from historical genesis locations. The length scale involved in the smoothing process is optimized through cross validation to avoid both over fitting and unrealistic genesis points. Once the locations of the first track point has been simulated, the central pressure (used as a measure of storm intensity) is sampled from the observed distribution of genesis central pressure. The track is then simulated forward in six-hour increments.

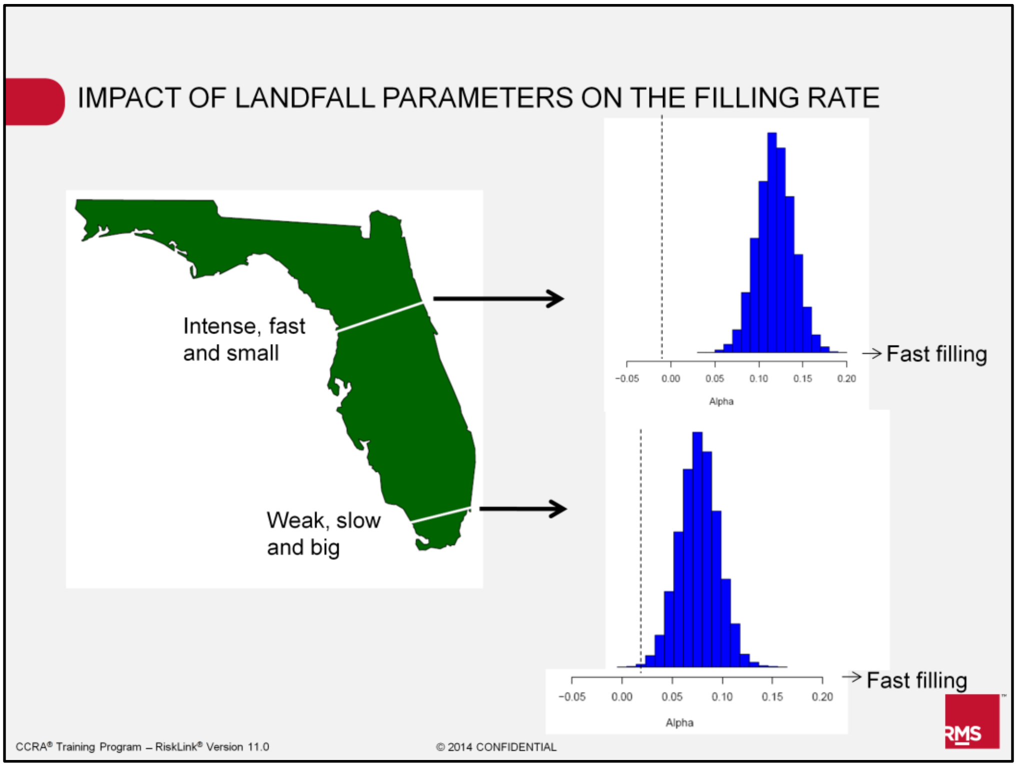


Inland filling describes how the storm fills over land, or decays, and the storm pressure increases. Filling assumes that a storm's central pressure will rise (storm will lose intensity) once a tropical cyclone moves inland, as a result of the loss of energy source to fuel the tropical cyclone (warm sea surface temperatures). As a result, the wind speeds calculated at the coast are degraded over time as a result of the increased pressure and lower intensity of the tropical cyclone.

Not all storms fill in the same way. To illustrate this, we will look at two historical storms: Hurricanes Charley and Irene. These two storms exhibited very different rates of decay after landfall.

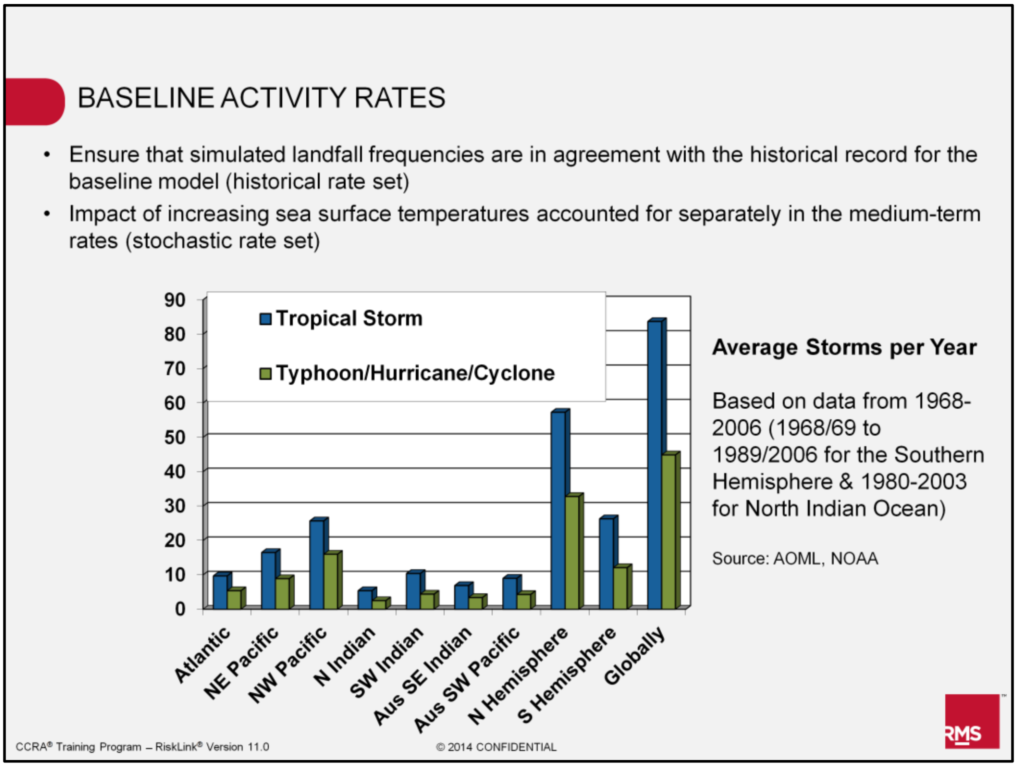
Hurricane Charley made landfall in Florida as a major hurricane in 2004 with a small radius of maximum winds, as shown by the blue shaded area in the image above. Charley's pressure time series after landfall is shown in red on the plot on the right. The slope is rather steep, which means that Charley had a very fast inland filling.

Now we will consider Hurricane Irene, which made landfall in Florida in 1999 as a category 1 hurricane with a large radius of maximum winds. As we can see form the image above, some parts of Irene's circulation stay over water after landfall. The pressure time series for Irene is shown in blue on the plot on the right. We can see that Irene has a very different behavior compared to Charley as the storm intensifies over land.



Let's look at the resulting impact of the landfall parameters on the filling rate. The first case we will consider is a fast, small, and intense storm making landfall North of Tampa. For this storm, the filling rate will be sampled from the distribution you see on the upper right plot.

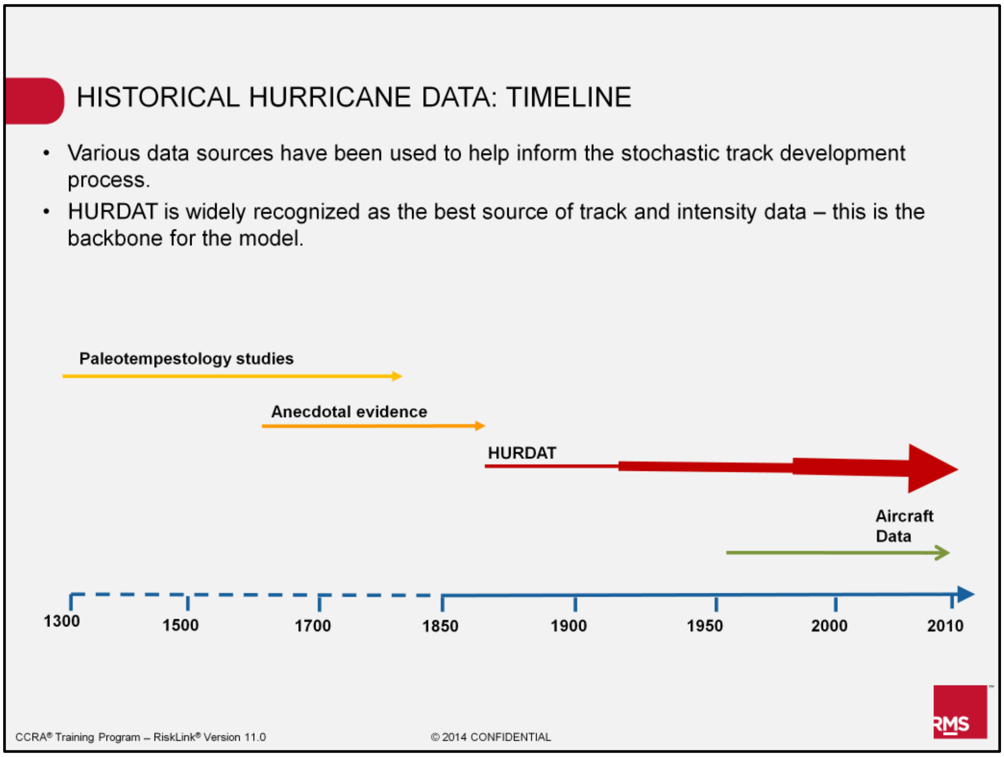
The second case we will consider is a slow moving, large, and weak storm making landfall in southern Florida. The filling rate will now be sampled from the distribution shown on the bottom right plot. The bulk of this distribution is shifted towards the slow filling side and you can see that there is a small but non-zero probability to have an intensification over land.



The last step in the process is to ensure that simulated landfall frequencies are in agreement with the historical record. Target landfall rates are computed on a set of linear coastal segments by smoothing the historical landfall rates. Importance sampling of the simulated tracks is performed to created the computationally efficient event set used for loss cost determinations. Each event has a frequency of occurrence given by its mean Poisson rate. Because event frequencies are calibrated against history (HURDAT 1900-2008), this set of Poisson rates represents the RMS baseline model and this rate set is called the RMS historical rate set.

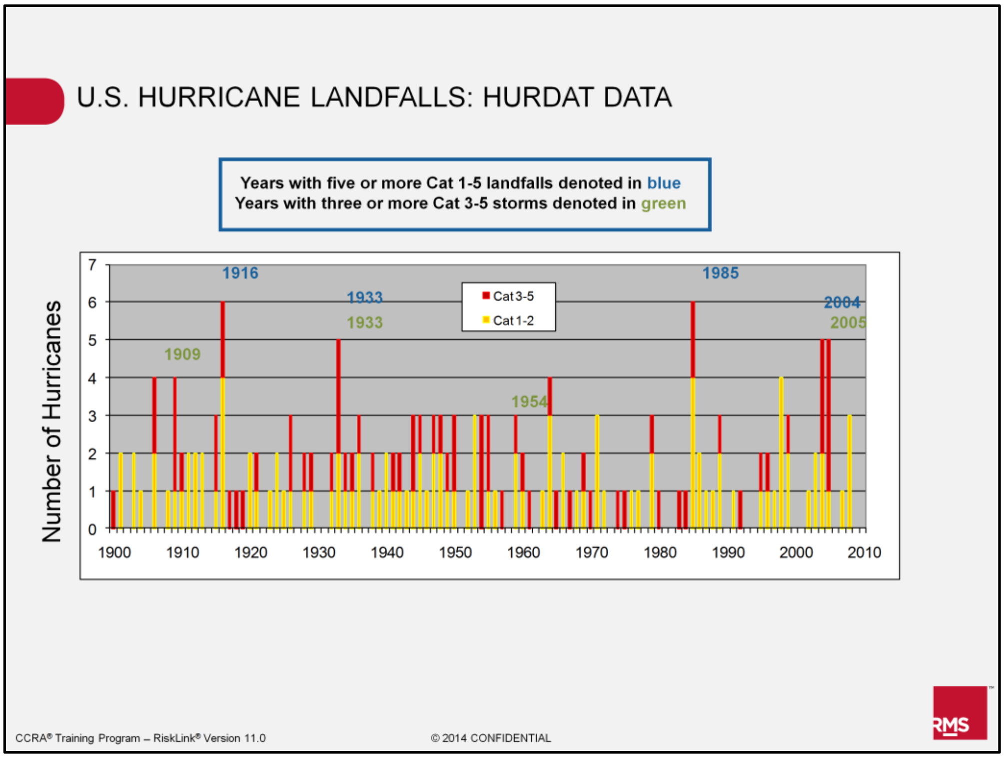
Frequency is largely dependent on local sea-surface temperature, atmospheric stability, and wind shear with higher sea-surface temperature increasing frequency but conversely higher atmospheric stability and wind shear acting to decrease frequency, though not fully compensating for the increase. In recognition of the non-stationary Atlantic basin, RMS took a leading role by introducing the concept of medium term activity to catastrophe modeling in 2005. This five-year forward looking perspective is represented by the medium-term rates, which deliver a probabilistic estimate of the annual average number of landfalls to be expected over the next five years. This rate set is called the stochastic event rate in the RMS model.

The graph on this slide depicts the average number of storms in the different tropical cyclone basins. You will notice the dominance of the northern hemisphere tropical cyclone numbers; in particular, the number of storms in the Northwest Pacific Ocean. Out of more than 80 storms each “average” year, 25 fall in the Northwest Pacific, whereas the Atlantic ocean sees only ten storms. This chart, however, tells us little about the overall risk, as landmasses and associated exposure are distributed very differently around the globe.

