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Topic: Multi-Radar/Multi-Sensor Products

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Welcome to the Multi-Radar / Multi-Sensor products course. Called MRMS, this represents a different way to use key inputs into warning and forecast decision-making for public, hydrological and aviation service sectors. MRMS became operational in October of 2014 and is now undergoing its latest evolution as of 2022. This course is designed to familiarize you with MRMS, how it's created, and initial steps of applying these data sets in operations.

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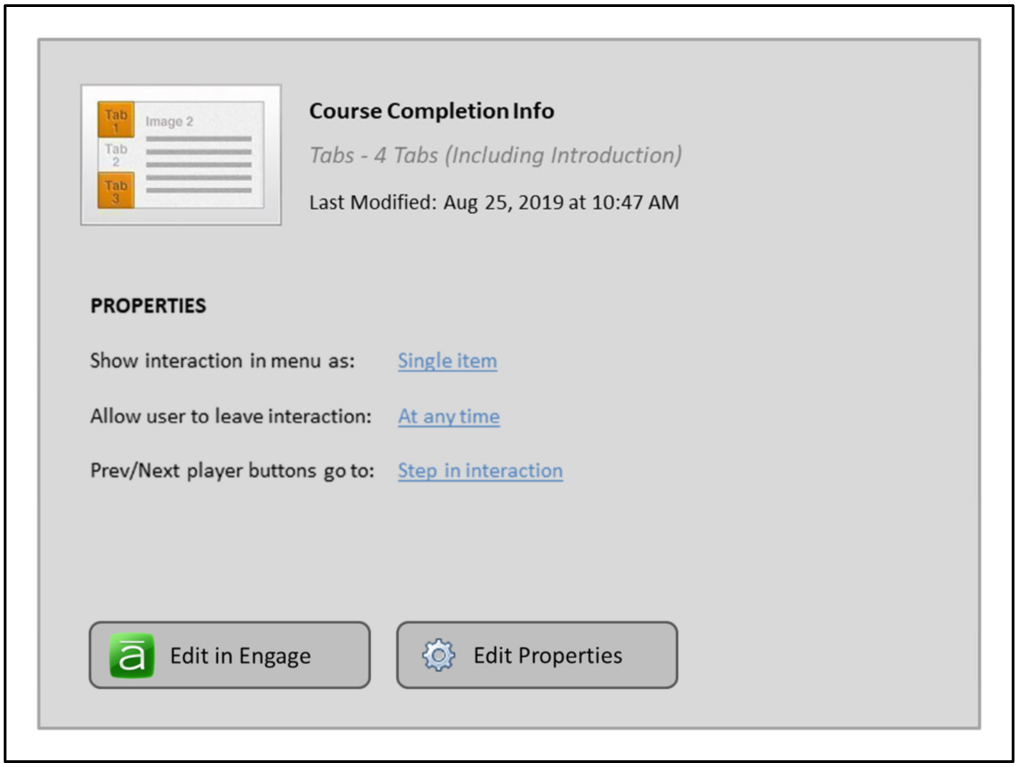
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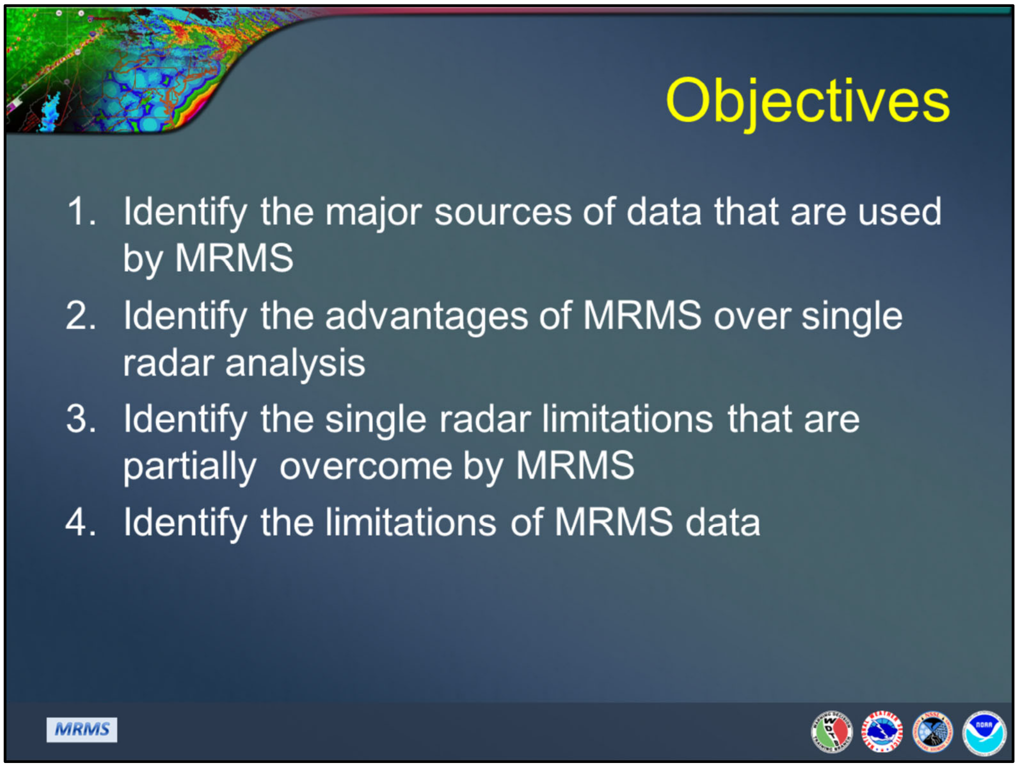
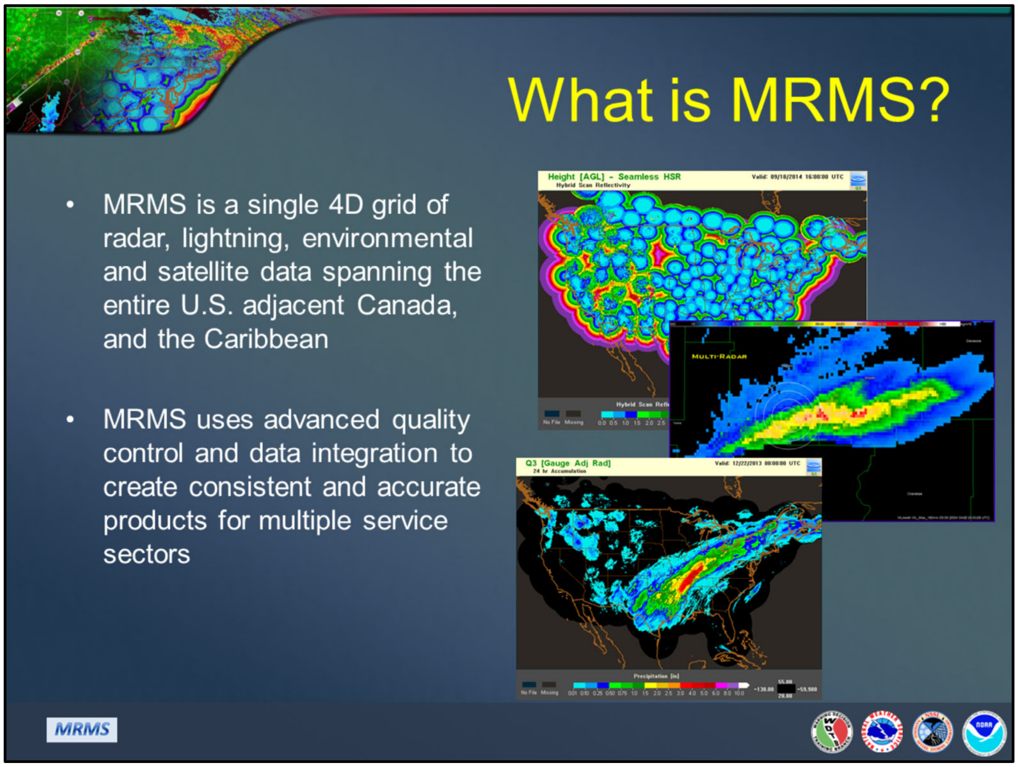


Let me introduce you to the objectives, which essentially are to identify the sources of data used by MRMS, and MRMS' advantages and limitations.



What is MRMS? MRMS is a single 4D grid of radar, lightning, environmental and satellite data spanning mostly the continental US (CONUS), adjacent Canada, and some neighboring outside CONUS sites. MRMS uses advanced quality control and data integration to create consistent and accurate products for multiple service sectors (e.g., hydrological, public severe warning, aviation).

MRMS has been in development for over two decades. In that time, many collaborators have become involved in the refinement of MRMS data and quality. On the US federal side, these include the NWS National Centers for Environmental Prediction (NCEP), the Radar Operations Center (ROC), testbeds, the Earth System Research Laboratory, and NWS Weather Forecast Offices (WFOs) and River Forecast Centers (RFCs). Other organizations span UCAR, NCAR, CAPS, Lincoln Labs, NASA, UNIDATA, CIMSS-Wisconsin, Environment Canada, and OU CIWRO.

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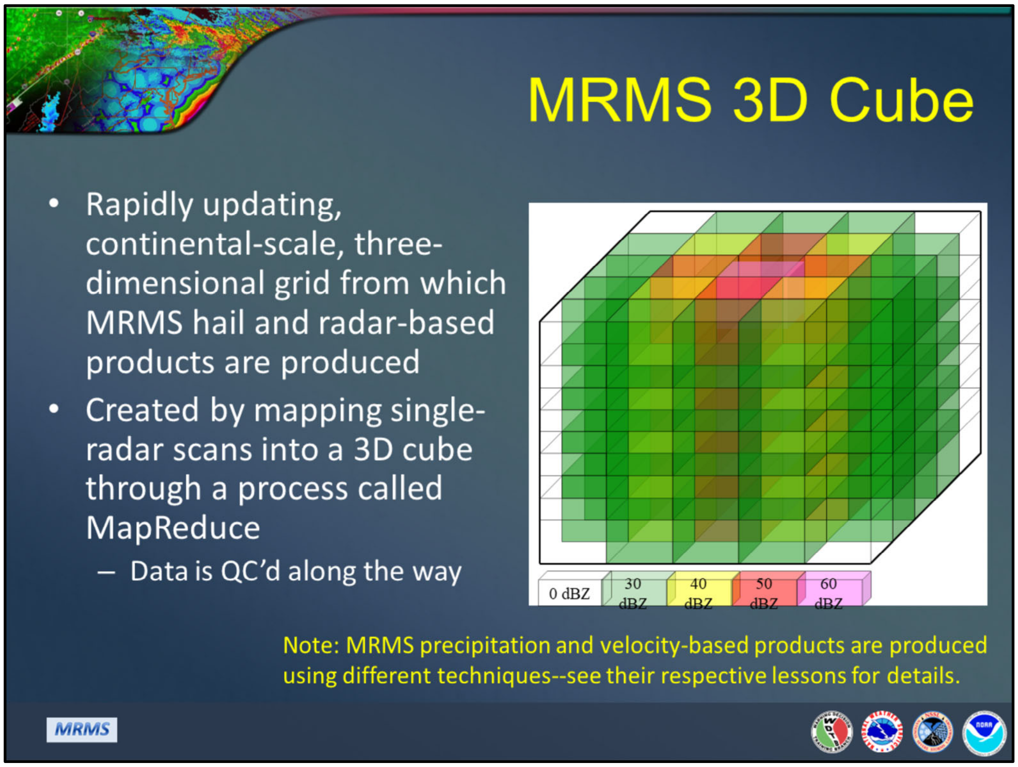
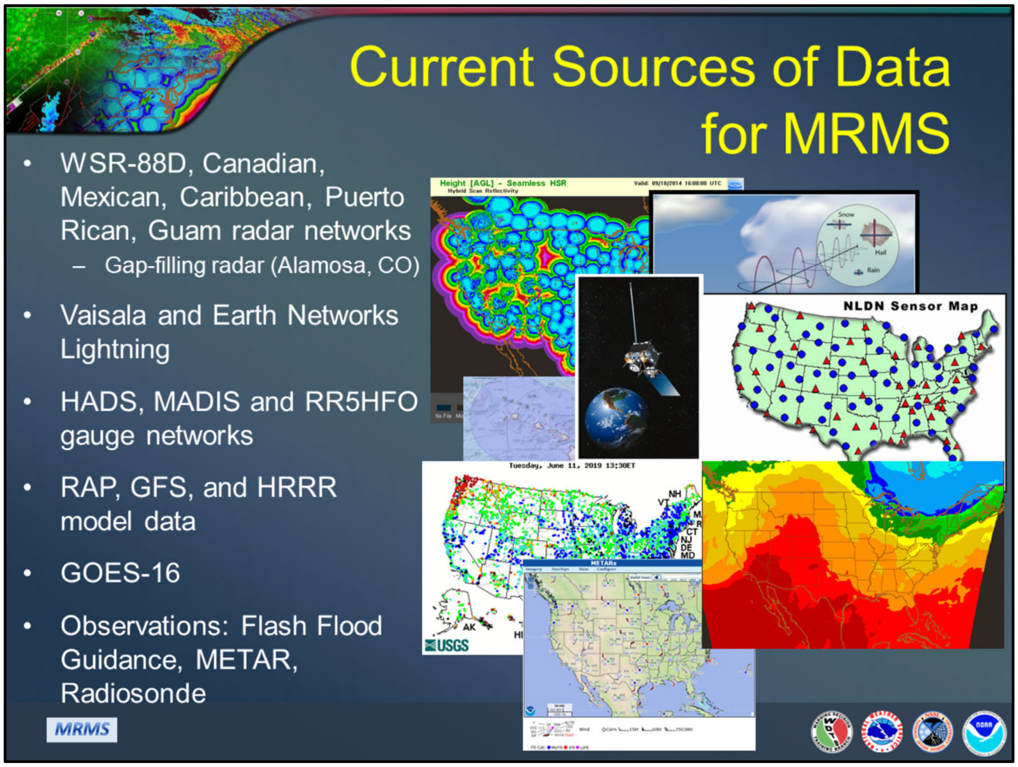
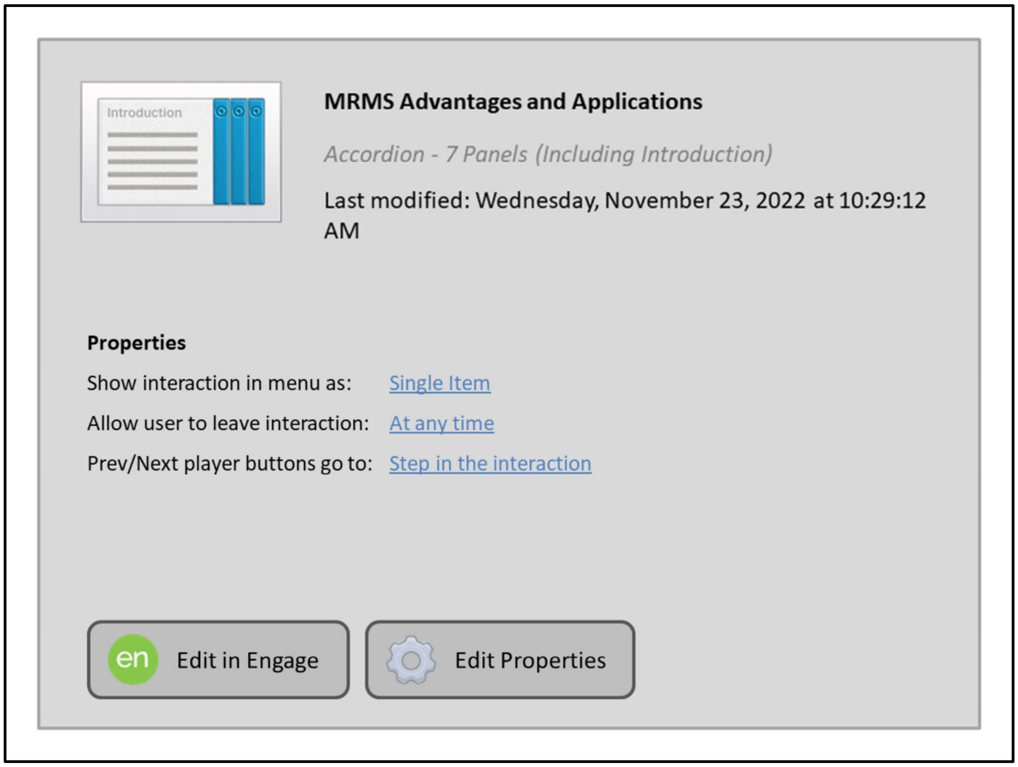


MRMS reflectivity and hail products are created using what's termed the MRMS "3D Cube." It is a 1 km x 1 km, continental-scale, 3D grid that updates every 2 minutes. This cube is created through a computerized process called MapReduce, where single-radar scans are grouped together and mapped into a cube using interpolation techniques. The data is QC'd in each group before it's mapped to the grid. Note that MRMS precipitation and velocity-based products are produced using different techniques and using different data sources.



Let’s talk about all those data sources that are used to create MRMS products. At this time, they include all WSR-88Ds and radars from Canada, Mexico, the Caribbean, Puerto Rico, and Guam, as well as a gap-filling radar in Colorado; lightning data from Vaisala and Earth Networks; the HADS, MADIS, and RR5HFO gauge networks; the RAP, GFS, and HRRR models for environmental analysis; GOES provides some data; and additional datasets include observations like Flash Flood Guidance, METARs, and radiosondes. Future MRMS updates may include more data from other sources.



This interaction will step you through multiple advantages and applications of MRMS products. This is not an exhaustive list.

First, the inclusion of multiple radars almost eradicates many single-radar limitations, including cones of silence, range degradation, clutter, and anomalous propagation.

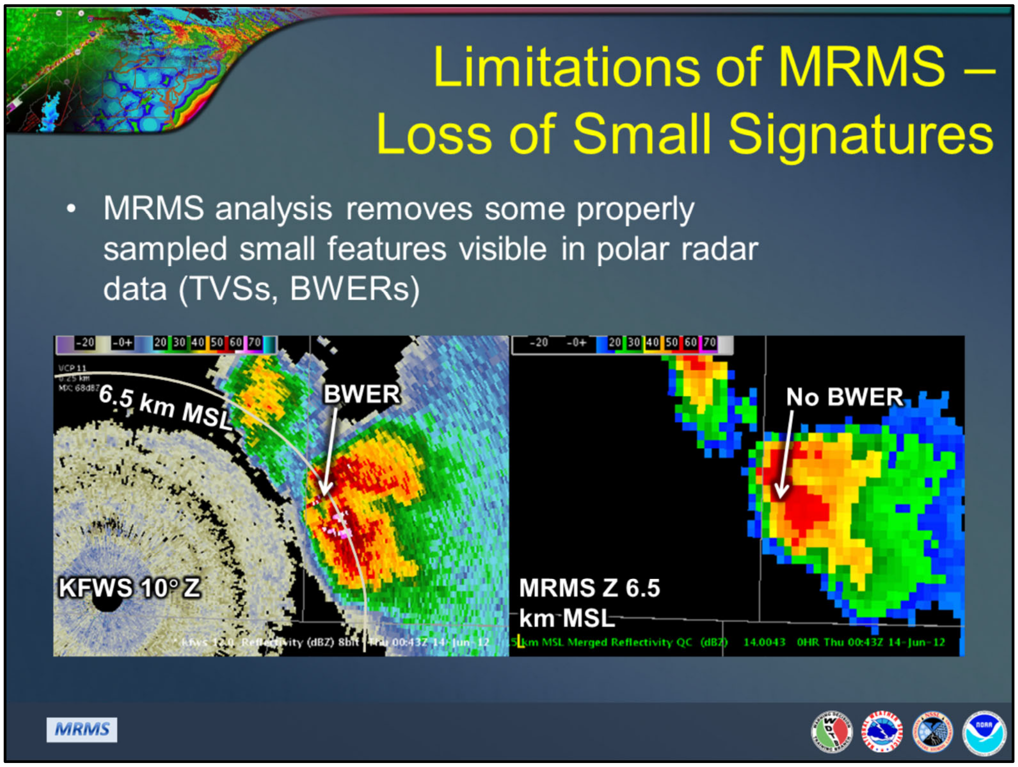
Multiple radars also reduce the effects of terrain blockage.

Another advantage is that some MRMS products include environmental data. An example of this is the isothermal levels inclusion in the reflectivity thickness products.

Next, MRMS QPE products leverage radar, gauge, and environmental data, with the latest enhancement being Dual-Pol rain rate relationships for improved rainfall estimation.

MRMS products are used as input for several models, including the National Water Model and the High-Resolution Rapid Refresh model.

Finally, archived MRMS data has become a very popular model training and verification tool, partially thanks to the Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS) dataset (see Williams et al. 2022).



As with all technologies, there are limitations to consider. I will discuss broad limitations that can apply across many products while the follow up lessons will discuss product-specific limitations. One of the first is resolution. While MRMS can add detail at long range to one radar, the same process can smooth valid small scale signatures. In this case, a Bounded Weak Echo Region (BWER) sampled by the KFWS radar at 6.5 km MSL failed to appear in the MRMS 6.5 km MSL reflectivity.

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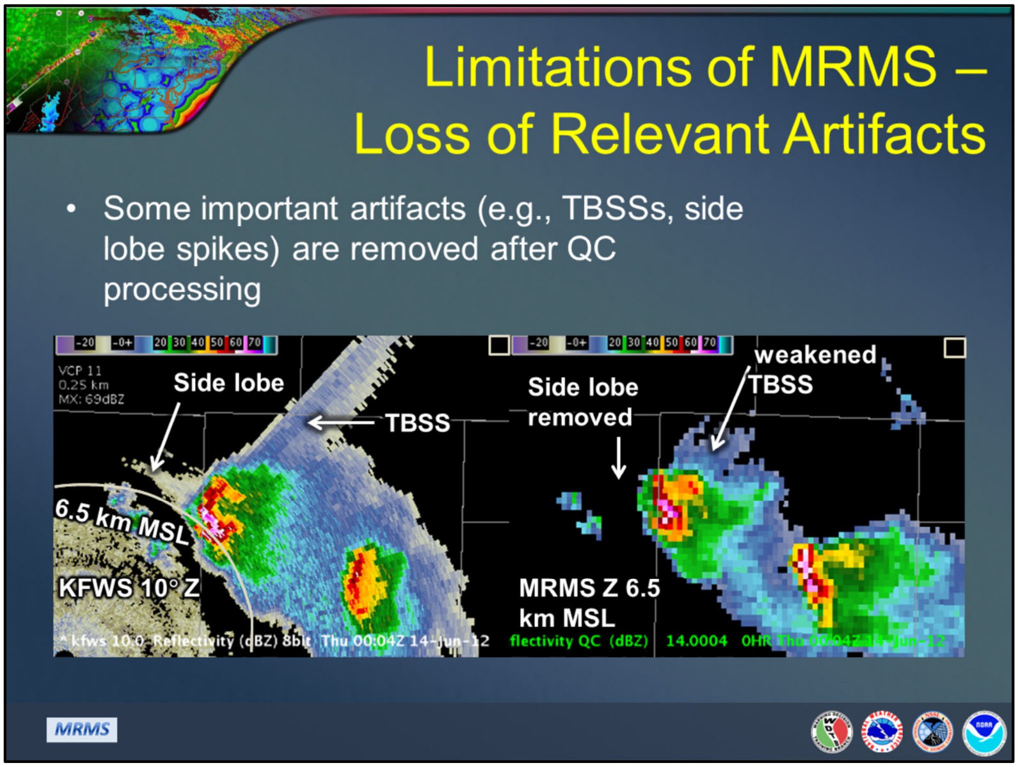
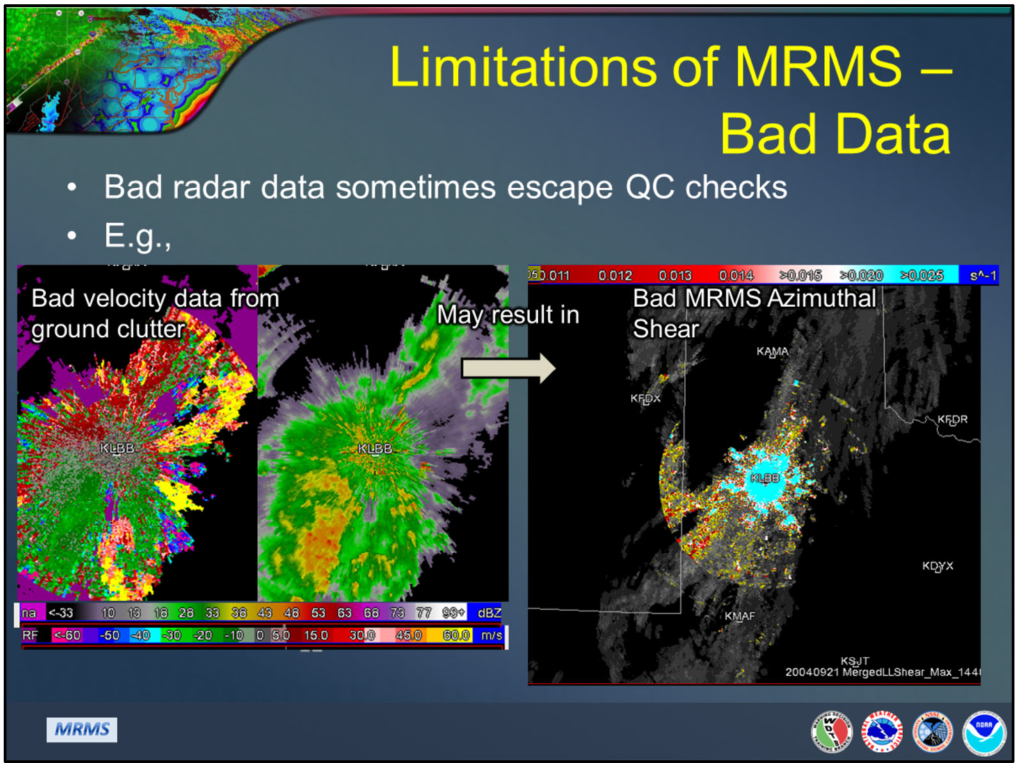


Likewise, the process that MRMS uses to eliminate non-precipitation echoes also removes useful echo artifacts forecasters use to evaluate a storm's severity. Any storm that exhibits a side lobe and Three-Body Scatter Spike (TBSS) like the one in the upper left, should support a large hail and downburst threat. Like with the BWER, MRMS also eliminated the side lobe and weakened the TBSS. The lat-lon grid nature of the MRMS also softened the prominent radial appearance of the remains of the TBSS that often helps in its identification.



Despite the improving QC algorithms in MRMS, bad data sometimes gets through to negatively impact its products. In the case above, spurious velocity data inadvertently caused the MRMS azimuthal shear product to produce extreme shear. This example is pretty obvious, but there may be more subtle errors.

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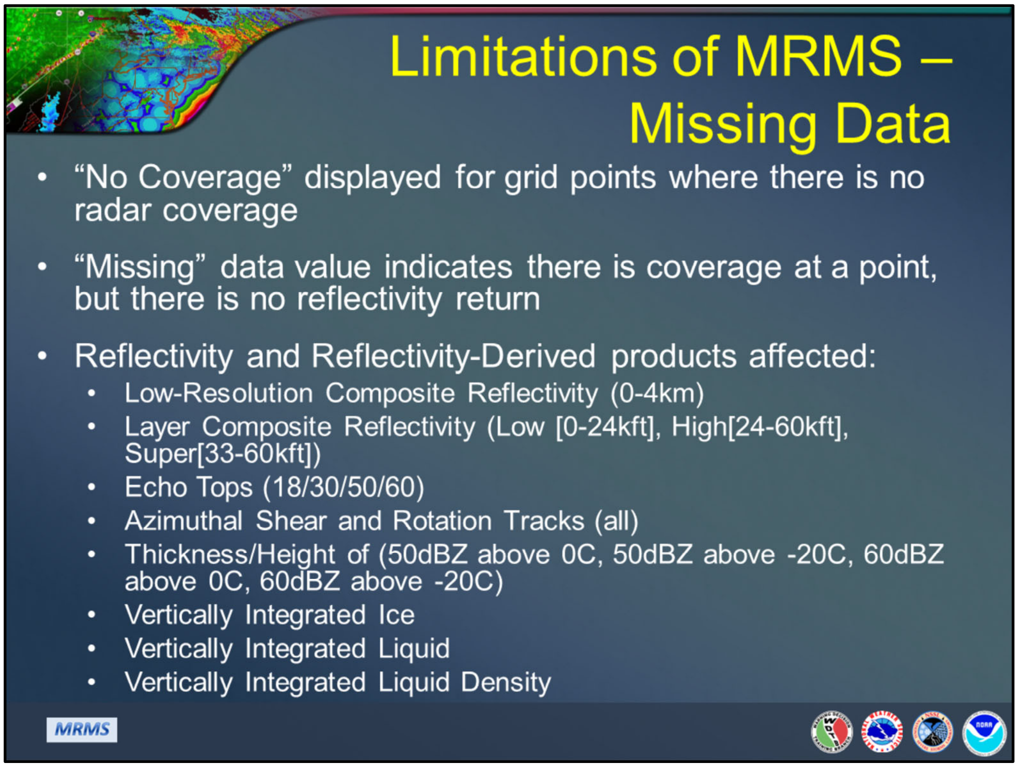

As of 2017, "no data" points are categorized by the reason data is missing. Specifically, all Reflectivity and Reflectivity-derived products display "no coverage" where there is no radar coverage. Where there is radar coverage, but no Reflectivity return, or if that return has been removed through the QC process, those areas display a "Missing" data value. The reflectivity products that follow this procedure are listed here.

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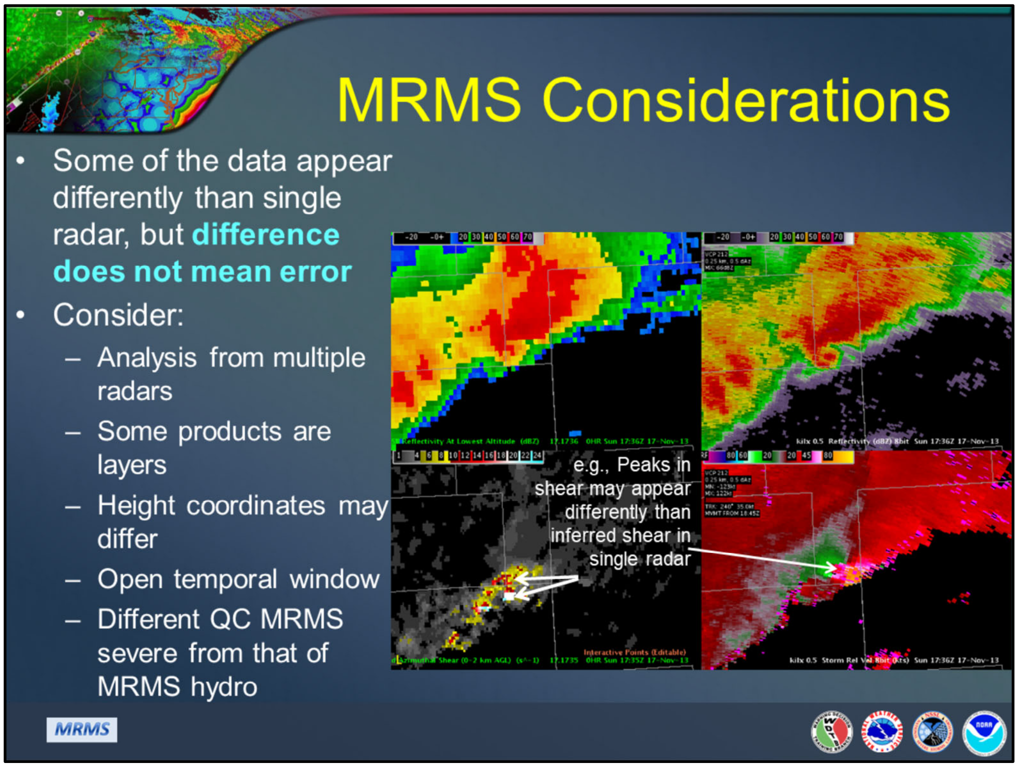
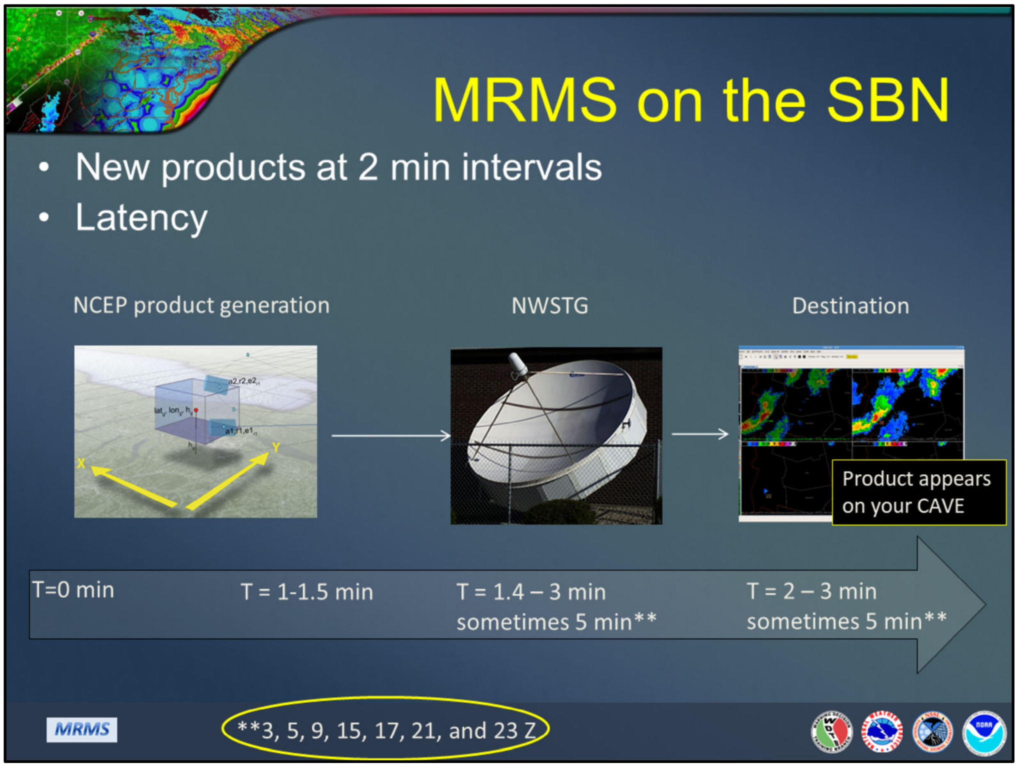


Some aspects of MRMS are neither limitations nor advantages. They are simply called considerations. The biggest consideration is that MRMS may look different from that of single radar. However that difference doesn't mean error. Consider that MRMS is analyzing multiple radars, each with their respective viewing angle. MRMS also produces some products that are layers (e.g., Azimuthal shear) that means a direct comparison to single radar data is not easy. Height coordinates may differ. MRMS often does MSL, but some products are in an AGL coordinate. The MRMS grid points collect data for a period of time. In combination with multiple contributing radar viewpoints, the data may appear different, such as the multiple peaks in azimuthal shear compared to what could be inferred from a single radar. Finally, the quality control for MRMS hydro products differs somewhat from the severe/aviation products. These differences are by necessity to do what's needed to ensure the highest quality of the respective products.



MRMS is available on the SBN where the data updates in 2 minute intervals. However how much later you get the product compared to the product legend time is the latency. Let's start with the beginning and show how the time latency builds. Products get generated at the NCEP National Computing Office (NCO), then get sent to the NWS Telecom Gateway, transferred to the SBN where then your local (EDEX) ingests the product for display on your machine (CAVE). At the beginning, MRMS generation software processes the raw data accumulated over a temporal window for each product. At this moment, a time stamp is created that eventually winds up in the product legend in CAVE, that's T=0 min. The time it takes to generate each product varies depending on the complexity of the algorithm, mostly 1 to 1.5 minutes (note that some QPE products take a long time). Then the product goes in a queue to be sent to the NWSTG for upload through the SBN. The queue can build the latency up to 1.4 to 3 minutes, but every 3 hours the queue raise the latency up to 5 minutes as MRMS data competes with model data. Once on the SBN, the product quickly goes to your ingester where a fraction of a minute is needed to make it visible on your CAVE. In summary, MRMS latency is 2 – 3 minutes with occasional spikes to 5 minutes or even more. NCO is aware of this latency issue and is taking steps to monitor and improve it.

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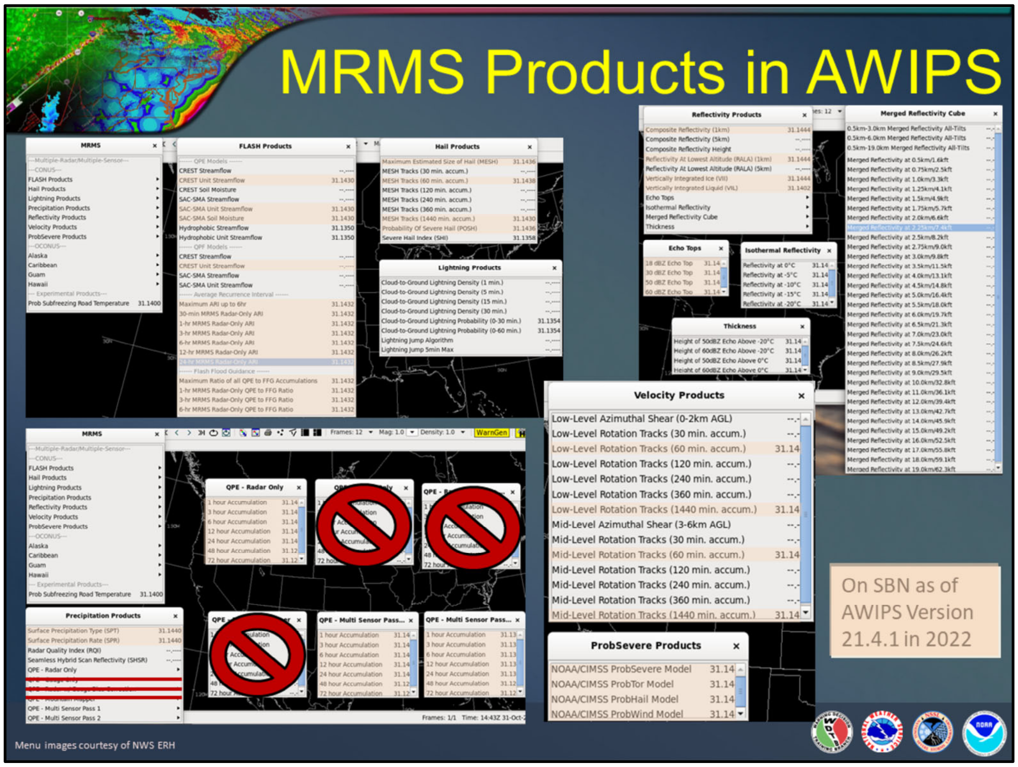

Beware, however, that many MRMS products are not currently on the SBN. These menus give you a general idea of which products are available via the SBN and which are from an experimental Local Data Manager (LDM) feed as of AWIPS version 21.4.1. Most of the products available via the LDM are operational, but were removed from the SBN to make room for other large datasets. However, since the LDM data feed is experimental and regional, menu arrangements and the products' availability are subject to change and may vary by region. Finally, note that you can ignore the menus for some discontinued QPE products. These include: QPE—Gauge Only, QPE w/ Gauge Bias Correction, and QPE-Mountain Mapper. Ask your AWIPS focal point for details about viewing MRMS products in AWIPS.

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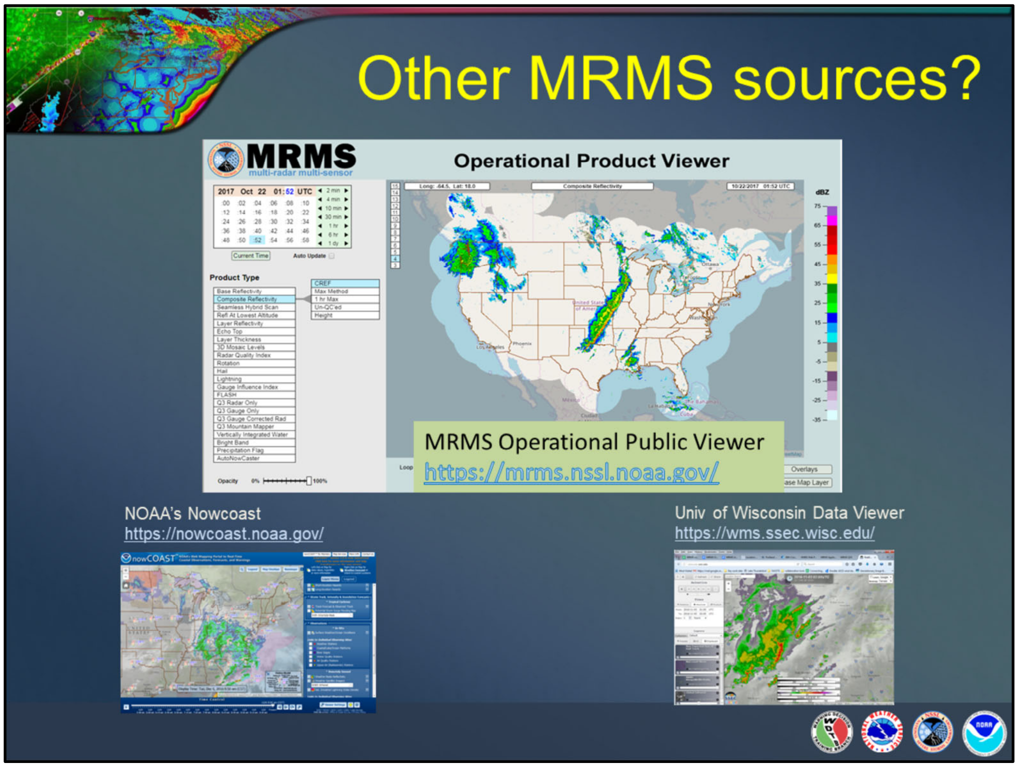

If you're comfortable viewing products outside AWIPS, you're in luck! There are several ways to view the MRMS products that aren't accessible via the SBN. The National Severe Storms Lab team that develops MRMS products hosts a Public Viewer that displays operational MRMS products and it can be accessed at this URL.

There are some other sites with publicly accessible MRMS data. NOAA's Nowcoast site supplies low-level reflectivity data for people interested in marine and inland weather.

A very comprehensive weather data viewer at the University of Wisconsin offers you a variety of MRMS products.

A word of caution about nonoperational sites is that the data may not always be available.

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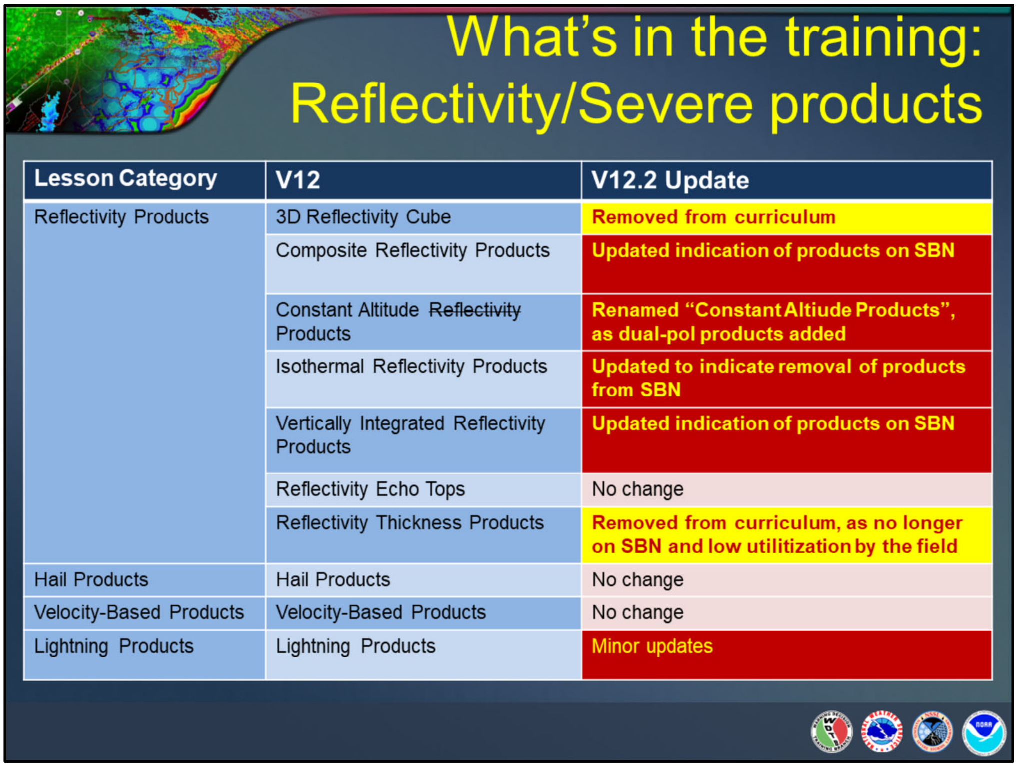
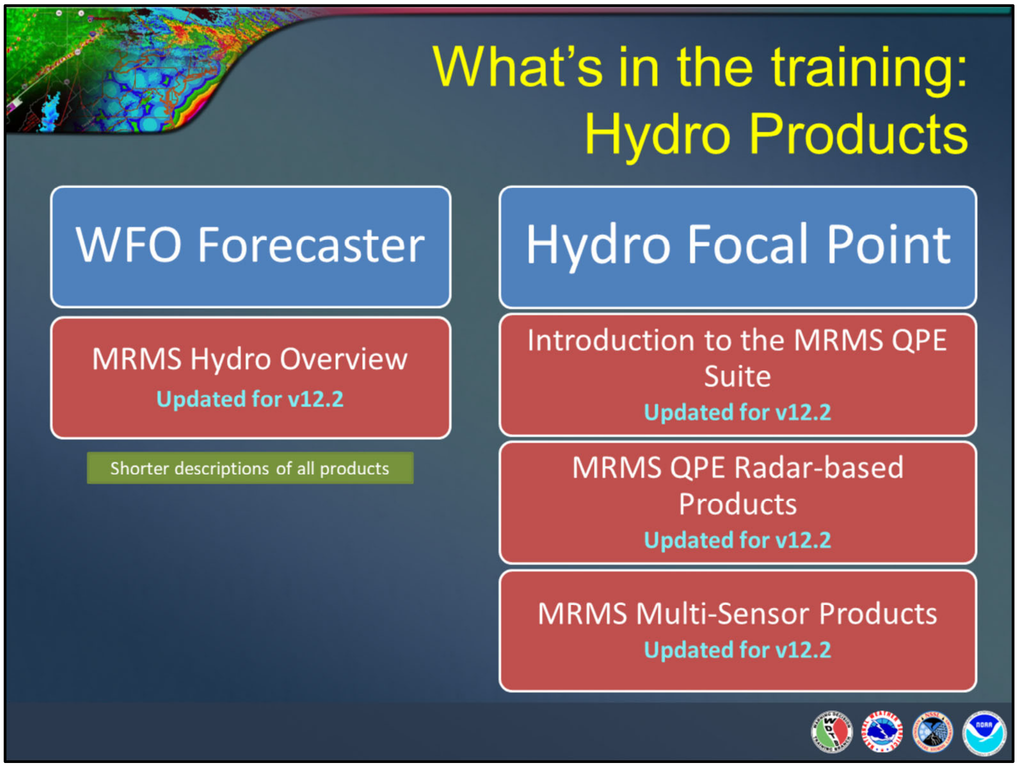


Lesson Category	V12	V12.2 Update
Reflectivity Products	3D Reflectivity Cube	Removed from curriculum
	Composite Reflectivity Products	Updated indication of products on SBN
	Constant Altitude ~~Reflectivity~~ Products	Renamed "Constant Altiude Products", as dual-pol products added
	Isothermal Reflectivity Products	Updated to indicate removal of products from SBN
	Vertically Integrated Reflectivity Products	Updated indication of products on SBN
	Reflectivity Echo Tops	No change
	Reflectivity Thickness Products	Removed from curriculum, as no longer on SBN and low utilitization by the field
Hail Products	Hail Products	No change
Velocity-Based Products	Velocity-Based Products	No change
Lightning Products	Lightning Products	Minor updates

Now let's talk about the actual course content. The MRMS products course is divided into two sections, reflectivity/severe products and hydro products. Here's a table that shows the reflectivity/severe lessons that have changed since the v12 release, with the v12 configuration in the middle column and v12.2 on the right. In the right column, lessons in light pink have had no changes from the version 12 of the course. Lessons in yellow have minor changes for version 12.2 where credit's applied if you've taken their previous version. Lessons in red have been removed from the curriculum either because they are outdated or because the entire product suite has been removed from the SBN.

None of the reflectivity product lessons have changed significantly, but minor updates were made. Also note that "Reflectivity" has been removed from the Constant Altitude Products lesson title since dual-pol products were added to this product suite.

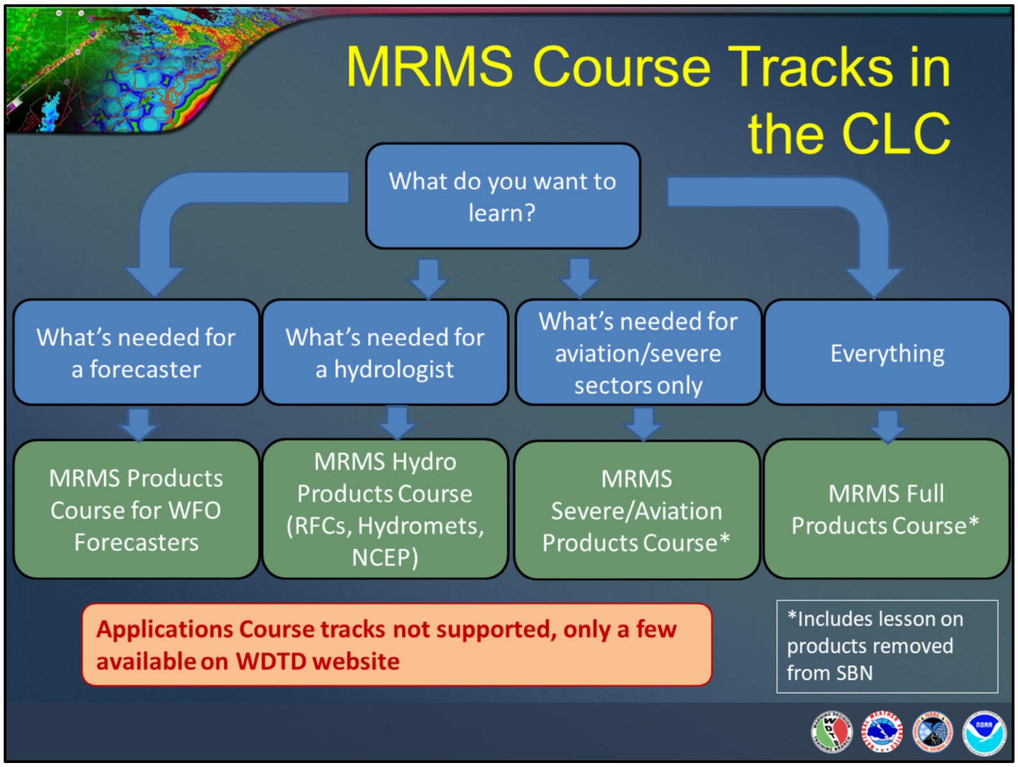
Lessons for other MRMS severe products include one for hail, velocity, and lightning products. Only minor updates were made to a couple of these lessons.



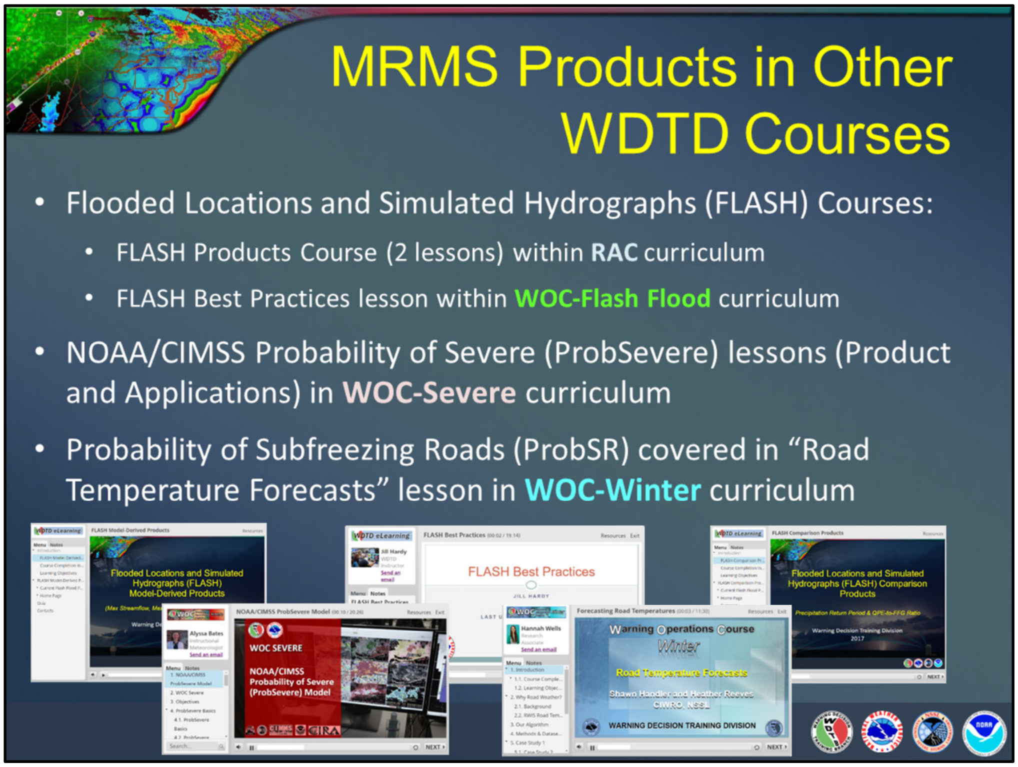
For the MRMS hydro-related products, there are two tracks to choose from depending on your job responsibilities.

For the WFO forecaster who just wants to know what products are out there, take only the Hydro Overview lesson. This lesson is simply a more condensed version of the full hydro course, and best meets the needs of most forecasters.

For hydro focal points who want to know the nitty-gritty behind the quality control processes and product creations, take all three lessons of the Hydro Products Course. These lessons cover everything in the Overview lesson, just in greater detail. Therefore, there is no need for a Focal Point to take the Overview before taking these three lessons.



On the Commerce Learning Center (CLC), there are four MRMS training tracks divided up by what you need out of this training.
If you're a forecaster then you may be most interested in taking the MRMS Products Course for WFOs.
If you're a hydrologist, you may want to take the MRMS hydro products course.
If you're only interested in the severe or aviation sectors, there's a track for you.
And finally, if you want to know everything, then take the MRMS Full Products course. Note that this curriculum includes a lesson for products that were removed from the SBN.
Also note that the MRMS Applications course lessons are not on the CLC, and most have been removed from WDTD's website. A few useful MRMS severe applications lessons are still on the site, but they are not maintained or updated.



But wait, there's more! Since the MRMS grid is being utilized for more applications, a handful of products are covered in other WDTD courses. First, the Flooded Locations and Simulated Hydrographs (FLASH) product suite is covered within 2 WDTD courses—you can learn about the products within the RAC curriculum, and learn how to apply the FLASH products in warning operations within the Warning Operations Course (WOC)-Flash Flood curriculum. Next, the NOAA/CIMSS Probability of Severe (ProbSevere) model lessons are within the WOC-Severe curriculum. Likewise, the Probability of Subfreezing Roads (ProbSR) product is covered within the "Road Temperature Forecasts" lesson of WOC-Winter's curriculum. Ask your training facilitator for more details.

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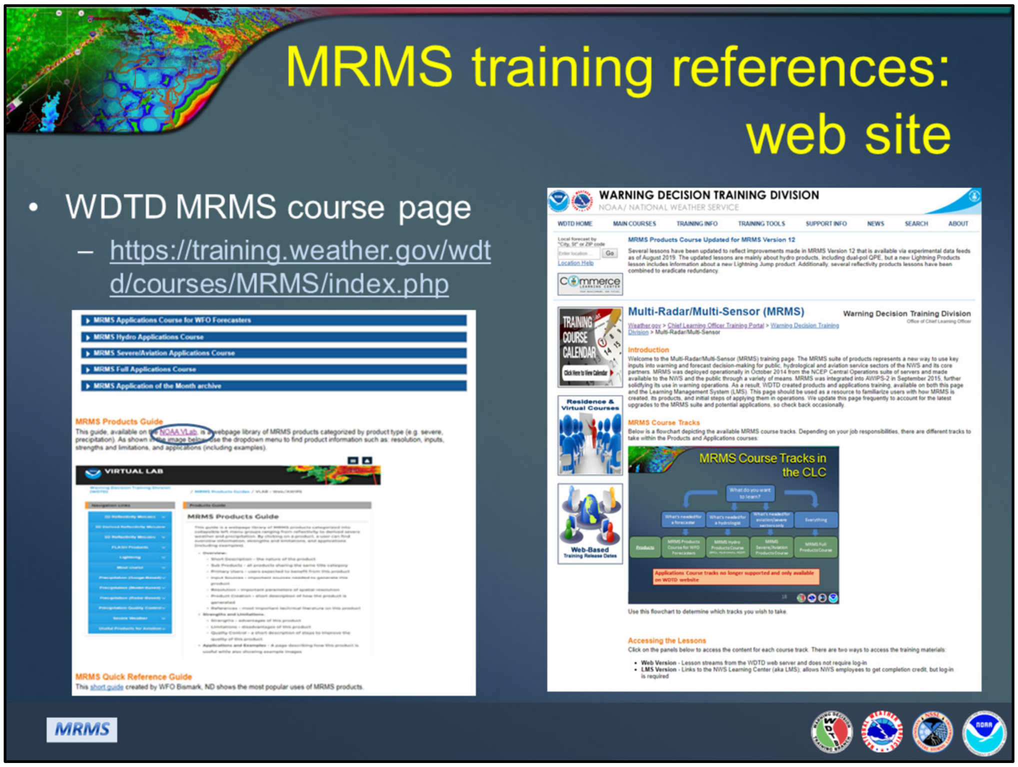
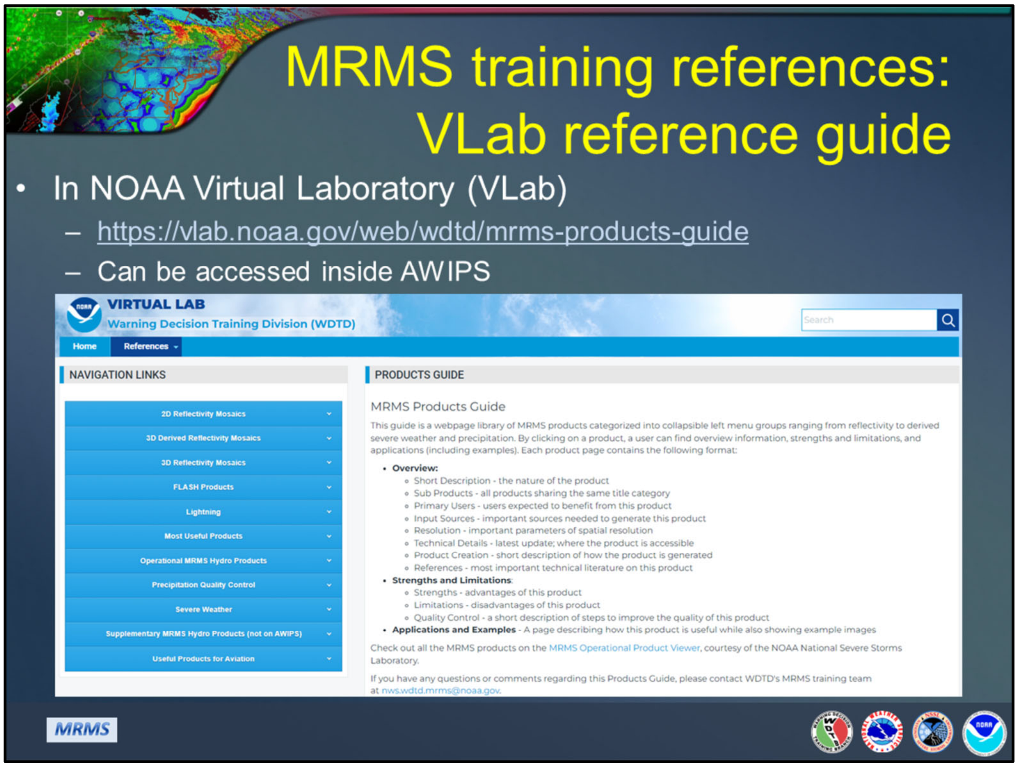
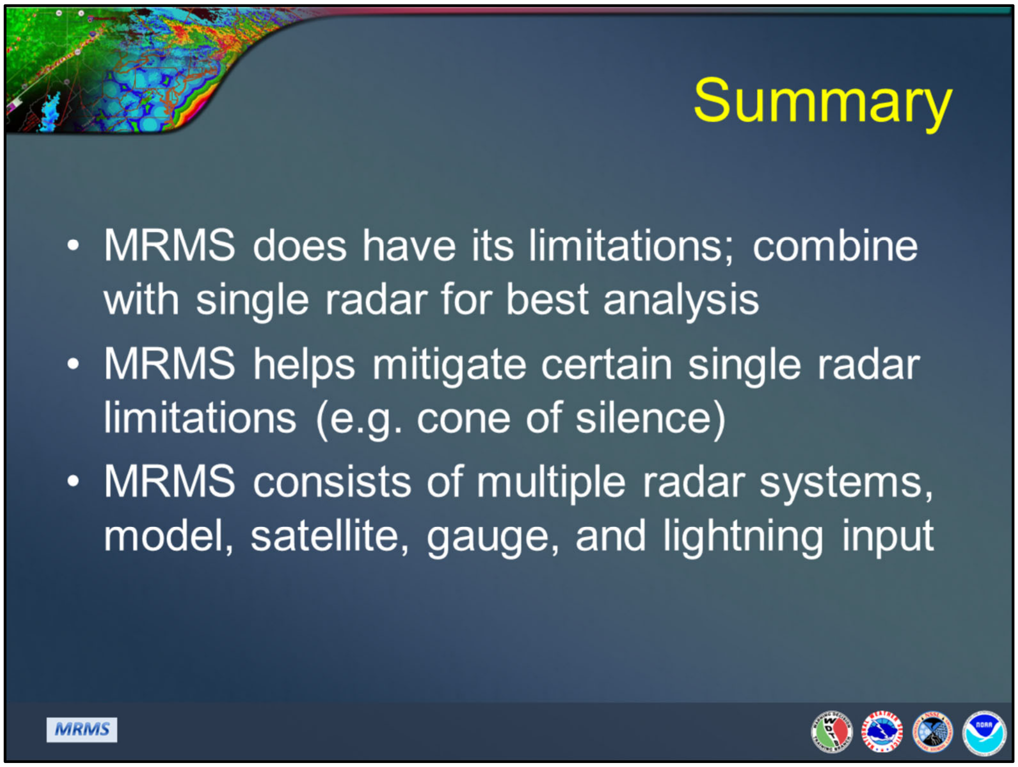


There are numerous references available concerning MRMS. The path to these starts at the MRMS web page in WDTD. In here you have access to our online courses, links to the lessons in the Commerce Learning Center and references. Note the link to the NOAA VLab MRMS Products Guide.



The reference guide is available in VLab, which means also inside of AWIPS. From there, it has content about every product that you can easily access, including a description, strengths and limitations, and primary applications.



In summary,
MRMS does have its limitations, especially in smoothing away important small scale signatures, so combine with single radar data for best analysis.
MRMS helps mitigate certain single radar limitations (e.g. cone of silence, better trends, more accurate QPE).
MRMS consists of multiple radar systems, model, satellite and lightning input.
Now you're ready to take the quiz!

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MRMS Overview Quiz

Quiz - 5 questions

Last modified: Monday, October 24, 2022 at 12:31:26 PM

Properties

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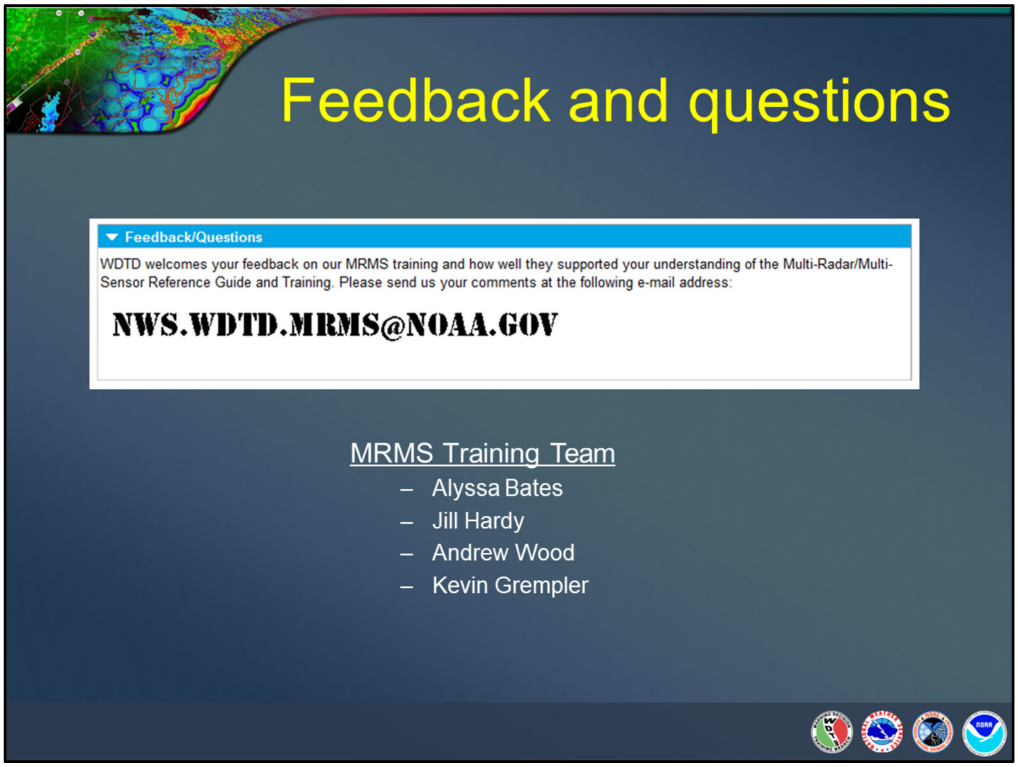

If you have any questions about MRMS, please contact the email address displayed here.

Welcome to the Multi-Radar/Multi-Sensor (MRMS) Training Course Lesson on the Composite Reflectivity products that was developed at the Warning Decision Training Division (WDTD).

Course Completion Info

Tabs - 4 Tabs (Including Introduction)

Last modified: Thursday, December 1, 2022 at 11:37:29 AM

Properties

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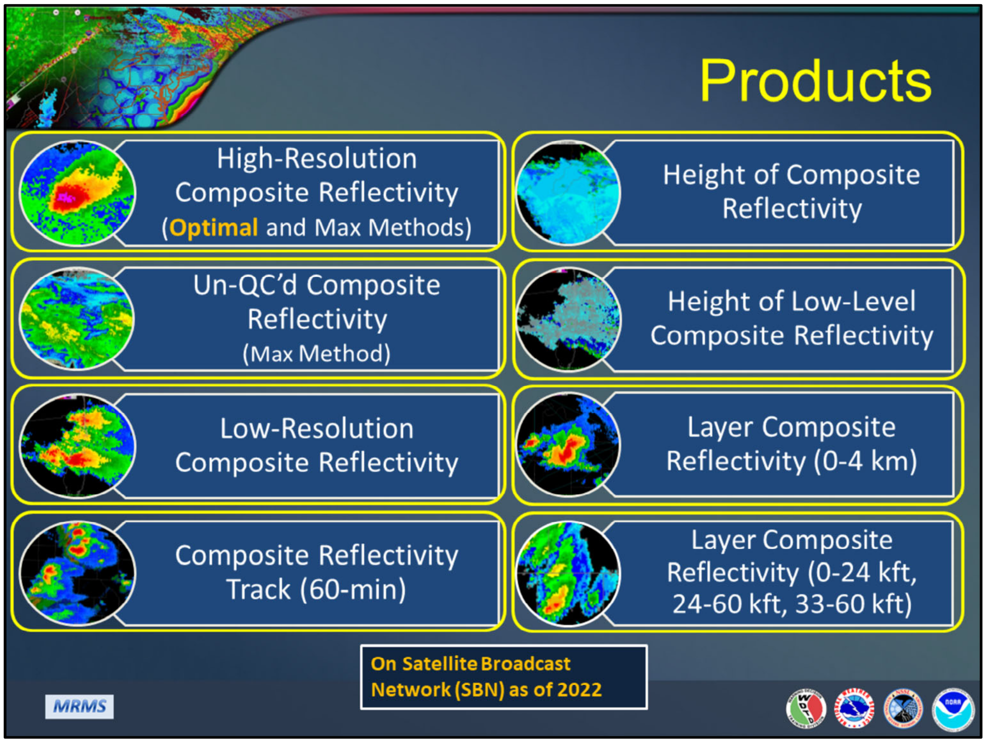
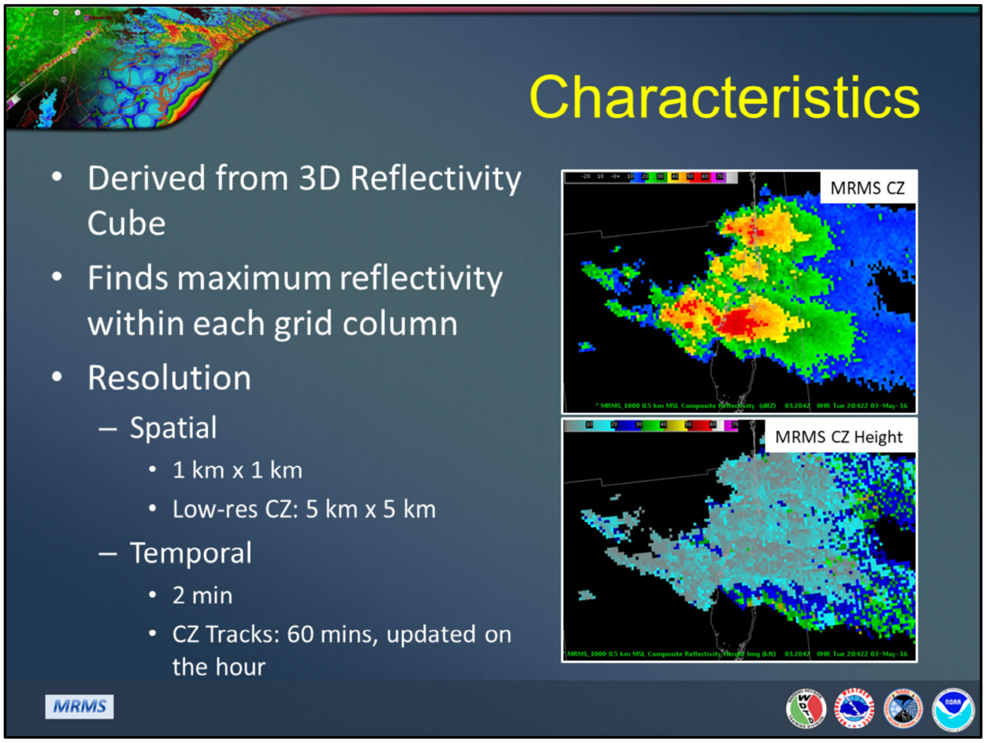
Here are the objectives for this lesson. Take a minute to review them before moving on to the next slide. You will be tested at the end of the lesson based on these objectives.



There are several MRMS products based on composite reflectivity (CZ). The most widely-used product is the High-Resolution Composite Reflectivity product calculated using what's called the "optimal" method. The max method product, primarily used in aviation, gives the maximum reflectivity value from any radar in a given domain, without regard to distance. There is also a raw CZ mosaic computed with the max method for aviation users. The rest of the products use the optimal method. There's a low-resolution version that allows for a CONUS-wide view of CZ. Next, there's a 60-min CZ Track that shows trends. In addition, since the maximum reflectivity does not always occur at the same height within each grid column, a separate product is generated showing the height of each grid value from the composite reflectivity product. Finally, there are several layer composite reflectivity products that are mostly used for aviation purposes. This lesson will mainly focus on the products that are used the most in NWS operations.



The composite reflectivity products are derived from the 3D reflectivity cube by finding the maximum reflectivity value within each grid column. The spatial resolution of almost all the products is 1 km x 1 km. The exception is the low-resolution CZ product with a 5 km x 5 km resolution. For temporal resolution, all the products except the CZ Tracks update every 2 minutes. The CZ Tracks update every hour.

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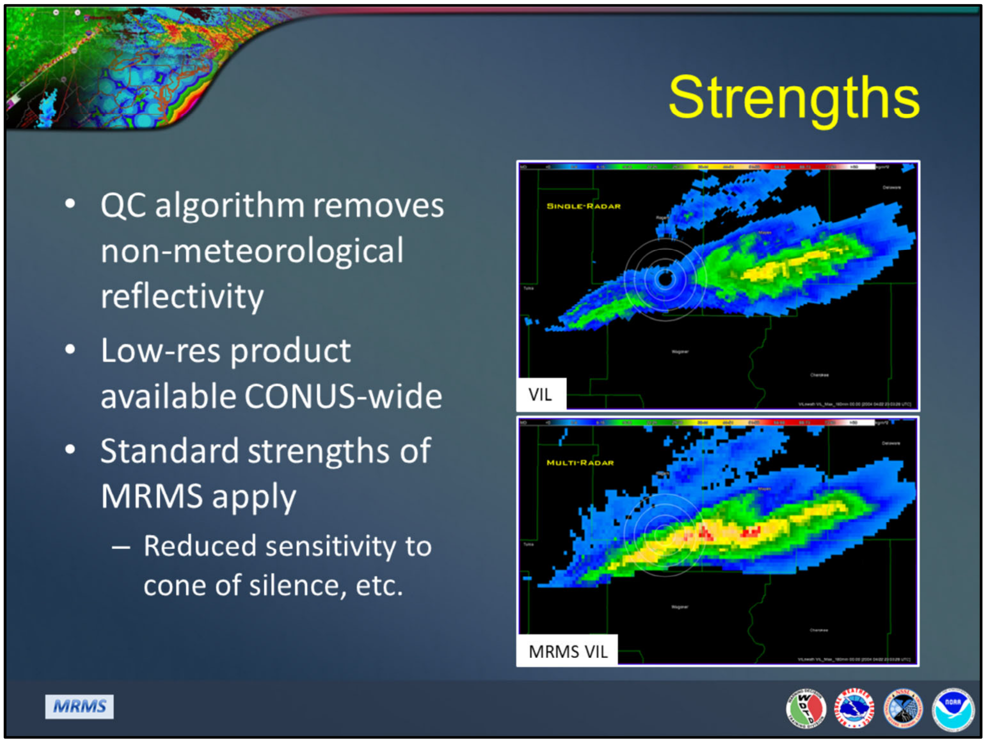

Due to the quality control algorithm removing the majority of non-meteorological echoes in the development of the 3D reflectivity cube, most non-meteorological echoes should not contaminate the composite reflectivity products. Therefore, high reflectivity from ground clutter should not be an issue. Additionally, the low-resolution product is available CONUS-wide, not just in a regional domain. Other standard strengths of MRMS also apply such as reduced sensitivity to the cone of silence, as seen here in this example of the VIL product from a single radar vs. MRMS.

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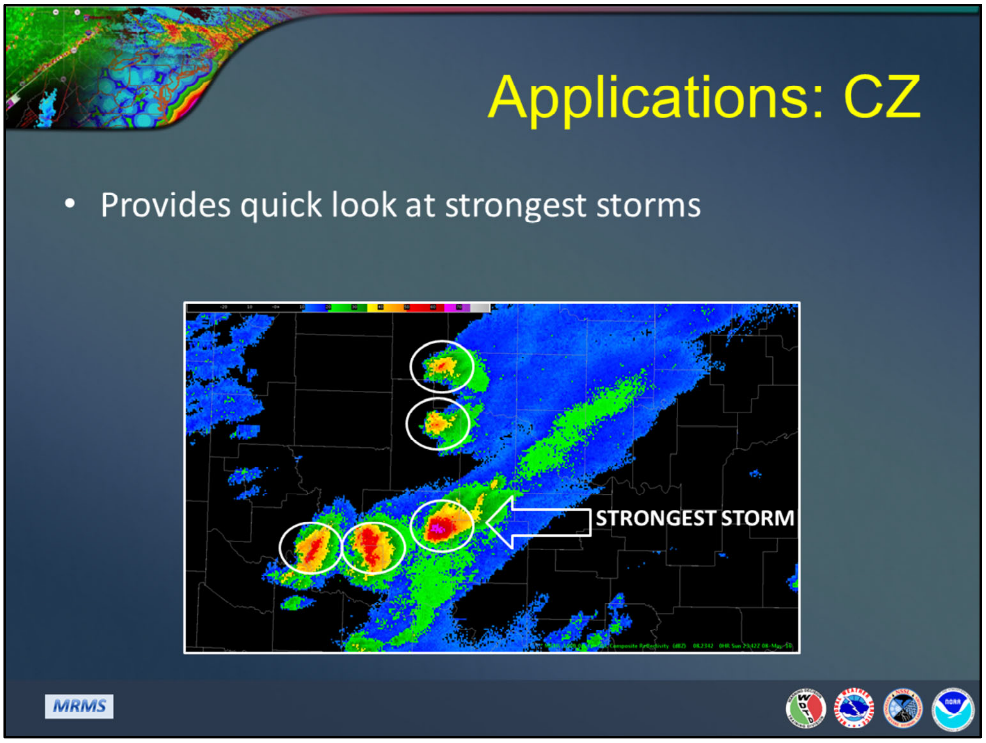
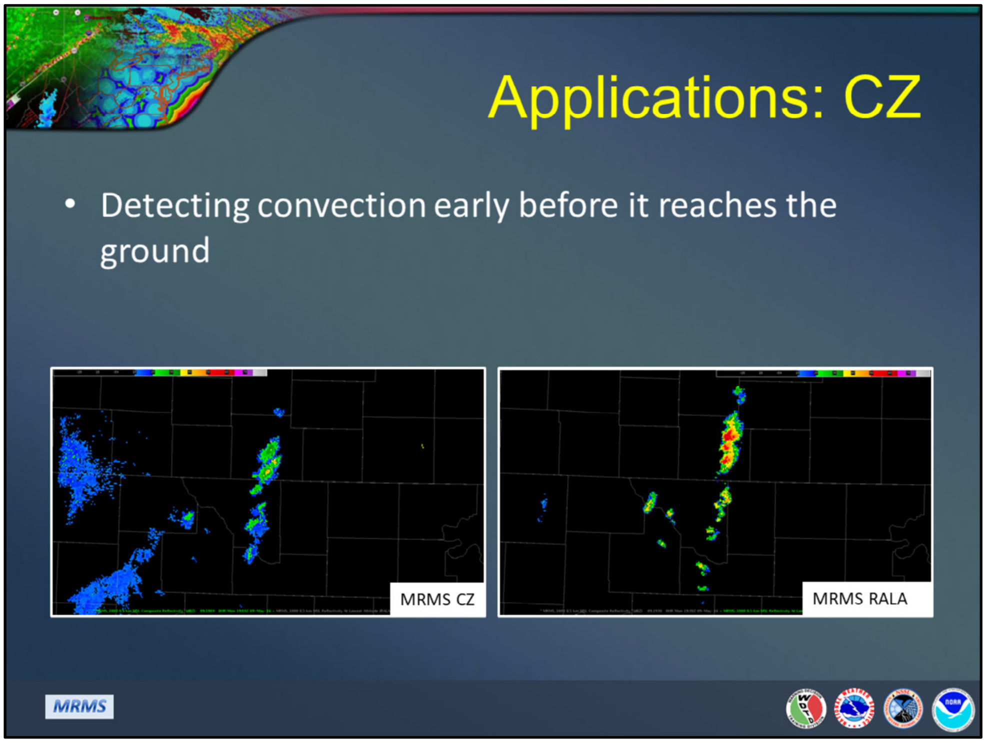


One of the applications of composite reflectivity is to quickly identify the strongest storms. In this example, notice there are 5 potential storms of interest. The one furthest south and east appears to be the strongest. Identifying the strongest storms can be most helpful to tell pilots which storms to avoid.



Another potential use of the composite reflectivity product is to identify regions of developing convection aloft before any low level features appear. In these two images, the left image is the Composite Reflectivity and the right image is the MRMS Reflectivity at Lowest Altitude. Notice how upper level reflectivity can be noted and is very significant before any low level reflectivity appears. If we look at low level reflectivity just 30 minutes later, these storms became strong very quickly. One caveat: in already mature convective events, it will be more difficult to identify high reflectivity aloft while there is weak reflectivity in the low levels.