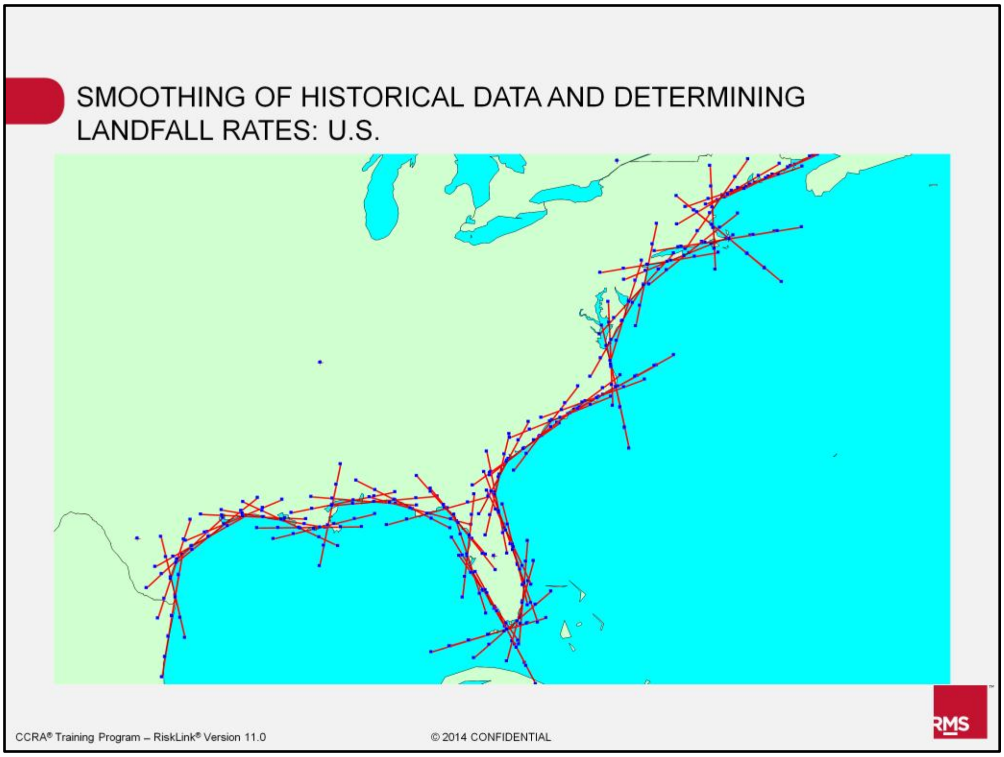


Now we can take a look at information regarding hurricane landfalls. What are the sources of data that help us develop our model? Shown on this slide is a timeline to identify what data has been used to help inform the landfall rates within the stochastic model. Paleotempestology data refers to looking at historical records of such data as salt marsh deposits that contain information on hurricane landfalls; more about this later. Historical storm information, in terms of anecdotal reports of storms, and books of such compiled information on historical storms also contain important information from which the strength and landfall location of storms can be obtained. And finally, the HURDAT database is the best compilation of historical storm tracks and intensities, taken from the known information available. The HURDAT data quality improves considerably with time, especially after about 1960 with the advent of satellite imagery, which has allowed real-time tracking of hurricanes over the sea. Also, weather observing techniques (and density of observing stations) have improved and increased with time, which improves the accuracy of tropical cyclone observations.

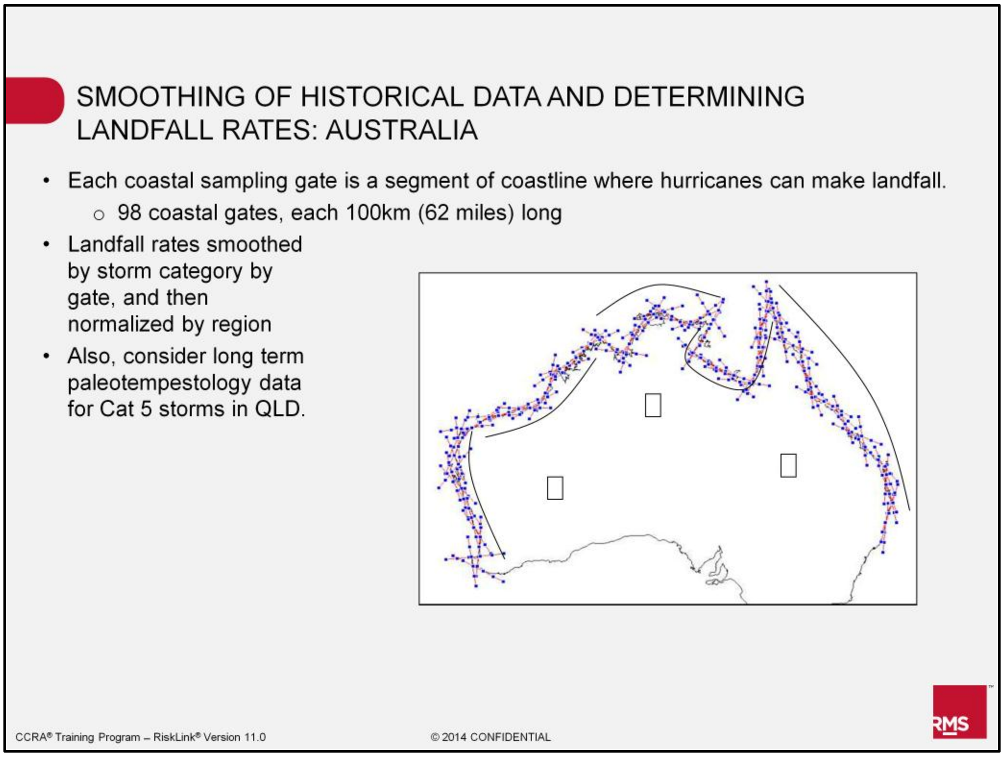
Also noted here is the role of aircraft data, which contributes to the understanding and accuracy of the intensity of storms, as well as the structure of the storms.



Naturally, capturing the behavior of the historical tracks across the basin is important, but of more importance is obtaining robust estimates of landfall rates on the U.S. coastline, as this clearly drives the loss. This slide concentrates on the U.S. landfalling hurricanes since 1900 and shows the number of landfalling hurricanes per annum. Years with five or more landfalling hurricanes (in blue) include 1916, 1933, 1985, and both 2004 and 2005. Considering cat 3-5 hurricanes only (called major hurricanes), three or more major landfalling events are reported five times in the last 100 years. Clearly, it is worth noting 2005, which as well as being the record year for activity in the Atlantic basic, also had four landfalling major hurricanes for the first time since 1900. Given that this occurred directly after the busy year in 2004, it has brought climate change to the forefront regarding hurricane activity and hurricane landfalls – this will be touched upon later.

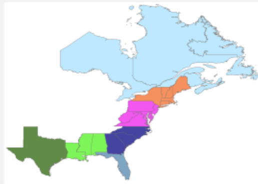


To calibrate the stochastic model, we break the historical landfalls down to a fine level. This is done by defining the landfall frequencies by storm category for “gates” along the coast. Shown here are 69 hurricane gates that extend along the coastline and also capture bypassing storms at the Florida Keys, Cape Hatteras, and Cape Cod. This requires a methodology for smoothing historical landfall data to remove the spikes caused by a limited historical record: we only really have 150 years worth of data to rely upon for hurricane landfalls, which for several thousand kilometers of coastline will mean that some areas that are at risk may not have received a direct hurricane hit in this time. RMS has put major efforts into deriving a robust approach to understand the completeness of the various track data records available to us. Once the stochastic tracks have been generated across the basin, as shown in the earlier slides, their landfall rates are checked for consistency with the smoothed historical data at landfall.



A similar gate-approach is shown here for our Australia Cyclone model. We have divided the active coastline into 98 equi-length segments of 100 km and have smoothed landfall rates by storm category by gate and have then normalized by region.

REGIONAL LANDFALL FREQUENCIES BY CATEGORY



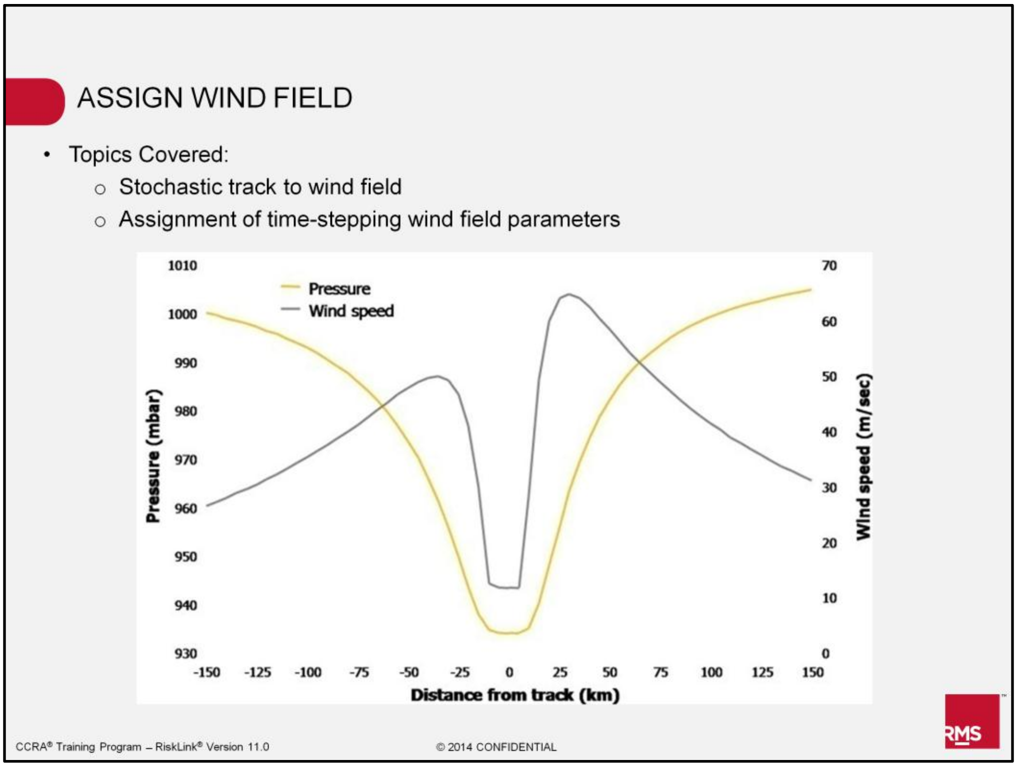
Mean Landfall Frequency by Region and Category – Historical Rate Set

	Texas	Central Gulf	Florida	Southeast	Mid-Atlantic	Northeast	All U.S.	Canada
All	0.32	0.39	0.56	0.37	0.01	0.09	1.57	0.26
Category 1-2	0.19	0.24	0.33	0.32	0.01	0.06	1.01	0.26
Category 3-5	0.13	0.14	0.23	0.05	0.00	0.02	0.56	0.01

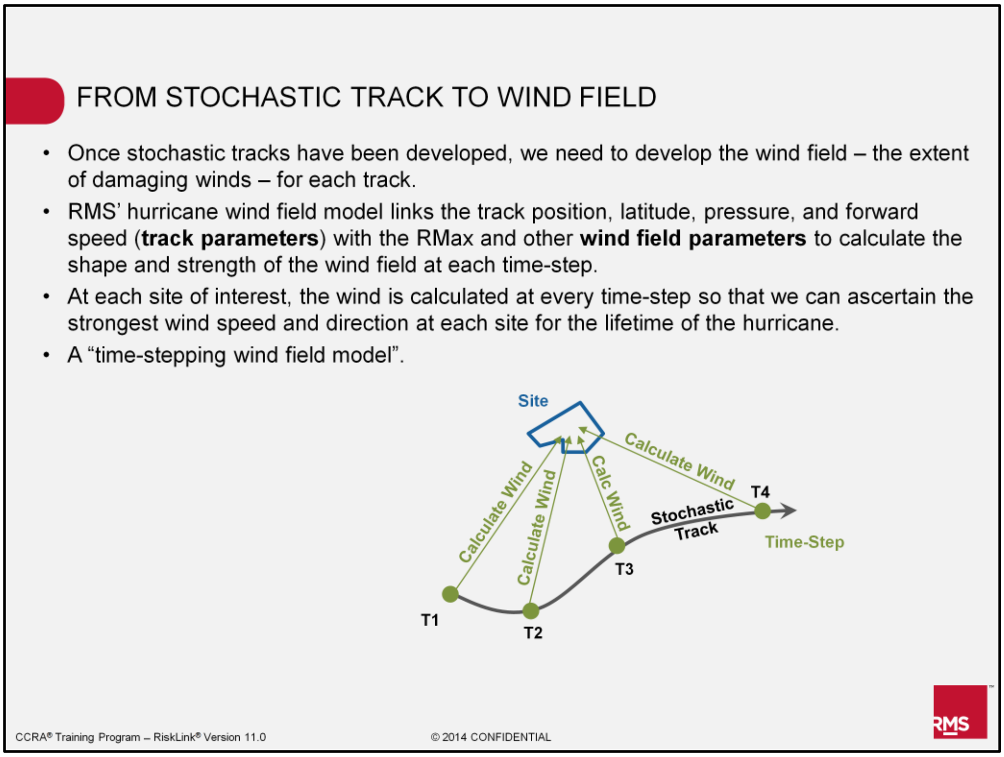
Mean Landfall Frequency by Region and Category – Stochastic Rate Set

	Texas	Central Gulf	Florida	Southeast	Mid-Atlantic	Northeast	All U.S.	Canada
All	0.38	0.47	0.73	0.44	0.02	0.10	1.91	0.29
Category 1-2	0.21	0.28	0.37	0.36	0.01	0.08	1.13	0.28
Category 3-5	0.17	0.20	0.36	0.08	0.01	0.03	0.78	0.01

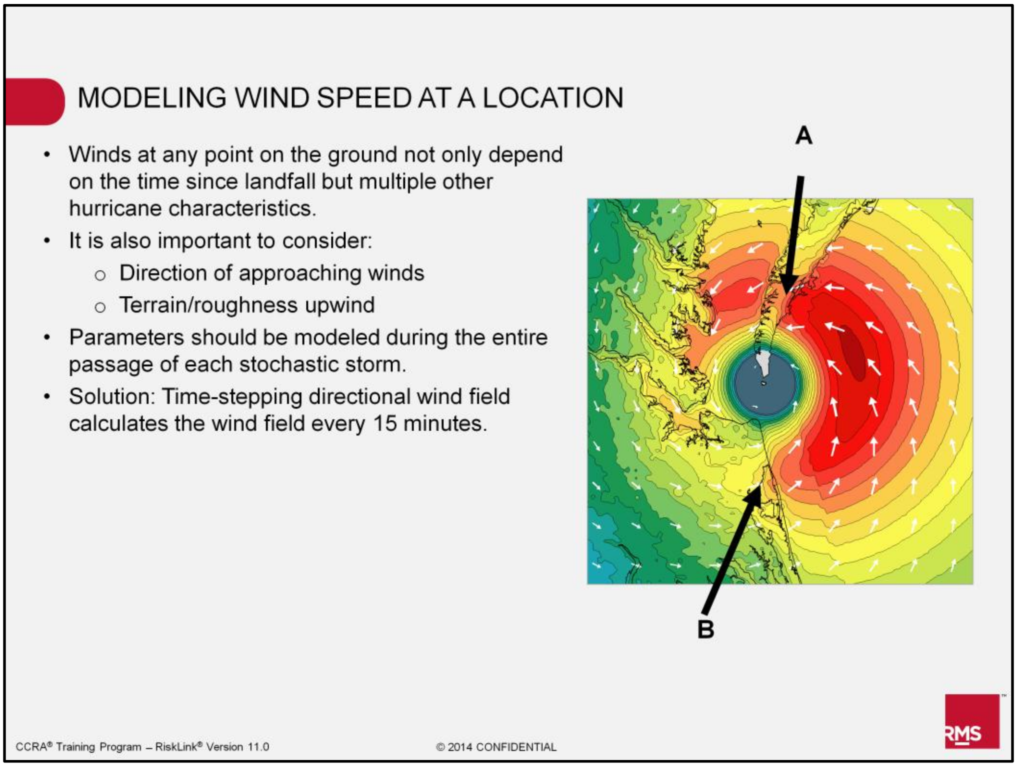
On a more regional level in the U.S. and Canada, the historical record is, however, deemed complete and our modeled landfall rates by category closely follow the historical record of the last 100 years, as is shown here. The landfalls by each hurricane category for history and the stochastic model are compared for each region along the U.S. coastline. As you can see, the modeled rates are very similar to the historical rates for all categories at this level.



The next step in the process is to assign the wind field, which will be discussed in the next several slides.



Now that we have developed our stochastic track set, the next step is to understand what risk each modeled tropical cyclone poses to land. To do this, we use a time-stepping wind field model. For each individual stochastic track, we work our way forward in time and calculate what the strength of the wind is at each site of interest for each time-step along the stochastic track. At each track point, the pressure, latitude, and forward speed are known. Going back to Unit 1, we discussed how to develop relationships between the central pressure of a storm and features of its wind field such as the size of the storm (given by the RMax). We use these relationships between the track parameters and the wind field parameters to develop the shape of the wind field at each time-step. At the end of the process, we then calculate the peak wind speed and direction at each site across the whole lifecycle of the storm. This wind speed is then converted into a damage ratio, and eventually, a loss using the financial model.



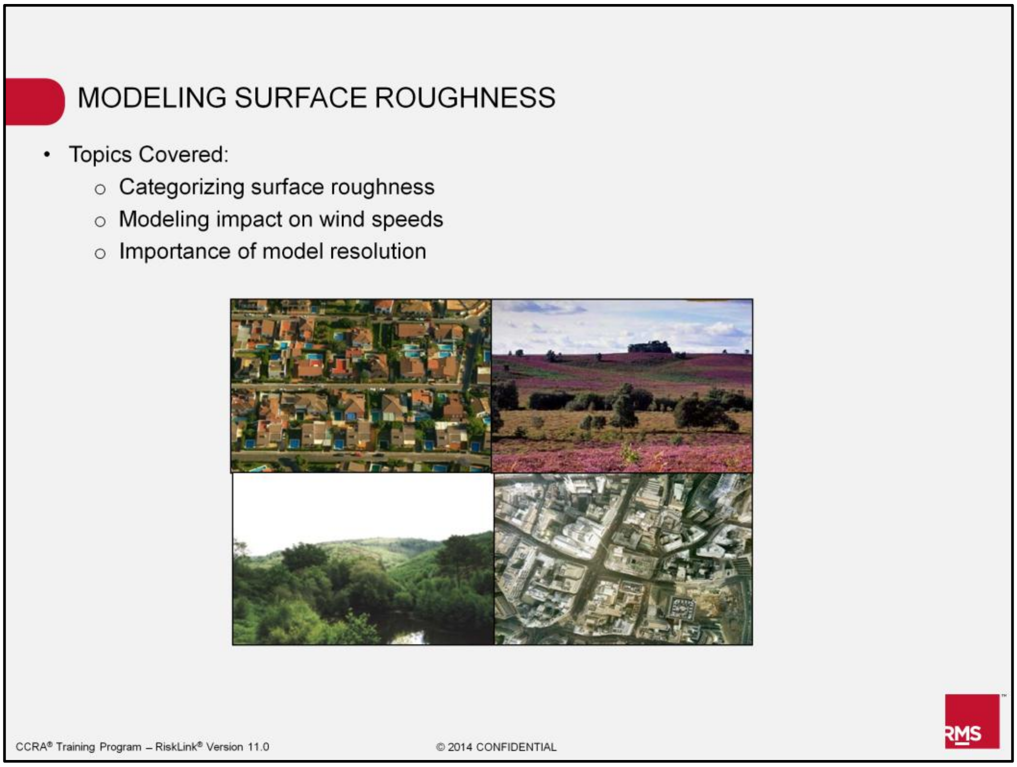
The wind speeds at any point on the surface are strongly influenced by the direction of the wind and the surface roughness upwind from the location of the property. Terrain also plays a factor in mountainous environments.

This map shows the wind field of a stochastic storm as it makes landfall near the mouth of the Chesapeake Bay. The wind speed contours are smooth arcs over the ocean, and abruptly reflect a reduction in wind speed as the wind field passes over land. This is due to land surface roughness and loss of heat energy from the sea. The highest wind speeds are shown in red, grading down to blue for the lowest wind speeds. Note that a property located on the peninsula (A) and a property located south of the eye (B) would have nearly the same distance to coast and distance to the center of the storm, however the winds are stronger at the location of the peninsula property. This is due to the combined effects of less surface roughness on the peninsula, and the fact that the storm rotation and direction of the storm track from SE to NW has an additive impact on wind speeds on the NE side of the storm.

Due to the changing nature of storm wind fields over time as the storm progresses, a time-stepping wind field model is implemented that takes into account the direction of the storm track, surface roughness and terrain, and the direction of the cyclonic winds.

As a first step, at each 15 minute interval of time (such as the snap-shot illustrated in this figure), the model uses the central pressure, location, and forward speed of the storm to assign an RMax to the storm. These and other model parameters are used to calculate the wind speed over the land for each VRG cell. The highest wind speed is stored at each location over the passage of a storm.

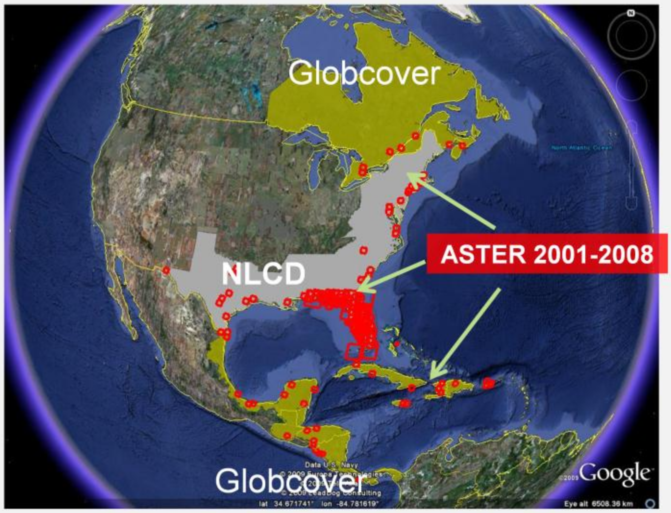
Once the wind field parameters have been assigned, the next step is to take the wind speed and convert it to three-second peak wind gusts by incorporating the impact of surface roughness. This step is covered in the next few slides.



The next step is to model the surface roughness. The next several slides will categorize surface roughness, and look at the impact it has on wind speeds in the model as well as the importance of model resolution.

ROUGHNESS LENGTHS FROM SATELLITE IMAGERY

- ASTER = high-resolution satellite data, used for Florida and metro areas.
- National Land Cover Data (NLCD) – free but lower resolution.
- Globcover – outside the U.S.



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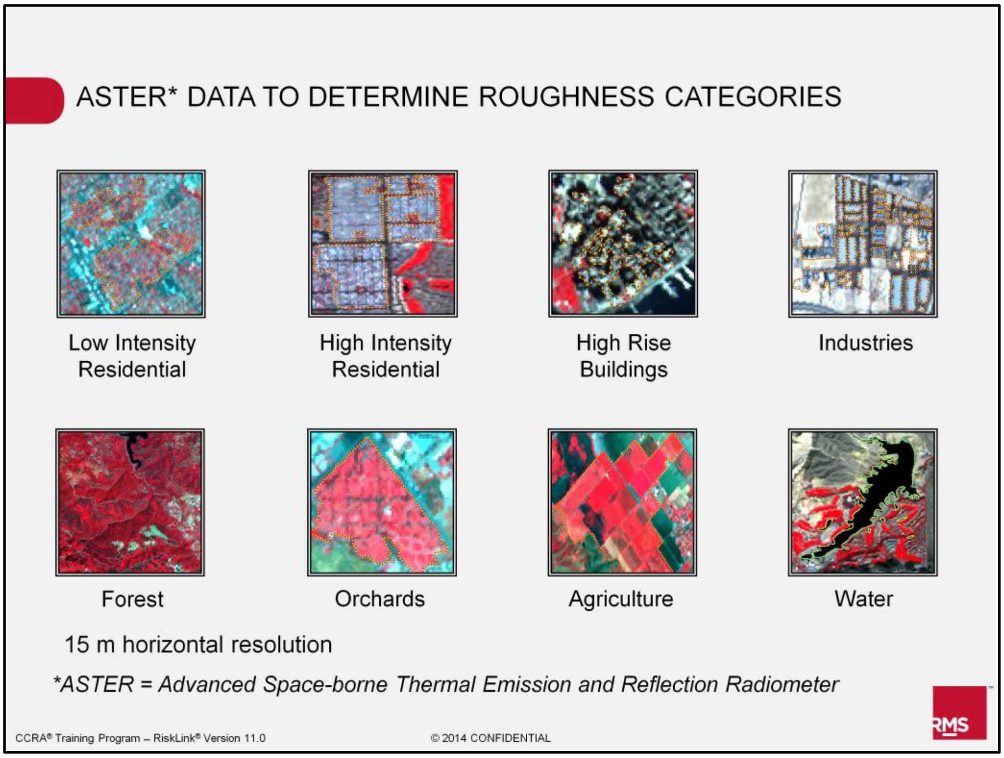
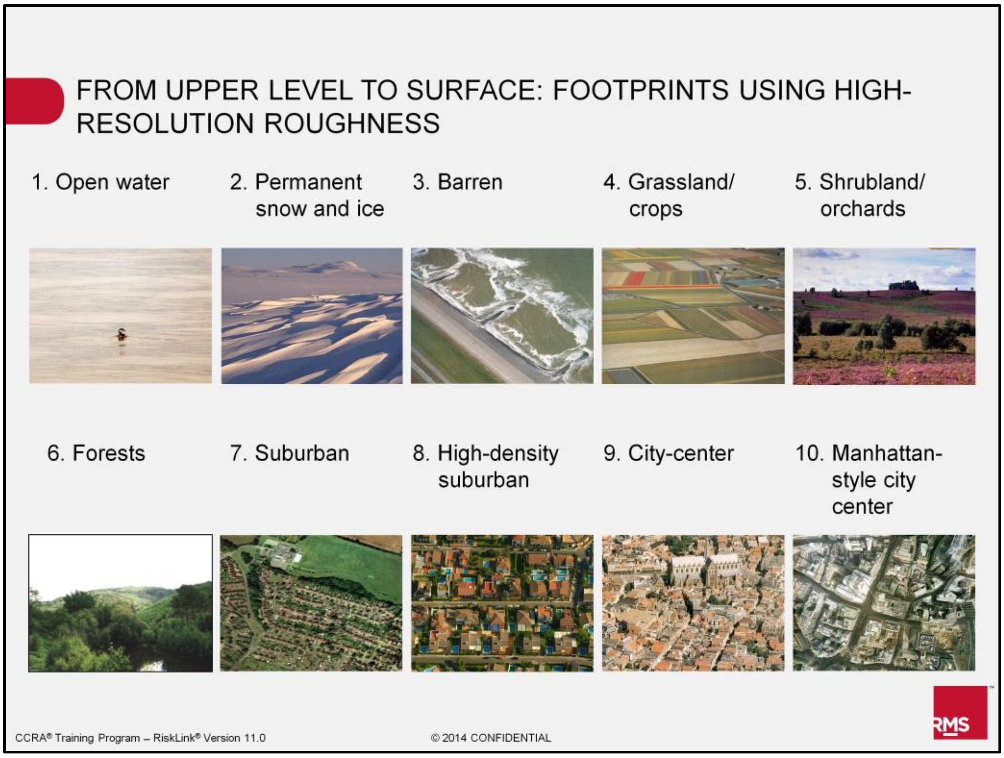
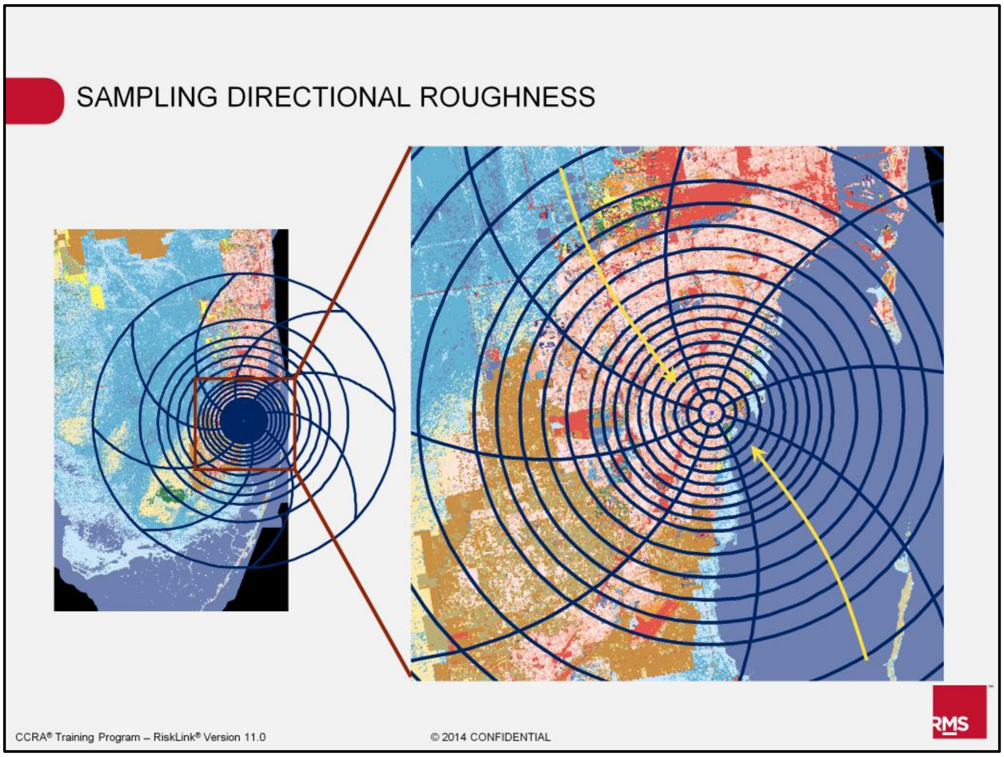
Both surface wind and wind gust factors are functions of upstream roughness. The roughness lengths in the RMS model are assessed from satellite imagery. On the map, you can see the entire domain. In the U.S., we are using NLCD 2001 as the background data and we are complementing this dataset using ASTER imagery covering Florida and all major cities. Outside of the U.S., Globcover is used.



To accurately calculate the wind speeds on the ground we need to know how "rough" the ground is itself. To determine roughness at high resolution, we use a roughness database that we have prepared with our partners at RMSI using satellite imagery that assesses thermal emission and reflection from the Earth's surface. Each 15 m x 15 m pixel is defined in terms of the land use and land cover everywhere. To minimize processing time, the data is degraded outside urban areas to provide a 250 m x 250 m roughness database.