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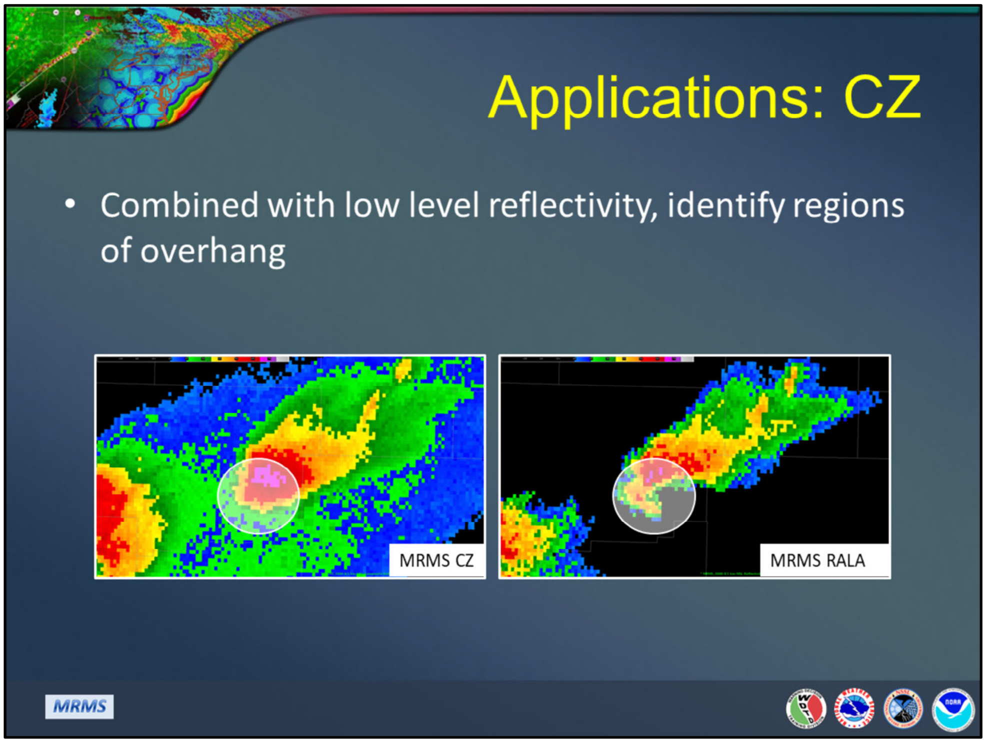

When combined with low level reflectivity, composite reflectivity can also reveal regions of overhang indicative of intense storms. Here is an example of a supercell with a very well defined inflow notch and hook echo. Directly above the inflow notch is very high reflectivity indicative of a significant weak echo region.

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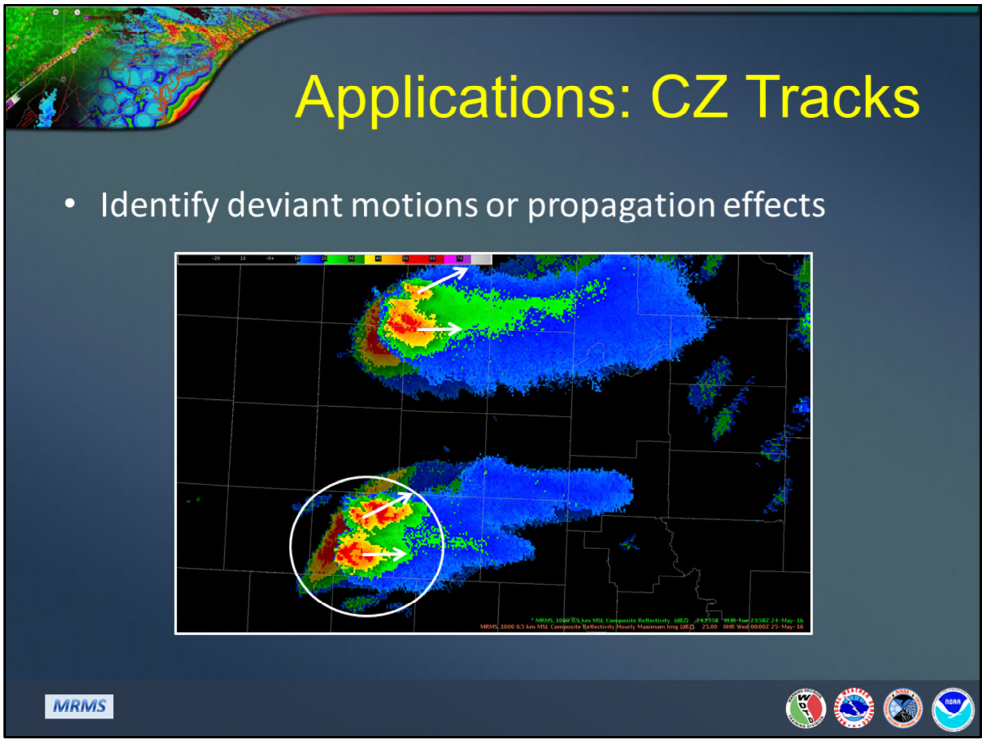

By displaying the maximum reflectivity within each grid box over the past 60 minutes, you can develop a feel for general storm motion (linear or deviant) or propagation effects. Here is an example. To the south, it appears as though there has been a storm split and a deviation to the right. If we look at the current composite reflectivity plot, we definitely see this split and tendency for the southern storm to be heading more east. A similar pattern can be seen to the north.

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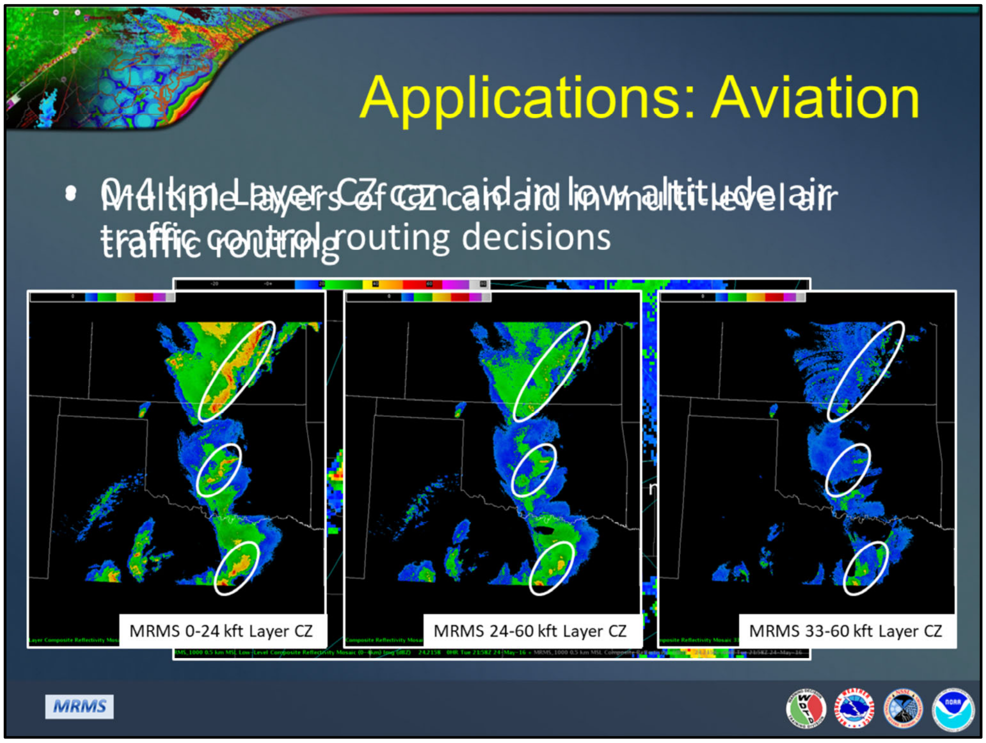

For aviation purposes, a couple of CZ products may be helpful. First, the 0-4 km layer CZ product can be used to identify the most intense areas of precipitation near the ground which can be helpful for incoming/outgoing traffic routing. In this example, the low level routes are overlaid on top of the 0-4km Composite Z. It would be advisable not to fly this route through the strongest core!

The rest of the layer composite reflectivity levels can be used for general air traffic routing decisions since they defined by units of feet. Where you see high reflectivity values at low, mid, and upper levels, airplanes most likely do not want to fly though those areas.

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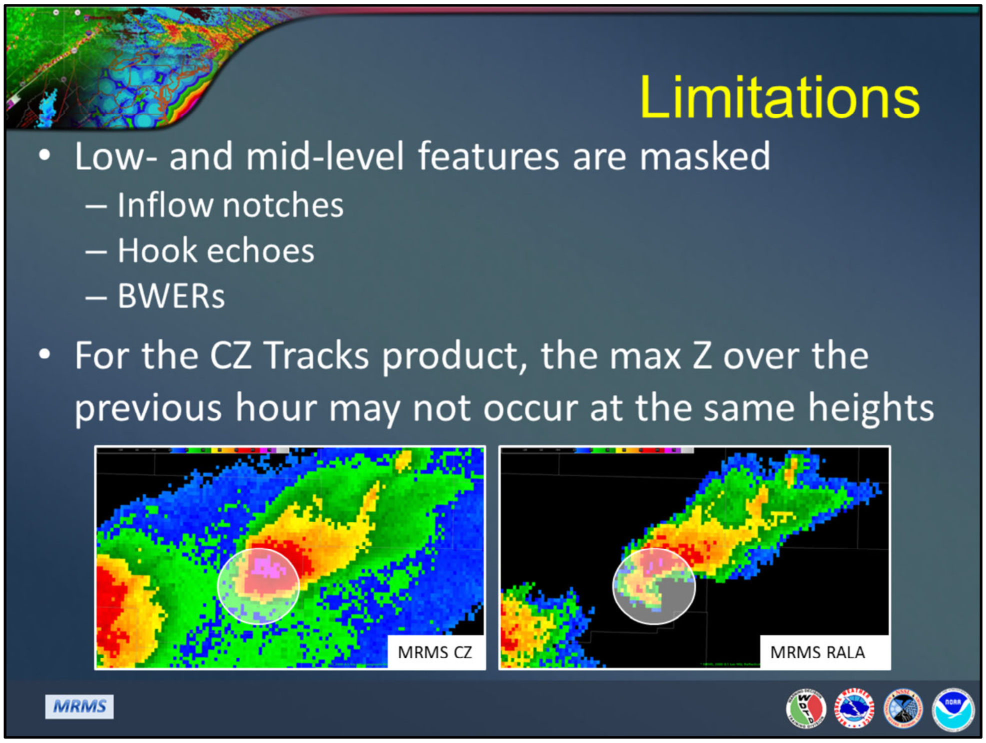

For most CZ products, the major drawback is low- and mid-level features are often masked. The associated height product could help alleviate this drawback by alerting you to the height of the composite Z, but more often than not, the highest Z values occur aloft. Using the example from before, if you just looked at the Composite Reflectivity without any low level context, you would miss the inflow notch and hook echo which would affect your interpretation of this storm. Additionally, the fact the maximum Z over the previous hour may not occur at the same heights is a significant limitation of the CZ Tracks product.

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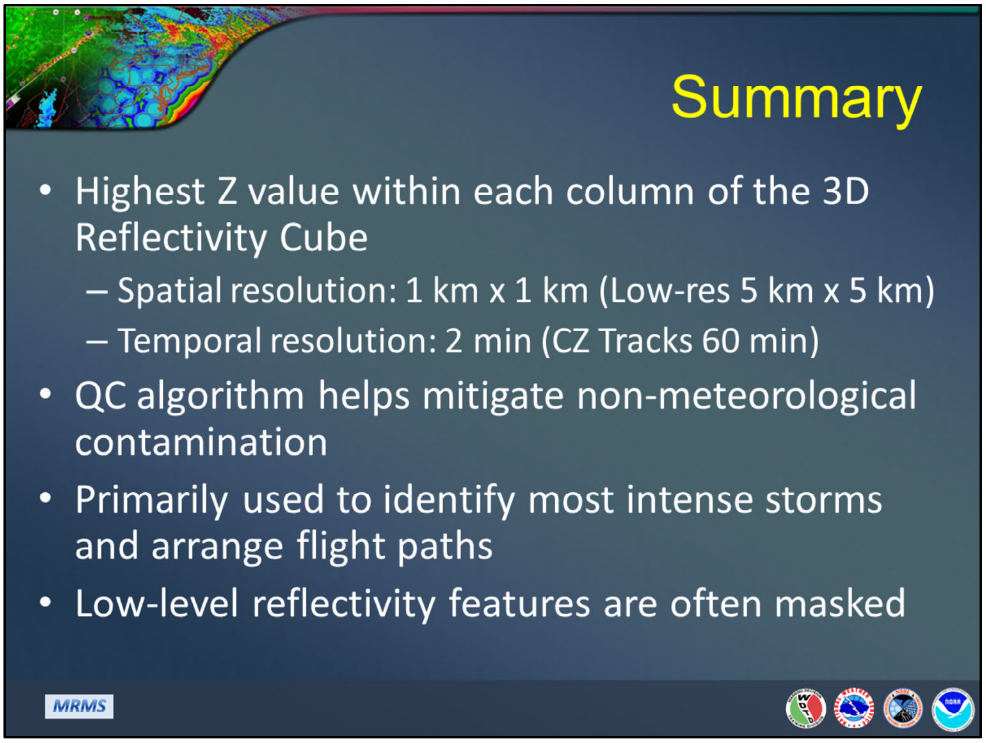

This concludes our lesson on the Composite Reflectivity products. They are derived products from the 3D reflectivity cube showing the maximum Z value within each grid column. They have a spatial resolution of 1 km x 1 km, except the low-res product, and temporal resolution of 2 min, except the CZ Tracks. Because the 3D reflectivity cube is QC'd to remove non-meteorological echoes, the composite reflectivity products should have very little contamination from ground clutter or anomalous propagation. Their primary uses in operations are to quickly identify regions of the most intense storms and arrange flight paths. Finally, do not use these products for in-depth storm analysis, as they often mask low-level features. Please complete the short quiz on the next slide.

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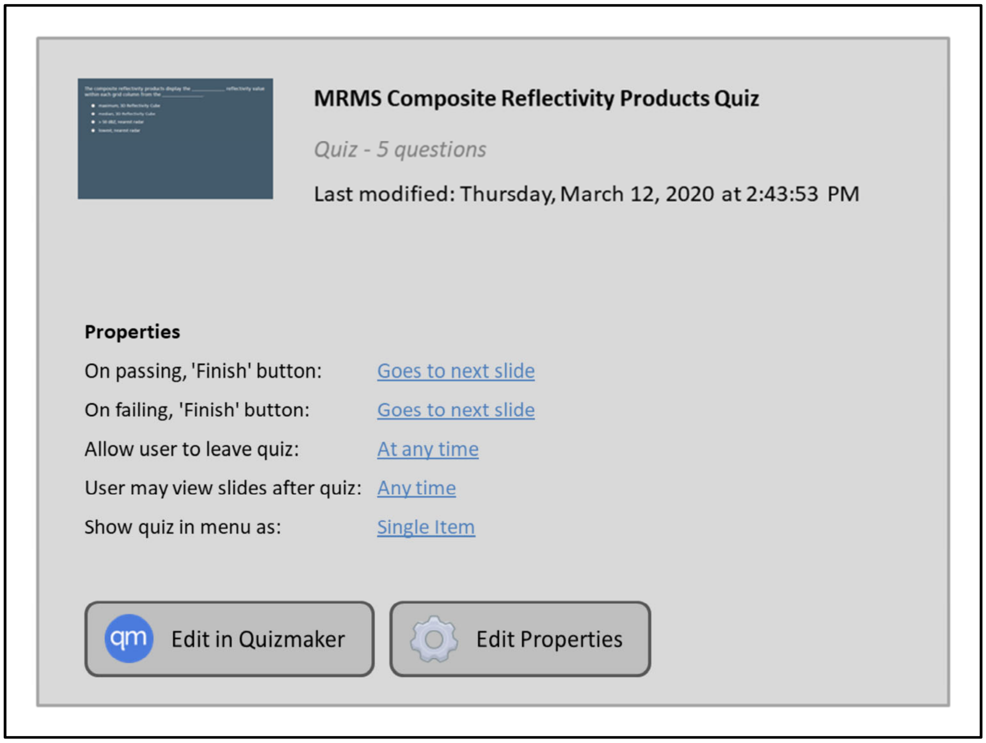
MRMS Composite Reflectivity Products Quiz
Quiz - 5 questions
Last modified: Thursday, March 12, 2020 at 2:43:53 PM
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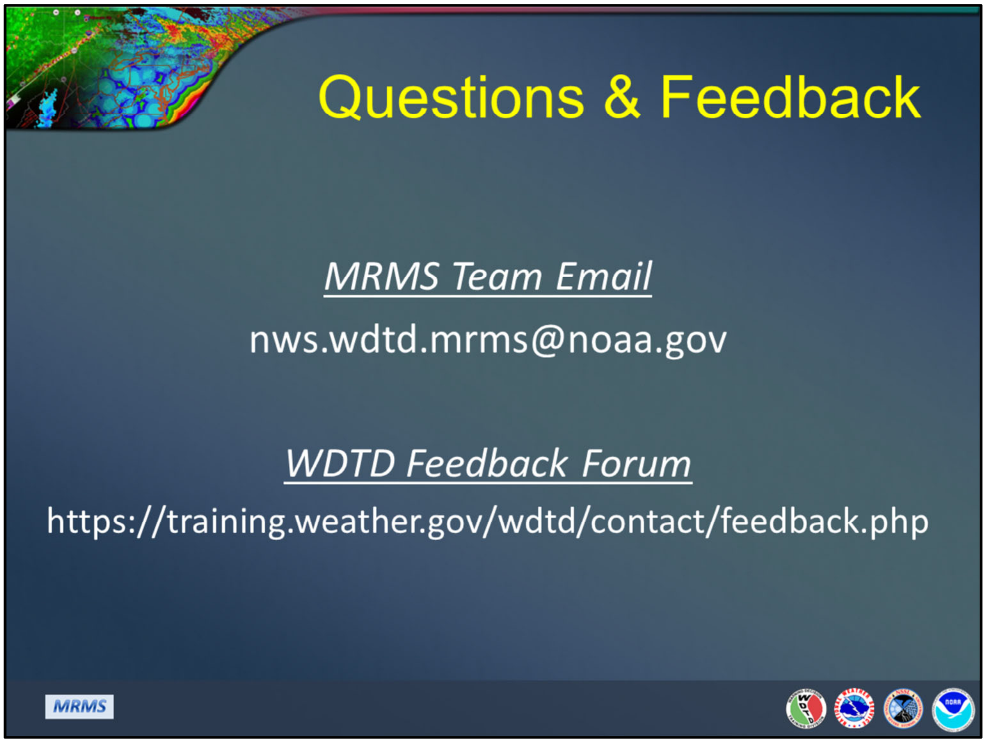

Thanks for completing this module. If you have any questions or feedback concerning this lesson, please feel free to contact us at the addresses below.

Welcome to the Multi-Radar/Multi-Sensor (MRMS) Products Course Lesson on the Constant Altitude products developed here at the Warning Decision Training Division (WDTD).

Course Completion Info

Tabs - 4 Tabs (Including Introduction)

Last Modified: Aug 25, 2019 at 10:47 AM

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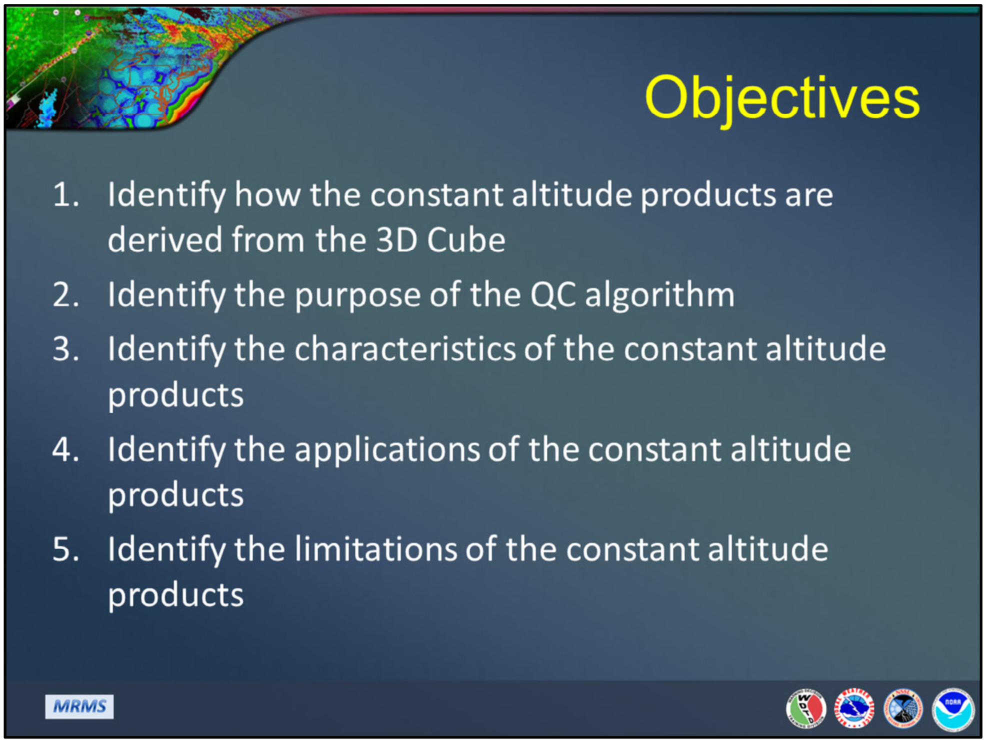

Here are the learning objectives for this lesson. Please take a minute to review them before moving on to the next slide. You will be quizzed on these objectives at the end of the lesson.

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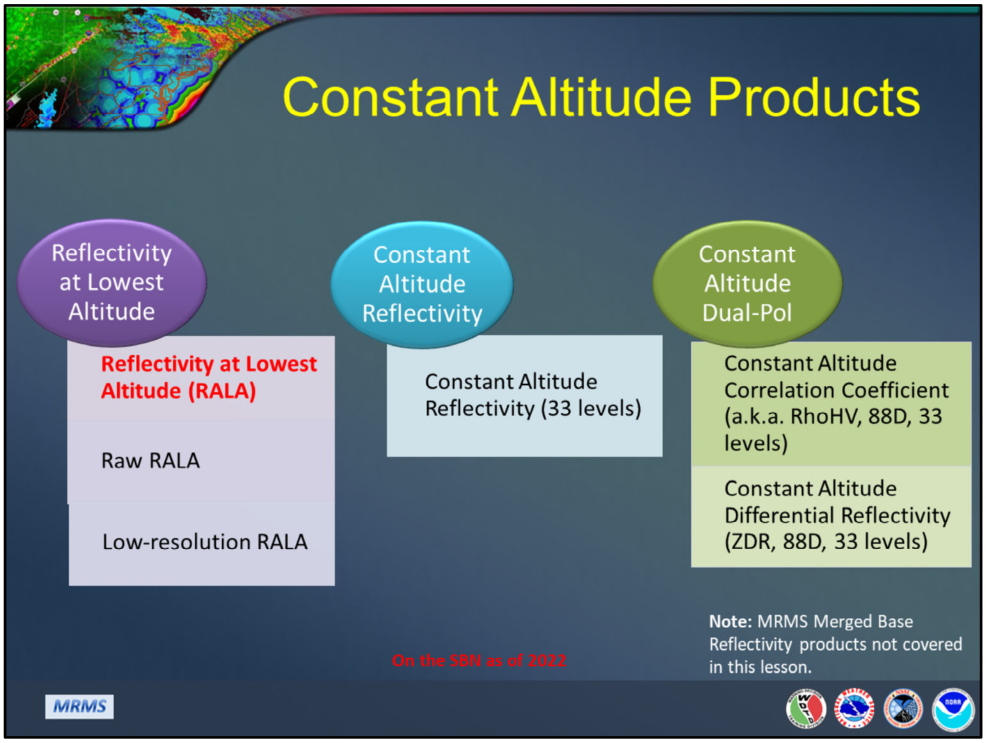

There are 3 primary constant altitude products, Reflectivity At Lowest Altitude (RALA), Constant Altitude Reflectivity, and Constant Altitude Dual-Pol products. The more widely-used of these is the RALA products. They include the original RALA product, as well as a raw (non-quality-controlled) and a low-resolution version. The sole constant altitude reflectivity product is available at several levels. Finally, the Constant Altitude Dual-Pol products include a constant altitude correlation coefficient product (also known as RhoHV) and a constant altitude Differential Reflectivity (ZDR) product.

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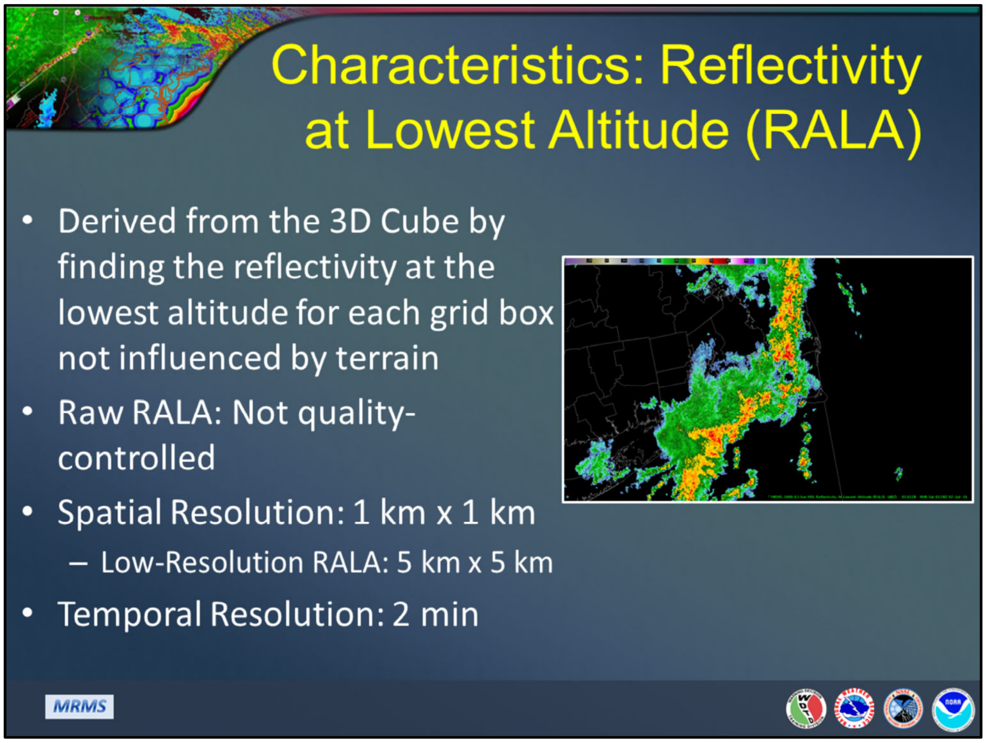
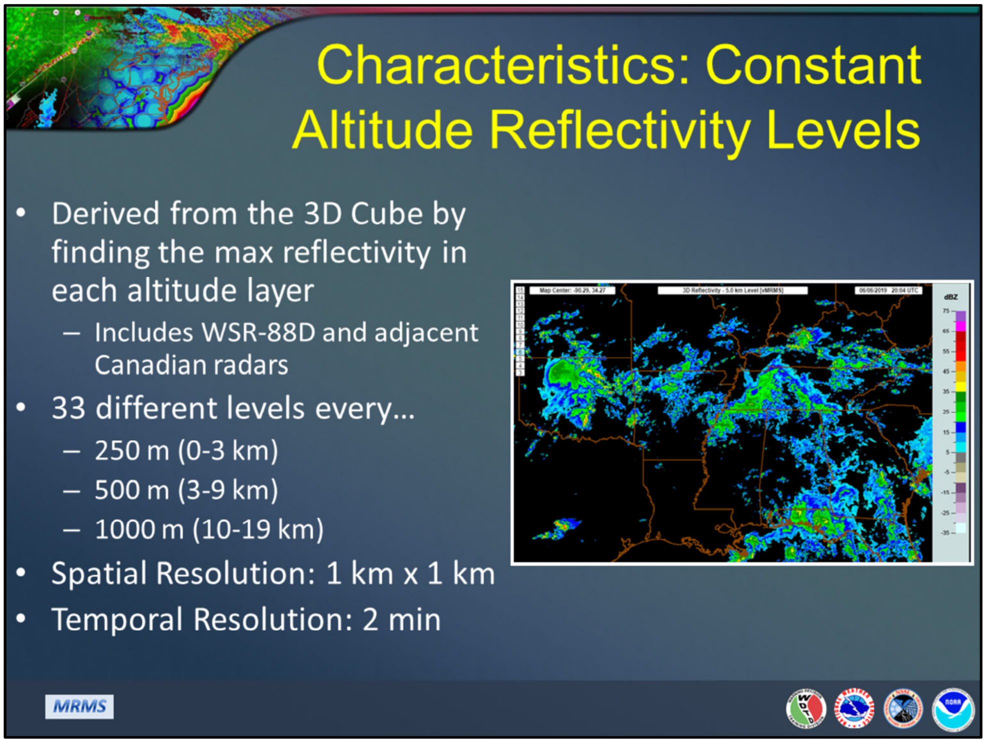


Let's discuss the characteristics of the RALA products. They are derived from the 3D Cube by finding the reflectivity at the lowest altitude for each grid box that is not influenced by terrain. However, all but the raw RALA product are run through the general MRMS quality control process. The spatial resolution for most of the RALA products is 1 km x 1 km, with the exception of the low-resolution RALA product that is 5 km x 5km. All of the RALA products are updated every 2 minutes.



The constant altitude reflectivity product is also derived from the 3D Cube, this time by finding the maximum reflectivity in each altitude layer. Both WSR-88D and adjacent Canadian radars are used as input. There are 33 different layers from 0 through 19 km altitude. At the lowest altitudes, the vertical separation of the layers is 250 meters. Between 3 and 9 km, the separation is 500 meters, and between 10 and 19 km, the separation is 1000 meters. The spatial resolution of the constant altitude reflectivity product is 1 km x 1 km, and its temporal resolution is 2 minutes.

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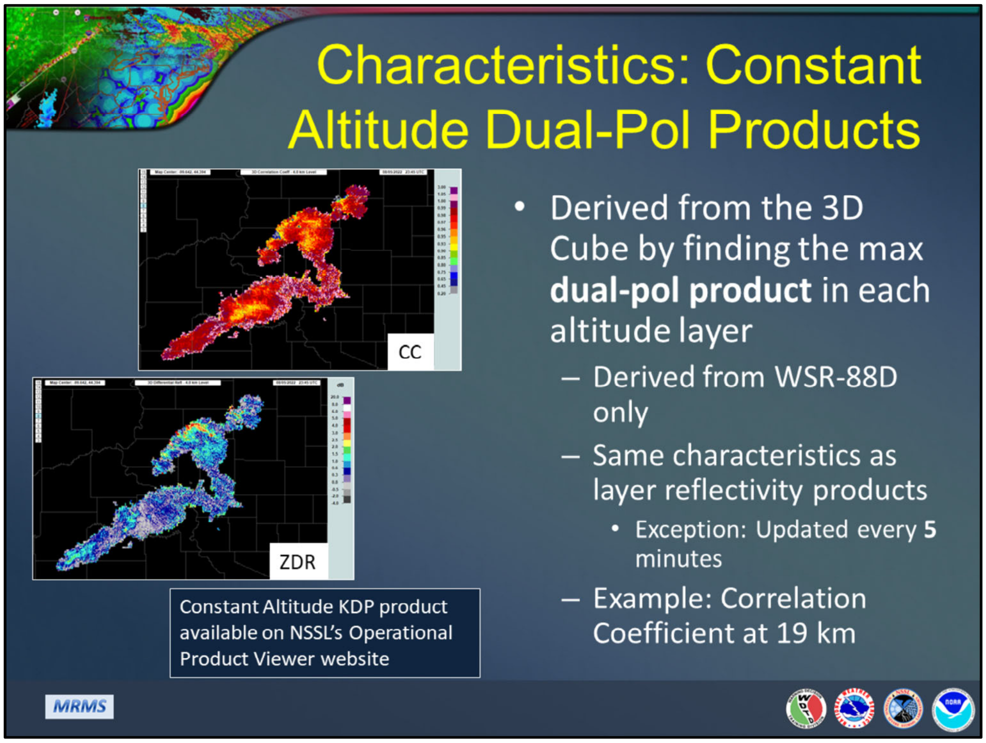
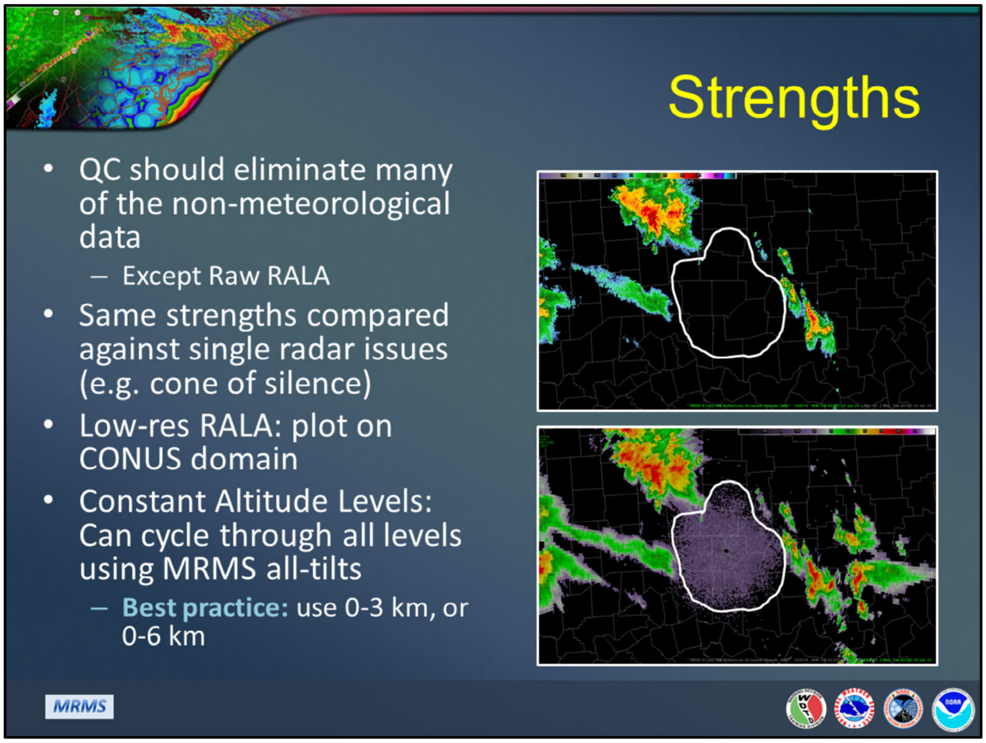


The constant altitude dual-pol products are very similar to the reflectivity products, in that they are also derived from the MRMS 3D Cube and they are available in 33 levels, their spatial resolution is the same, etc. The only differences are they are only derived from the WSR-88Ds, they only update every 5 minutes, and the displayed products are dual-pol. For example, you could load the CC at 19 km to assess hydrometeor drop size in the upper levels, as shown in the top image.



Now let's get into some of the strengths of all the constant altitude products. First, the QC algorithm should eliminate most of the non-meteorological echoes from appearing in all of the products with the exception of raw RALA.. Here is an example of RALA. Notice remnants of the radar bloom as convection is approaching. In the MRMS RALA product, the radar bloom echoes are gone. For all the constant altitude products, all of the general strengths of MRMS over single radar analysis still apply (e.g. mitigation of cone of silence). For specific strengths, the low-resolution RALA product allows you to plot MRMS reflectivity on the whole continental U.S. domain. And with the constant altitude levels, you can actually use MRMS All-Tilts! A best practice is to use 0-3 or 0-6 km.

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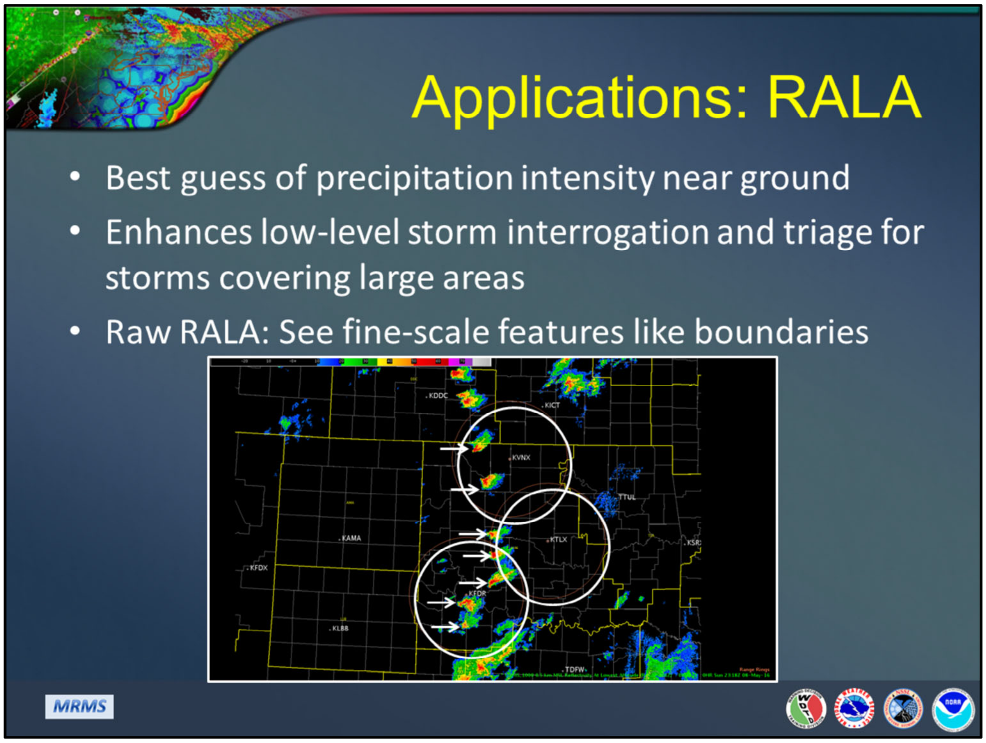
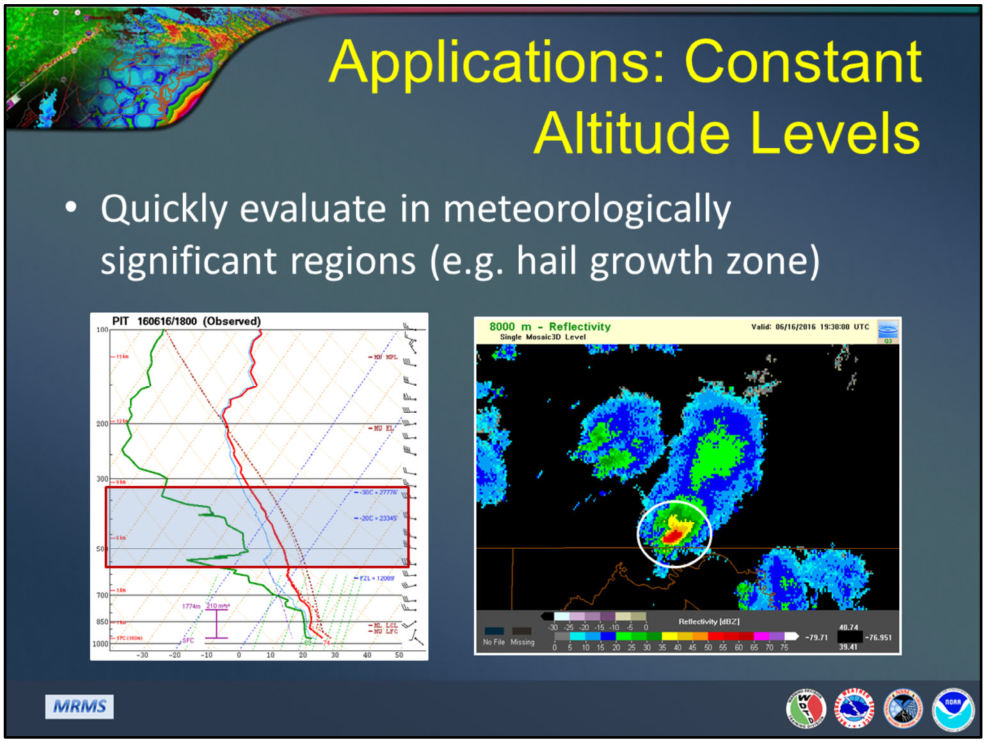


Here's a brief look at the main applications of the RALA products. RALA is best used as a first guess at the precipitation intensity near the ground. You can also use RALA to do a storm triage for areas experiencing wide spread coverage of storms. In this example, there are seven different storms spanning the entire CWA. I've plotted the three different WSR-88Ds available in this CWA and drawn a 60 nm range ring around each one. Notice how each of these storms fall within the range ring of different radars. In order to determine which storm you should focus on first using just single radar analysis, you'd need to load up base reflectivity for each radar and switch between the three and mentally keep track of which storm was strongest. With RALA, you can quickly do this screening and ranking process with one product. Also note that with Raw RALA, you can actually see fine-scale features like boundaries since clutter is not removed.



The primary application of the constant altitude level plots are to be able to quickly interrogate reflectivity, ZDR, and CC in regions of meteorological significance such as the hail growth zone. Here is an example from Pennsylvania where there was baseball sized hail. Looking at the sounding, the hail growth zone was between roughly 5 and 9 km. Looking at the 5 through 9 km constant altitude reflectivity plots, the storm to the south that produced the baseball sized hail is showing 50-60 dBZ echoes through the entire hail growth zone. So, we can feel confident there is hail with this storm.