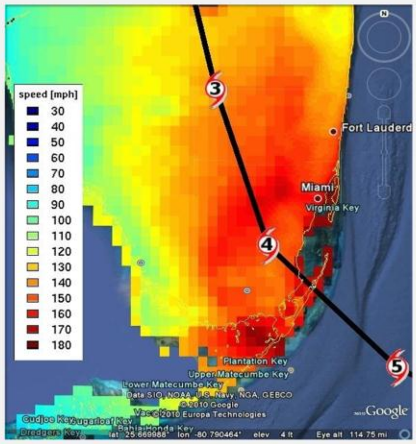
This slide illustrates the ten roughness categories that we are currently using worldwide. Each roughness category is assigned a parameter, called the roughness length, that describes its frictional impact on the wind passing over it. The frictional impact on the wind changes each time the roughness category changes.



When we calculate wind speed at a particular site, upwind roughness is sampled 80 km in eight directions the site. To do this, the wind field is divided into eight topography and roughness sections as indicated on this slide. Depending on the upstream roughness and topography features, the wind speed is modified to account for the type of roughness that wind must pass over to reach the site. Topography is not deemed significant for the continental U.S. Hurricane model, but other tropical cyclones models (e.g., the Caribbean model) do consider the effect of topography, where terrain issues are more important in determining wind speeds. Wind direction can have a great influence on the wind speed felt at a site – in some coastal peninsulas, wind from one direction can come from directly over the land, with reduced strength because of the roughness, but from another direction can come from over the sea, with more strength owing to the reduced roughness of the sea surface – this is shown with the two yellow arrows above.

ESTIMATE SURFACE WIND FIELD

- Topics Covered:
  - Conversion of mean wind speeds over water to peak gust wind gust over land
  - Time stepping wind field example
  - Bypassing storms



Example of a Three-Second Gust Footprint Over South Florida. The Six-Hourly Track is Given in Black Along with the Saffir-Simpson Intensity (inside the red circles)

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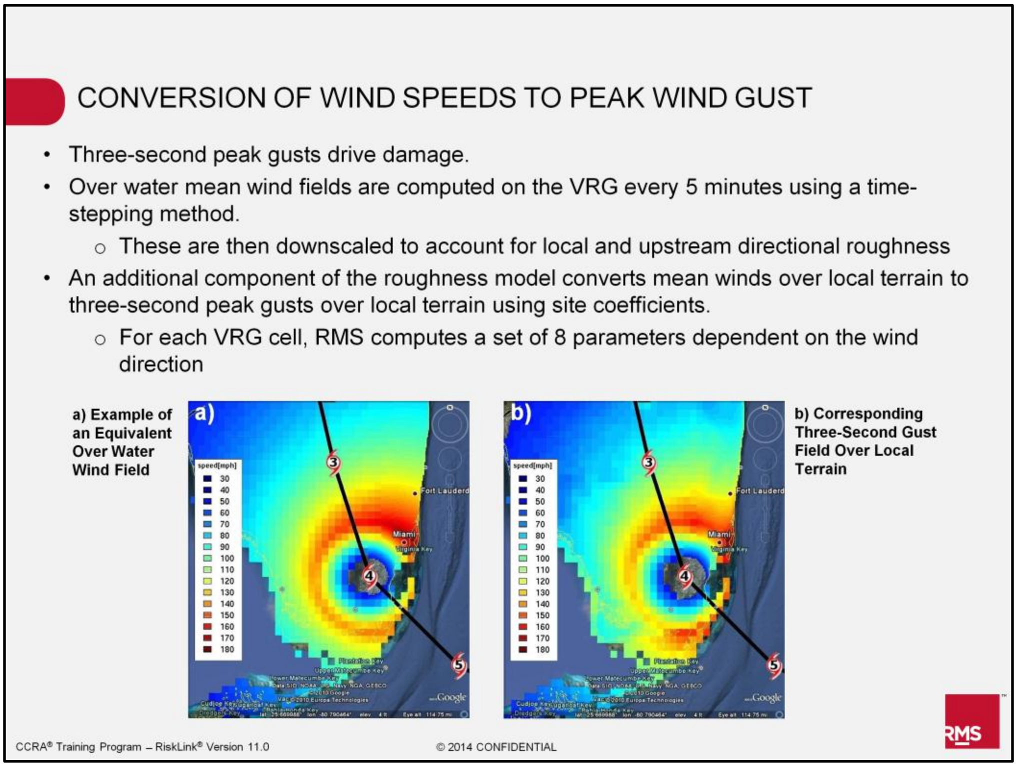
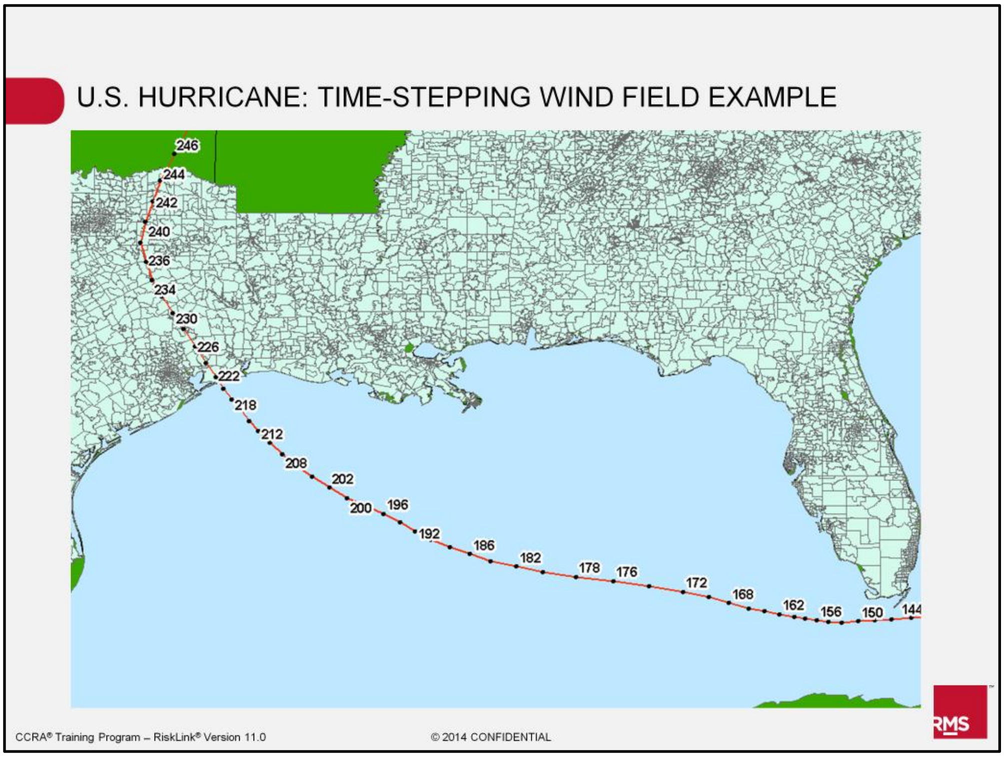
In estimating the surface wind field, RMS examines historical wind field patterns to ensure that historical wind fields closely resemble the stochastic representation of the wind field. Furthermore, after real time events, such as in 2004 and 2005, RMS conducts an analysis to see how closely the hurricane events match stochastic representations of the wind fields. In both the 2004 and 2005 season, the wind fields of the hurricanes were replicated quite closely with several stochastic tracks and wind fields.

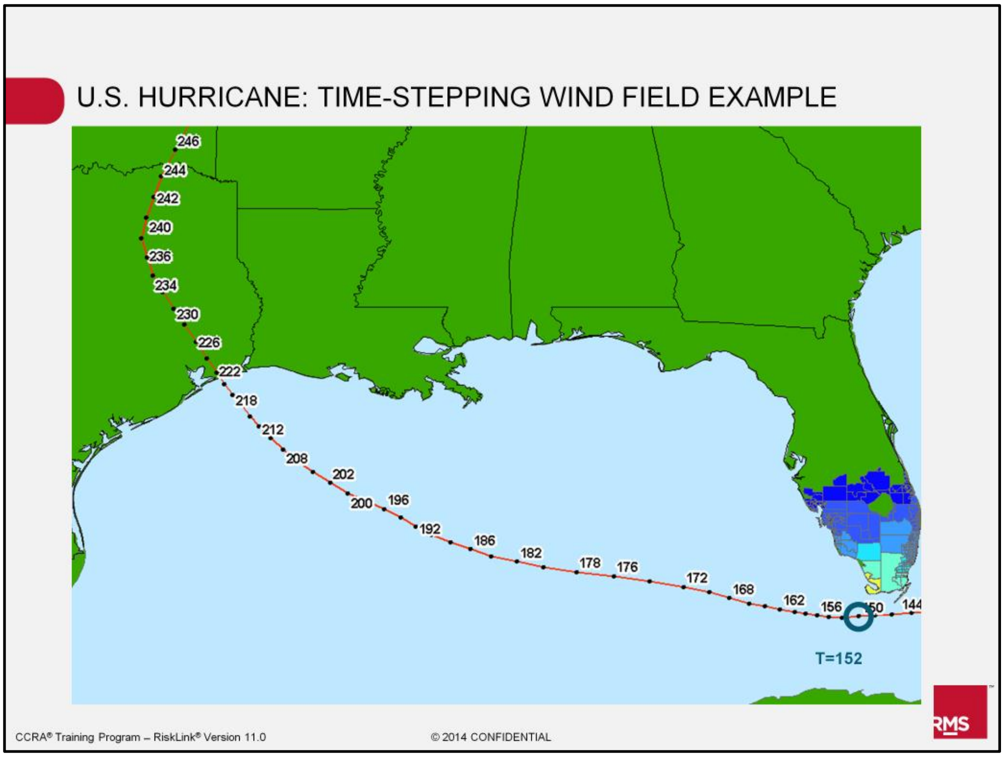


Once the wind field parameters have been assigned, and both the upwind surface roughness and the site roughness assessed, the final step is to calculate surface wind speeds along the wind field, and ultimately the peak wind gust.

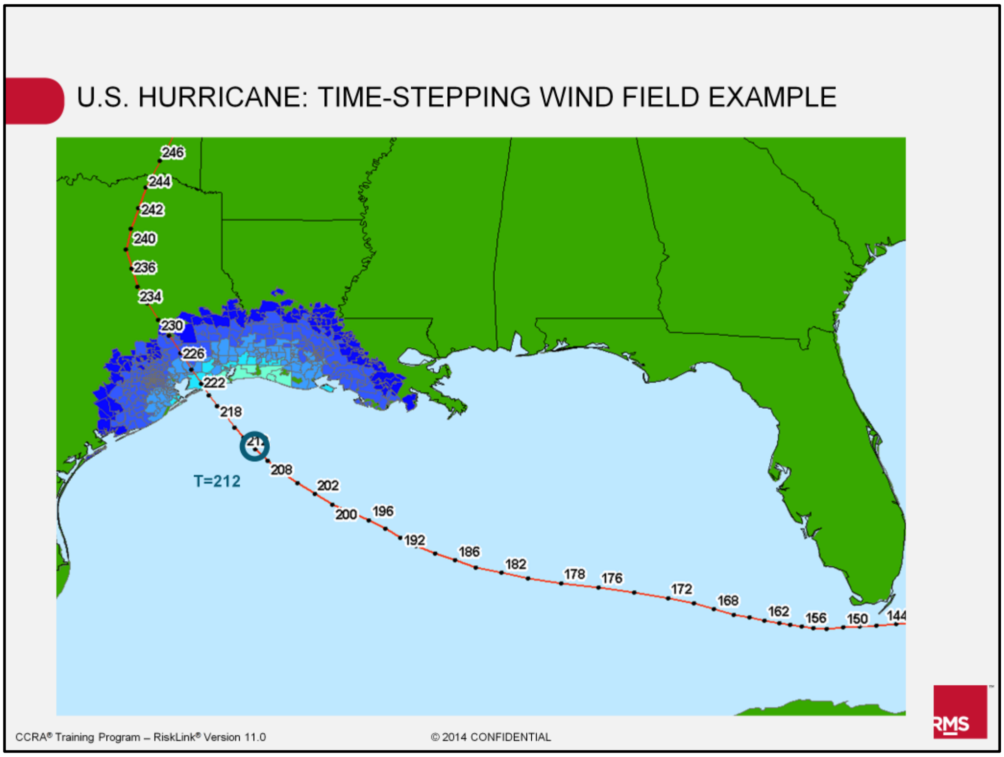
Standard relationships are used to estimate near surface winds 10 meters above the ground from upper level winds. Using the methodology from this research, the directional wind field model is used to calculate the conversion from 1-minute maximum sustained wind speeds to 3-second peak wind gusts.



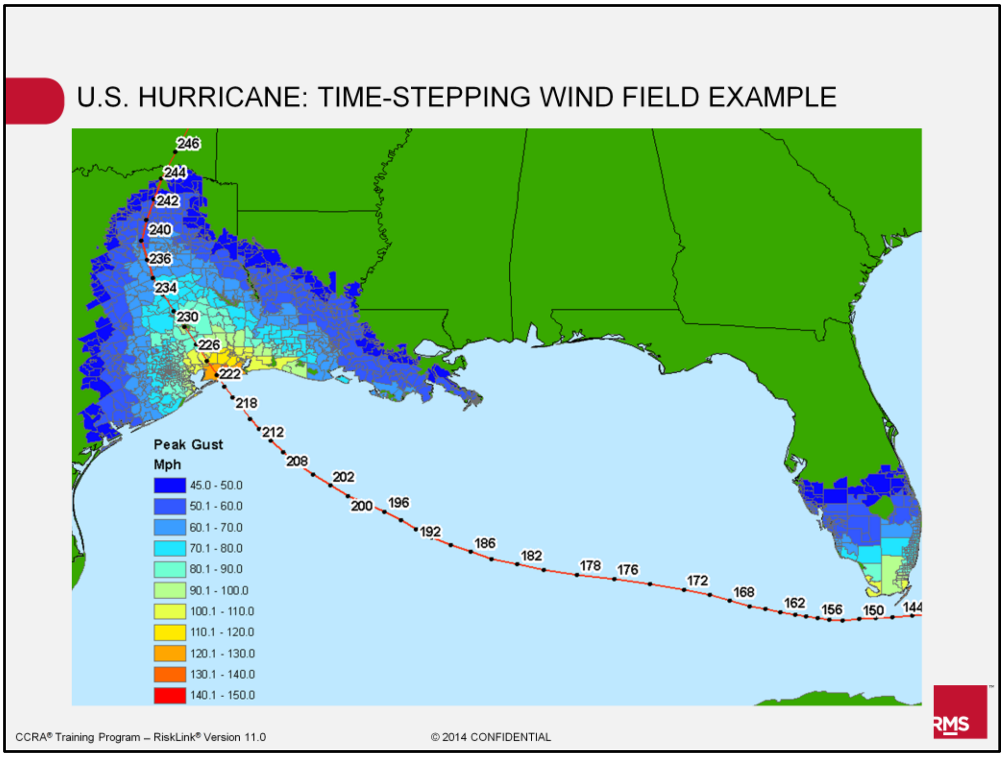
To provide an example of the calculation of losses due to a storm, here we show a stochastic track and all the time-steps on the track along which we calculate the wind speed. The irregular pattern shown over land are ZIP Codes. For the convenience of this example, this will be the geocoding level to which we calculate the wind speed and subsequent losses.



This is the wind calculated at our first time-step at 152 hours after becoming a named storm (T=152 hours). The model uses the pressure, location, and forward speed of the storm to assign an RMax to the storm. These parameters, along with others, are used to calculate the wind over the land at each ZIP Code.

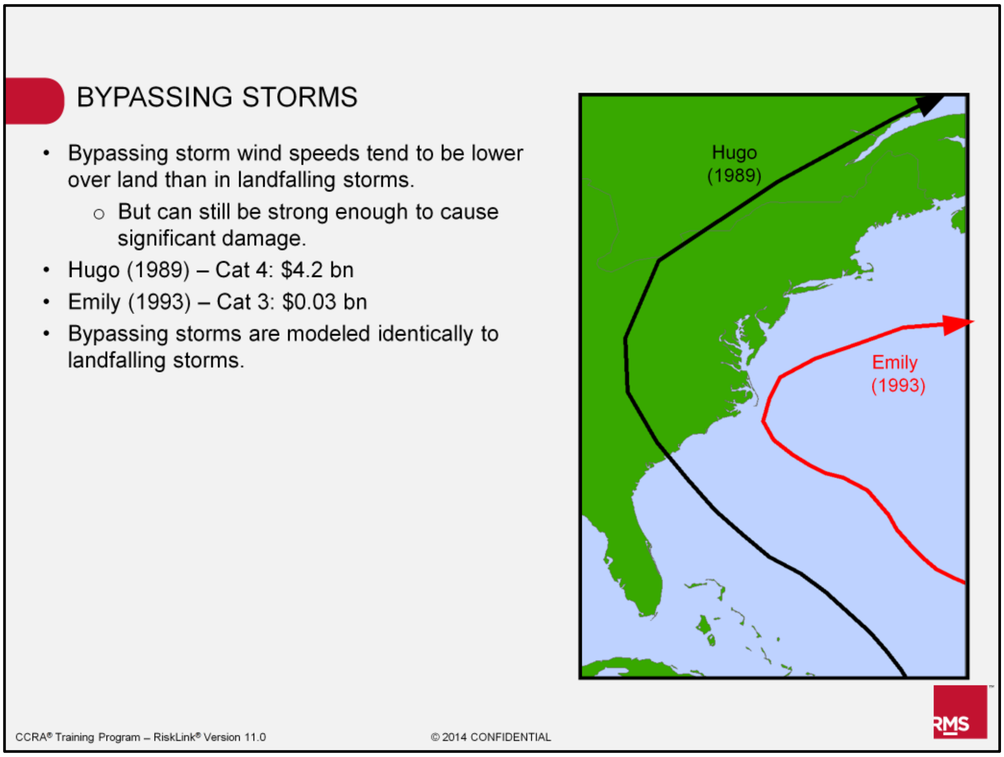


This process is repeated for every time-step during the lifecycle of the storm. Here we show the wind distribution at a later time-step, some 60 hours later.



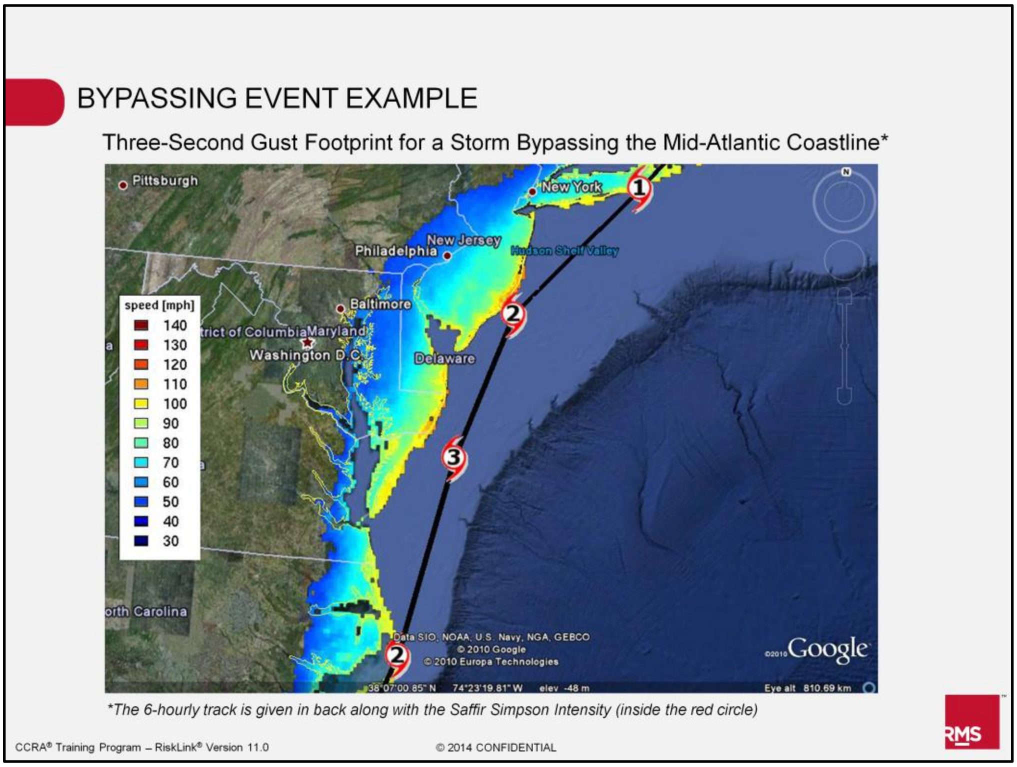
Finally, the maximum wind at each ZIP Code is obtained to give what is known as a wind swath. This wind speed can then be converted into damage and then loss.

As you can see, this particular storm causes loss in Florida as well as in Texas and Louisiana, where it finally makes landfall. This highlights that storms do not need to make landfall in order to cause losses. These are called bypassing storms and are discussed further on the following slides.

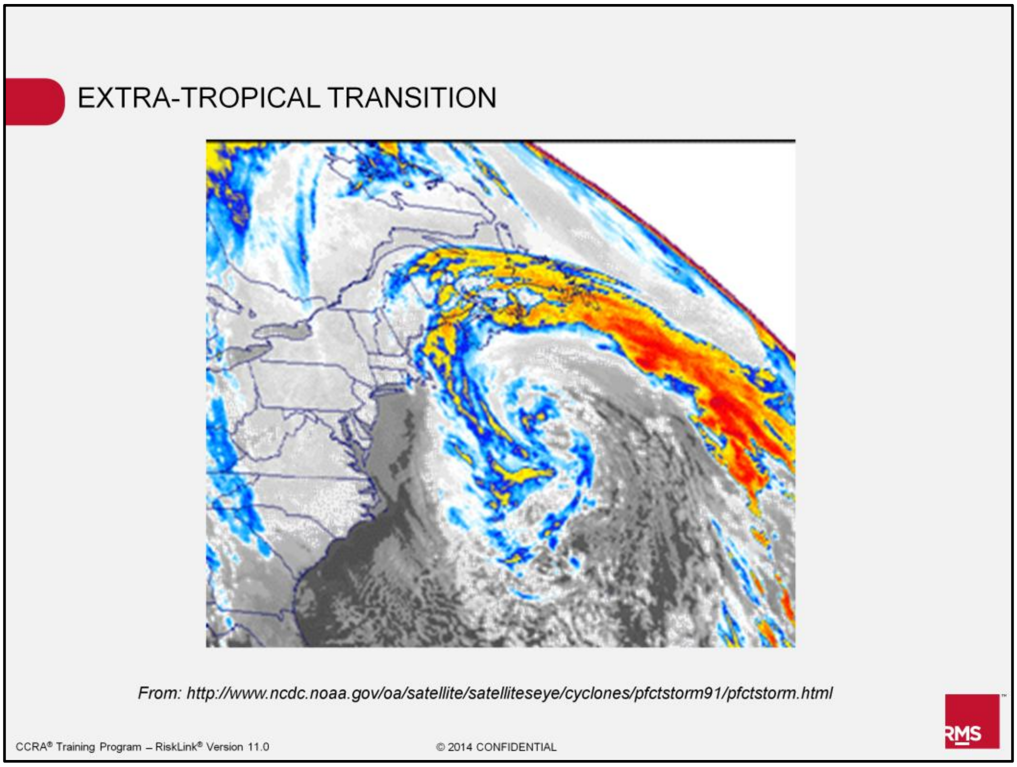


Storms do not have to make landfall to cause loss. Storms can graze the coastline without the center of the storm crossing the coast, and their winds can still cause damage. As an example, Hurricane Emily, while causing less damage than Hurricane Hugo, still caused damage due to its wind field passing over land. Bypassing storms are modeled identically to landfalling storms. These storms tend to contribute to short return period losses rather than long return period losses. This is due to their grazing nature, resulting in lower wind speeds over land when compared to storms whose eyes make landfall.

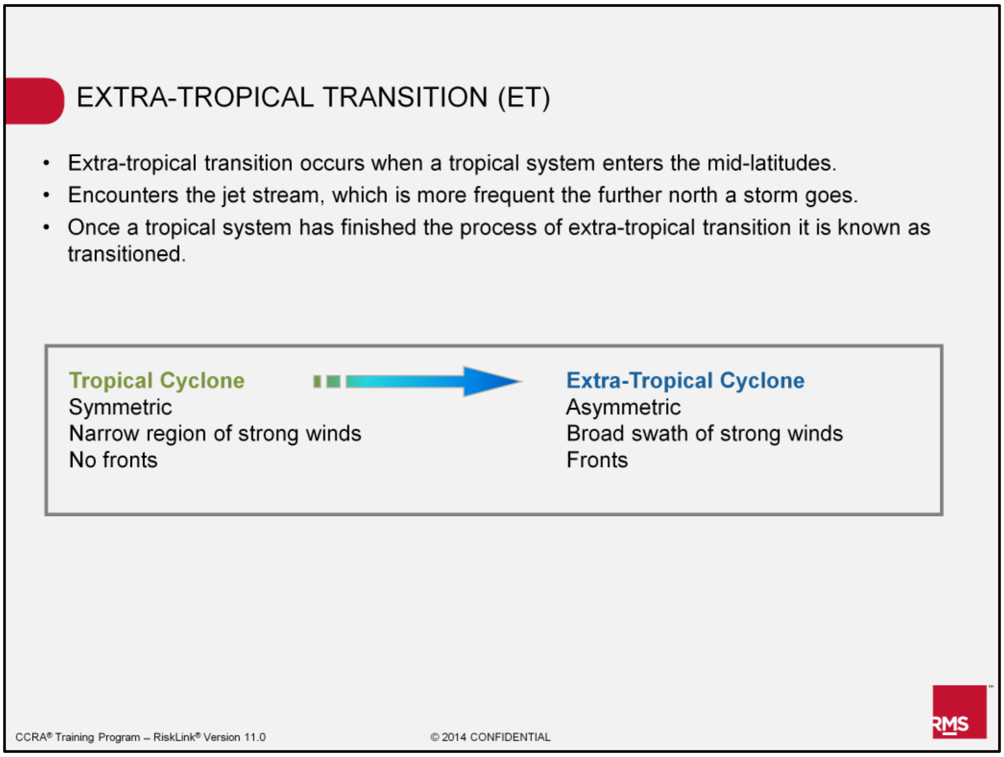
The rates of bypassing storms are calculated much in the same way they are for actual landfalling tropical cyclones. On various segments of the coastline prone to bypassing events (Key West, Cape Hatteras, Cape Code, Mississippi River delta of Louisiana, for example, in the United States), gate extensions exist that protrude into the ocean. These bypass gate extensions are used to calculate the amount of historical activity that has passed through the gates, and is used to calibrate the overall stochastic event rates through these gate extensions.



This slide shows an example of a bypassing storm in the Mid-Atlantic. Even though the storm did not make landfall, there were significant wind speeds experienced along the coast from this event.

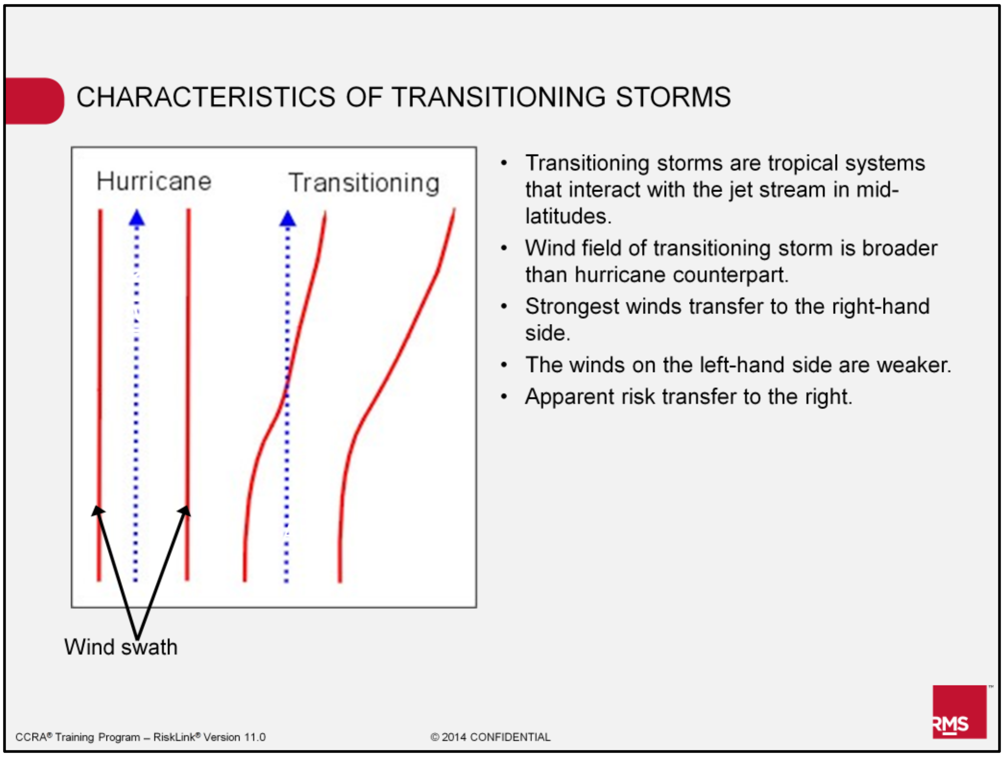


This is a satellite image of the October 30, 1991 Halloween Storm, a famous extra-tropical cyclone that sank the swordfishing boat Andrea Gail, whose story became the basis for the best-selling novel "The Perfect Storm" by Sebastian Junger.