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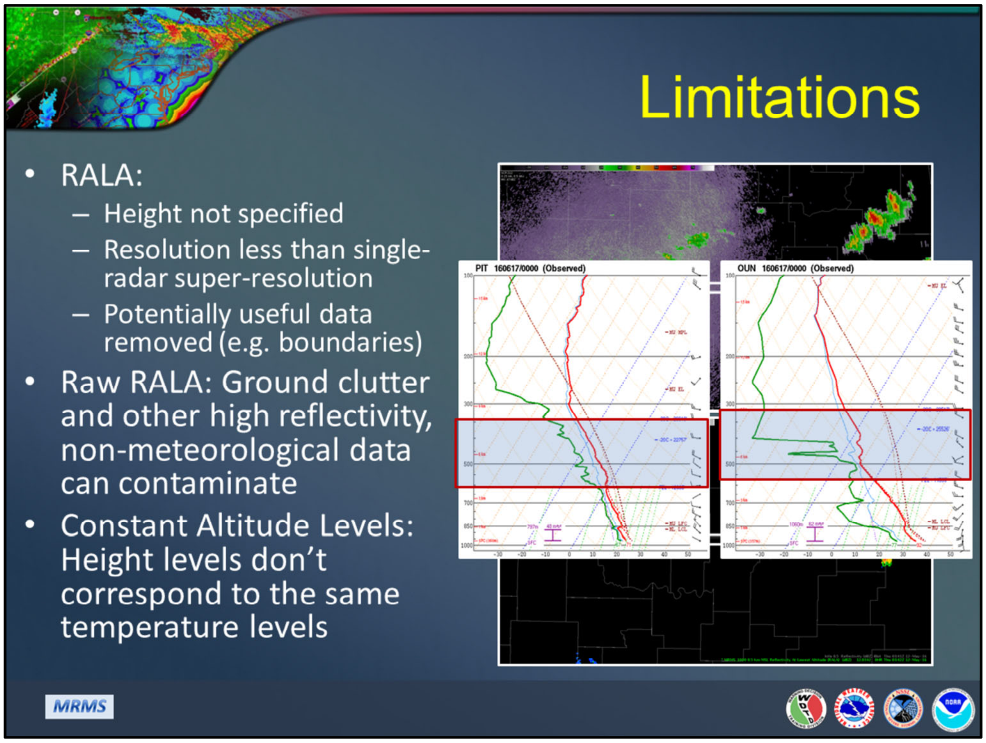

There are a few limitations to these constant altitude products. First, a couple of drawbacks to RALA. One, the height of the RALA is not specified. Two, since the spatial resolution is 1 km x 1 km, the RALA will not show as much detail as single-radar super-resolution reflectivity. Finally, because some non-meteorological echoes are useful (e.g. boundaries), but the QC algorithm remove most of them, these features usually never show up in RALA. Here is an example where the radar reflectivity fine line is clearly evident in the single radar display, but MRMS has completely removed it.

Next, the raw RALA product's limitation is because the QC algorithm isn't removed, ground clutter, etc. can contaminate it.

Finally, for the constant altitude levels products, the height levels don't always correspond to the same temperature levels. Either have model data loaded to determine important temp/height levels, or look at the latest skew-T diagram to determine height levels of the most important temperature levels. Here are two Skew-T diagrams where the hail growth zones are different depths and occur at different heights.

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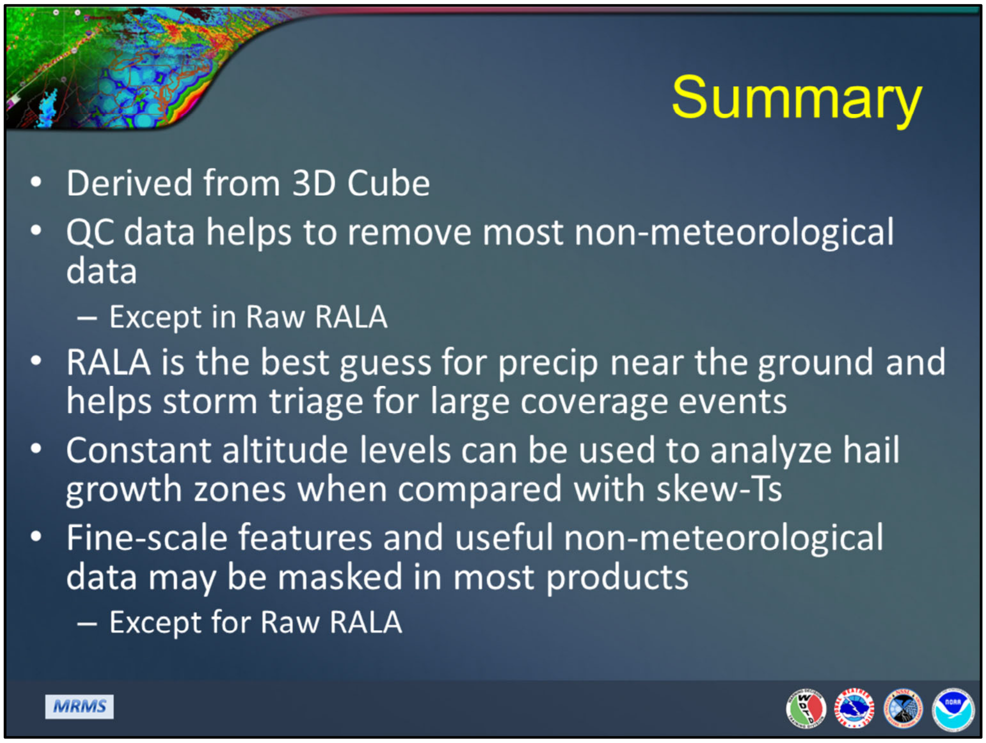

In summary, the constant altitude products are all derived from the 3D cube. The QC algorithm helps to remove most of the non-meteorological data, except in the raw RALA product. RALA is best used for storm triage during events that have a large coverage of storms. One application of the constant altitude levels products is they can be used in conjunction with skew-Ts to analyze hail growth zones. Remember most are lower resolution than single radar super resolution, so some fine-scale features might be easily overlooked, and useful non-meteorological data like boundaries may be removed in some products. Now, you're ready to take the quiz for this lesson!

MRMS Constant Altitude Products Quiz

Quiz - 5 questions

Last modified: Monday, November 14, 2022 at 2:56:35 PM

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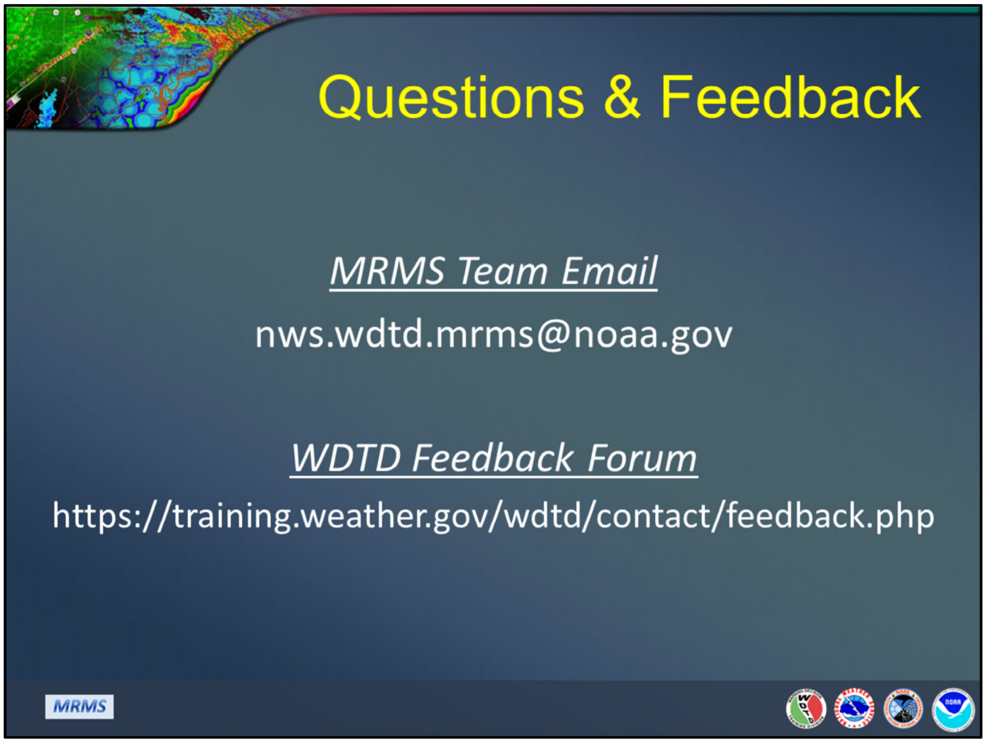

Thanks for completing this module! If you have any questions or feedback concerning this module, please feel free to contact us at these addresses.

Welcome to the Multi-Radar/Multi-Sensor (MRMS) Products Course Lesson on the Isothermal Reflectivity products developed at the Warning Decision Training Division (WDTD).

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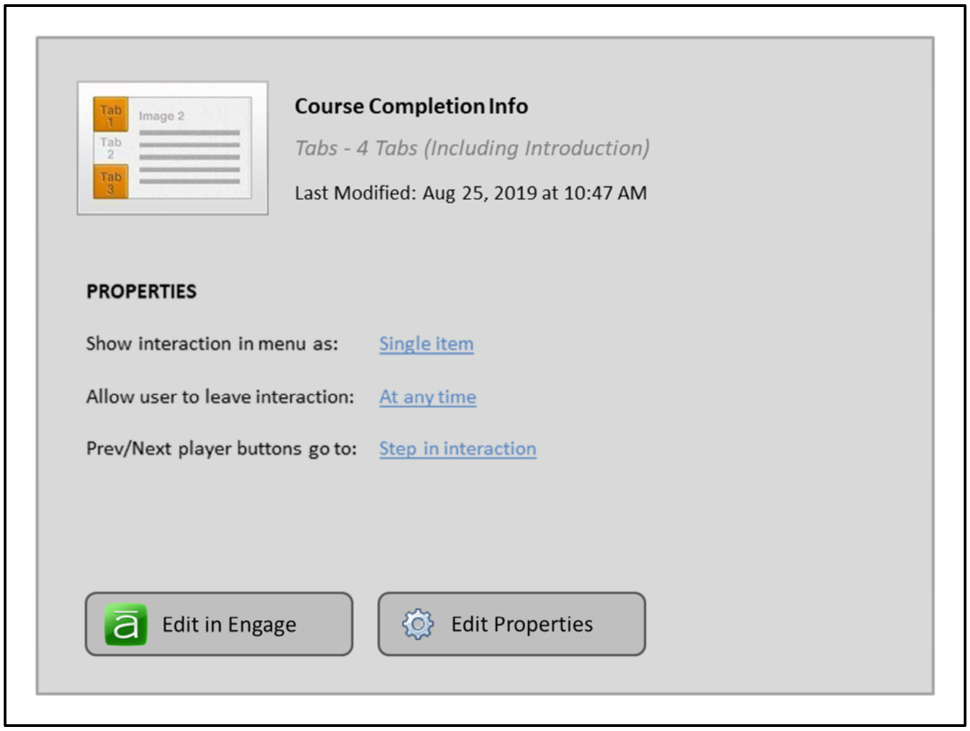
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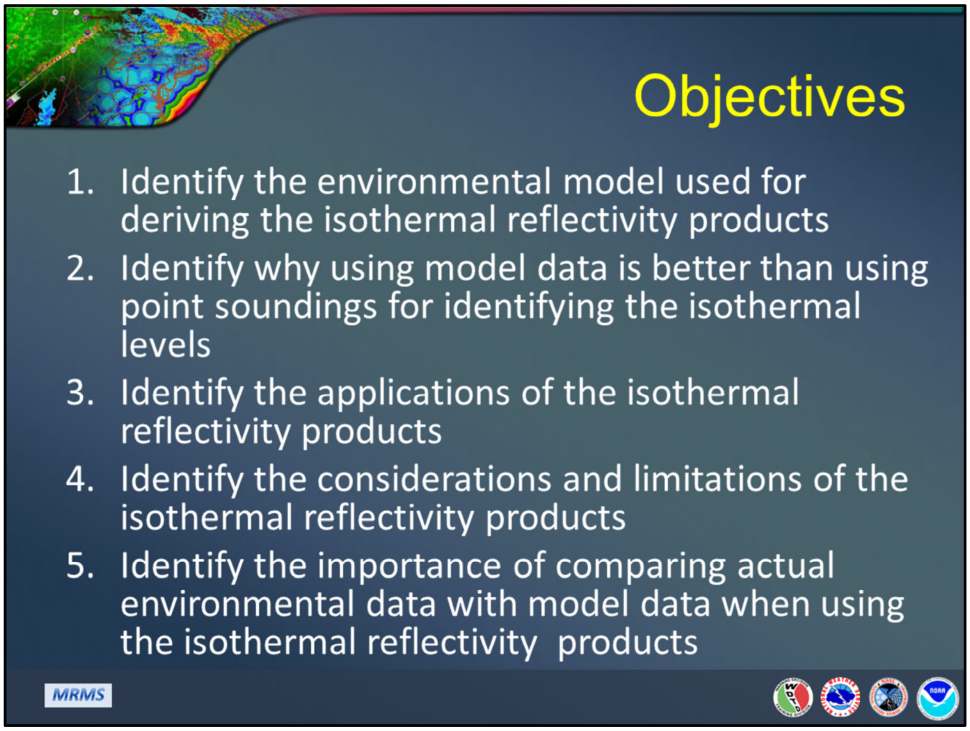

Here are the objectives for this lesson. Please take a minute to review them before moving on to the next slide. You will be quizzed on these objectives at the end of this lesson.

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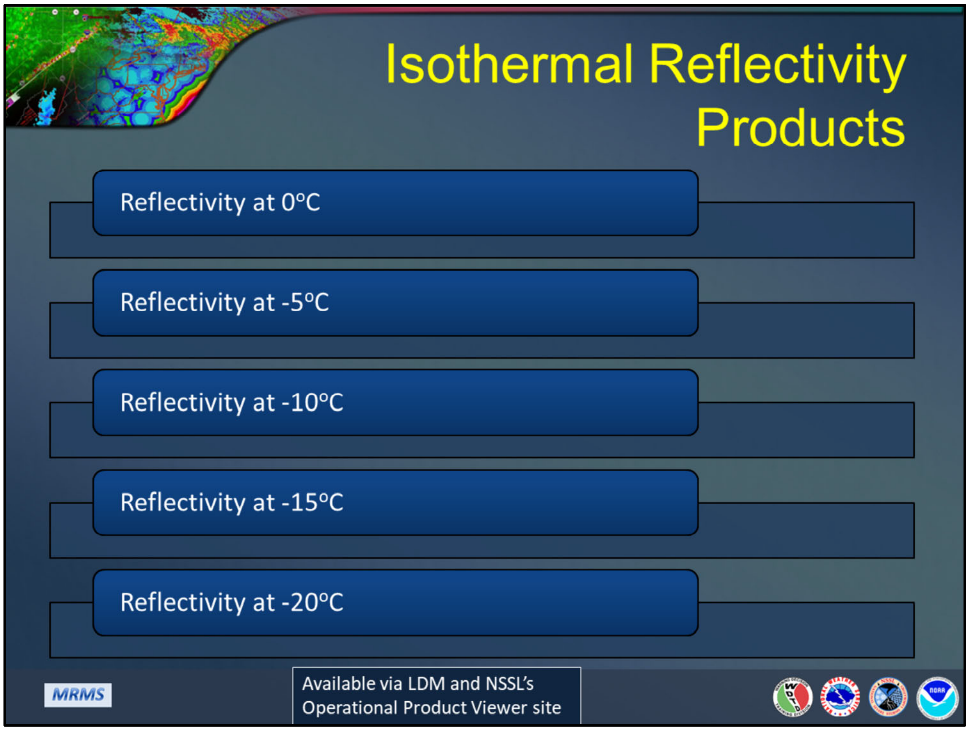
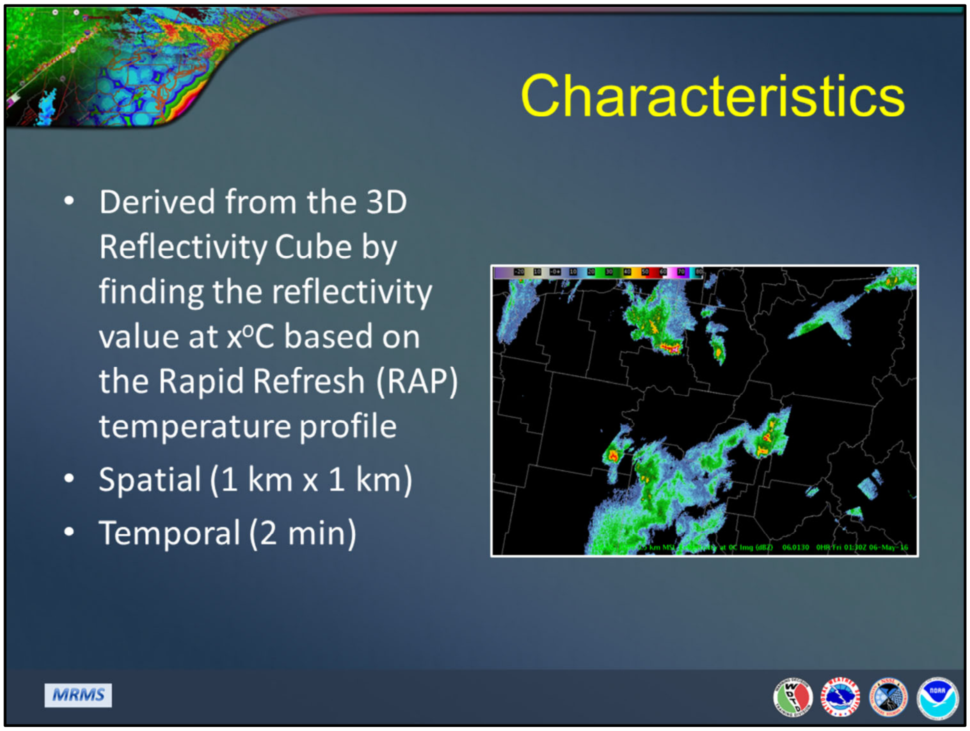


There are 5 MRMS isothermal products, from 0 to -20 deg C in 5 deg C increments. These products are useful for hail and lightning interrogation, and for winter and aviation purposes.



The isothermal reflectivity products are derived from the 3D reflectivity cube by finding the reflectivity value within the cube that resides at respective temperature levels based on the Rapid Refresh (RAP) temperature profile. Their spatial resolution is 1 km x 1 km and they are updated every 2 minutes.

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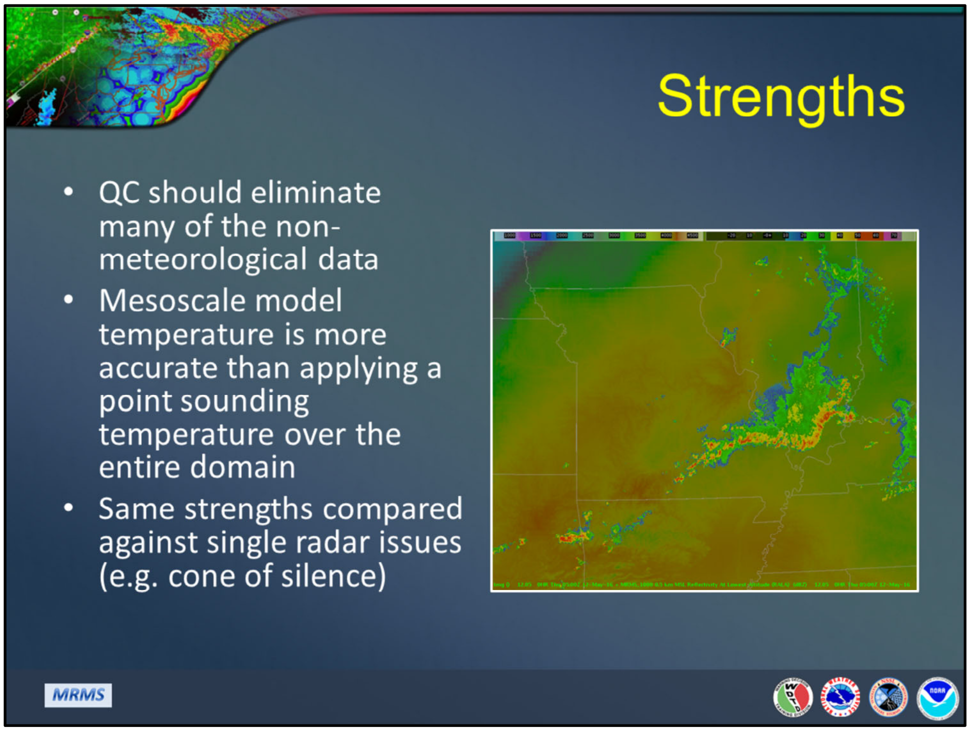
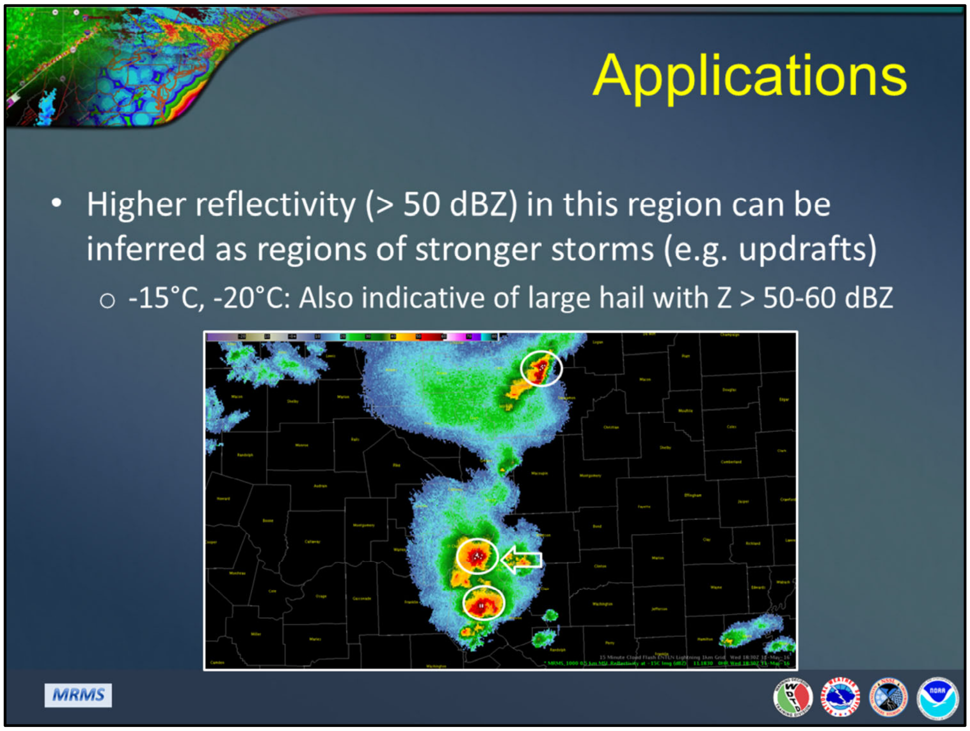


While most non-meteorological data will not contaminate echoes at or above the freezing level, it is still worth noting that non-meteorological data is filtered out by the QC algorithm. Because temperature heights are never constant across a particular domain (as shown here in this example where I have plotted the bright banding height across the MRMS domain), applying a mesoscale temperature field instead of uniformly applying a point sounding results in more accurate interpretations. Notice how the bright banding heights vary by as much as 1,000 feet. Finally, all strengths associated with MRMS vs single radar analysis are still valid (e.g. mitigating cone of silence).



At all the isothermal levels, higher reflectivity cores, typically greater than 50 dBZ, can be inferred as regions of stronger storms due to updrafts being able to loft larger raindrops above the environmental freezing level. Additionally, in order for significant reflectivity values to occur at the lowest temperature levels, either very large supercooled liquid drops or significantly large hail must be present. Both of these are evidence of very strong updrafts. In this example, there are three areas with Z > 60 dBZ at -15°C. These three areas are most likely experiencing the strongest updrafts and most likely generating significant hail. In fact, the middle storm has produced 4-inch hail recently!

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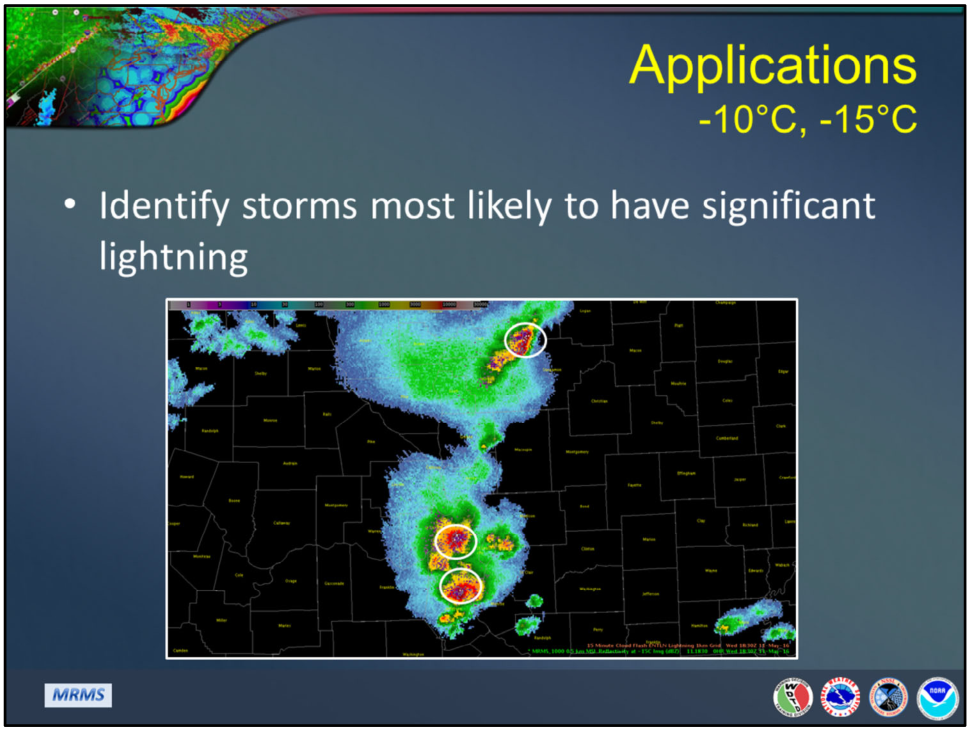
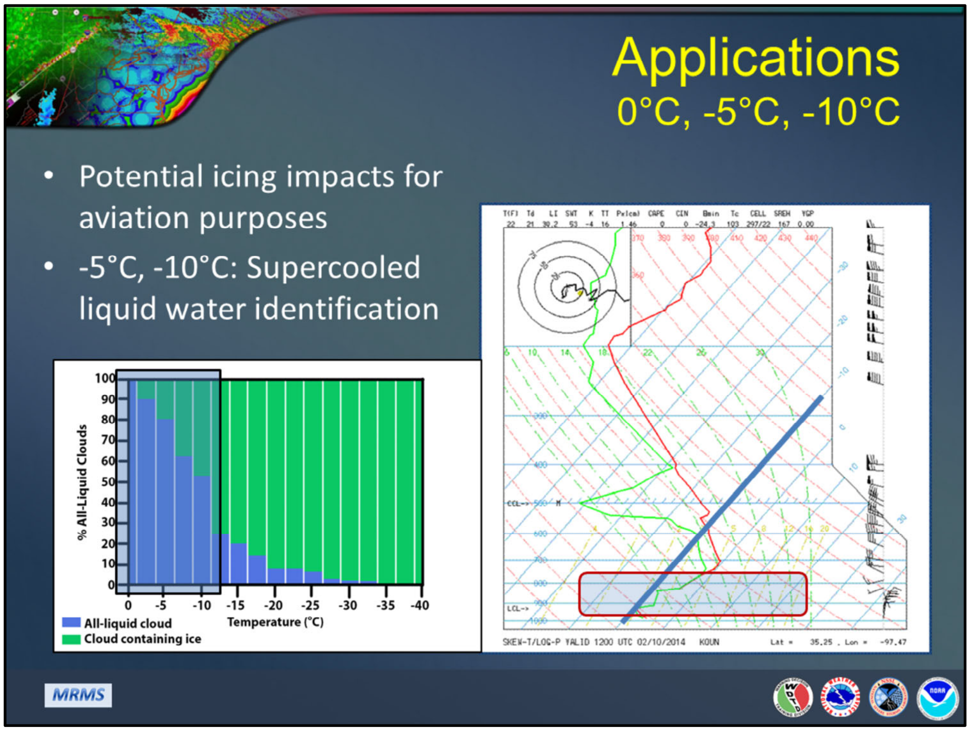
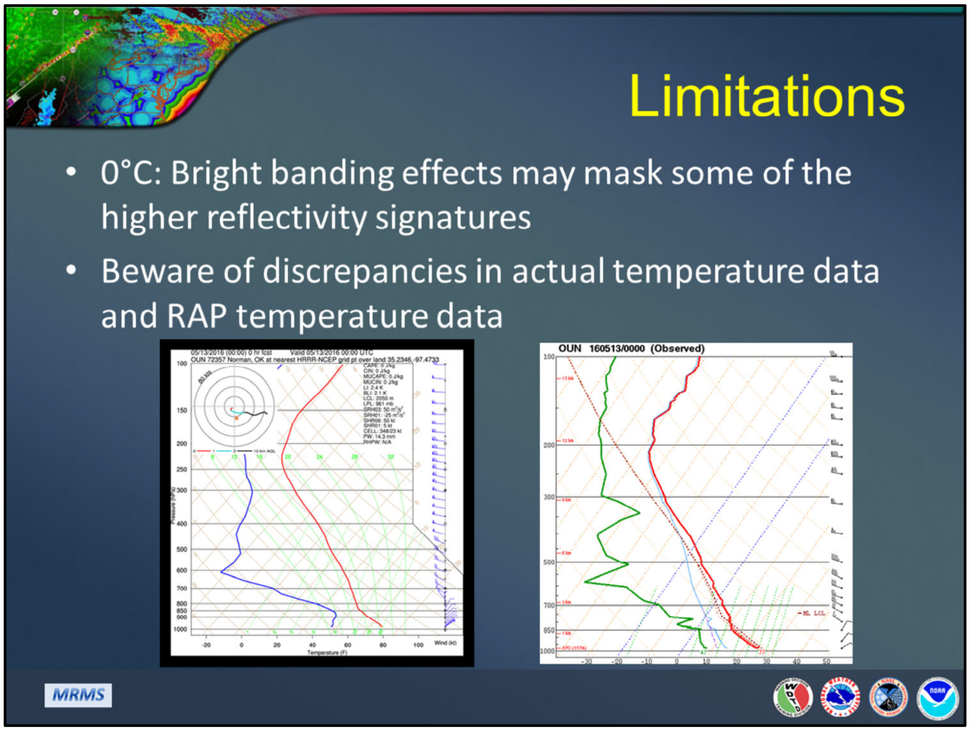


Now let’s look at a couple of applications that apply to smaller subsets of the isothermal products. The -10ºC and -15ºC levels are regions of favorable dendritic growth, and this dendritic growth is partially responsible for electric charge separation. Therefore, this product might be useful for identifying regions of potential lightning development. Notice in this example, the lightning (denoted by the purple dots) is very well correlated with the higher Z.



Lastly, here are a couple of applications of the warmer isothermal levels. First, all of these levels can be helpful to discern icing impacts for aviation purposes. In addition, with environmental context, the -5°C, and-10°C products can be very useful for identifying regions of potentially supercooled liquid water, which can greatly aid in alerting aircraft to potential icing issues, or with winter weather nowcasting for icing conditions at the surface. For example, check if a column of air below -10°C is saturated, and the best way to determine this is to analyze a representative sounding (see the image on the right). Therefore, if you have a sounding, then you can load either of these products and assume most of the returns have a high likelihood of being supercooled and may lead to icing issues at the surface.



There are only a couple limitations to these products, and the first only applies to the 0°C level product. Because its level is where bright banding occurs, be careful interpreting large reflectivity regions as updrafts. Finally, for all the isothermal reflectivity products, beware of the potential discrepancies in actual temperature data vs. the RAP temperature data. There can be model biases that may inhibit your interpretations. This example shows a RAP sounding on the left and the corresponding actual sounding on the right. You can see they pretty well agree, but it is always to good to double check.

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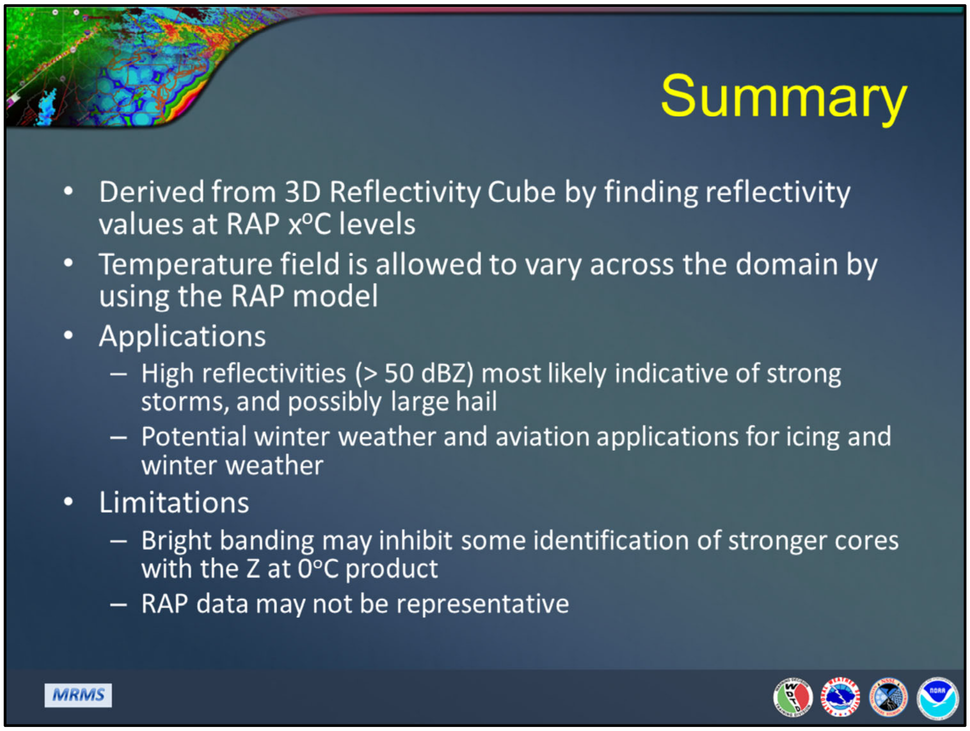
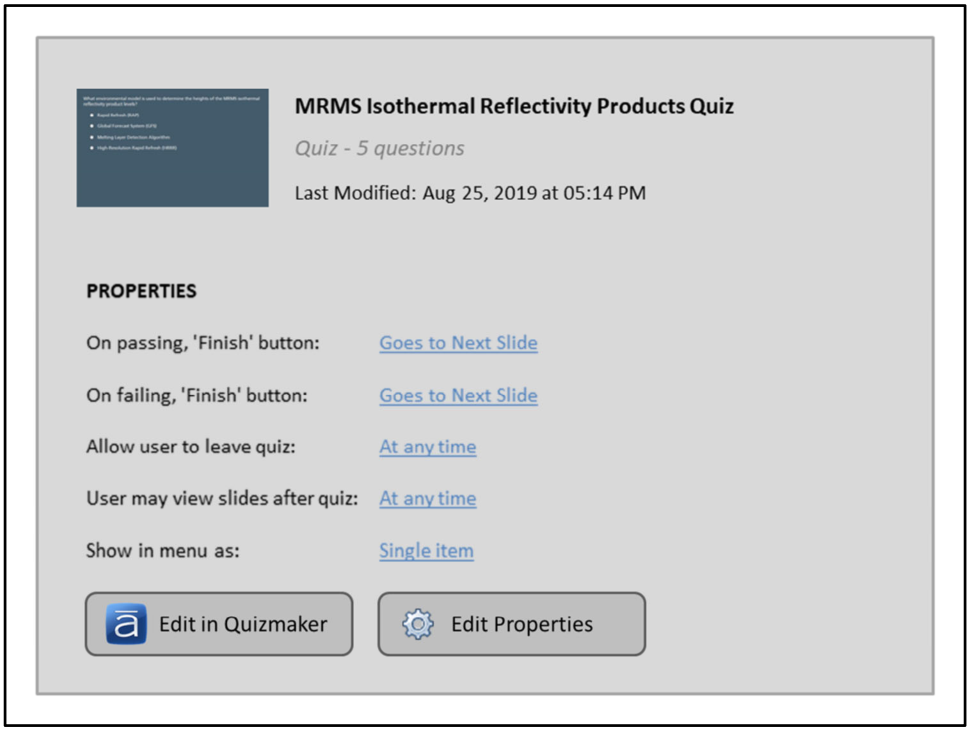


In summary, MRMS isothermal reflectivity products are derived from the 3D Reflectivity Cube by finding the reflectivity value at various isothermal levels using the RAP model. Using the RAP model allows for temperature to vary across the MRMS domain, unlike using a single point sounding. For applications, high reflectivity values in these regions likely indicate strong updrafts, and sometimes large hail. Additionally, reflectivity in these temperature ranges can have potential uses in identifying icing regions for aviation and for winter weather purposes. A couple drawbacks to using these products are that bright banding can inhibit the identification of the stronger cores in the 0 deg C product, and the RAP data may not be representative in all of them. Next up is the quiz!


MRMS Isothermal Reflectivity Products Quiz
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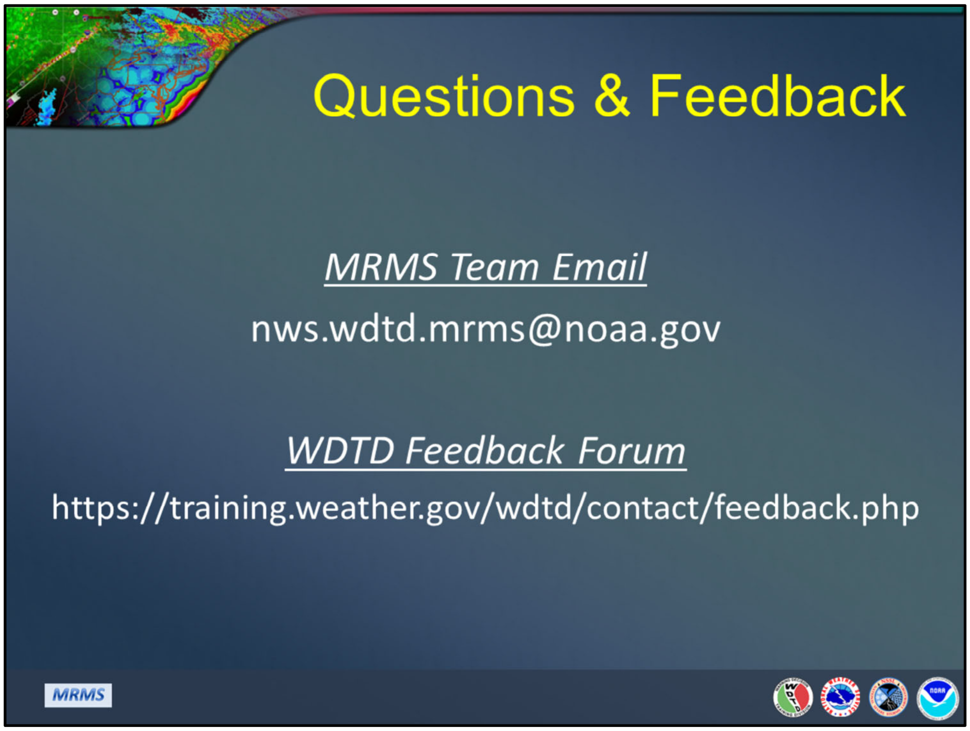

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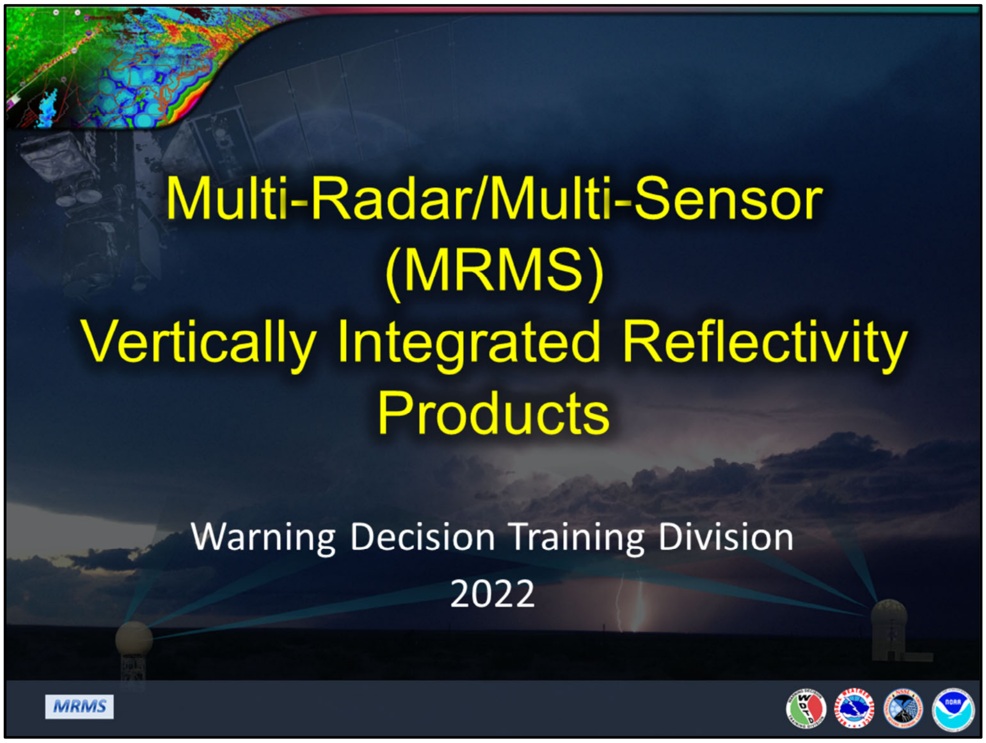

Welcome to the Multi-Radar/Multi-Sensor (MRMS) Products Course Lesson on Vertically Integrated Reflectivity products developed at the Warning Decision Training Division (WDTD).