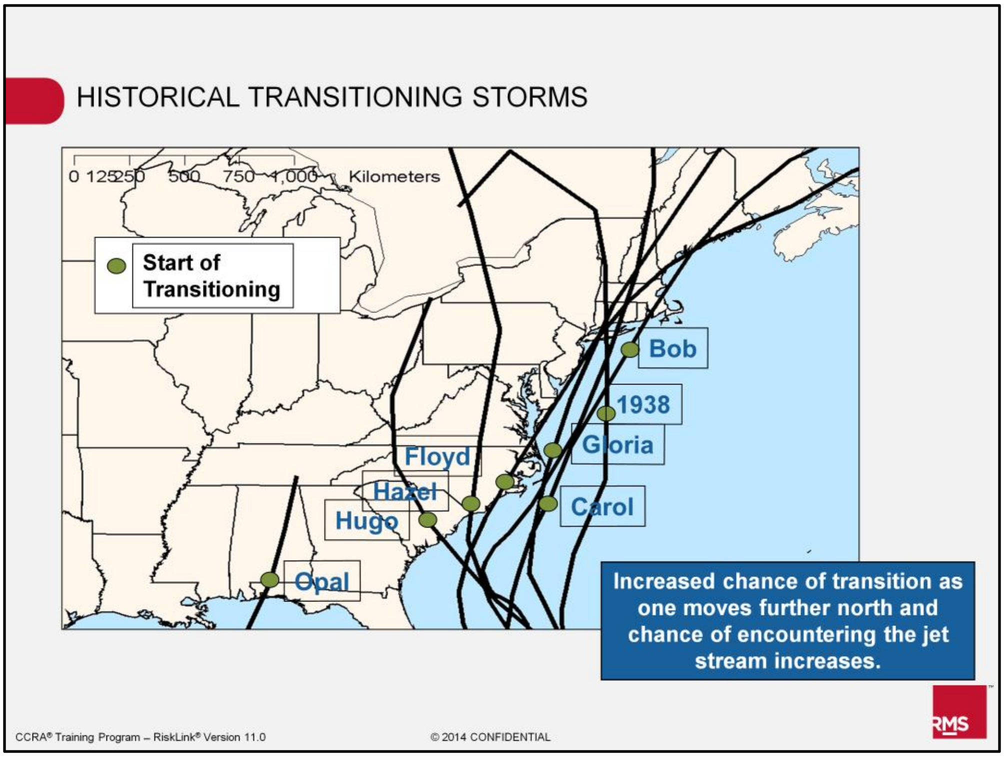


Extra-tropical transition is a typical phenomenon for many hurricanes that move towards the north/south pole from a tropical basin and are subject to the influence of the jet stream. The jet stream is the ribbon of fast-moving air in the upper levels of the atmosphere caused by large temperature changes between the tropics and mid-latitudes. While hurricanes derive their energy from warm oceans, extra-tropical cyclones receive their energy from the temperature differences between the tropics and mid-latitude, and the resulting jet stream that occurs due to that temperature contrast.

In general, extra-tropical transition describes a process during which storms broaden, become asymmetric, and their strongest winds push to the right hand side of the storm (in the Northern Hemisphere). Over 70% of the storms that reach the Northeast Atlantic in the U.S. are undergoing transition. This is even more extreme for storms in Japan. Most of the storms will have undergone the extra-tropical transition process if they reach Hokkaido (the northern-most island of Japan).

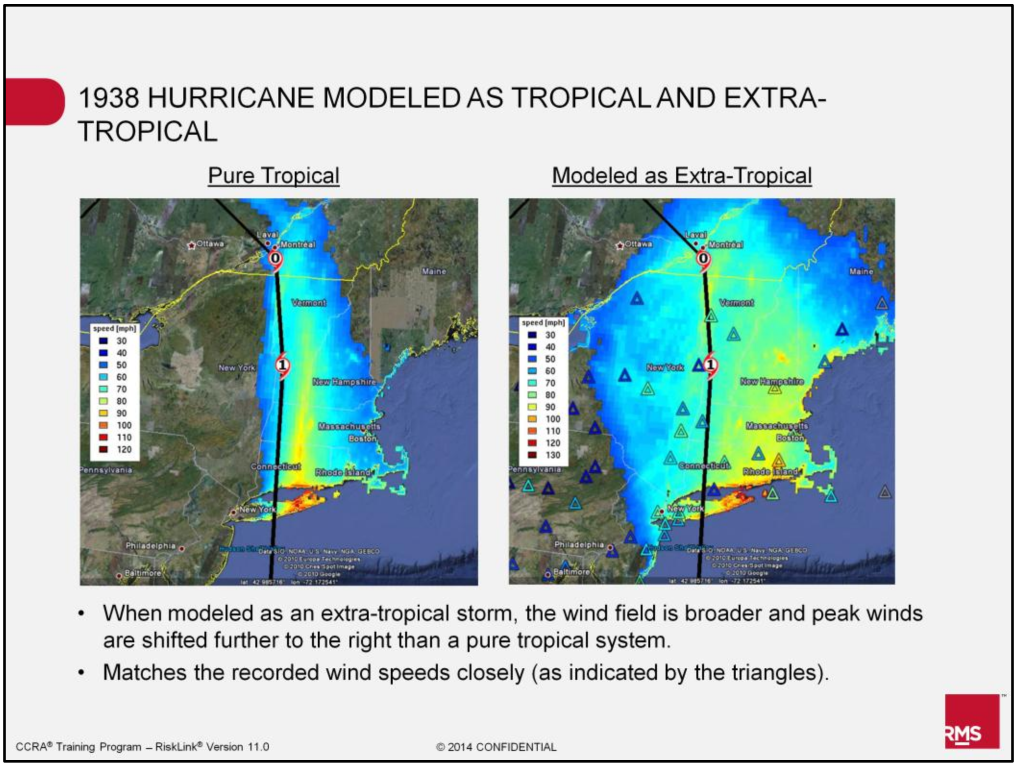


This diagram explains the important difference in wind fields between a tropical cyclone and a storm that is undergoing extra-tropical transition and interacting with the jet stream in mid-latitudes. Wind fields of transitioning storms broaden as they go through the extra-tropical transition process. Assuming the tropical cyclone is in the northern hemisphere, the strongest winds are transferred to the right-hand side of the storm, and the winds on the left-hand side are weaker. Although not shown here, the heaviest precipitation switches to the left-hand side of the storm as well, with drier air often on the right hand side of the storm. The wind/precipitation patterns of a fully transitioned storm are very similar to those of a well-developed extra-tropical cyclone, such as those that effect northwestern Europe and the northwest Pacific coastline of the U.S. in winter.



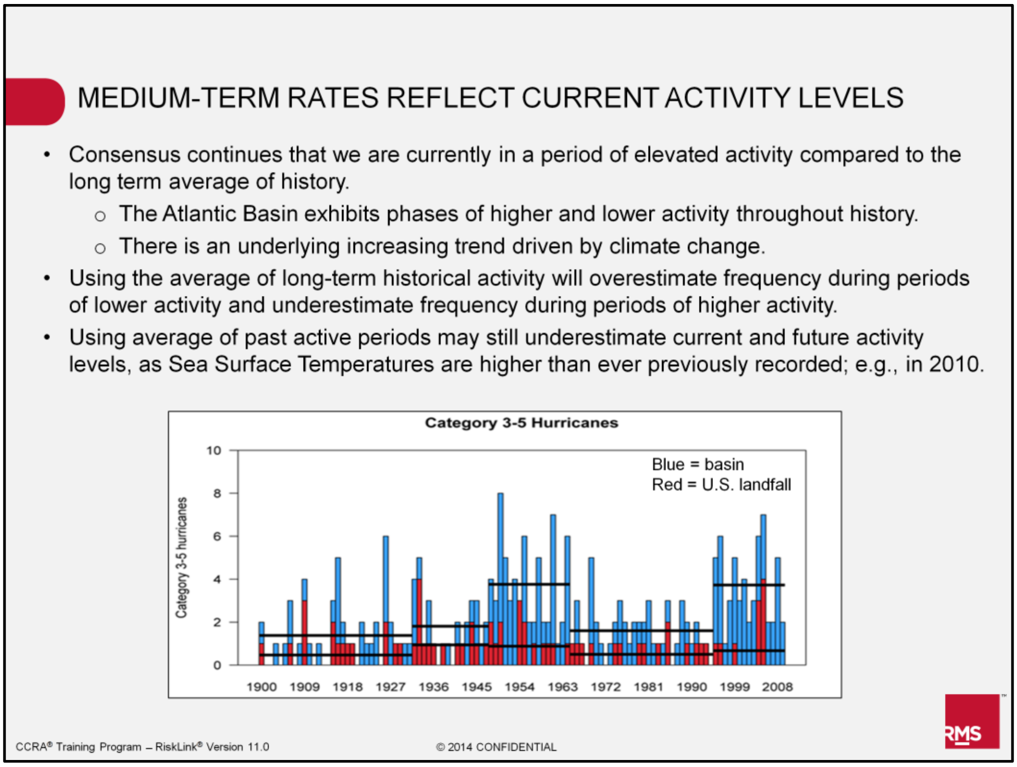
Several storms, especially those affecting the northeastern U.S., have already begun the process of transitioning when they cross over land or are close to land. The plot here shows green dots indicating when the storms began to undergo transition.

Hugo started to transition towards the end of its lifecycle after making landfall in South Carolina, as did Hurricane Opal in the Gulf. Both of these systems had a wind field that widened on its right-hand side towards the end of the lifecycle when the winds were becoming much less damaging, but this broadening was still very much evident. It is the 1938 storm, however, that still remains the most striking and well-documented case of extra-tropical transition that occurred in the 20th Century. We now look at this in terms of implications for modeling tropical cyclones, with particular reference to the 1938 storm in the figure above.



The figure on the right shows the results of modeling the 1938 Long Island Express Category 3 hurricane using a pure hurricane wind field model. The grey and black data shows timber blow-down data collection from an extensive study directly following the event.

Adjusting the model to simulate the storm as a transitioning storm forces it to become much broader and more asymmetric with time, as seen in the figure on the right. It also means that we match the observed damage more adequately, and have an accurate representation of the loss. The triangles in the image show the recorded wind speeds.



Next we will discuss the RMS medium-term rates for hurricane. There is consensus that we are currently in a period of elevated hurricane activity compared to the long term average of history. The medium term rate forecast is the RMS view of hurricane activity over the next five years. Throughout history, the Atlantic Basin has exhibited phases of higher and lower activity. Using the average of long-term historical activity will overestimate frequency during periods of lower activity and underestimate frequency during periods of higher activity. The chart on this slide illustrates the frequency of storms in the Atlantic basin (in blue) and those making landfall in the U.S. (in red) from 1900 through 2010. The average rates over active and inactive periods are shown by the black horizontal lines.

These historical changes in Atlantic hurricane activity levels are closely linked to changes in sea surface temperature in the main development region for Atlantic hurricanes.

WHAT ARE THE RMS "MEDIUM-TERM RATES"?

- Prior to 2005, all hurricane cat model activity rates based on the average of the long term historical record (since 1900).
- In 2006, RMS introduced the concept of the forward-looking medium-term view:

The average number of hurricanes making landfall per year, expected over the next 5 years.

- The five-year forward-looking medium-term perspective envelopes all standard insurance industry (and capital markets) applications of the hurricane catastrophe model.
  - Independent of short-term seasonal forecasts, and the uncertainties of long-term global warming.

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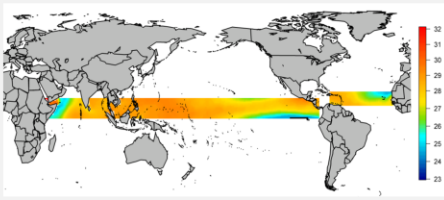
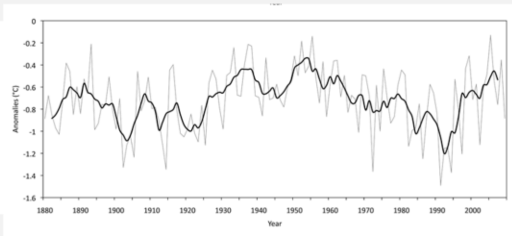
This forward-looking concept of medium-term rates was introduced in 2006 and represents a new way of being able to determine the frequency for hurricane landfalls in the Atlantic Basin that builds upon the historical record and looks at the average number of hurricanes making landfall per year over the next five years. Prior to that, all hurricane catastrophe model activity rates were based on the average of the long term historical record back to 1900. The next several slides provide more detail on the hurricane rates within the RMS model.

MECHANISMS DRIVING INCREASED ACTIVITY

- Increased Atlantic SSTs increase hurricane frequency and intensity.
- Conversely, a warmer Pacific Ocean acts to inhibit hurricane activity, through two principal mechanisms:
  - Increased wind shear in the Atlantic
  - Increasing atmospheric stability which suppresses the convection associated with hurricanes.
- Overall impact is increased hurricane activity and intensity – as the Pacific influence does not fully counteract that of the Atlantic SSTs.



Hadley Centre average July-September sea-surface temperatures from 1950-2009 the Indo-Pacific and Atlantic Main Development Region SST Regions



Main Development Regions (MDR) – Indo-Pacific SST from 1880-2009 (grey line) and the 5-year running-mean (black line).

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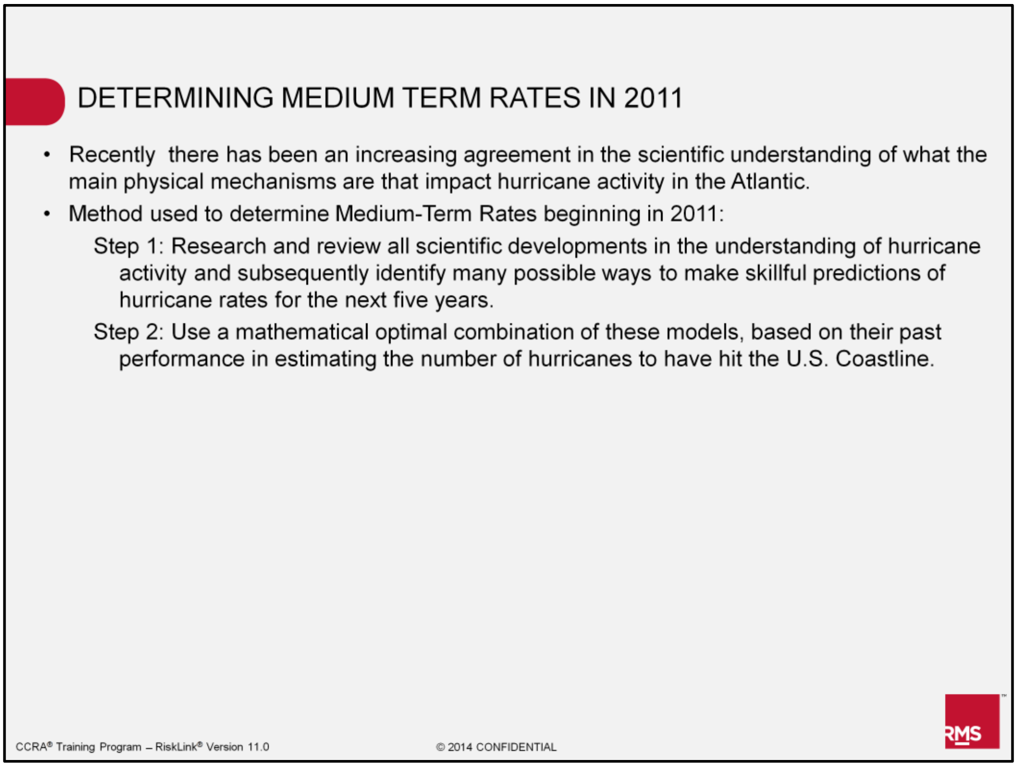
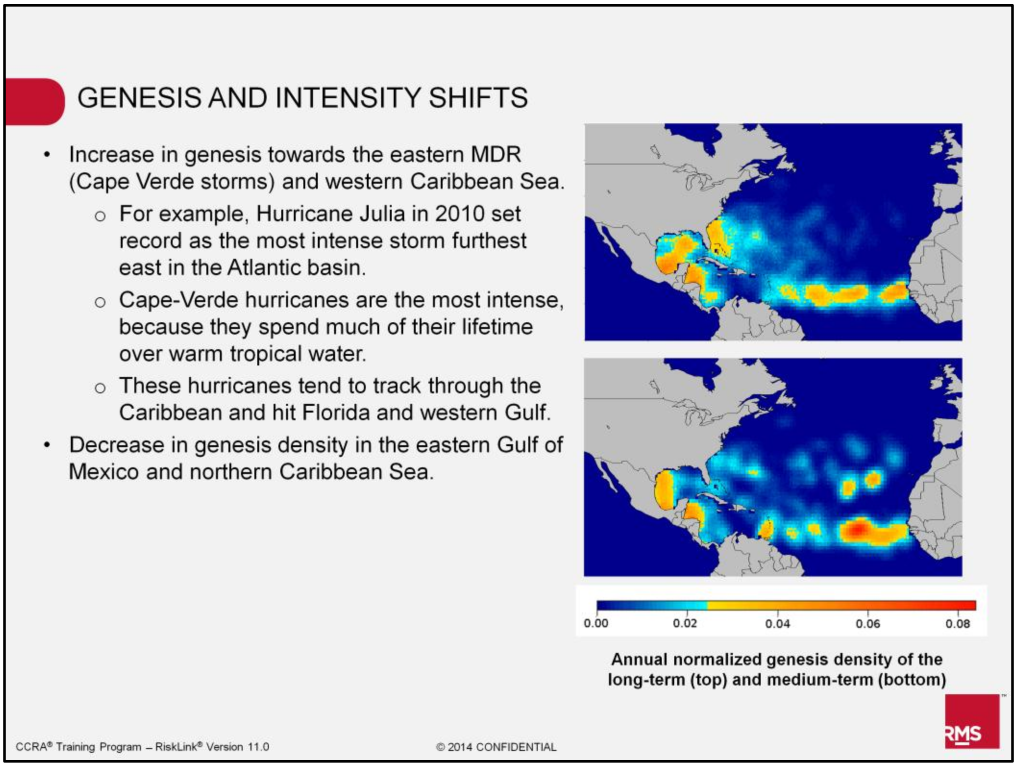
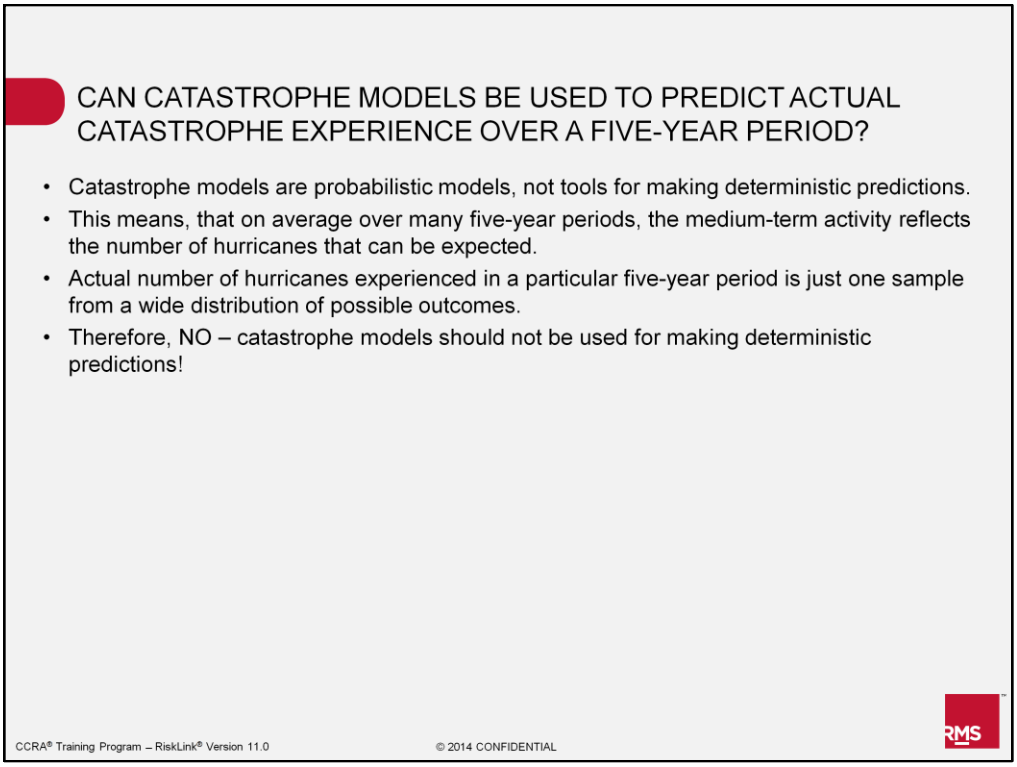
The mechanism that drives the increased hurricane activity is the increased Atlantic sea surface temperatures (SSTs). It not only increases the frequency but also the intensity. Conversely, a warmer Pacific Ocean acts to inhibit hurricane activity through increased wind shear in the Atlantic and increased atmospheric stability, which suppresses the convection associated with hurricanes. The overall impact of these mechanisms is increased hurricane activity and intensity, as the Pacific influence does not fully counteract that of the Atlantic SSTs.



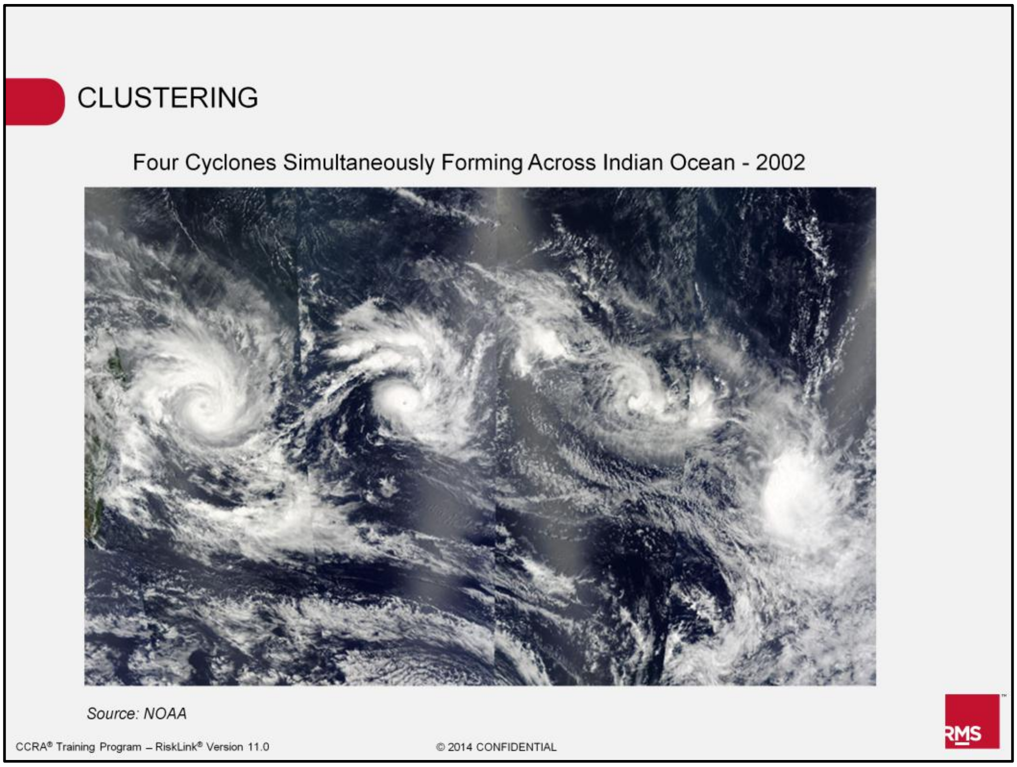
There has recently been an increasing agreement in the scientific understanding of what the main physical mechanisms are that impact hurricane activity in the Atlantic Basin. To determine the medium-term rates in 2011, the first step was to research and review all scientific developments in the understanding of hurricane activity and identify all the possible ways to make skillful prediction of hurricane rates for the next five years. The next step was to use a mathematical optimal combination of these models based on their past performance in estimating the number of hurricanes to have hit the U.S. coastline.



With the medium-term rates, there is an increase in the genesis towards the eastern main development region (MDR) near Cape Verde and the western Caribbean Sea, and a decrease in genesis activity in the eastern Gulf of Mexico and northern Caribbean Sea. For example, Hurricane Julia in 2010 set a record for the most intense hurricane furthest east in the Atlantic Basin. Hurricanes with an MDR of Cape Verde are the most intense because they spend a significant part of their lifetime over warm tropical water. These hurricanes tend to track through the Caribbean towards Florida and the western Gulf region.



Catastrophe models are not tools for making predictions but probabilistic forecast models. The answer to the question posed on this slide is no, catastrophe models should not be used for making predictions. A probabilistic activity rate forecast means that, on average, over many five-year periods, this is the number of hurricanes that can be expected based on the latest research and understanding. However, the actual number of hurricanes experienced in a particular five-year period will be just one sample for a broad distribution of possible outcomes.

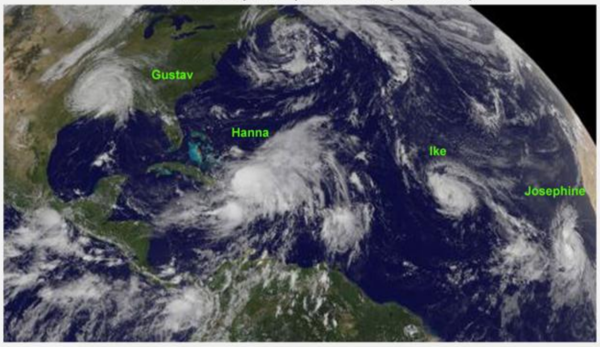


Next we will move on to the topic of clustering. This photo depicts four cyclones simultaneously forming across the Indian Ocean in 2002 (From NOAA).

CLUSTERING

- Clustering refers to the tendency for similar storms to occur close both in space and time to a previous event.
- For meteorological perils, clustering occurs in response to low frequency modes of atmospheric variability, which can cause the conditions governing the formation and paths of storms to remain stable for extended periods.

Figure shows a satellite image from September 2, 2008 showing Gustav (over Texas), Hanna (in the Bahamas), Ike, and Josephine (both over open water).



NASA/NOAA GOES Project
http://www.nasa.gov/images/content/271615main_fourstorms_HI.jpg

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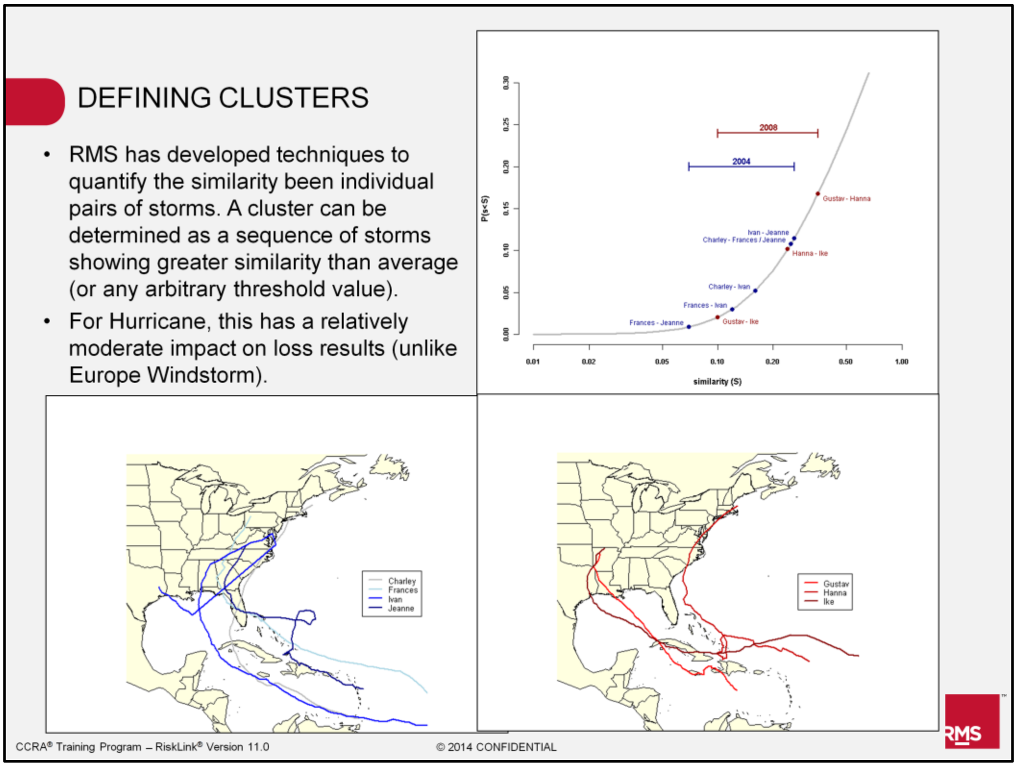
Clustering is the term used to describe the tendency for similar events to occur close to previous events. For meteorological perils, including tropical cyclones, it is the persistent and extended stability of atmospheric conditions which govern the formation and behavior of storms that can lead to clusters of storms. For example, the phase of the North Atlantic Oscillation (NAO), the location and stability of the Bermuda high, high sea surface temperatures, or persistent favorable wind shear can either individually, or more often in combination, influence the formation of clusters.