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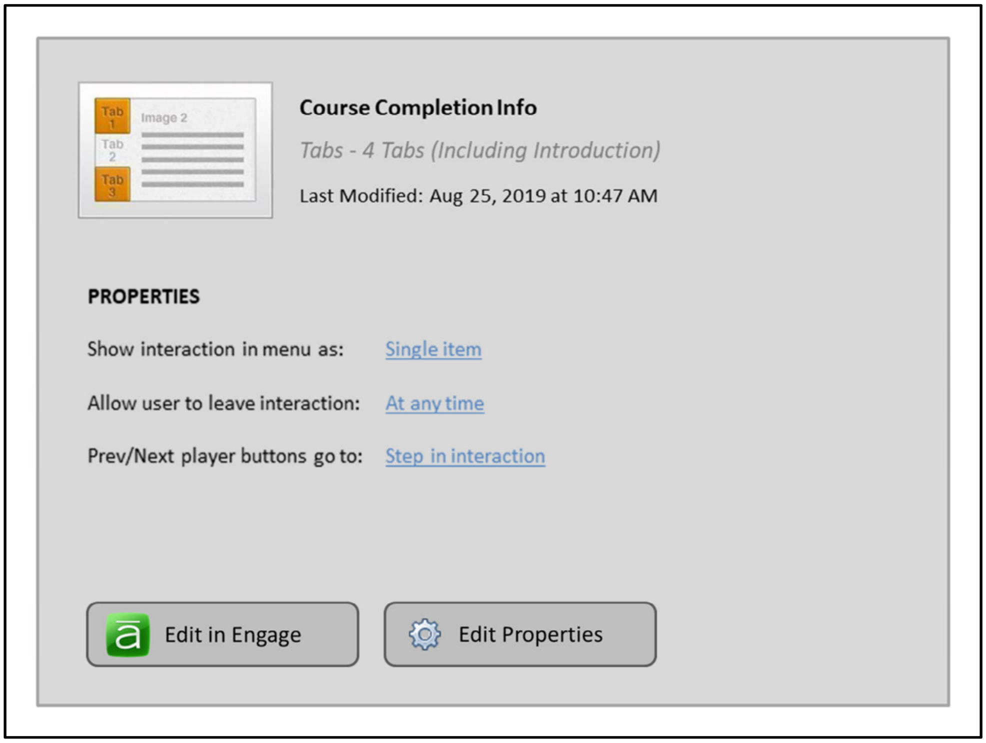
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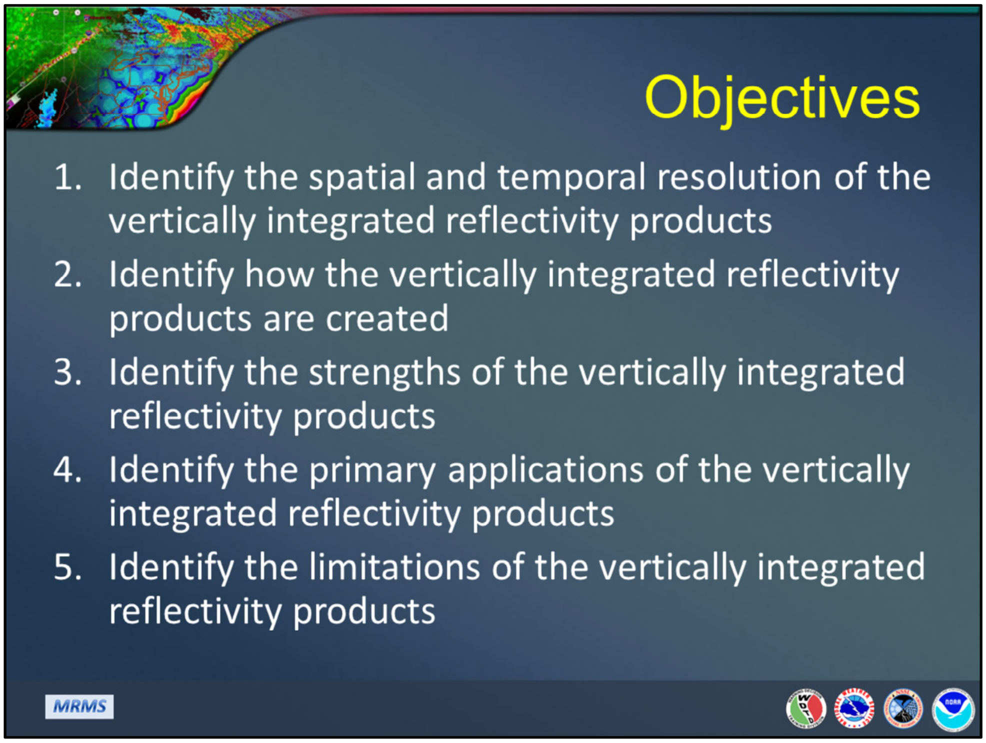
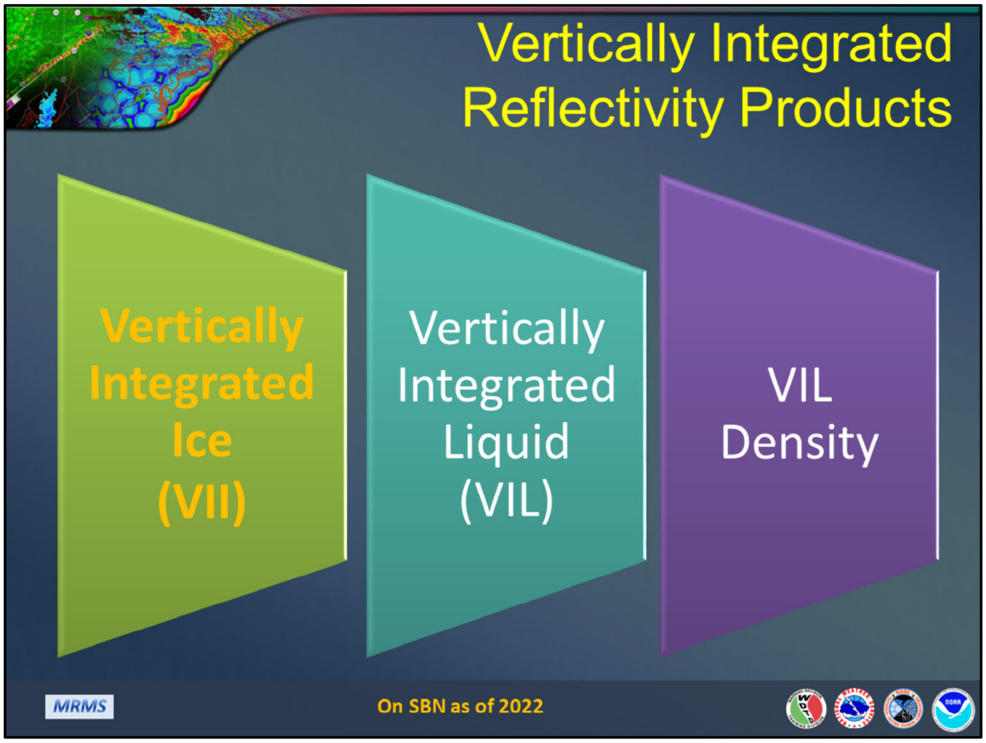


Here are the learning objectives for this lesson. Please take a minute to review them before moving on to the next slide. The quiz at the end of this lesson is based on these objectives.



There are 3 MRMS products that are derived from vertically integrated reflectivity. They are Vertically Integrated Ice (VII), Vertically Integrated Liquid (VIL), and VIL Density.

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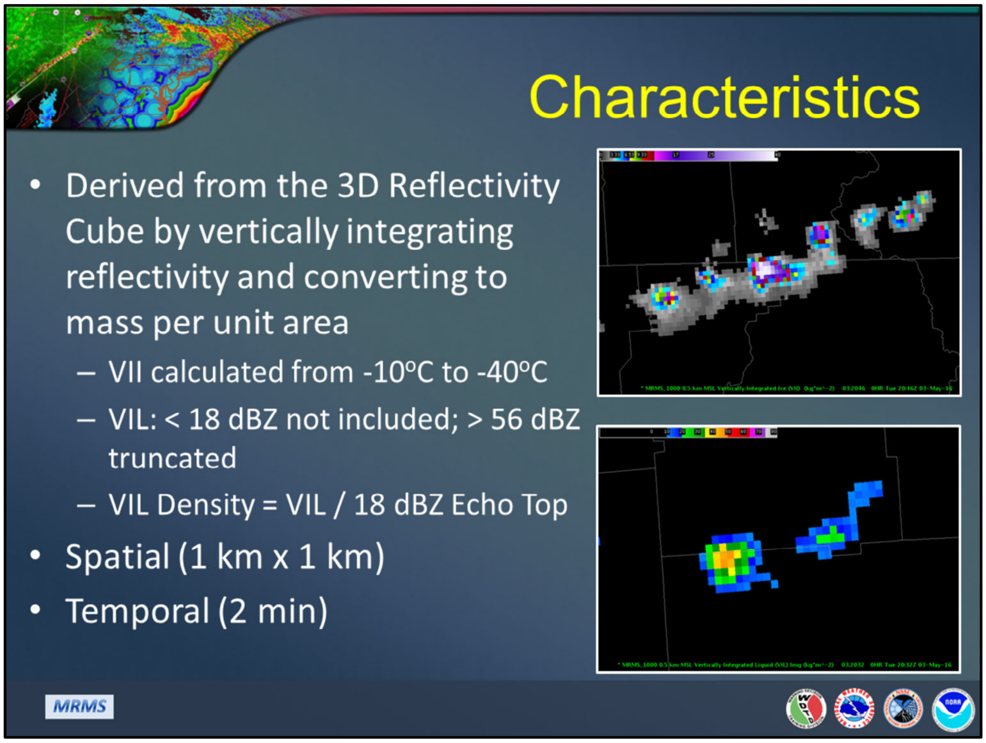

The vertically integrated reflectivity products are derived from the 3D Reflectivity Cube by vertically integrating the reflectivity and converting it into a mass per unit area. VII is only computed in the temperature region of -10°C and -40°C. For VIL, values of reflectivity less than 18 dBZ are not included and values of reflectivity greater than 56 dBZ are truncated. The VIL Density product is just the VIL value divided by the 18 dBZ Echo Top. These products have a spatial resolution of 1 km x 1 km and they update every 2 minutes.

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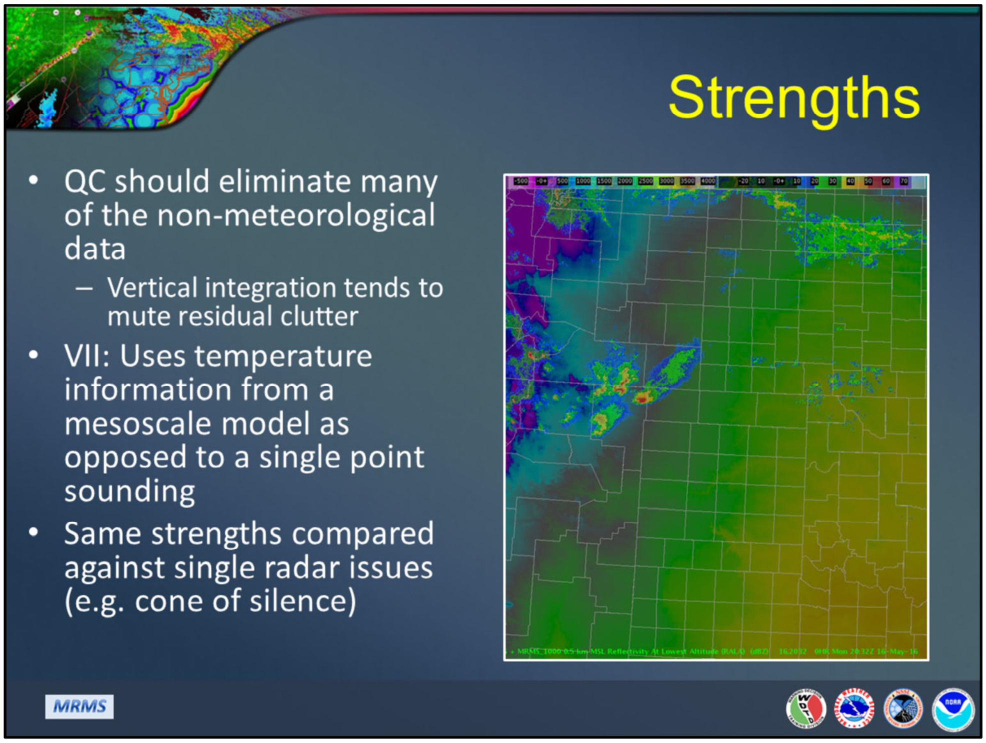

The 3D Reflectivity Cube's quality control algorithms eliminate many non-meteorological echoes. If any made it through, though, the vertical integration of those echoes' values would be very low. In addition, the temperature layer used for VII integration comes from the RAP model so the temperatures applied vary across the domain and are not tied to a single point sounding. In the example on the right, the melting level height varies by as much as 2,000 feet across the domain. Additionally, the same strengths of MRMS compared to single radar still apply (e.g. cone of silence).

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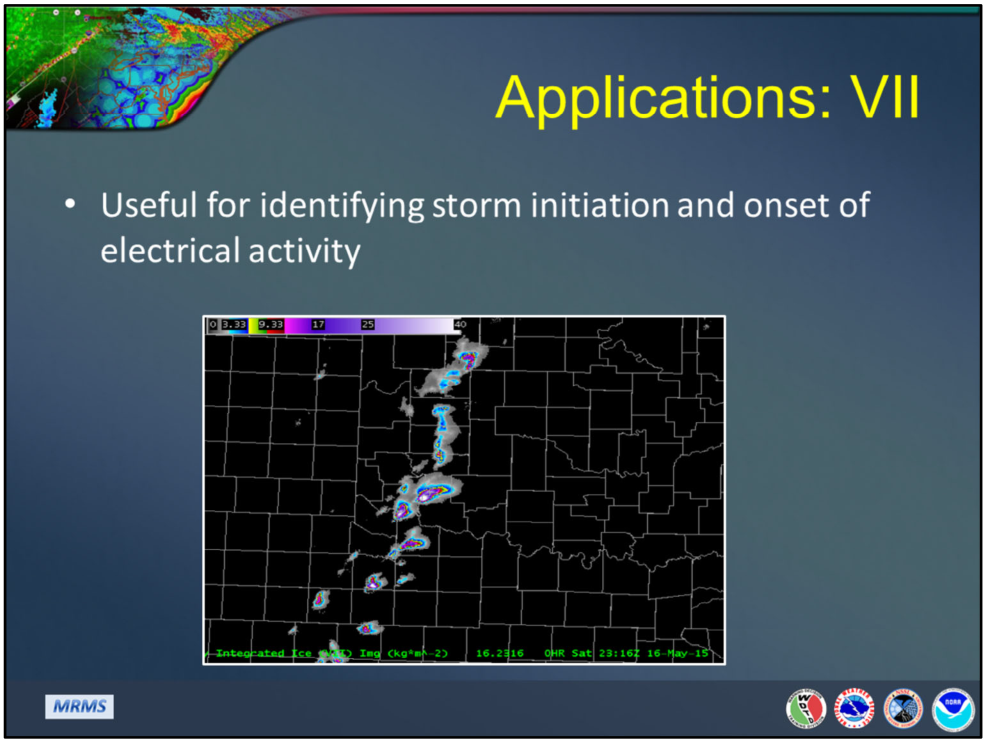
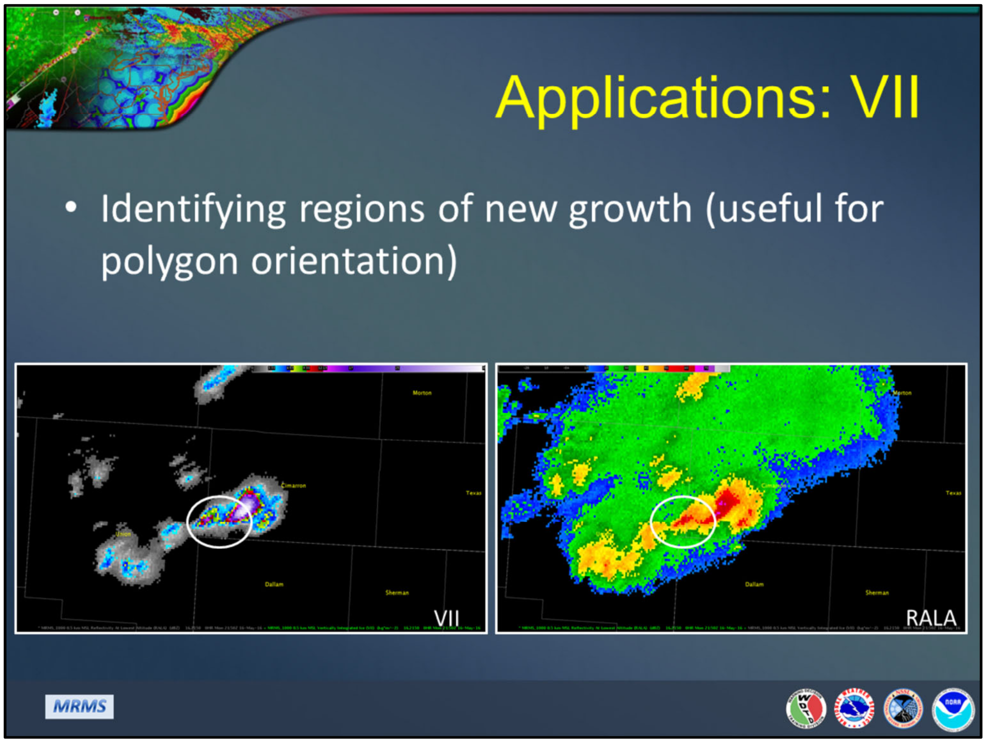


For applications, let’s first address the many uses of VII in operations. First, it is great for identifying convective initiation and storms at the onset of electrical activity. Here is an example from western Kansas. Notice in the first time period, VII values begin to appear and there are some moderate reflectivity in the low levels. Stepping forward about 15 minutes later and now VII has increased in value and coverage. Notice how RALA has also increased. And, if we step forward another half hour, this storm has become severe. Note that in 2018, the lowest VII value threshold was lowered to 0.5 kg*m^-2. This permits even earlier detection of deep convection initiation.



Another VII application is it can be used to identify new regions of updrafts and help orient warning polygons to better follow the threats. In this example, notice how it appears there is new development to the southwest of the main storm. Being able to identify this new development before low level features reflect it can help you better orient polygons so that new development does not occur outside your polygon.

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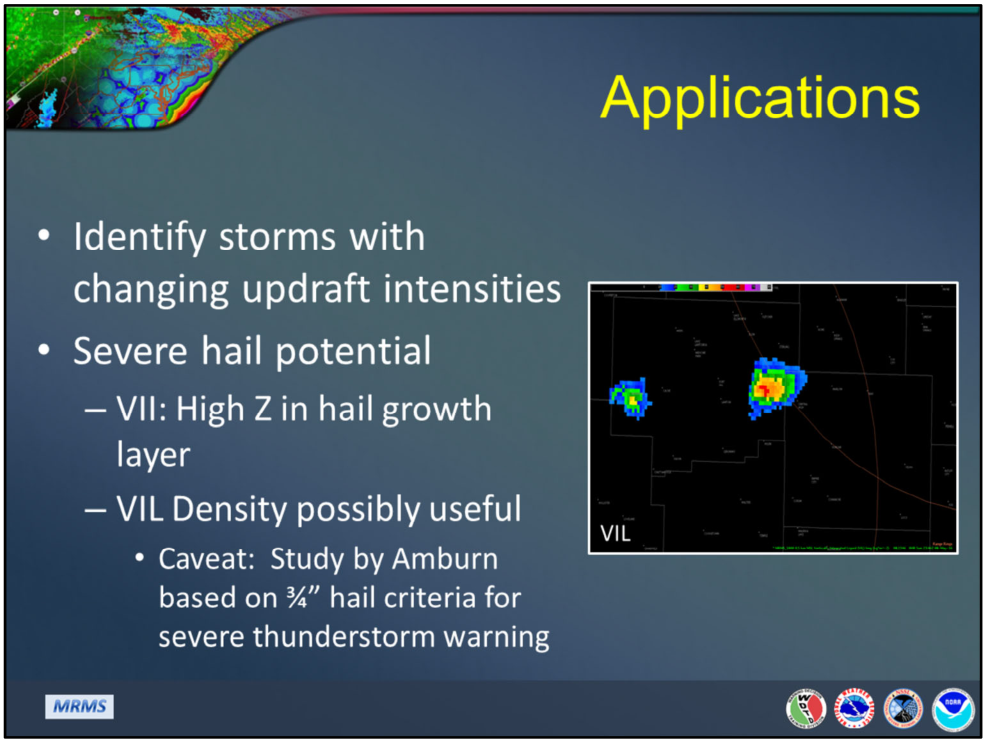

Now for applications of all the vertically integrated products. Rapid increases in both VII and VIL can be used as a proxy for identifying intensifying updrafts. Likewise, decreases in VII or VIL can also indicate decreasing intensity in updrafts.
One other application tied to updraft intensity is severe hail potential. Of these products, VII is the best at severe hail detection because it is computed in the temperature range that's often associated with severe hail. A study by Amburn and Wolf (1997) showed VIL Density can also be used to ascertain severe hail, but that study is based on ¾ in hail criteria instead of 1".

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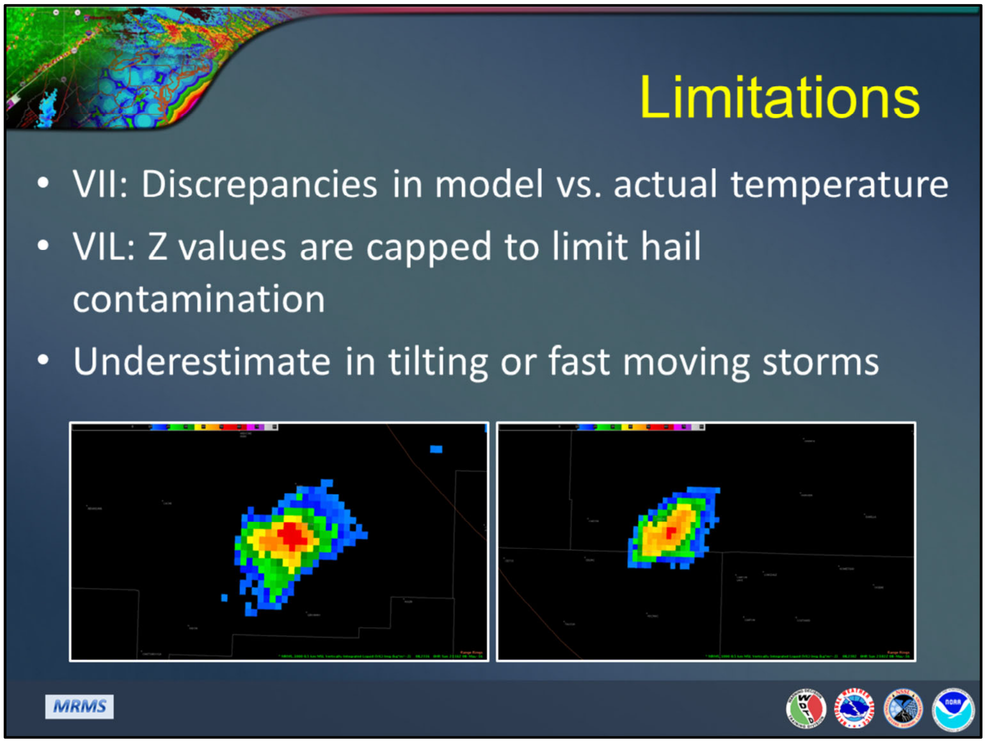
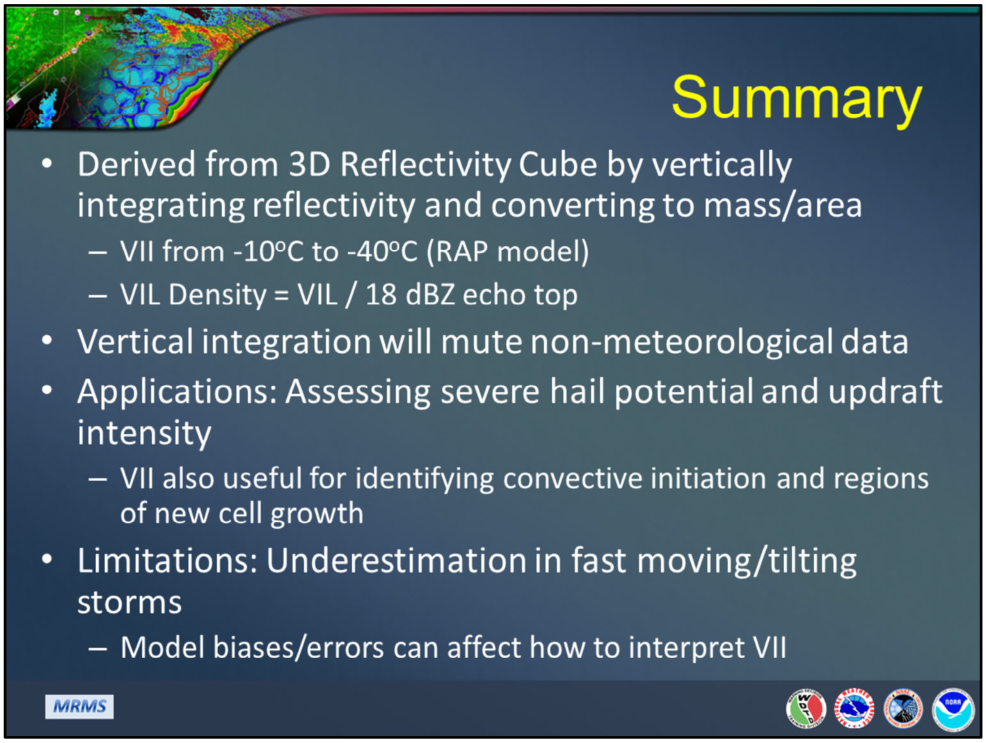


There are a few limitations of these products. Specifically for VII, stay aware of the fact the temperature layer used for integration comes from the RAP model. If the RAP model is not representative of the actual atmosphere, there could be some errors in interpreting the VII product. For the VIL products, remember reflectivity values are capped above 56 dBZ to limit hail contamination. Finally, for all vertically integrated reflectivity products, fast moving storms may result in underestimations. Note this limitation is less of a factor for the VII product because of the shorter depth of integration. Here's an example from VIL. The image on the left is from a storm that was moving slowly to the east, and the image on the right is from a left split that was moving much faster to the northeast. Notice how the slower moving storm had slightly higher values that were over a larger area, where the fast moving storm had slightly lower values over a smaller area.



In summary, all the vertically integrated reflectivity products are created by vertically integrating reflectivity through the depths of each grid column from either a temperature range or up to a reflectivity cap. A strength of these products is vertical integration can mute non-meteorological data. For applications of these products, all of them are good for assessing severe hail potential and updraft intensity. Additionally, VII is useful for identifying areas experiencing convective initiation and regions of new cell growth for polygon orientation. Finally, remember these products can be underestimated in fast-moving or tilting storms and that RAP model biases/errors can affect how to interpret VII. Up next is the quiz!

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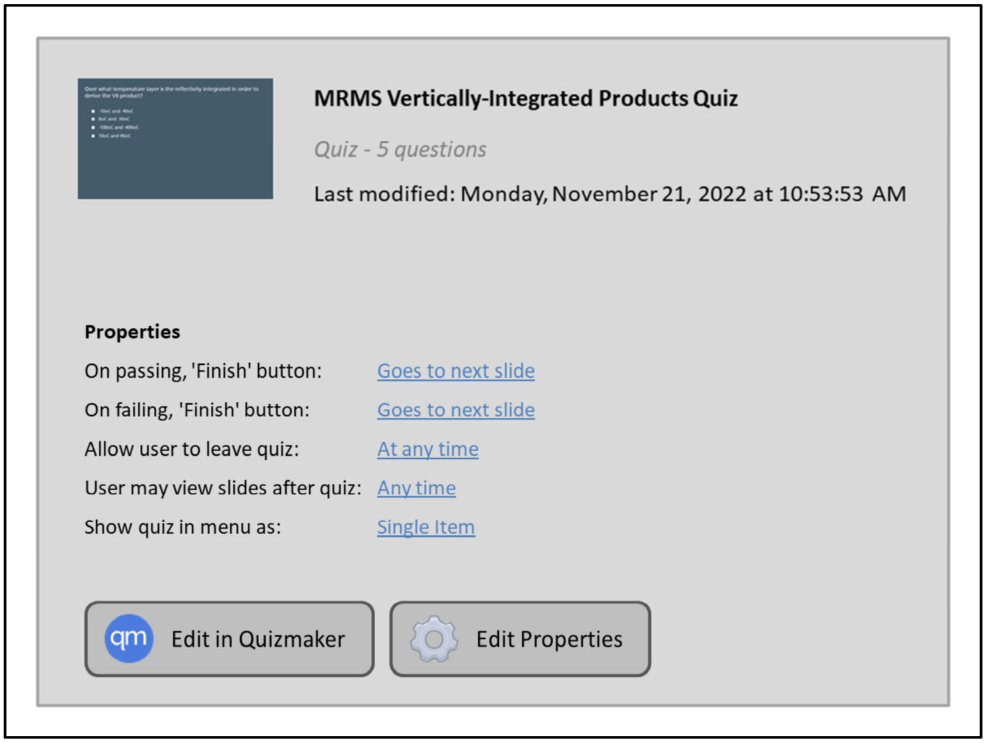
MRMS Vertically-Integrated Products Quiz
Quiz - 5 questions
Last modified: Monday, November 21, 2022 at 10:53:53 AM
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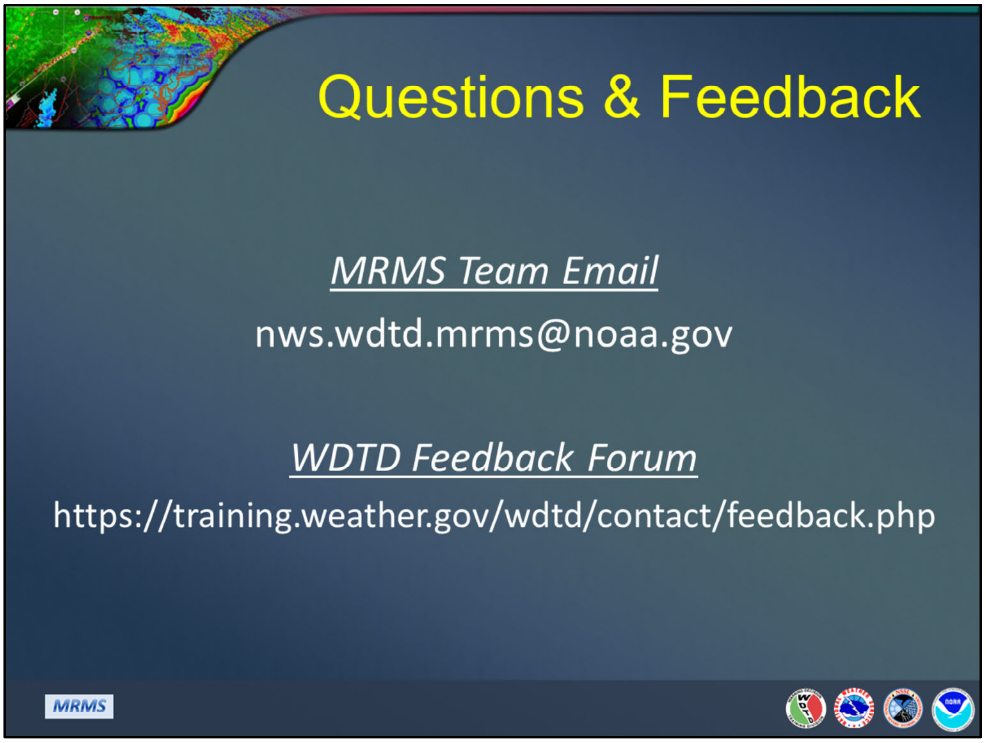

Thanks for completing this module. If you have any questions or feedback concerning this lesson, please feel free to contact us at the addresses here.

Welcome to the Multi-Radar/Multi-Sensor (MRMS) Training Course Lesson on Echo Tops (ETs) developed at the Warning Decision Training Division (WDTD).

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Course Completion Info

Tabs - 4 Tabs (Including Introduction)

Last modified: Wednesday, March 25, 2020 at 3:58:53 PM

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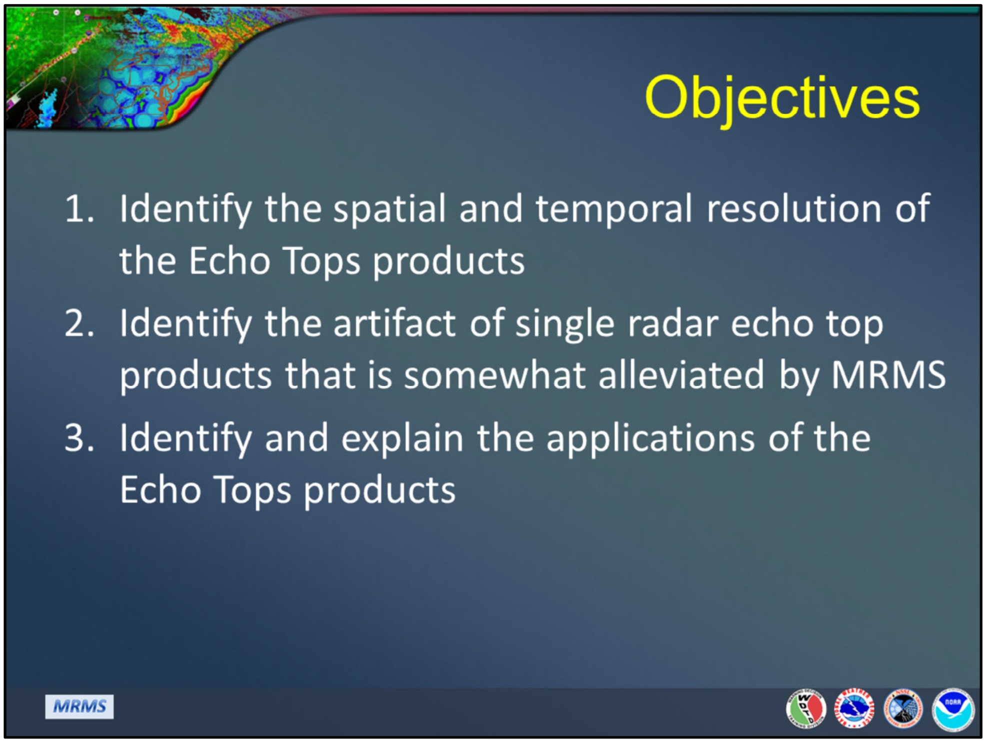

Here are the learning objectives for this lesson. Please take a minute to review them before moving on to the next slide. You will be tested on these objectives at the end of the lesson.

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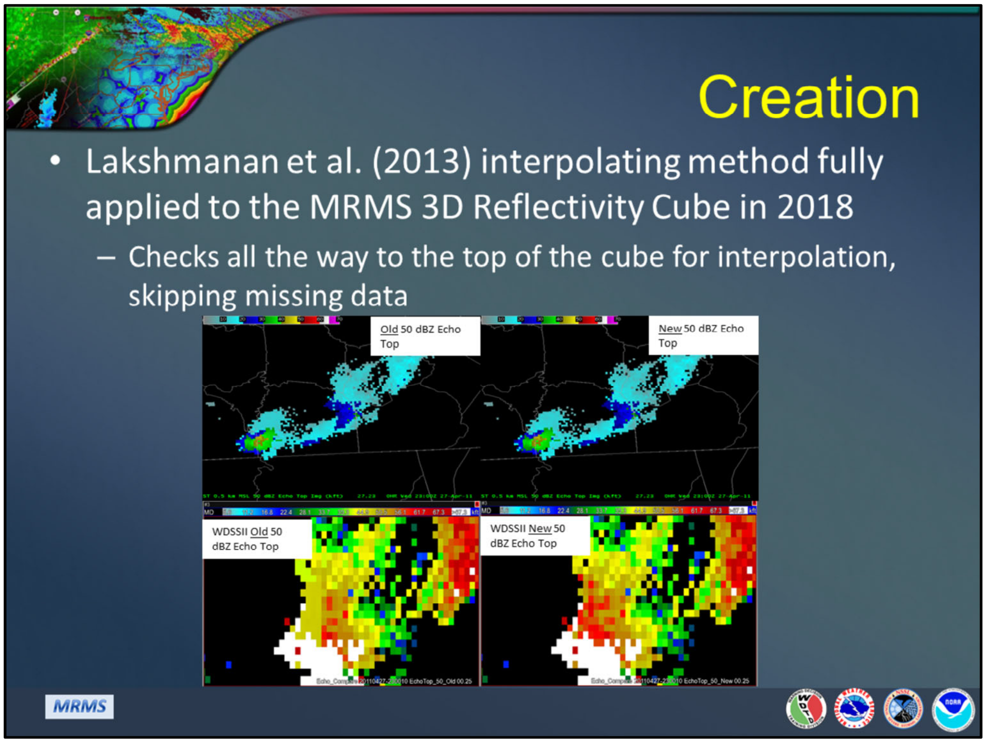
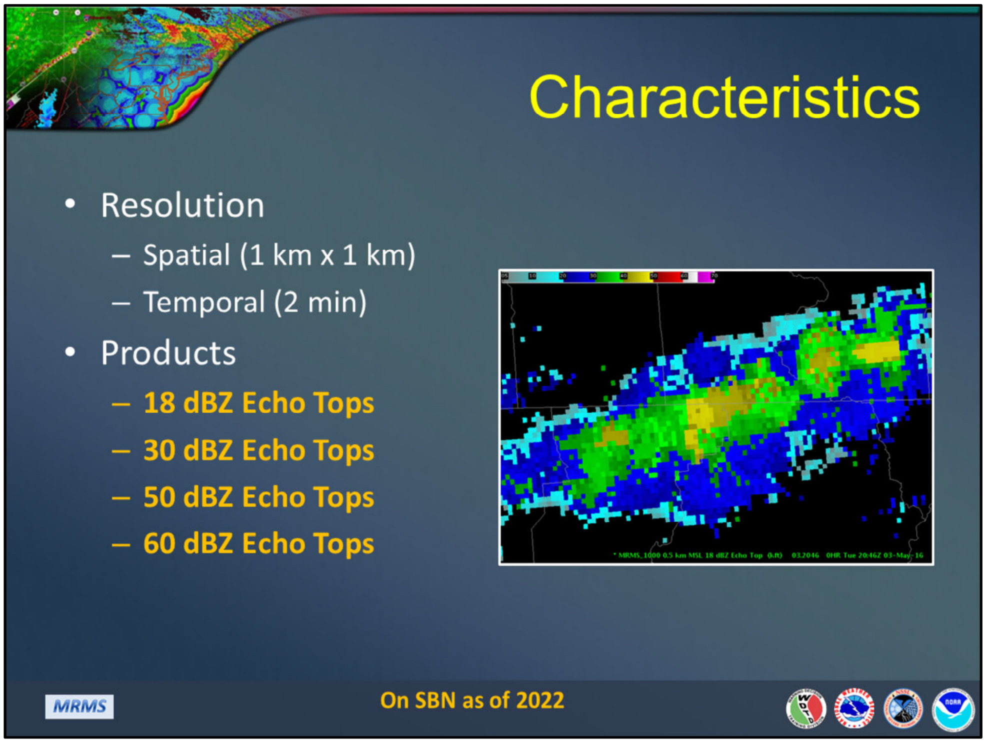
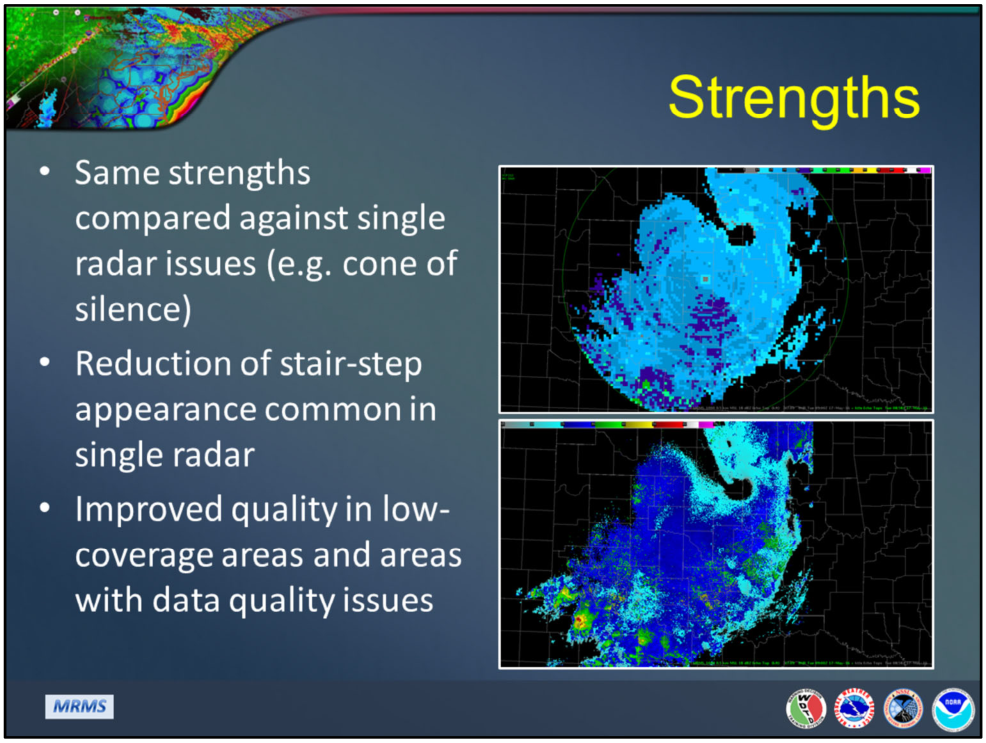


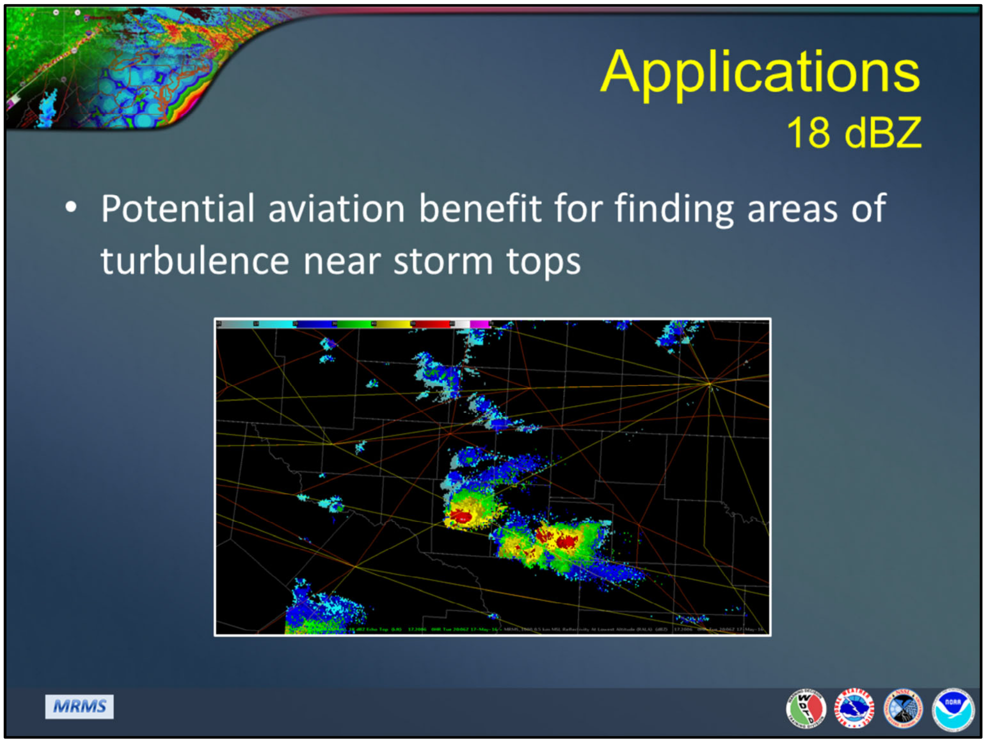
As of 2018, the echo top products are created using the elevation angle interpolation method detailed in Lakshmanan et al. (2013). Instead of simply selecting the highest elevation within a volume, this method interpolates between elevation scans to get a more accurate estimate of the echo top. Additionally, the MRMS algorithm now checks the entire 3-D cube to find elevation scans to interpolate. This figure compares the new product with the old method that did not look for non-missing data. The AWIPS display is on the top and the National Severe Storms Lab display, whose color curve more markedly shows the improvement, is on the bottom.