Note that the term clustering, or seriality, is often also used to describe the greater variability in the number of events within a season than could be expected at random. While this greater variability (or over-dispersion) is strongly related to clustering and does influence the occurrence of clusters of storms, it is actually a feature of non-stationary or seasonal variability of tropical cyclones genesis and behavior, and care must be taken with the terminology.



RMS has developed techniques to quantify the similarity been individual pairs of storms. Using this information, a cluster can be determined as a sequence of storms showing greater similarity than average (or any arbitrary threshold value).

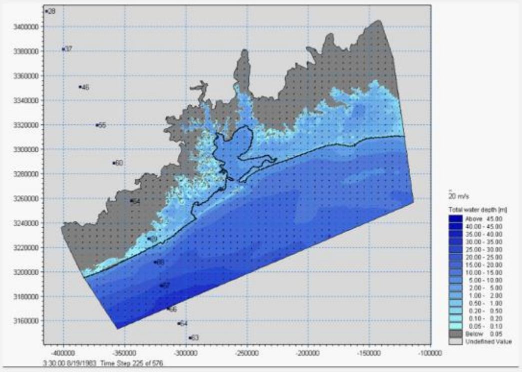
The chart on the top right shows the empirical probability of a given similarity based on all combinations of observed storm tracks form HURDAT (1950-2008). Individual values observed for pairs of storms from clustering in 2004 and 2008 are also indicated with the corresponding tracks shown in the maps below.

Both Frances–Jeanne and Gustav-Ike fall in the lower 2-3% of the probability distribution of similarity. The often cited cluster of Charley, Frances, Ivan, and Jeanne in 2004 can be demonstrated to be tighter than that of Gustav, Hanna, and Ike in 2008, although the 2004 storms occurred over a longer period with multiple smaller storms occurring during this period, thus breaking up the cluster.

This type of quantification allows RMS to develop simulations which capture the expected increase in similarity between sequential storms and clustered simulations. This historical clustering behavior in the Atlantic basin has been included in the RMS Simulation Platform.

STORM SURGE MODELING

- Numerical storm surge model dynamically linked with the windstorm model throughout entire lifecycle.
  - Better captures the surge build up at sea; e.g., Ike and Katrina
  - Penetrates realistically inland along rivers, channels, etc.
- Model allows user-defined input of local flood defenses and base-flood elevations.
- Storm surge analysis options allow user to change model default assumptions on the proportion of surge loss that is covered by the insurance policy in place, by line of business.



Snapshot of Cat 5 Storm Surge Simulation

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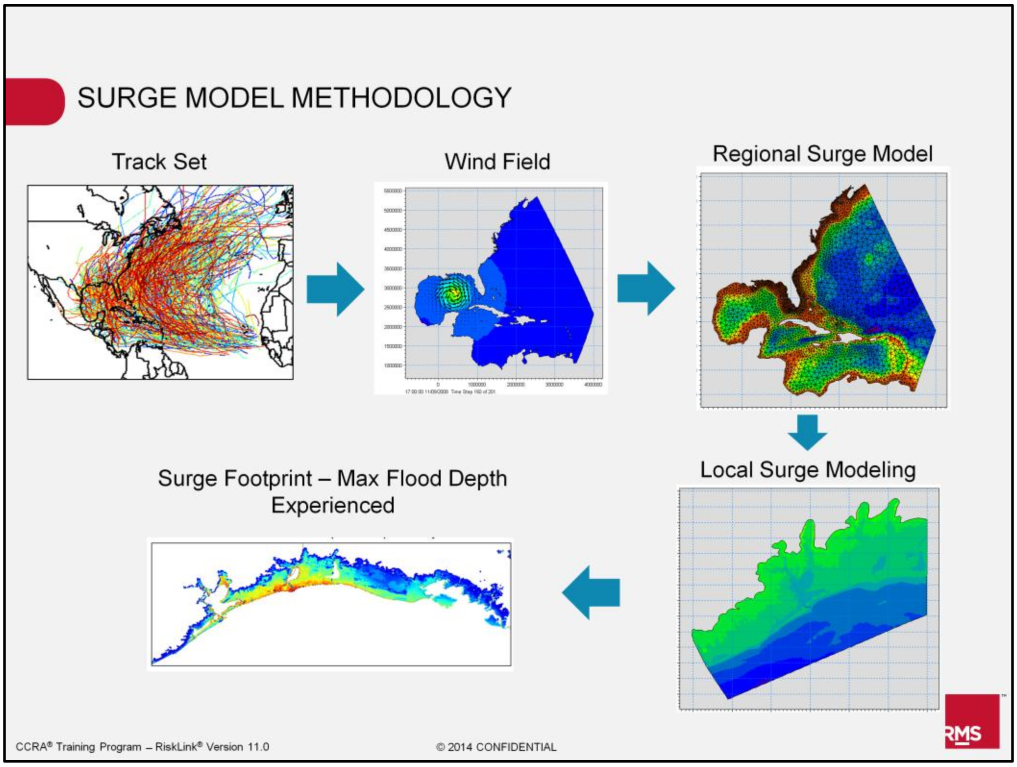
Next we will discuss the storm surge model. A physical numerical model dynamically links the storm surge model to the windstorm model throughout the entire lifecycle of the storm for the Atlantic and Gulf coastlines of the U.S. This method better captures the surge build-up at sea as was seen in Hurricanes Ike and Katrina, and it also realistically penetrates inland along rivers and channels.

The model allows the user to input local flood defenses and base flood elevations. Storm surge analysis options also allow the user to change model default assumptions on the proportion of storm surge loss that is covered by the insurance policy in place by line of business.

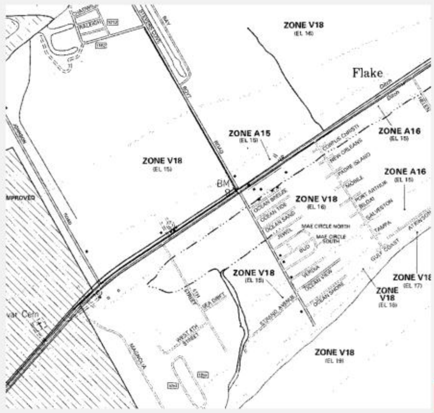


The storm surge modeling system uses individual stochastic hurricane tracks from the stochastic hurricane event set, and two-dimensional time varying wind and pressure fields created for the life of each hurricane. These wind and pressure fields are applied to the various storm surge model domains to determine storm surge hazard values. The stochastic set was simulated using the regional model and maximum storm surge levels obtained at regular intervals along the coast. These results, along with a geographical boundary, are then used to select which storms to simulate for each local fine scale model. The fine scale model simulations are forced by the two-dimensional time varying wind and pressure fields, and the boundary conditions from the regional model results, which ensure sea level changes and flow generated outside the local model domains were represented with the fine scale simulations.

BASE FLOOD ELEVATION HEIGHTS – IMPACTS PROPERTY FLOOD RISK

- The FEMA Base Flood Elevation (BFE) is the 100-yr RP flood height.
- Has been the basis of design codes on the design of buildings and their height above sea-level since the 1970's
- Number of different zones, for different types of flooding

Bolivar Pen., TX



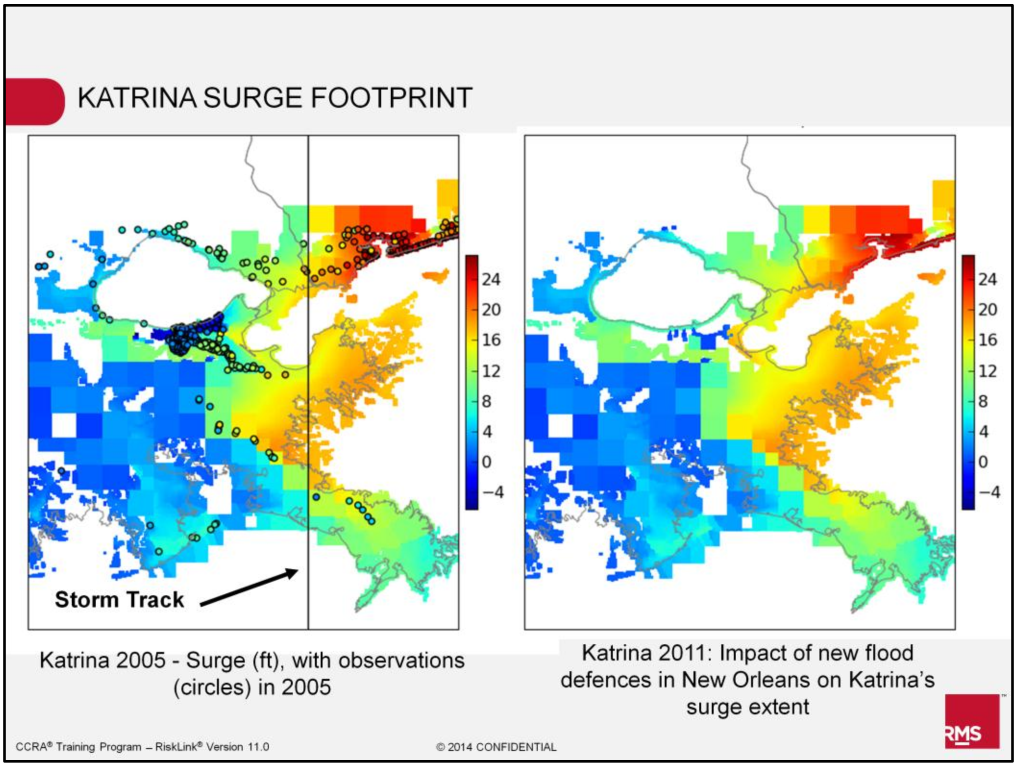
Base Flood Elevation is a FEMA determined building height requirement based on the 100 year flood, or the "flood having a one percent chance of being equaled or exceeded in any given year." The requirement largely affects new structures and those seeking flood insurance. For example, the picture in the bottom left shows a structure built to a proper height with the bottom floor at the required BFE.

CHANGING RISK - NEW ORLEANS LEVEES

- Since Katrina, the USACE has significantly improved the storm surge defenses.
- Risk today has been lowered since 2005 because of investment.
- But there is still a risk of levee failures – though reduced in many places

Inner Harbor Navigation Canal barrier – Compete June 2011

After Hurricane Katrina in 2005, New Orleans has improved the storm surge defenses in place. Because of this investment, the storm surge risk is lowered in this area; however, there is still a risk of levee failure though it is reduced in many places.



This slide shows the storm surge footprint produced for Hurricane Katrina. Katrina was an interesting storm in that although it was only classified as a Category 3 storm when it made landfall on the Gulf Coast, the surge that accompanied the storm was more akin to a Category 5 storm in places.

On the left is the footprint of Katrina's surge at the time, generated by the RMS storm surge model. On the right it is re-run with all the new flood defenses in place, which lowers the flood risk in New Orleans compared to 2005.

HOW MUCH STORM SURGE LOSS WILL YOU PAY?

- Location specific Base-Flood elevations
  - Model defaults
  - User-defined options
- Flood defenses, and their failure
  - Model incorporates New Orleans, Galveston Sea Wall, Port Arthur Sea Wall
  - Users can input localized flood walls
- Storm surge losses being paid by wind policies.
  - RMS model default of "surge leakage" varies by LOB and increases with damage severity.
  - Can explore user-defined options up to 100% surge payout
  - Can now run surge-only analysis

Elevated Properties Post Ivan - Dauphin Island

Post-Katrina Wind and Wave Damage in Waveland

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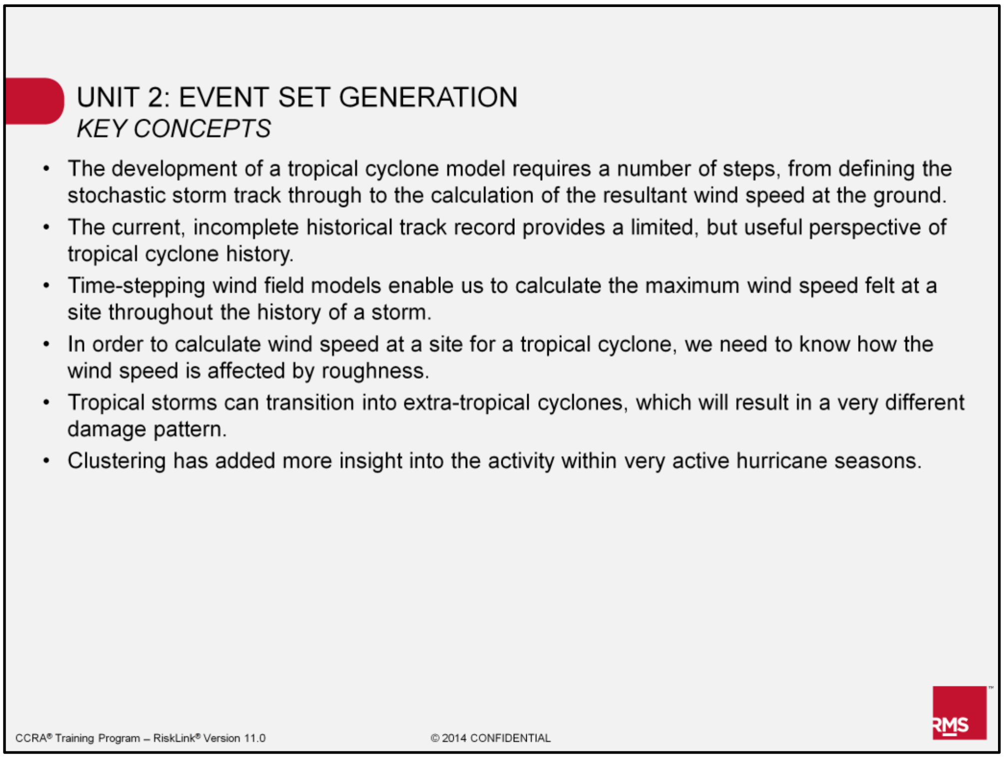
How much storm surge loss you will pay depends on a number of factors. The RMS model allows you to input user-defined options for the location of base-flood elevations, or to accept the model defaults. Flood defenses are also included in the model, such as those in New Orleans, the Galveston Sea Wall, and the Port Arthur Sea Wall. User can also input their own localized flood walls into the RMS model. Storm surge losses are often being paid out by wind policies due to the difficultly of claims adjusters to discern wind-related damage from storm surge-related damage. The RMS model default of surge leakage varies by line of business and increases with damage severity. User-defined options allow uses to explore up to 100% surge payout, as well as running surge-only analyses.



This unit has taken you through some of the important steps and challenges to overcome in developing a tropical cyclone model, from developing stochastic tracks, through to the calculation of wind speeds using a time-stepping wind field model, as well as some of the recent developments in the modeling arena. The learning objectives listed here highlight the key concepts from this unit. We encourage you to review these and make sure you are comfortable with each before proceeding to Unit 3.

This concludes Unit 2 of the Tropical Cyclone Modeling course.