The spatial resolution of the echo top products is 1 km x 1 km and is updated every 2 minutes. 18, 30, 50, and 60 dBZ echo tops are available via the MRMS menu in CAVE.



The same general strengths for MRMS also apply to the Echo Top products (e.g. cone of silence). One particular strength to mention is in single radar echo top products there is the stair step appearance due to the scanning strategy. With multiple radars scanning the same areas in MRMS, the stair step appearance is somewhat mitigated. In addition, the 2017 interpolation method improves quality in low-coverage and low-data quality areas.



In aviation, the 18 dBZ Echo Top can be used as a proxy for areas of turbulence near storm tops and anvil layers. Here is an example where aviation routes are overlaid with the 18 dBZ echo tops. Some of these routes pass right through the maximum echo tops, therefore, a route change may be in order.

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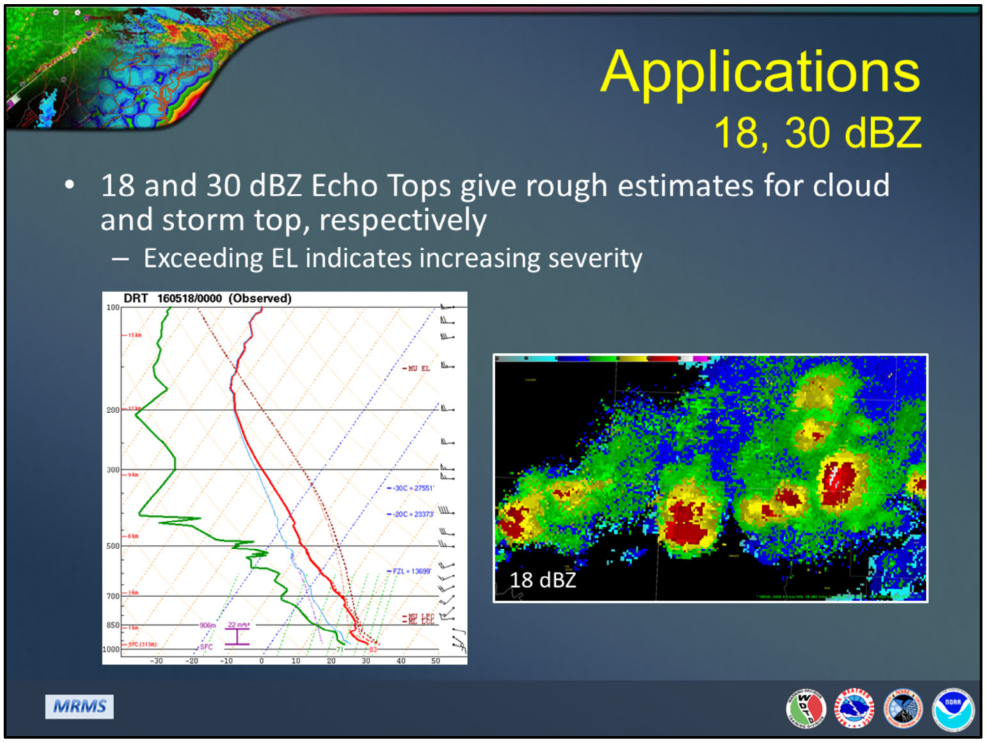

The lower dBZ Echo Top products can give rough estimates of cloud and storm tops, respectively. Here's an example of how 18 dBZ ET can be used to estimate a cloud top. If these echo top values exceed the equilibrium level height, then you can confidently say those storms are experiencing overshooting tops, indicating more severity. Here is an example from south Texas where the EL from the sounding was approximately 45,000 feet. The 18 dBZ Echo Tops were exceeding 50-55 kft.

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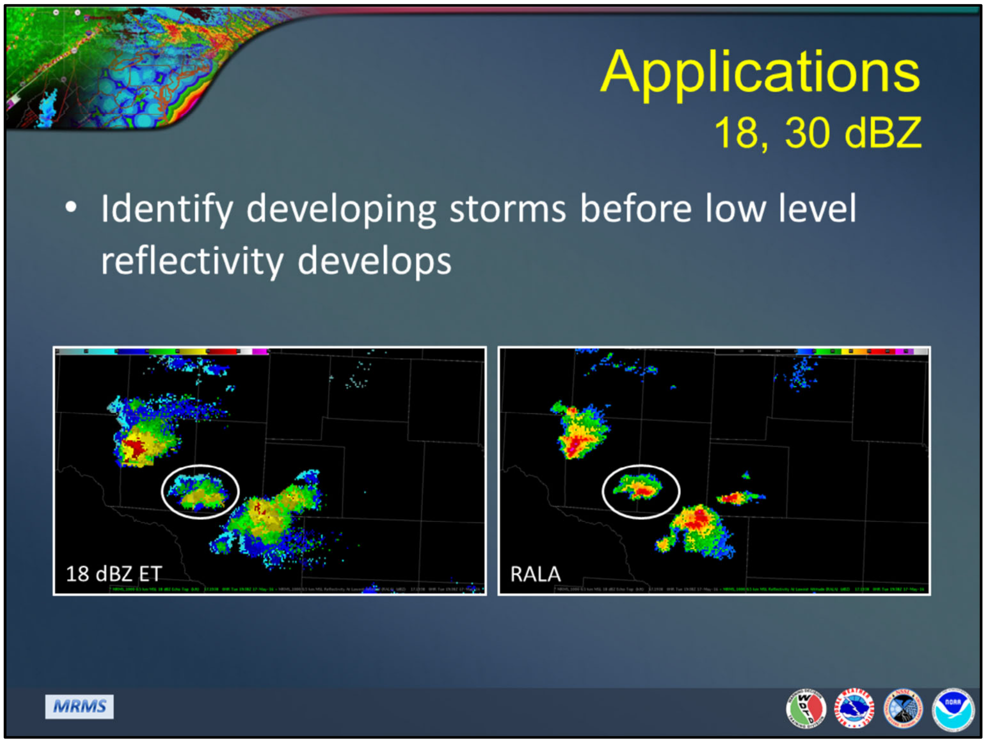
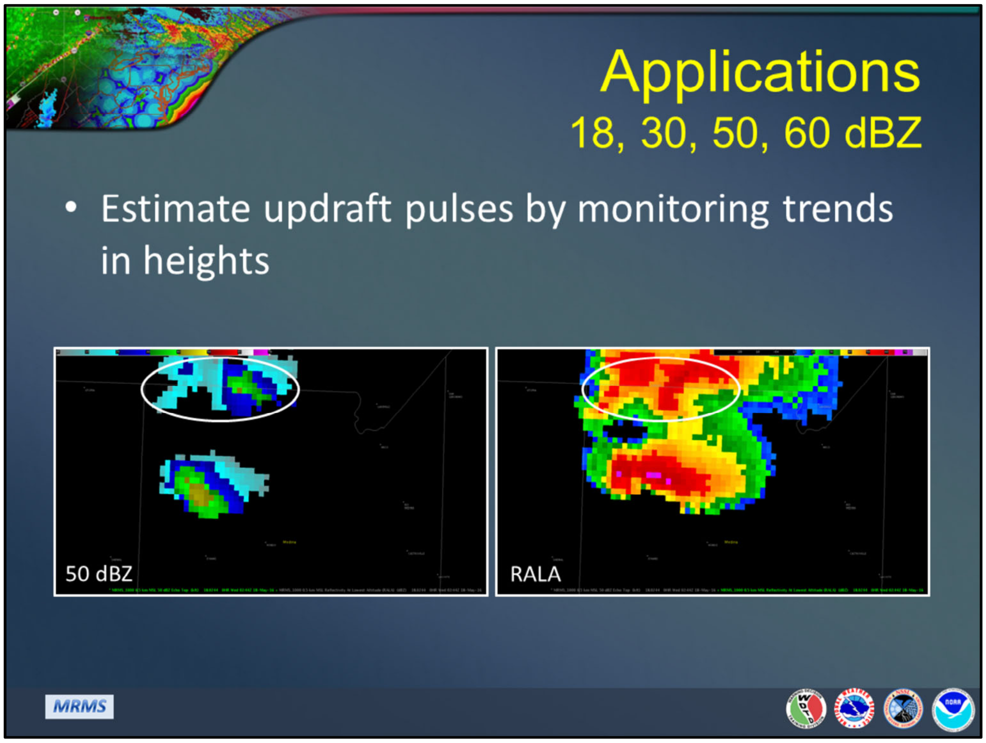
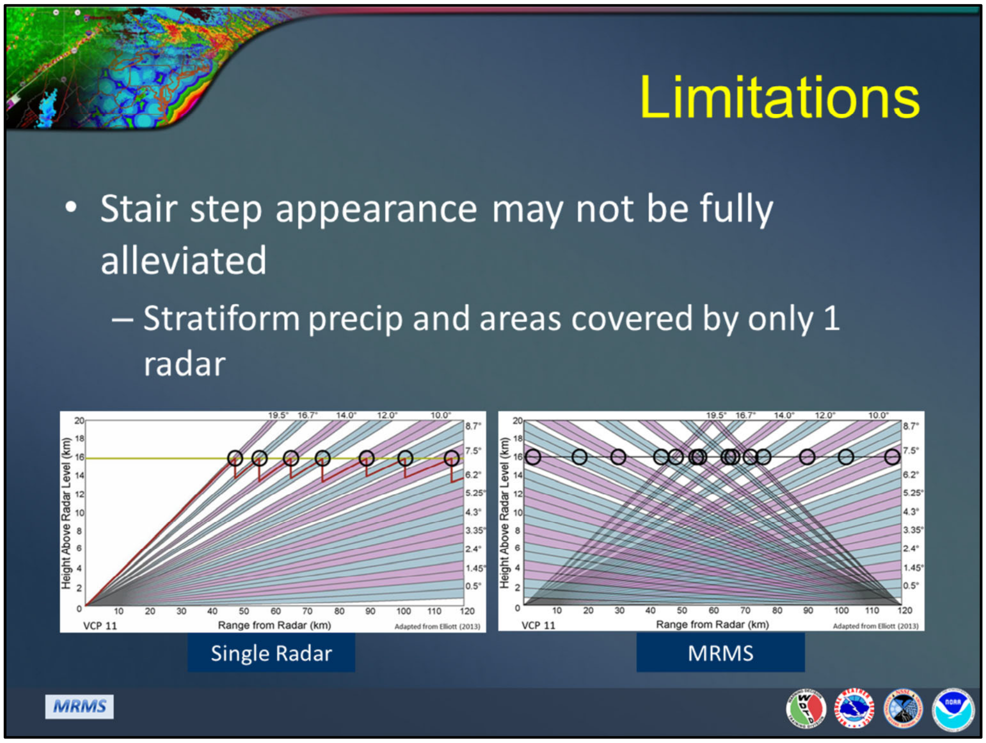


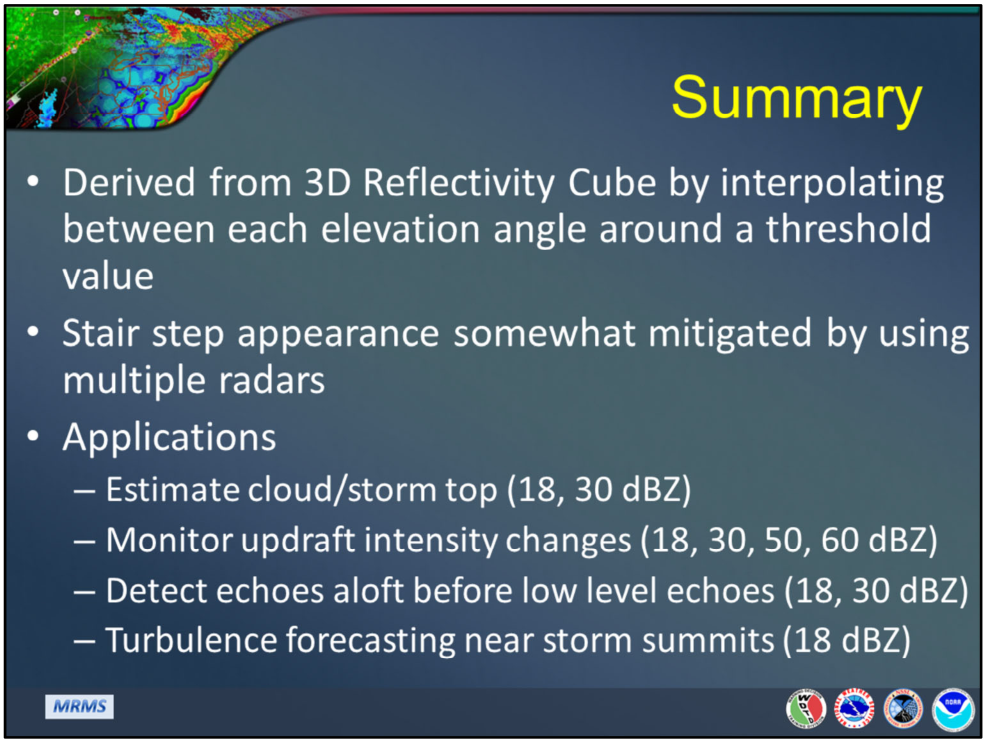
Again the lower dBZ echo tops can detect echoes that occur aloft before reaching the ground early on in a storm's lifecycle. For example, the 18 dBZ Echo Top may appear aloft before any echoes show up in the low levels. Notice in the 18 dBZ echo tops (left) there are values approaching 20 kft in an environment favorable for thunderstorm development, and yet there is no corresponding reflectivity at the lowest levels. If we step through the next few frames, we see the 18 dBZ echo top increase in value and areal coverage and the low level reflectivity responds in intensity. By monitoring the 18 dBZ echo tops, this product could have given you a few extra minutes lead time for any potential warning considerations.



All the ET products can be used to detect updraft pulses at various levels. For instance, updraft pulses will often result in increased 50 dBZ Echo Top heights. In this example, the southern storm already has some significant low level reflectivity with 50 dBZ echo tops reaching near 20 kft. However, as we step through roughly the next 20 minutes, the 50 dBZ echo tops increase to over 40 kft, and the low level reflectivity increases dramatically. If we look to the north, the 50 dBZ echo tops attempted to reach higher heights but never as much as the southern storm, and the low level reflectivity reflected this trend.



Even with the advantage of having multiple radars with these Echo Top products, the stair step appearance does not fully go away. This is especially true in areas of the country where only 1 radar covers the area, or in regions of stratiform precipitation.



In summary, the Echo Top products are derived from the 3D Reflectivity Cube by interpolating between each elevation angle. The stair step appearance is somewhat mitigated. The major applications of these products are the lower dBZ ETs are a good estimate for cloud and storm tops. By monitoring height trends, you can estimate regions experiencing updraft intensity changes with any ET product. Early on in convective initiation, echoes will occur aloft before any low level echoes develop and can be seen on the lower dBZ ETs. Finally, aviation uses the 18 dBZ ET product to estimate regions of turbulence near storm summits. Up next will be the quiz!

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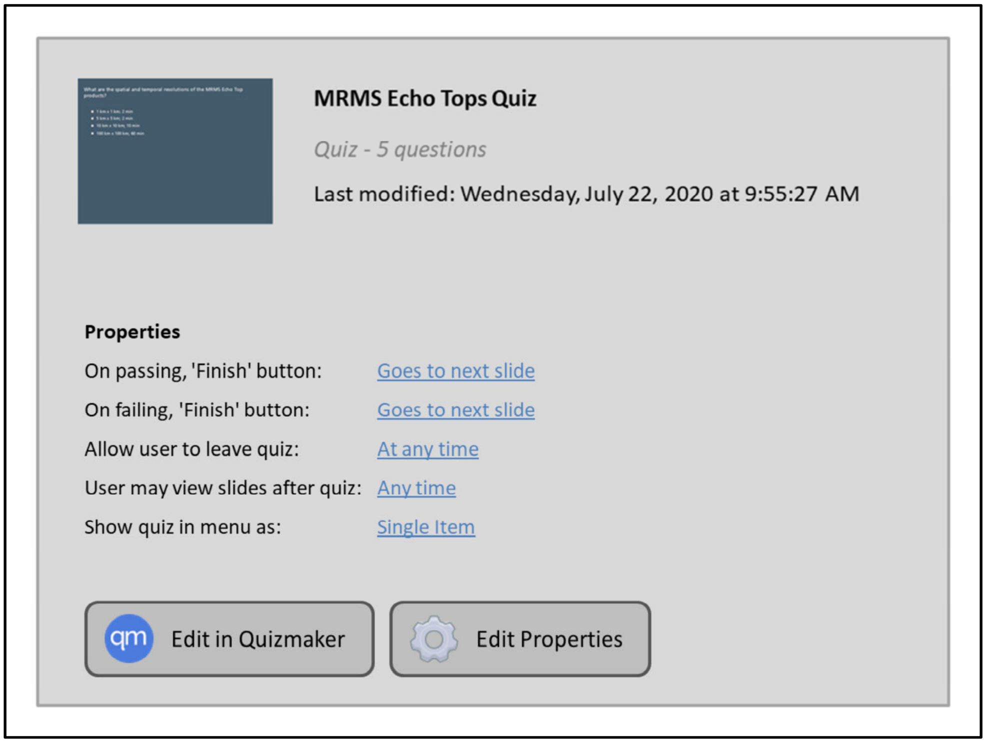
MRMS Echo Tops Quiz
Quiz - 5 questions
Last modified: Wednesday, July 22, 2020 at 9:55:27 AM
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User may view slides after quiz: Any time
Show quiz in menu as: Single Item
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Edit Properties

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Welcome to the Multi-Radar/Multi-Sensor (MRMS) Products Course Lesson on Hail Products! I am Alyssa Bates with the Warning Decision Training Division (WDTD).

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Course Completion Info

Tabs - 4 Tabs (Including Introduction)

Last modified: Wednesday, March 25, 2020 at 3:58:53 PM

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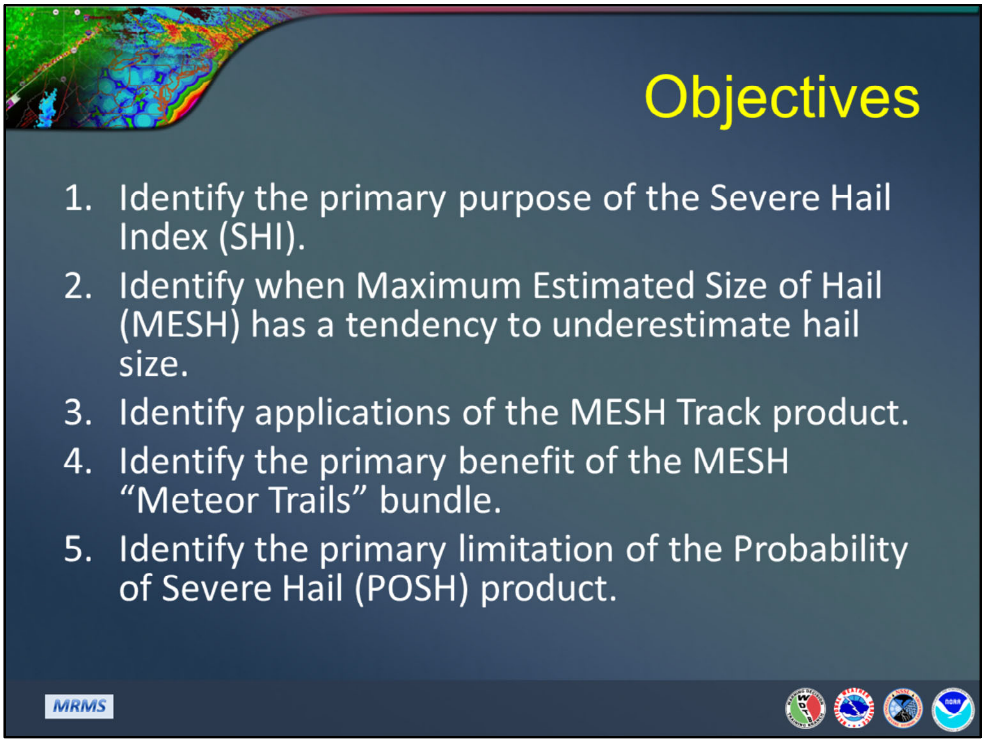

Here are the objectives for this lesson. Take a minute to review them before moving on to the next slide.

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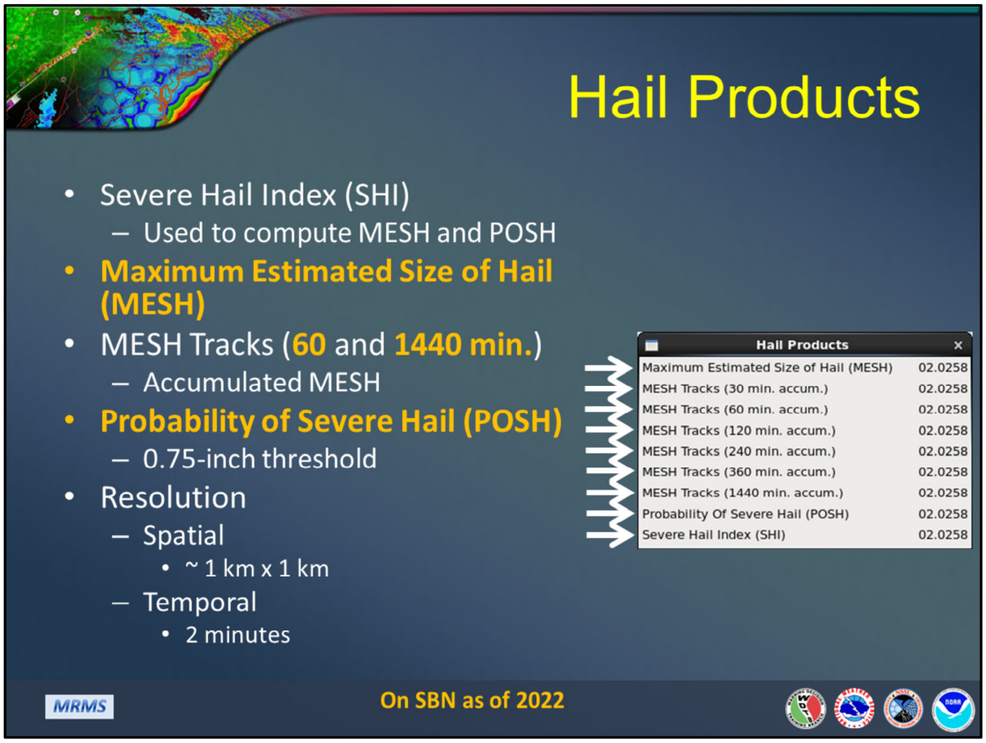

There are four MRMS hail products:

- The Severe Hail Index or SHI is used to calculate the Maximum Estimated Size of Hail and the Probability of Severe Hail.
- The Maximum Estimated Size of Hail or MESH provides an estimate of the maximum hail size that can be expected.
- MESH Tracks display the maximum MESH value during a specified time period. Available intervals include 30, 60, 120, 240, 360, and 1440 minutes.
- Lastly, the Probability of Severe Hail or POSH is the probability of 0.75-inch diameter hail occurring.

The spatial resolution of these products is approximately 1 km by 1 km and the temporal resolution is 2 minutes.

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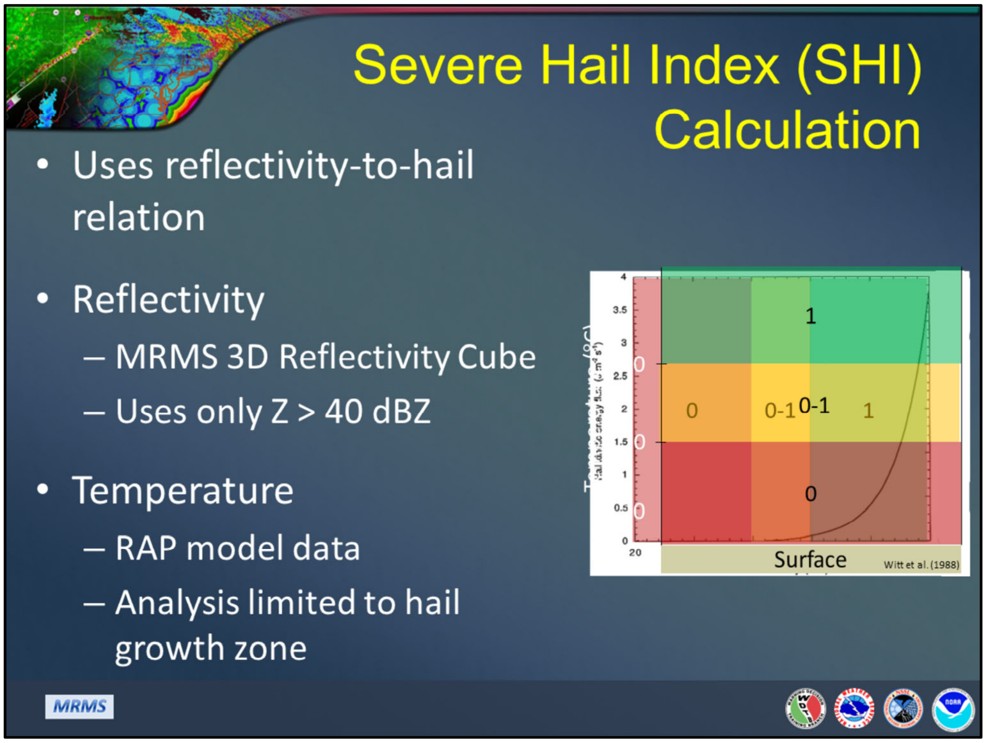
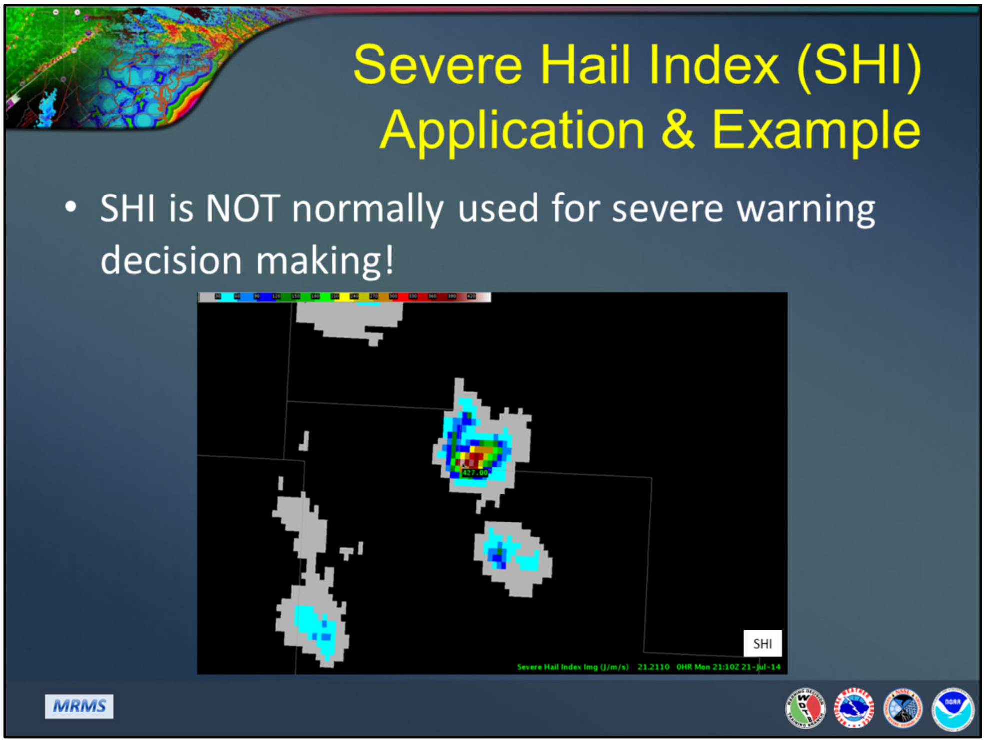
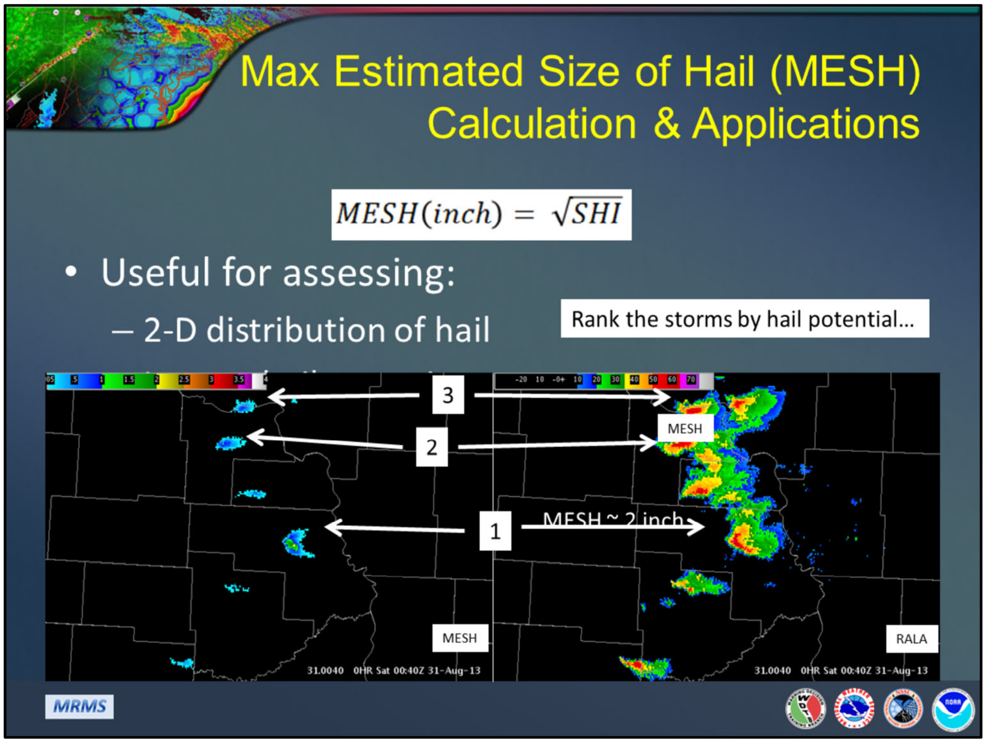


The Severe Hail Index (SHI) uses a reflectivity-to-hail relation to detect the presence of severe hail. SHI receives reflectivity input from the 3D Reflectivity Cube, where only reflectivity values greater than 40 dBZ are used. Vertical temperature profiles from the Rapid Refresh (RAP) model are also used in the calculation of SHI, where the algorithm's analysis is limited to the hail growth zone, meaning temperatures from -10 to -20 deg C.



It is important to note that SHI is not normally used alone for severe warning decision making. It’s primarily used to compute the Probability of Severe Hail (POSH) and Maximum Estimated Size of Hail (MESH).



The MESH calculation is simple; just take the square root of the Severe Hail Index.

MESH has shown to be very useful for assessing the 2D distribution of hail. Can you quickly rank these storms by their potential to produce severe hail? It's easy with MESH!

MESH is also useful for assessing the largest hailstone size associated with a storm.

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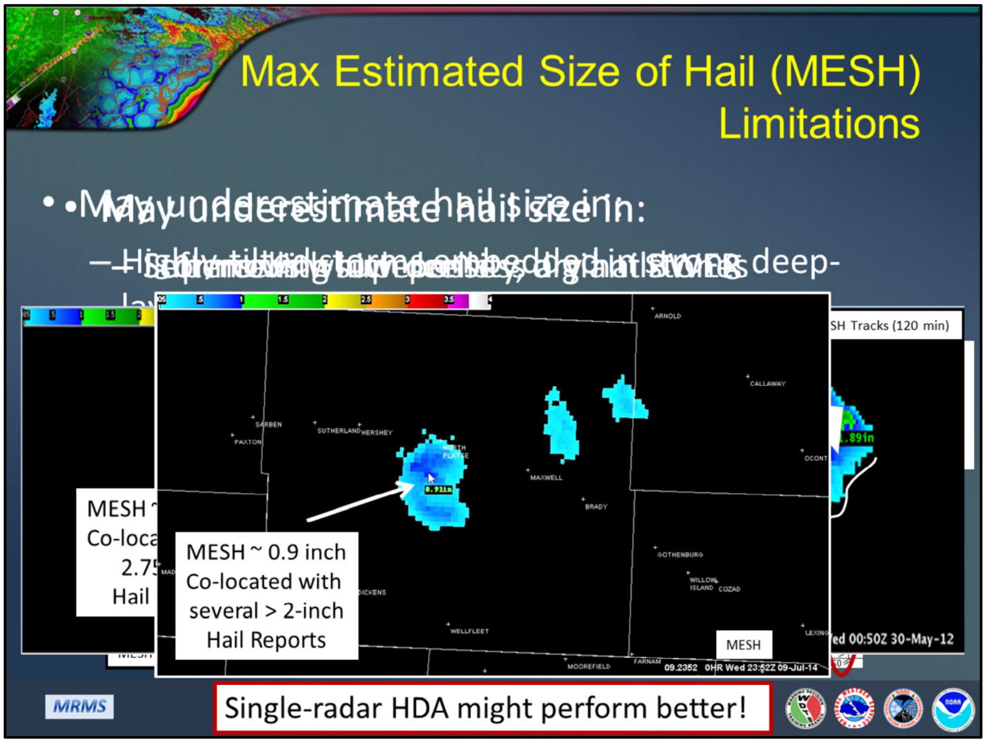
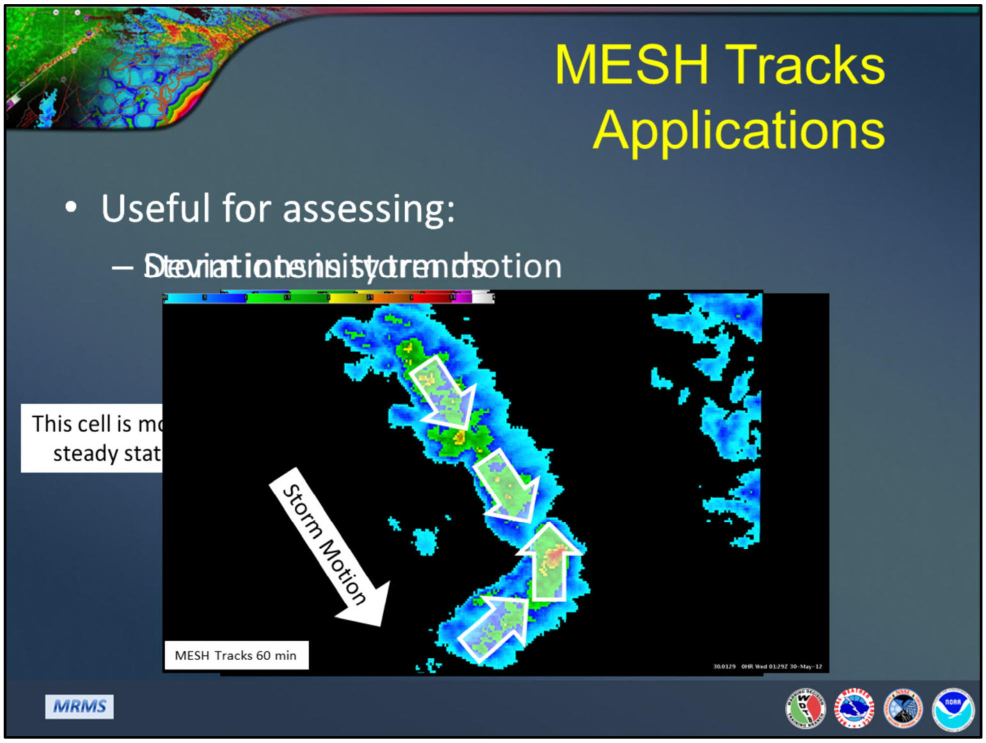


Like many other hail size estimation techniques, which use reflectivity and vertical temperature input, MESH has a tendency to underestimate hail size in highly-tilted storms embedded in strong, deep-layer shear. In these cases, the traditional single-radar hail detection algorithm might perform better than the multi-radar product.

MESH also tends to underestimate hail size in Left-moving supercells.

MESH may also underestimate hail size in supercells that possess a giant Bounded Weak Echo Region. As shown in this example, a low MESH value hole is sometimes co-located with the bounded weak echo region. The presence of a “MESH hole” is a strong indicator that MESH is underestimating hail size! As was the case with highly-tilted storms, the traditional single-radar hail detection algorithm might perform better than the multi-radar product in these cases.

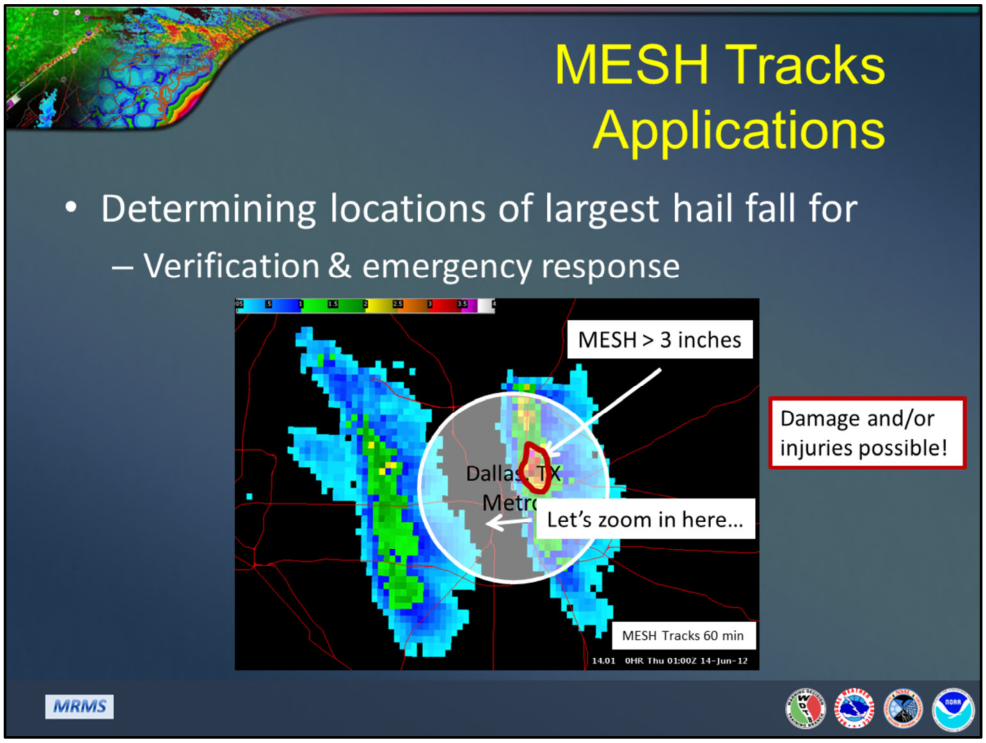
Lastly, MESH may underestimate hail size in storms with low-density, dry hailstones.



MESH Tracks are useful for assessing storm intensity trends.

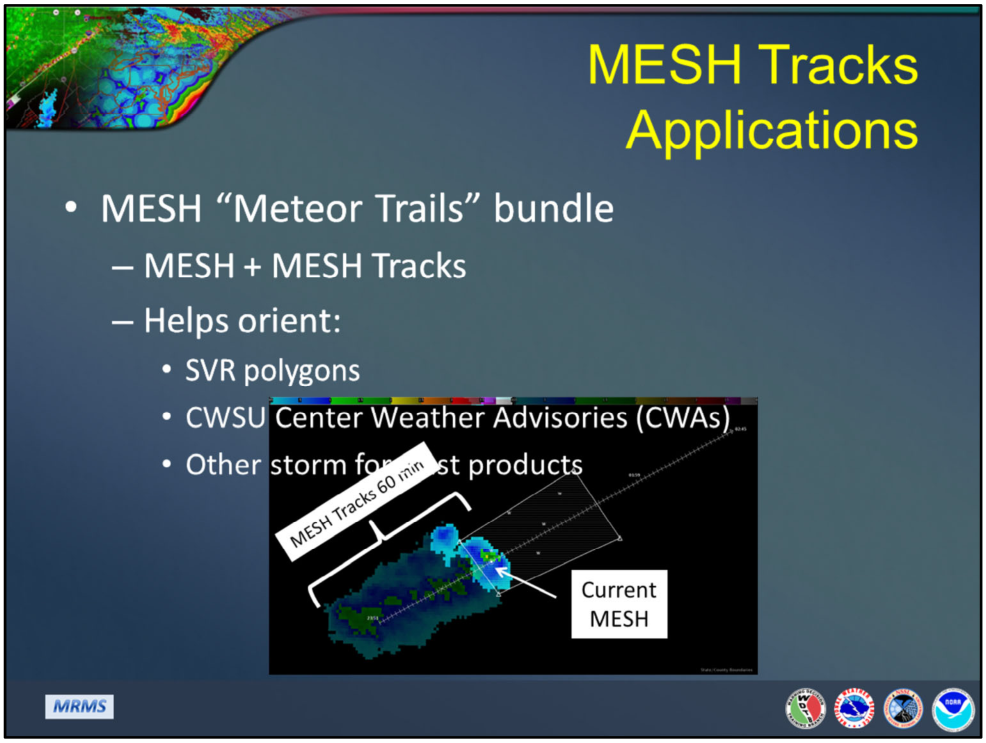
A quick look at MESH tracks with these storms reveals the eastern cell cycled in intensity before steadying, while the western cell remained intense throughout.

MESH tracks can also help identify deviations in storm motion. The arrows here indicate the direction of movement of the two cells. As they approach each other, the southern cell takes a sharp left turn. This is easy to identify using MESH tracks.



MESH tracks can help forecasters define an area for verification calls during and after severe weather events.

MESH tracks can also aide emergency response by identifying locations with possible damage or injuries.



MESH Tracks can be image combined with instantaneous MESH to create a MESH "Meteor Trails" bundle which is very useful for the orientation of NWS WFO Severe Thunderstorm Warning polygons CWSU Center Weather Advisories (CWAs), and other storm forecast track products.

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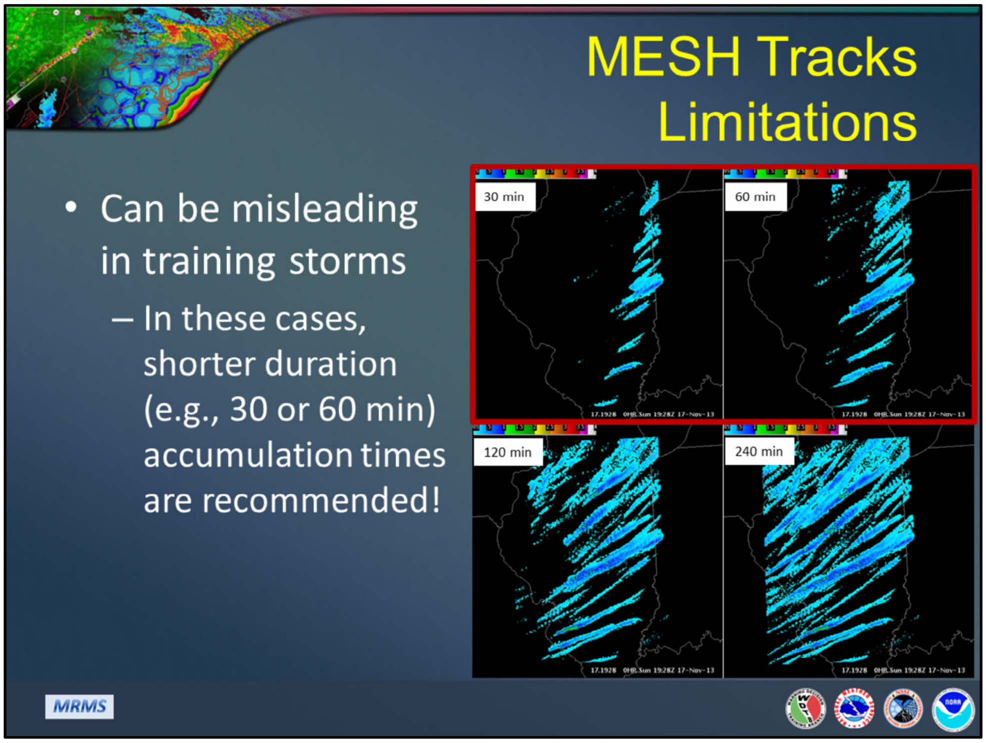

MESH tracks at longer accumulation times can be misleading in training storms, since it is difficult to determine which cell is responsible for the maximum MESH during the period. In these cases, shorter duration accumulation times are recommended.

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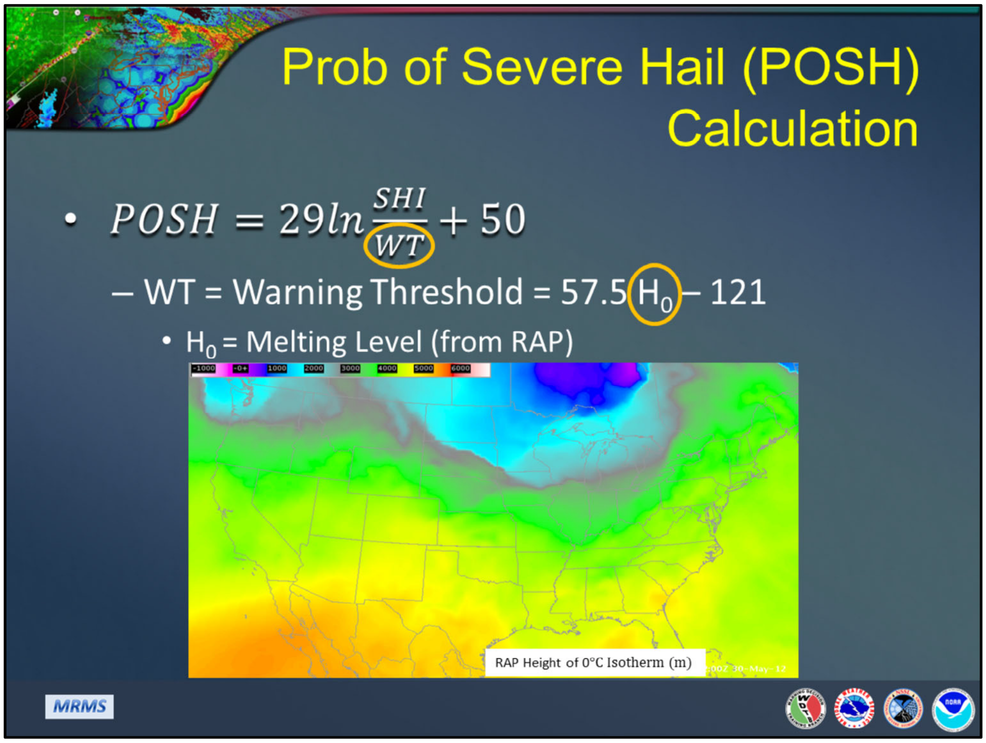
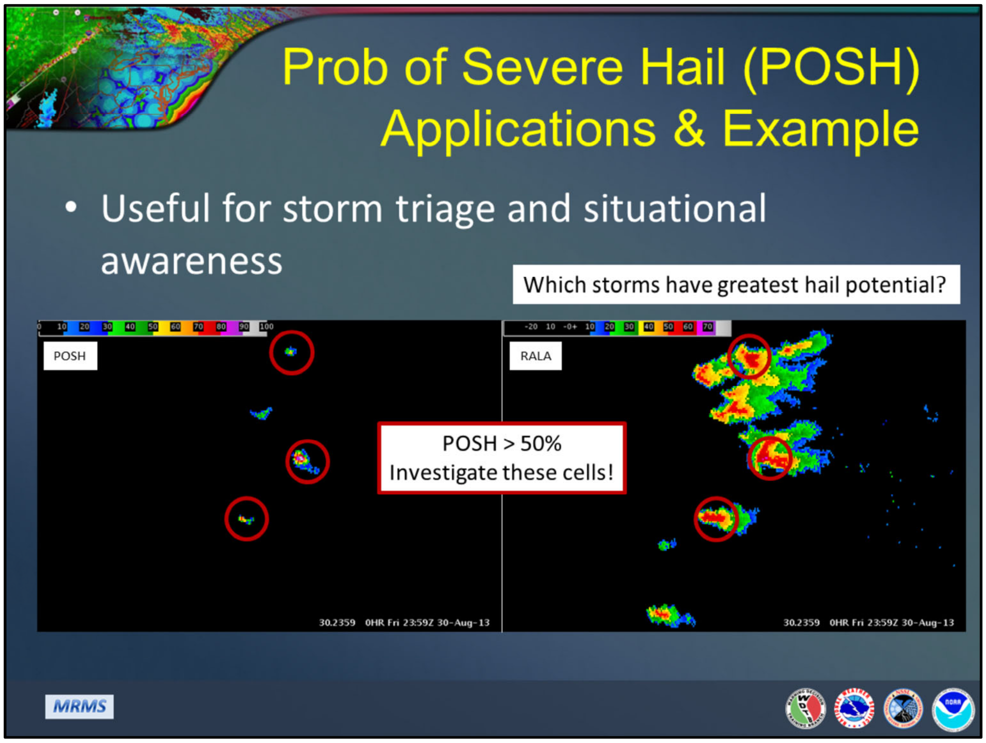
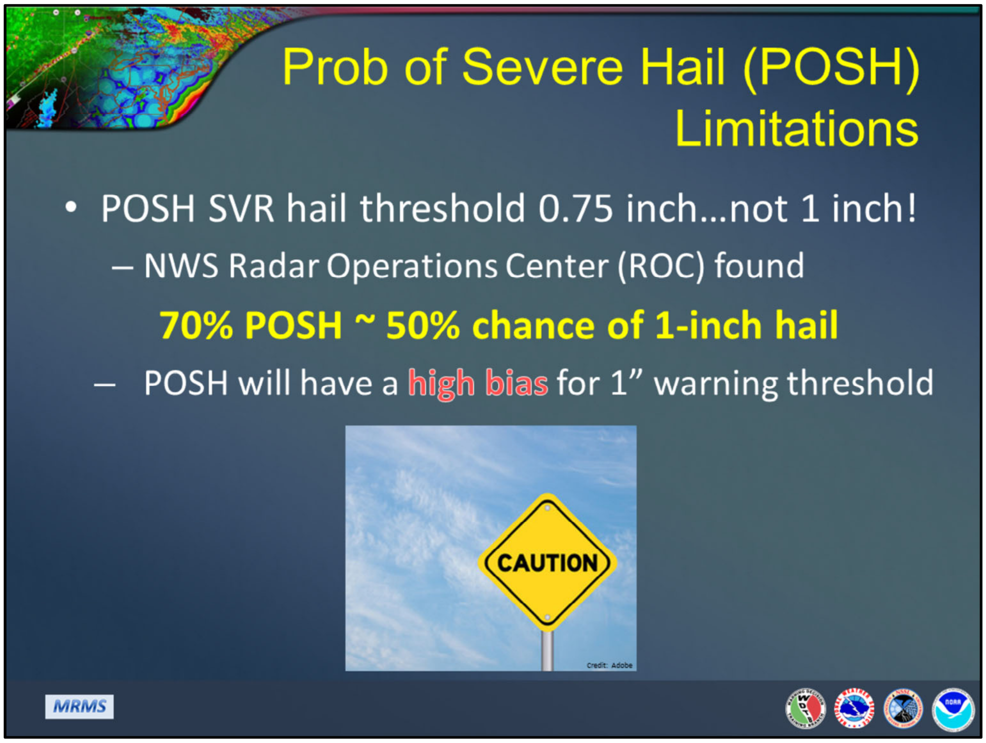


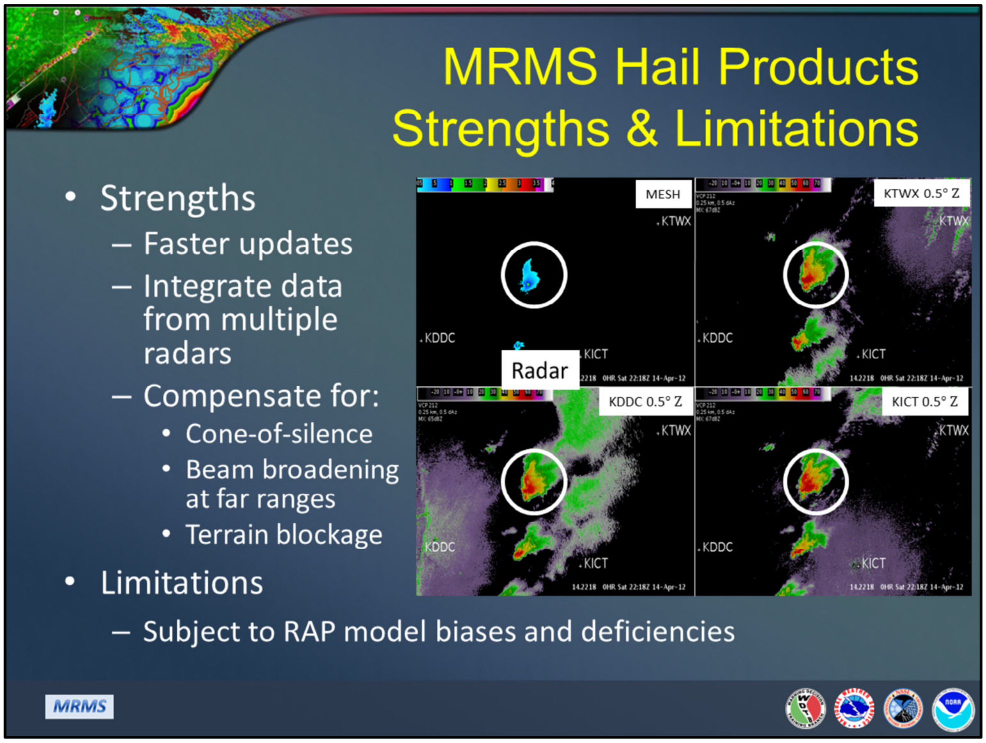
The probability of severe hail product has two inputs in its calculation, the SHI and a warning threshold. The warning threshold is a linear equation with the melting level as the only input.



POSH is useful for storm triage and situational awareness. Can you tell which storms have the greatest hail potential? It's easy with POSH!



But beware! POSH was developed when the NWS severe hail criteria was 0.75-in diameter, rather than the current 1-inch criteria. The NEXRAD Radar Operations Center (ROC) determined that a 70% POSH is approximately the same as a 50% chance of 1-in hail. This means that POSH will have a high bias for the 1" warning threshold, so please do not issue a warning based on POSH alone.

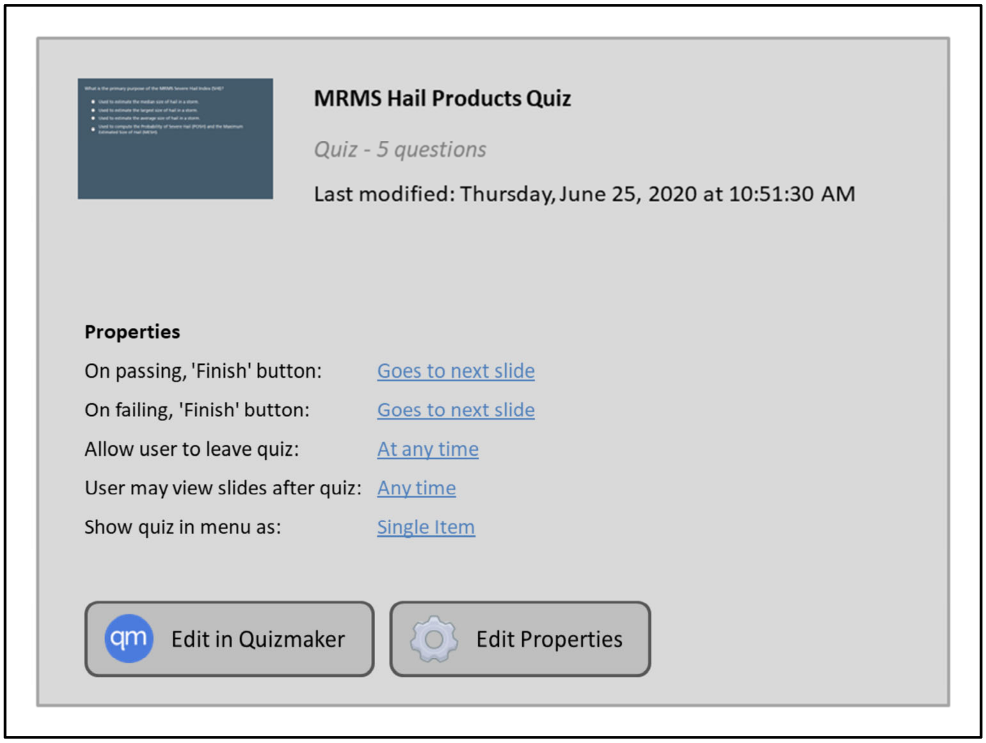


Like all MRMS products, the use of multiple radars is more robust than single-site radar alone.

It provides faster updates and helps the forecaster integrate data from multiple radars. That is illustrated here, with a cell located equidistant between three radars, which radar would you use to analyze the cells hail potential? You could use MESH, it uses data from all of these radars!

The MRMS hail products also compensates for cone-of-silence, beam broadening at far ranges, and terrain blockage.

Do note that the data are subject to the biases and deficiencies of the mesoscale model used to derive the vertical temperature profile.


MRMS Hail Products Quiz
Quiz - 5 questions
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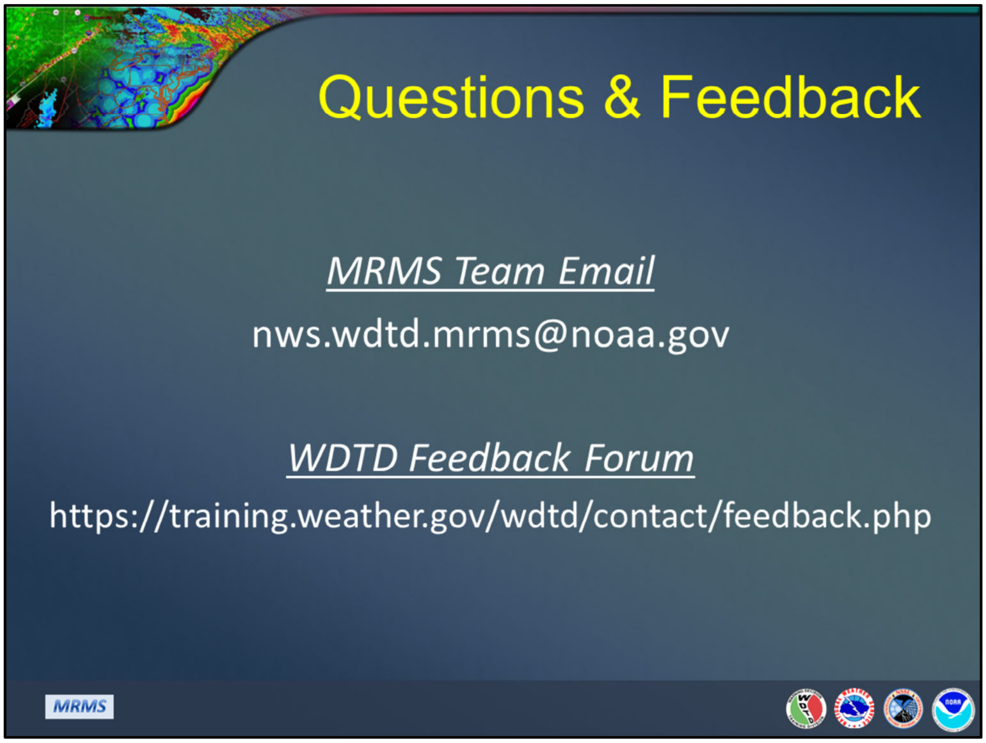

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Welcome to the Multi-Radar/Multi-Sensor (MRMS) Products Course Lesson on Velocity-based Products! I am Alyssa Bates with the Warning Decision Training Division (WDTD).

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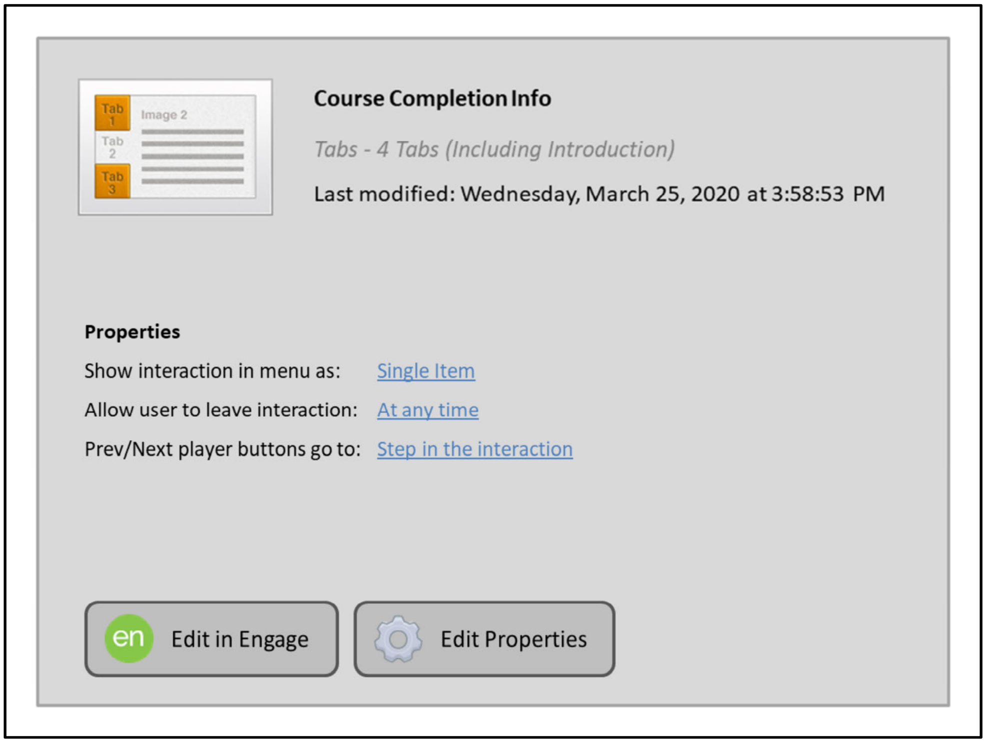
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Last modified: Wednesday, March 25, 2020 at 3:58:53 PM
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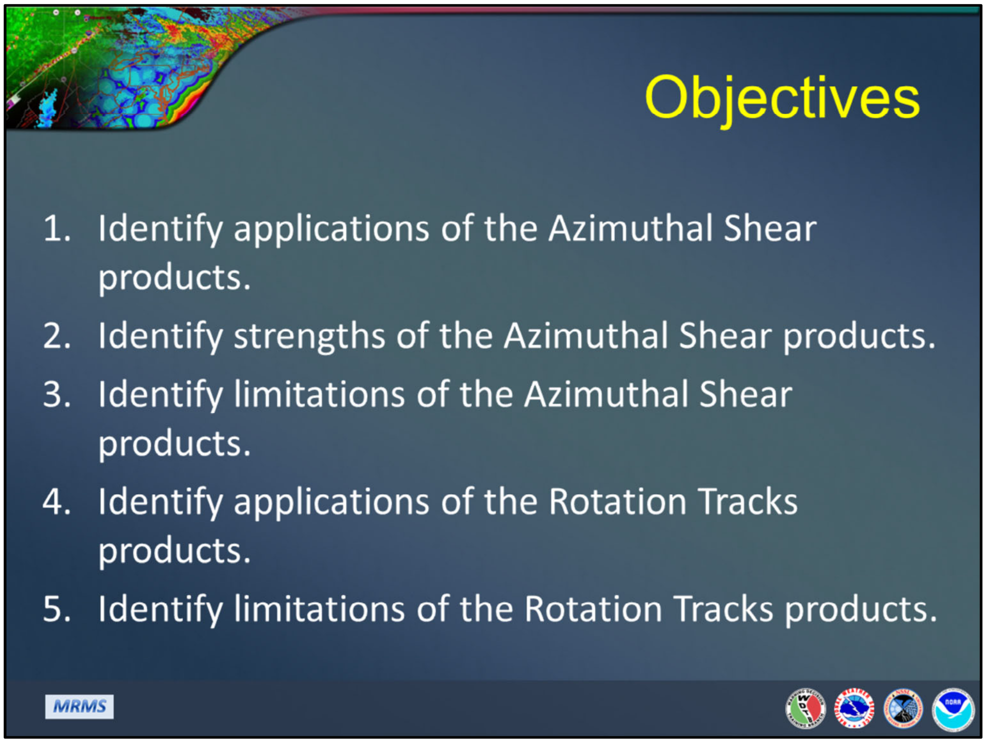

Here are the objectives for this lesson. Take a minute to review them before moving on to the next slide.

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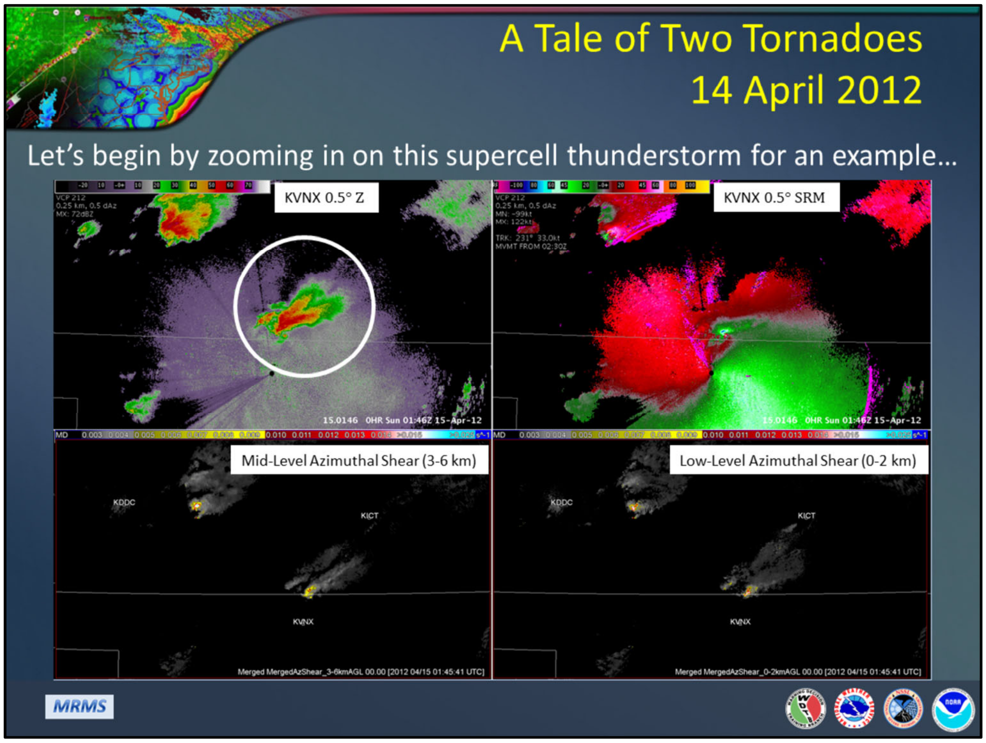
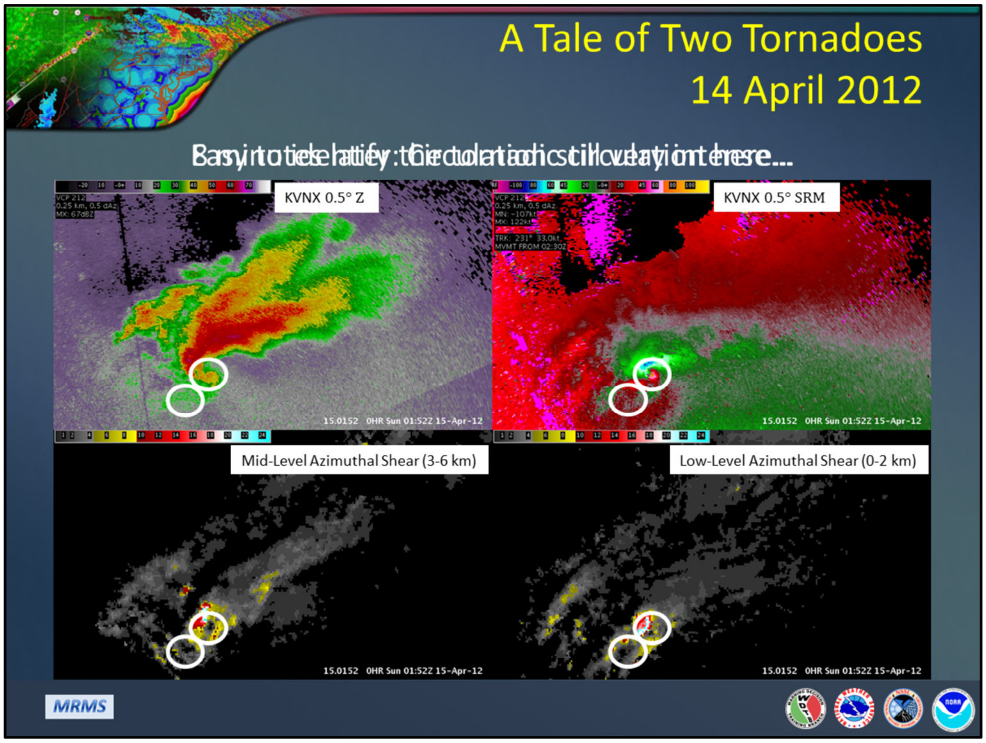


Let's begin this module by showing a comparison of MRMS and base radar data. The top two panels are reflectivity and SRM from a single-site, while the bottom two panels are Mid- and Low-Level Azimuthal Shear. Our example will focus on this supercell.



In this case, it's easy to identify the tornadic circulation in both the base and MRMS data. And if we advance eight minutes, we can see that the circulation is remaining very intense.

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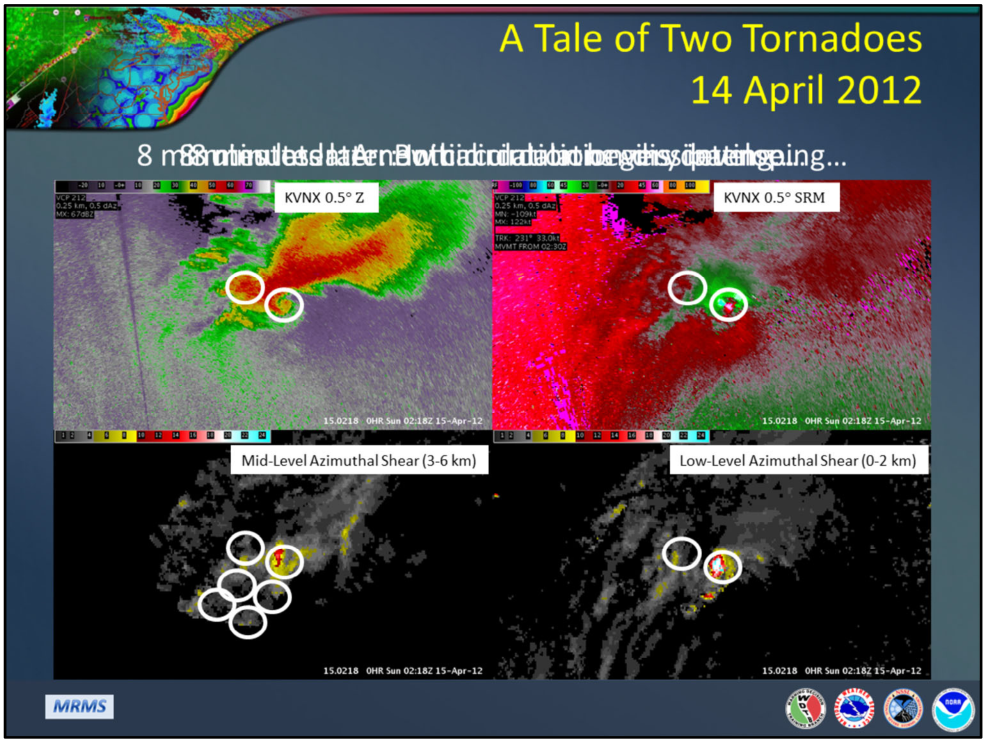
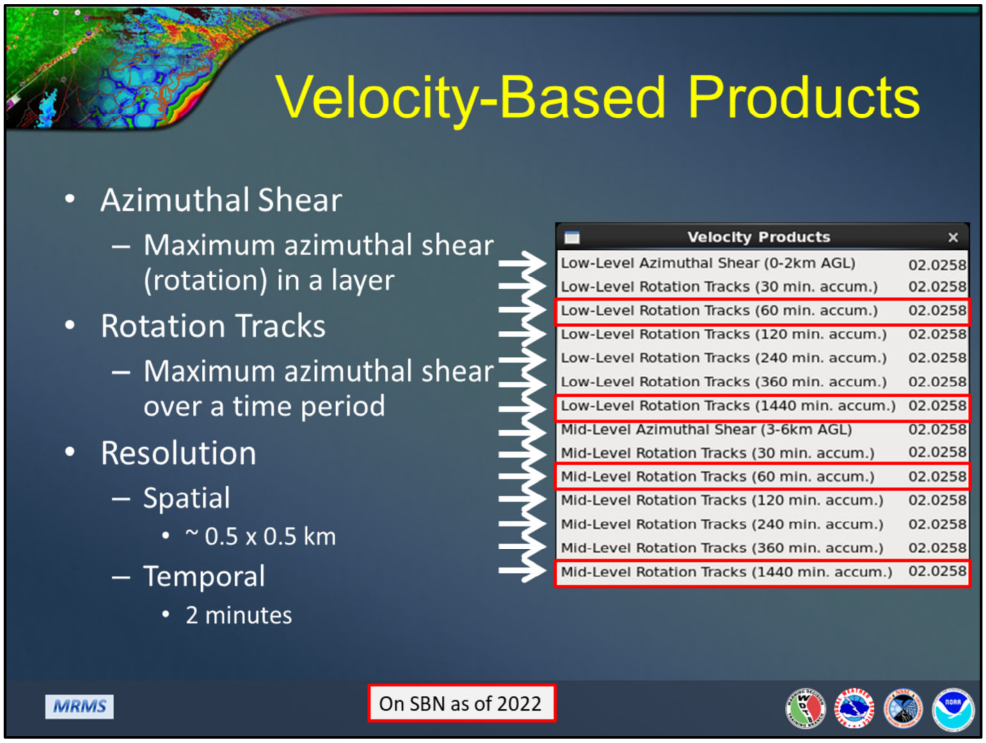


Advancing 8 more minutes, a new mesocyclone begins to develop to the east. At the same time, MRMS and base data indicate the initial circulation is at its strongest. 8 more minutes and both circulations are now intense with two tornadoes occurring simultaneously. Lastly, if we advance 8 more minutes, we see that the initial tornadic mesocyclone has occluded and been replaced by the secondary mesocyclone.
This example illustrates how MRMS data can complement traditional base radar velocity analysis.



There are two MRMS velocity-based product suites:

- The Azimuthal Shear products display the maximum azimuthal shear or rotation divided by diameter in units of per second. Available Azimuthal Shear products include Low-Level, which uses the 0-2 km above ground level (AGL) layer and Mid-Level, which uses the 3-6 km above ground level (AGL) layer.

- The Rotation Tracks products display the maximum azimuthal shear in the low-level or mid-level layer for a specified time period. Available intervals include 30, 60, 120, 240, 360, and 1440 minutes.

The spatial resolution of these products is approximately 500 m by 500 m and the temporal resolution is 2 minutes.

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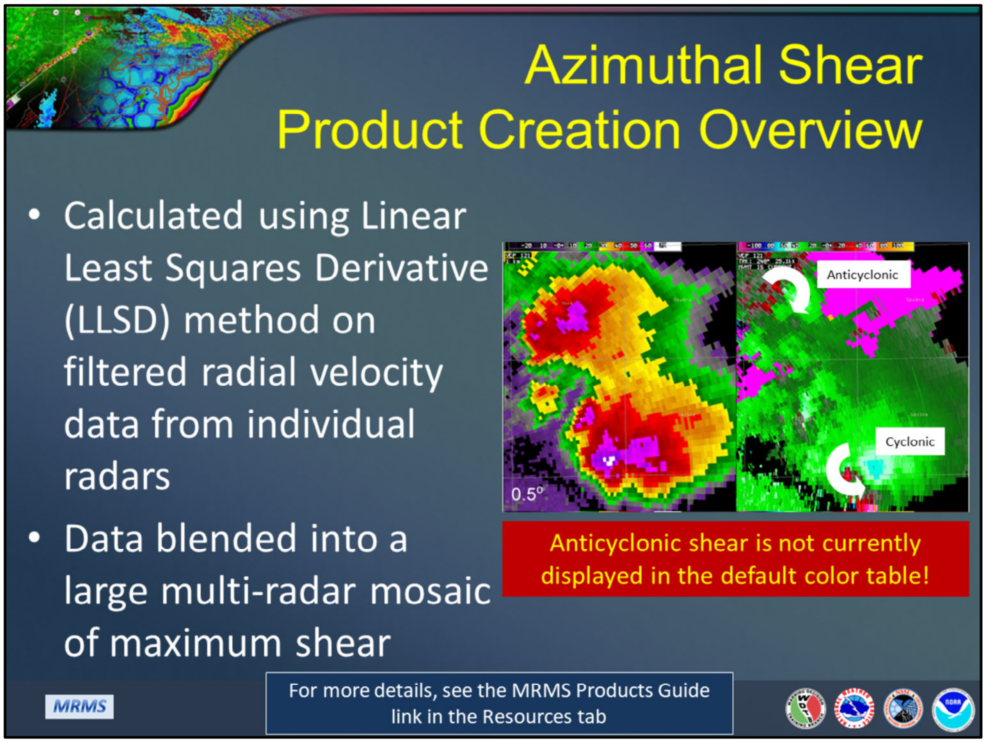

Let's get into a little bit about how the Azimuthal Shear product is created. This will help us better understand its applications, strengths and weaknesses. Azimuthal shear is calculated by applying a Linear Least Squares Derivative or LLSD algorithm to the radial velocity data from individual radars. We'll talk about that later. Once this process is complete, the maximum shear from each radial layer is then blended to create the multi-radar Azimuthal Shear product. It is also important to note that anticyclonic shear is not currently displayed in the default color table.

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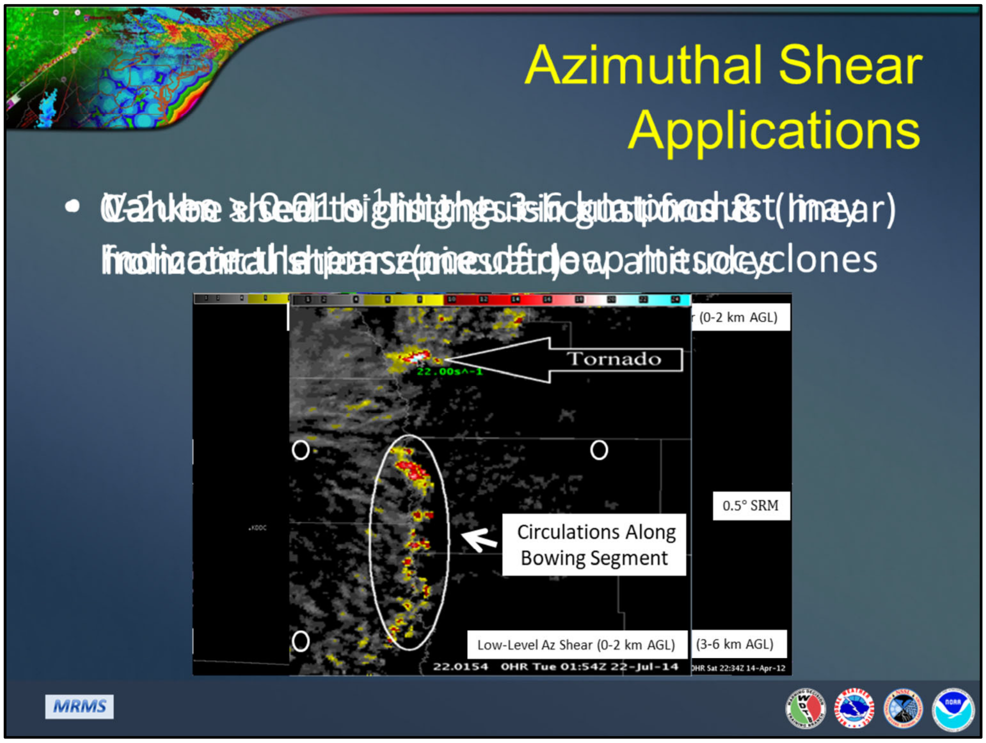
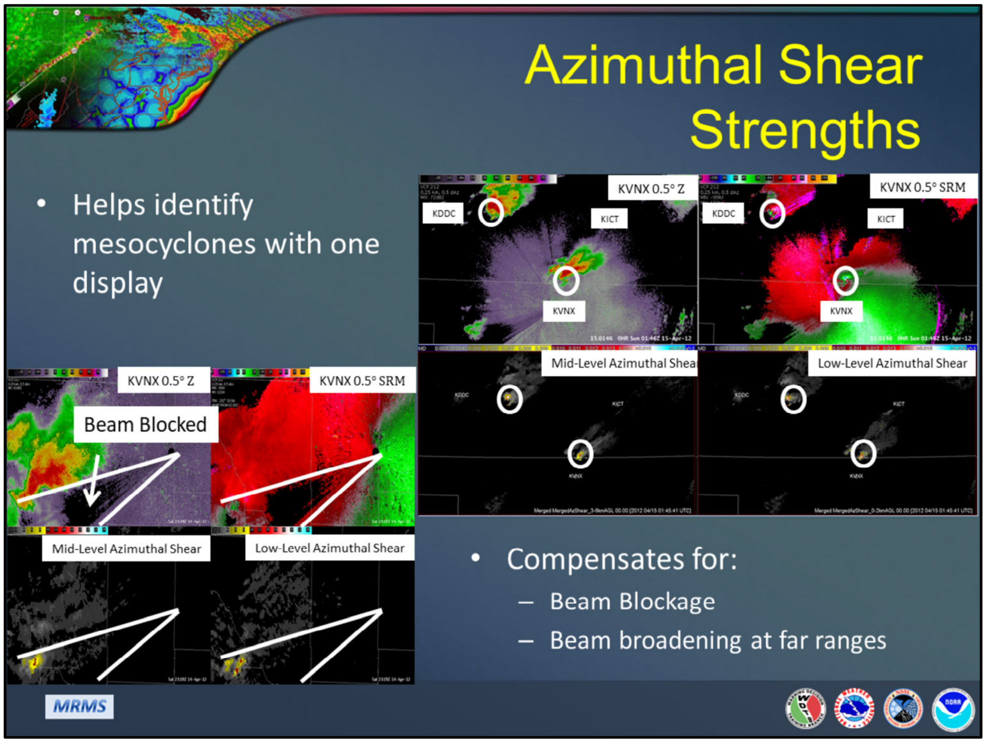


The Azimuthal Shear products have many applications:

- For example, the 0-2 km Azimuthal Shear product highlights circulations and horizontal shear zones in the low altitudes of storms that may be associated with mesocyclones and/or tornadoes.

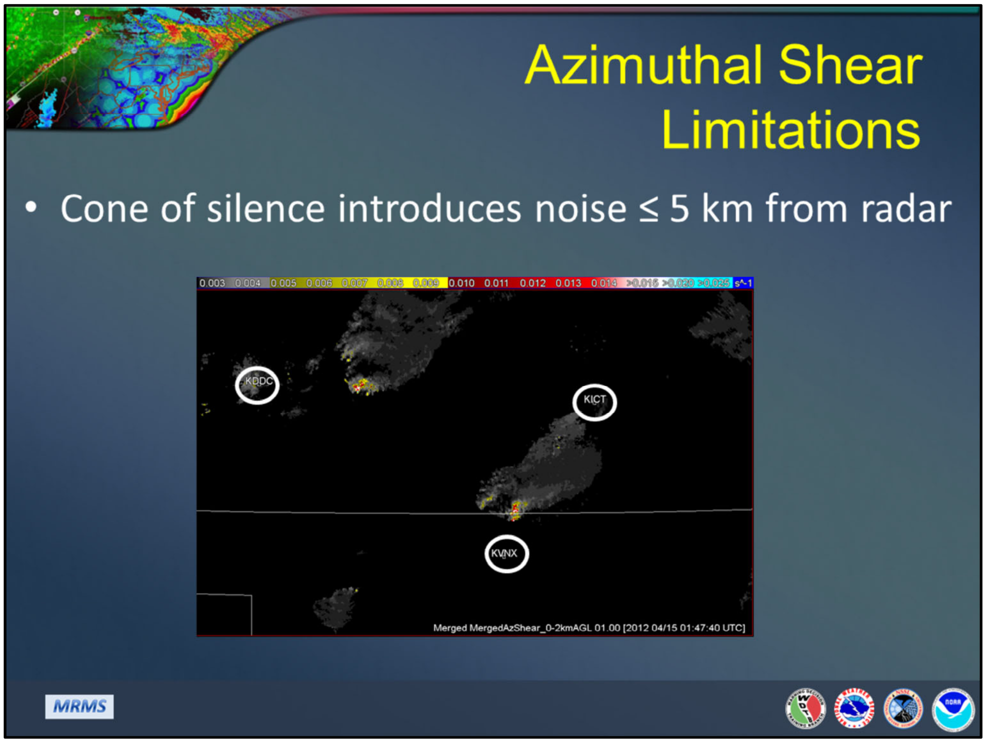
- Additionally, large values in the 3-6 km product may indicate the presence of a deep mesocyclone, indicative of a supercell thunderstorm.

- Lastly, Azimuthal Shear could also be associated with a gust front or another feature, depending on the viewing angle of the nearest radar. Well-sampled circulations generally appear circular, while gust fronts and shear zones are linear.



Some strengths of the Azimuthal Shear Product are:

- That it helps identify mesocyclones and tornadoes with one display. In this example, there are three radars that could be used to analyze these storms. Instead of having to flip between radars, you could use Azimuthal Shear!
- Also, the Azimuthal Shear product compensates for beam blockage and beam broadening at far ranges.



The Azimuthal Shear product does have a few limitations:

- The Azimuthal Shear calculations break down within 5 mi of a radar, so RDAs can sometimes be ringed with false Azimuthal Shear.

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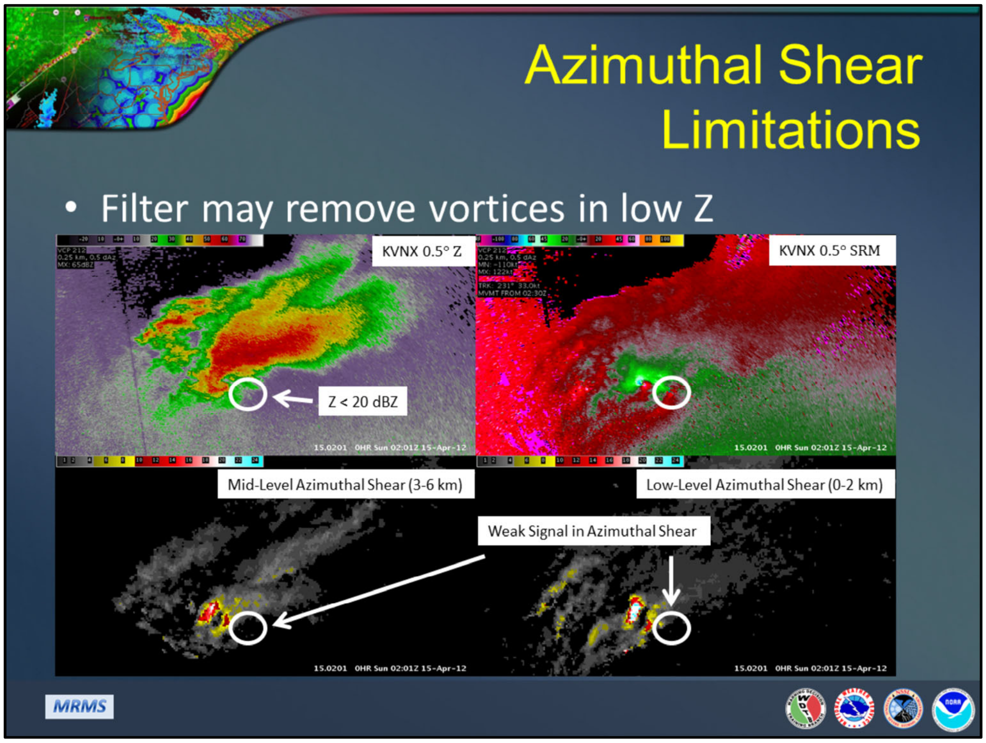

- Valid circulations can also be removed by the reflectivity mask when the dilation process is insufficient to compensate for low-reflectivities. This can occur with tornadoes associated with a low reflectivity hook echo or a non-mesocyclone tornado under a yet-to-be precipitating updraft column.

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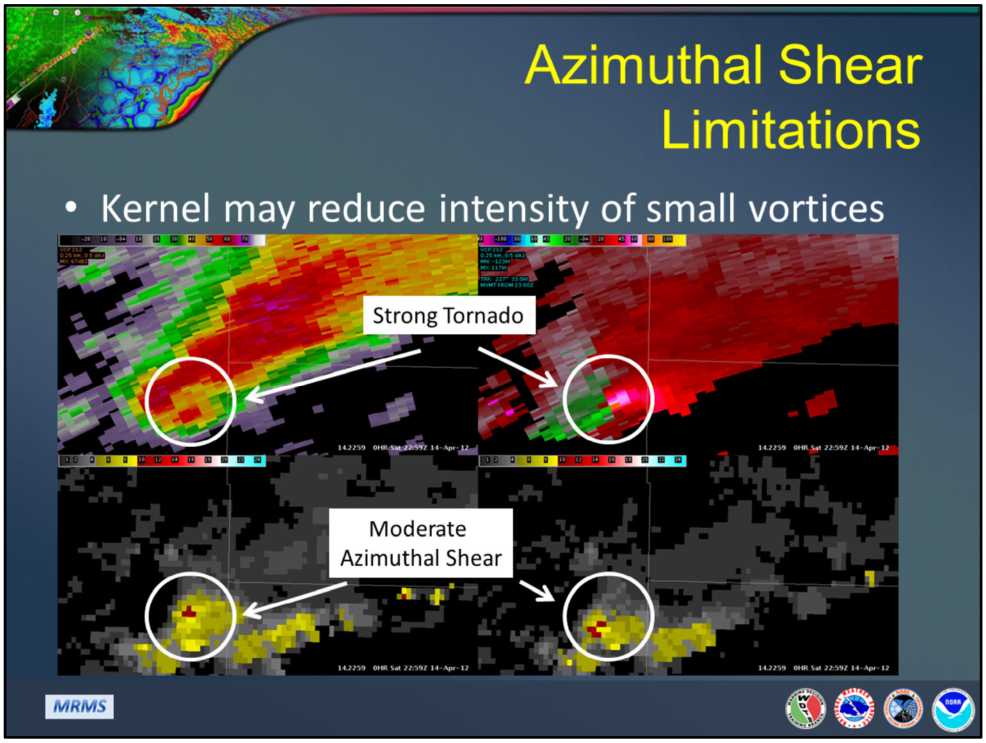
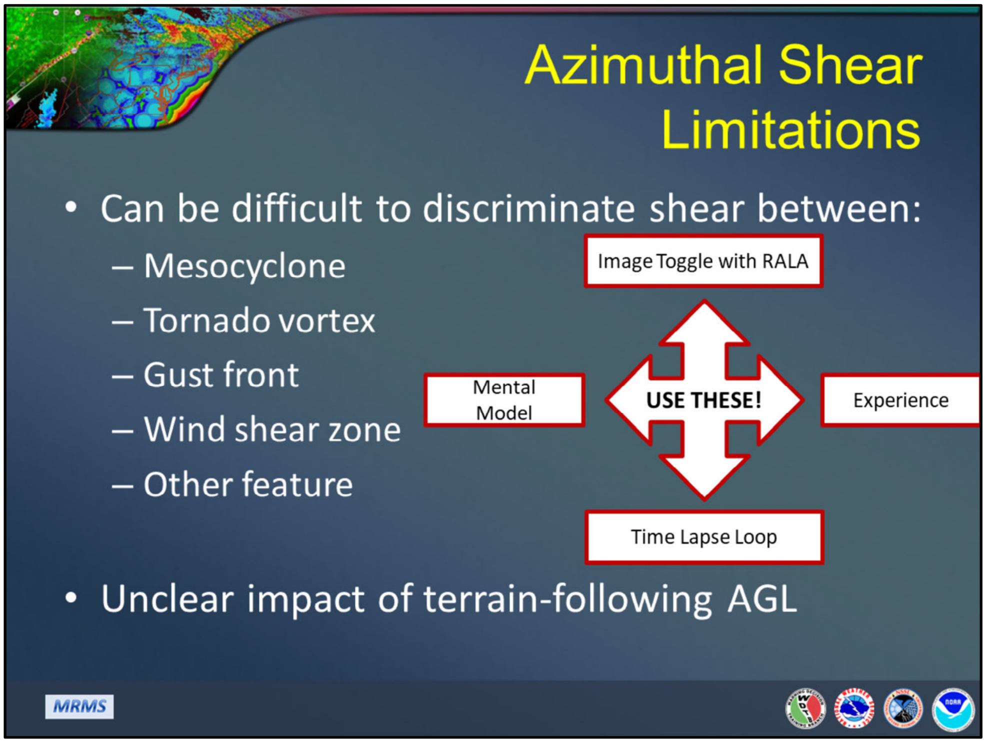
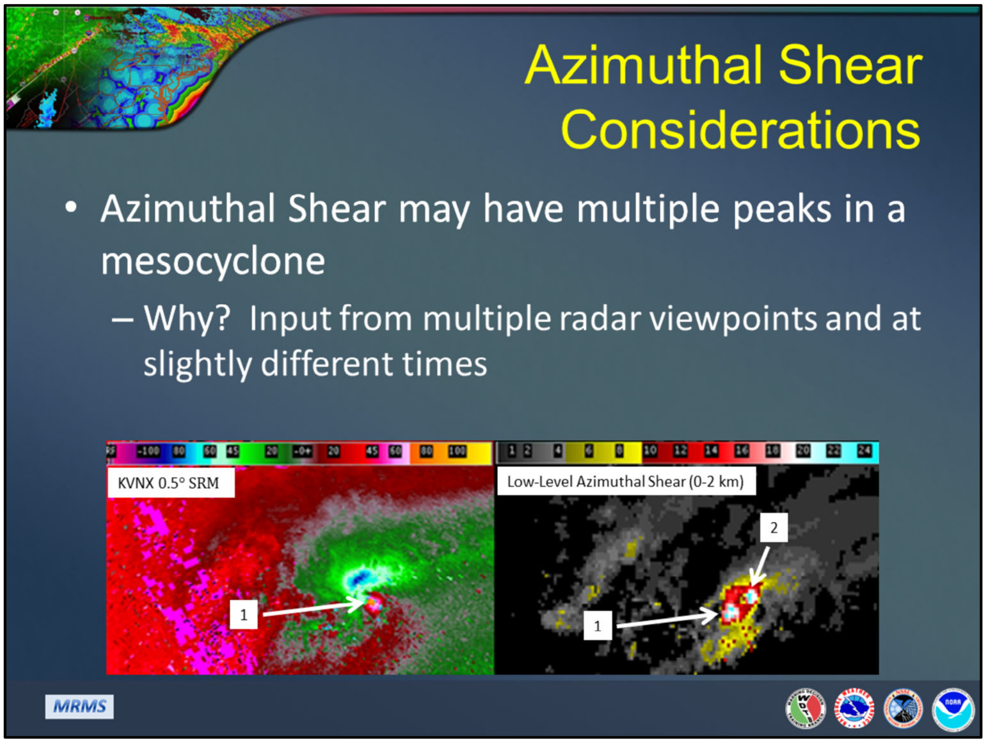


- The Azimuthal Shear kernel may remove or underestimate the full intensity of well sampled vortices, especially when they are small.



- Also, it can sometimes be difficult to discriminate between shear associated with a mesocyclone, tornado vortex, gust front, wind shear zone, or other feature. In these cases, a time lapse loop, image toggling between Reflectivity at Lowest Altitude and Azimuthal Shear, a mental model of the storm's structure, and experience can all help you make the proper interpretation.

- Note that it is unclear what impact a terrain-following Azimuthal Shear value will have when trying to assess trends in mesocyclone strength for elevation changes. It's possible that a steady state mesocyclone may appear to increase or decrease in intensity as the terrain rises and falls. In other words, changes of altitude may lead to artificial changes of mesocyclone intensity.



This final azimuthal shear topic is merely a consideration. A single mesocyclone can sometimes have multiple azimuthal shear peaks. This misplacement can occur as a result of input from multiple radar viewpoints and because each radar provides data at slightly different times. Be aware that when a supercell mesocyclone occludes, a new mesocyclone typically forms at the point of occlusion. When this occurs, the dual azimuthal shear couplets are valid.

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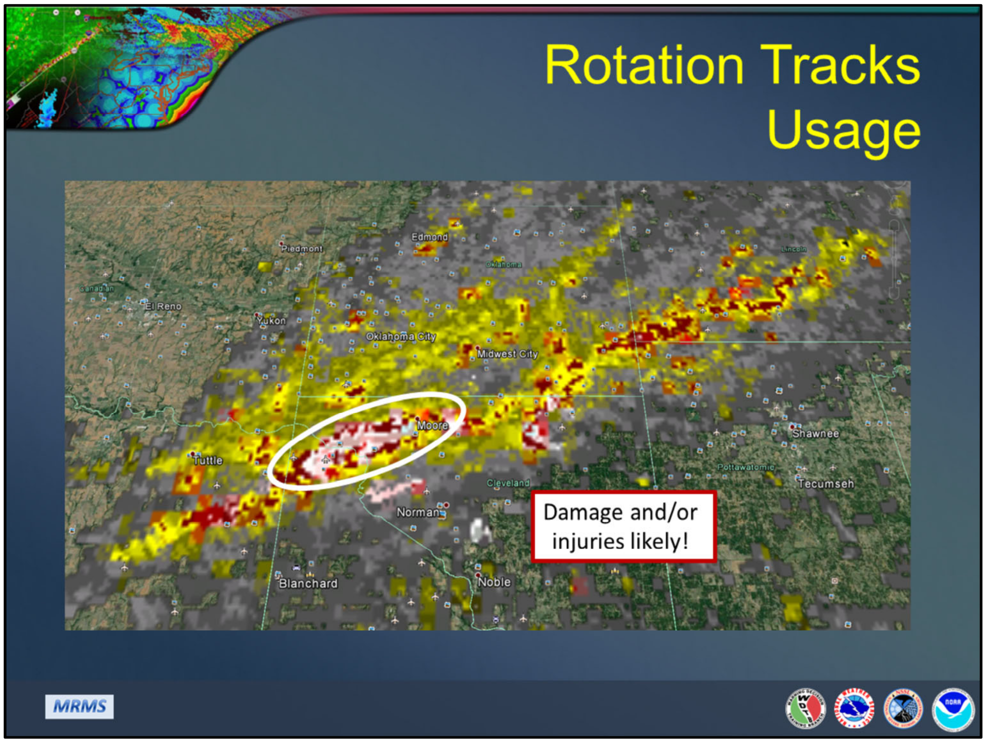

On May 20, 2013 an EF-5 tornado strikes Moore, Oklahoma. Is there a quick and easy way to provide a first guess of the tornado track to Emergency Managers and First Responders?

Yeah you can use Rotation Tracks!

You can use the product to quickly disseminate the possible tornado track to National Weather Service partners. Zooming in, here's the surveyed tornado track overlaid on the rotation tracks product.

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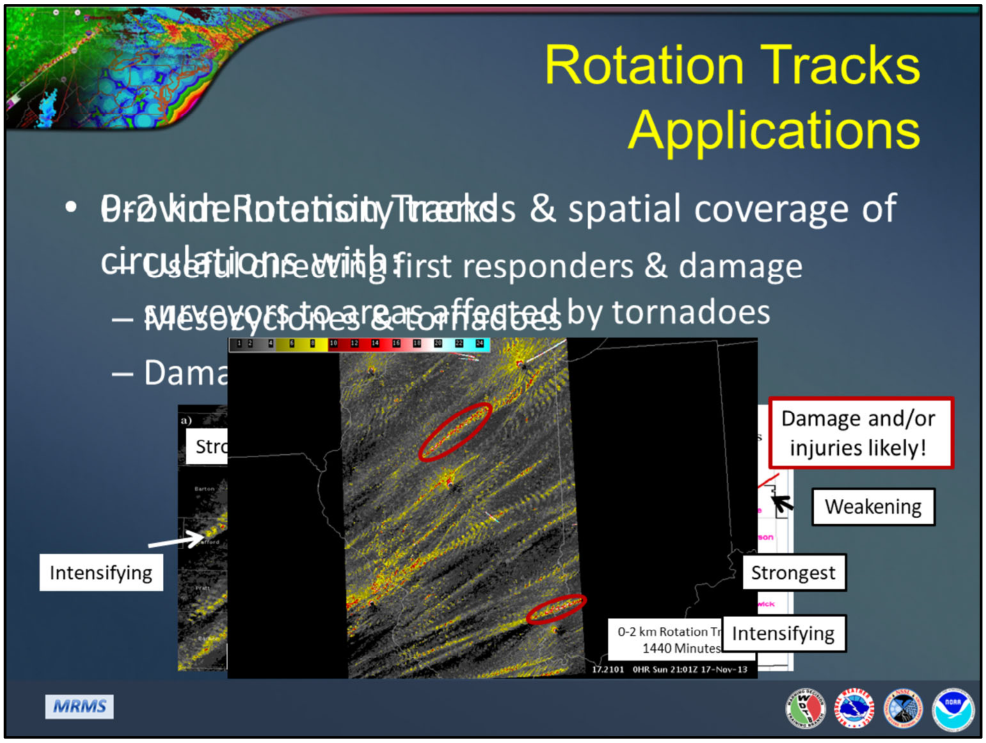
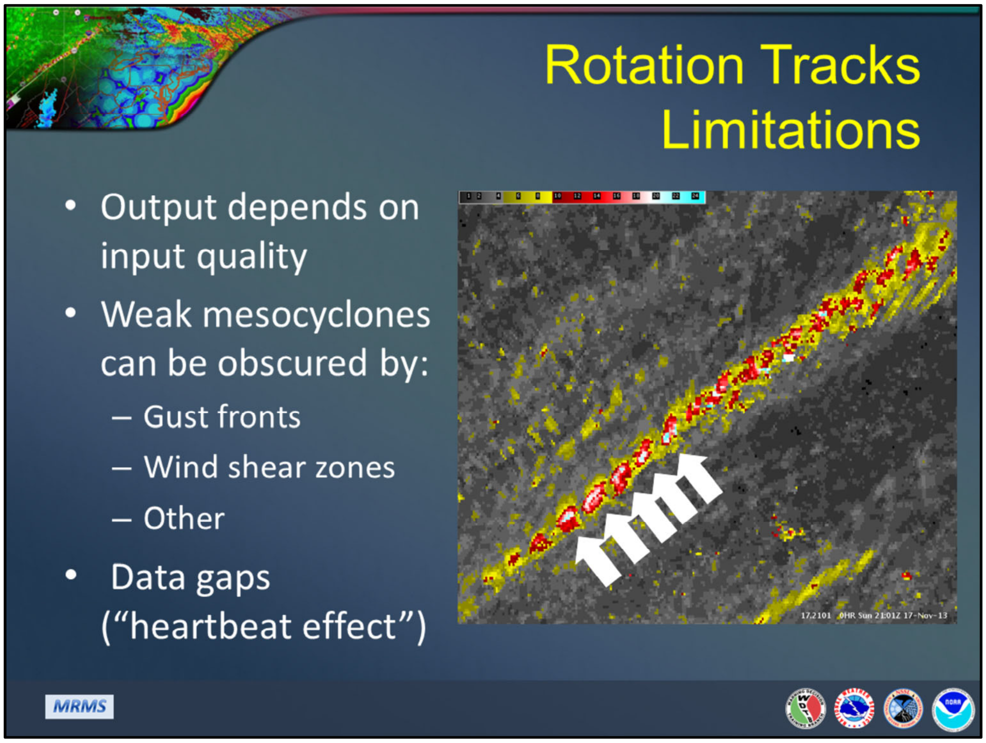


Rotation tracks provide a history of the intensity and spatial coverage of strong storm circulations that may be associated with mesocyclones, tornadoes, and/or damaging winds. This example shows a good correlation between the intensity and location of the rotation track and the associated tornado reports.

Also, as discussed previously, Low-Level Rotation Tracks have shown enormous utility after events in providing guidance to first responders and damage surveyors to direct them to areas most likely affected by tornadoes.

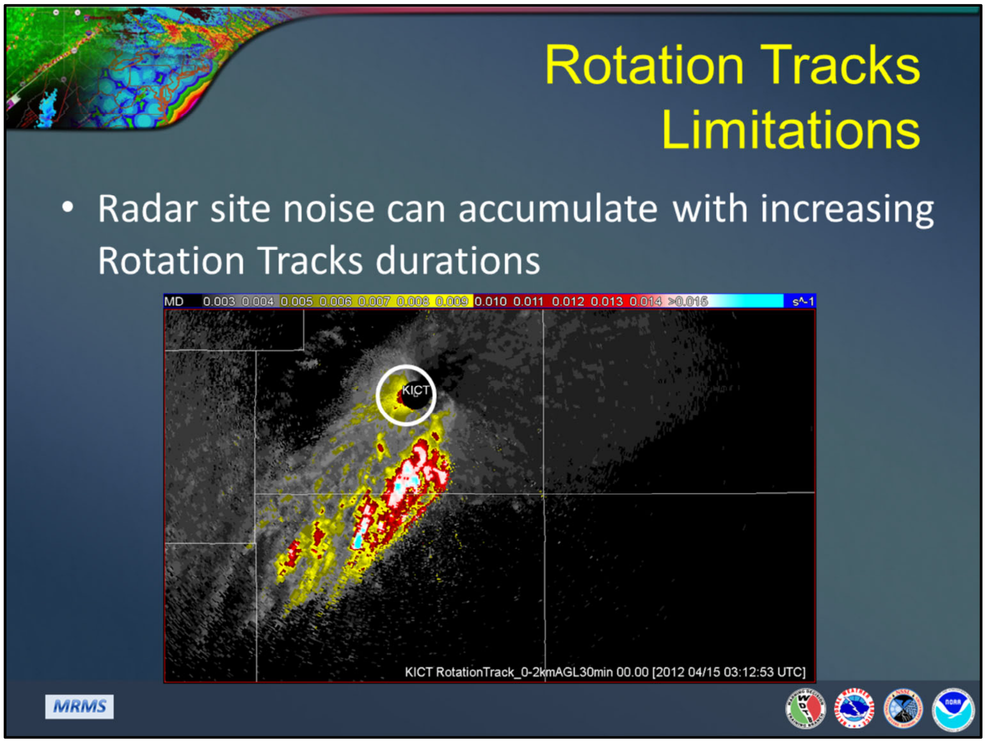


The Rotation Tracks product does have a few limitations:

- For example, if the quality of the Azimuthal Shear data is bad, the quality of the Rotation Tracks will also be bad.

- Some mesocyclones, particularly weaker ones, can be obscured within the noise generated by gust fronts, wind shear zones, and other phenomena.

- Data gaps, which are known as the heartbeat or strobing effect are sometimes observed between product scan times. This effect is most noticeable for fast moving storms and when only one radar samples the storm. Note that some forecasters may consider this a strength because it can provide a sense of the speed of motion of the event.



- Finally, be aware that the rings of Azimuthal Shear around RDAs mentioned previously can accumulate with increasing Rotation Tracks durations. Don't mistake these accumulated rings for strong mesocyclones.

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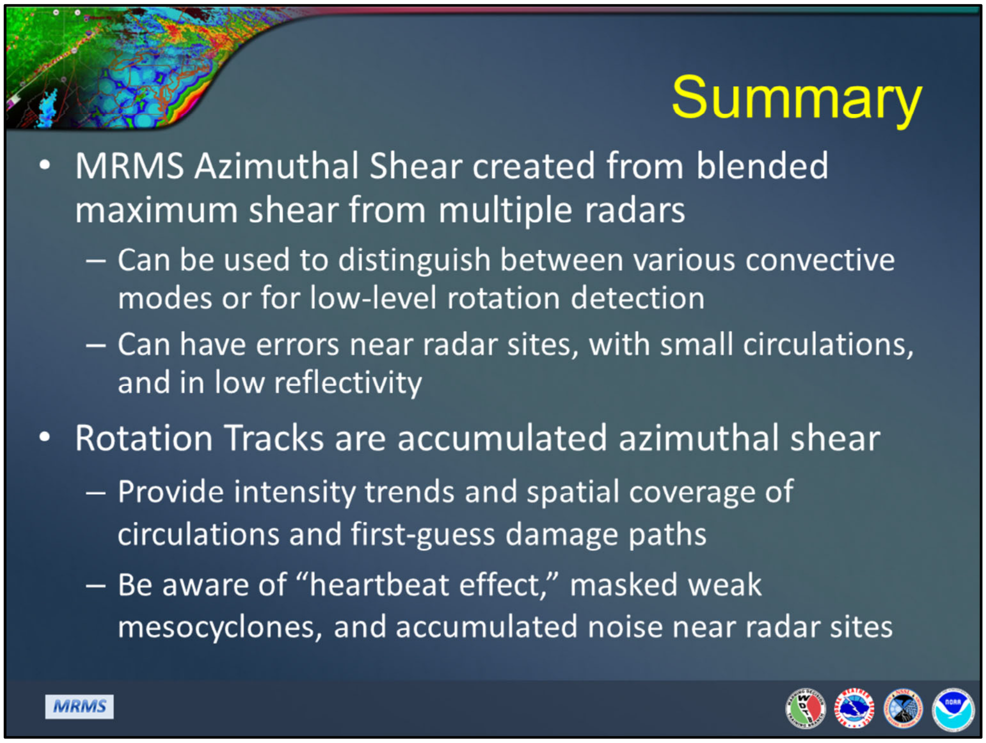

In summary, MRMS Azimuthal Shear is created from blended maximum shear from multiple radars. It can be used to distinguish between various convective modes or for low-level rotation detection. However, be mindful that it can have errors near radar sites, with small circulations, and in low reflectivity.

Also, Rotation Tracks are simply accumulated azimuthal shear. They provide intensity trends and spatial coverage of circulations, as well as give first-guesses of damage path locations. Finally, note the Rotation Tracks’ limitations of a “heartbeat effect,” masked weak mesocyclones, and accumulated noise near radar sites.

Following this slide is a quiz covering what you’ve learned in this module. Please complete it before moving on.

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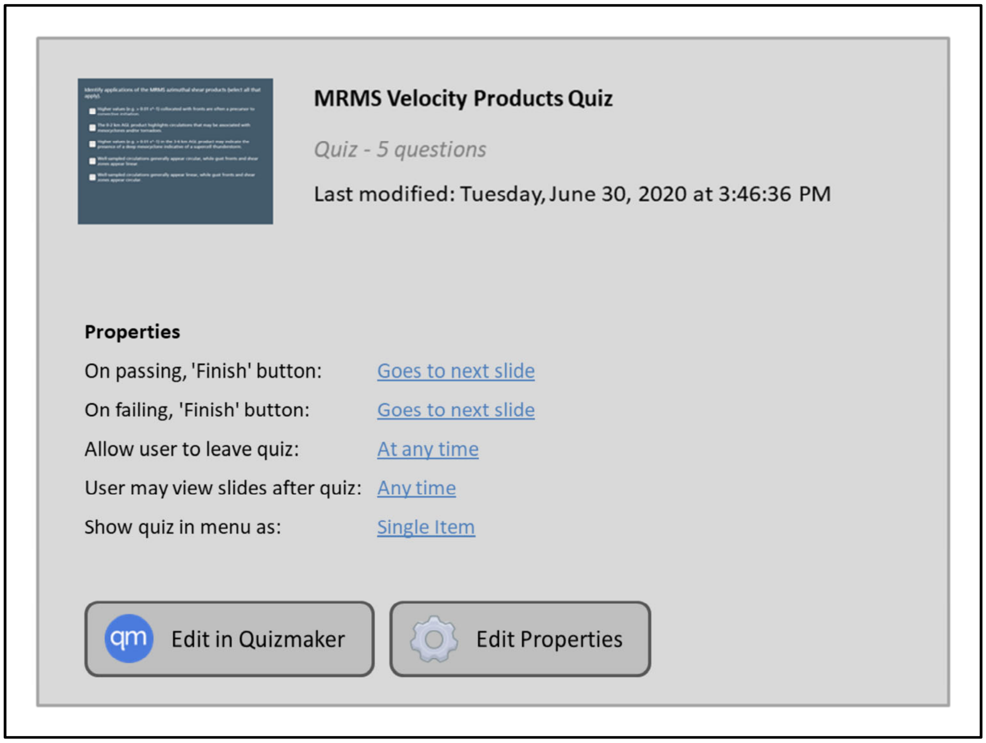
MRMS Velocity Products Quiz
Quiz - 5 questions
Last modified: Tuesday, June 30, 2020 at 3:46:36 PM
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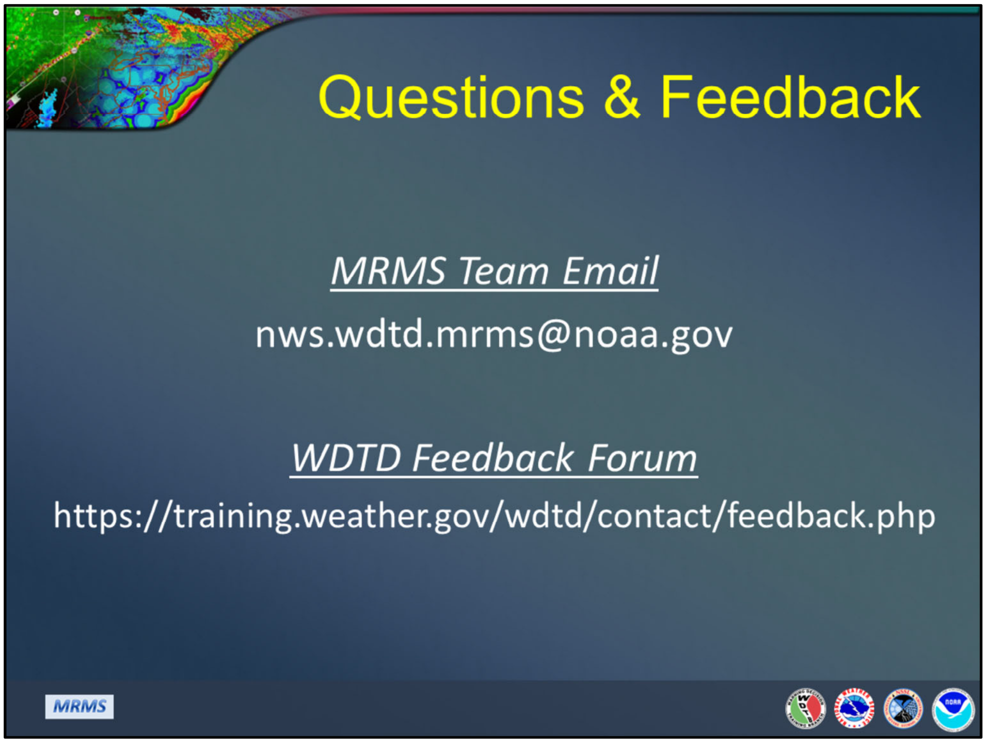

Thanks for completing this module. If you have any questions or feedback concerning this lesson, please feel free to contact us at the addresses here.

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Welcome to the Multi-Radar/Multi-Sensor (MRMS) Training Course Lesson on Lightning Products developed at the Warning Decision Training Division (WDTD).

Course Completion Info

Tabs - 4 Tabs (Including Introduction)

Last modified: Wednesday, March 25, 2020 at 3:58:53 PM

Properties

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Here are the learning objectives for this lesson. Please take a minute to review them, and move on to the next slide when you are ready.

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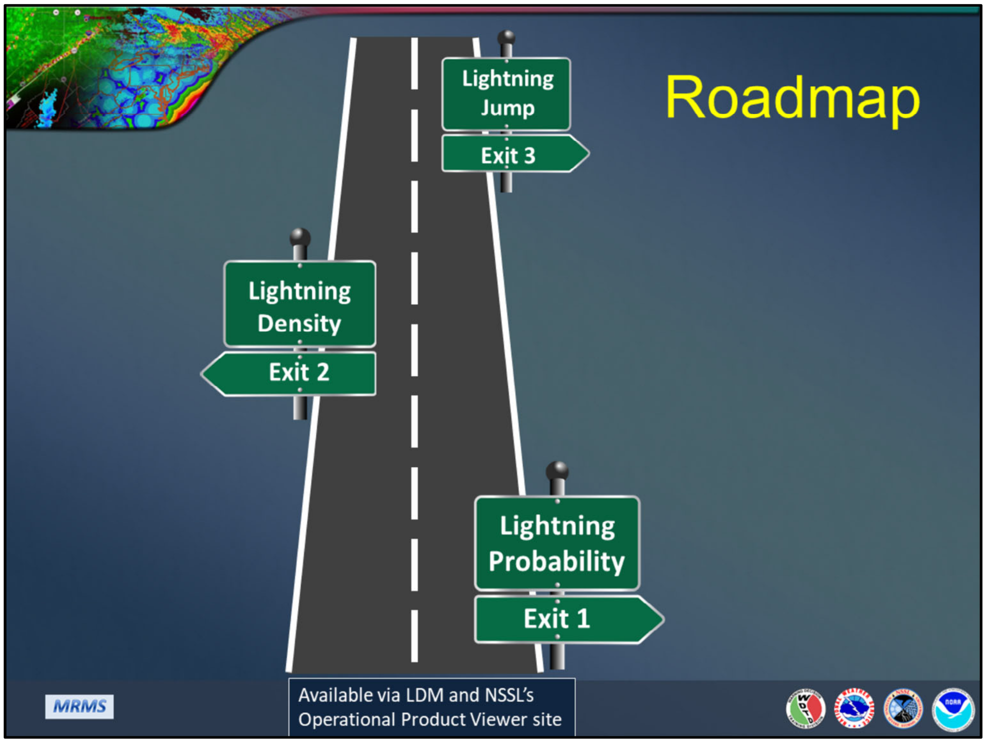

Since we will be discussing 3 different lightning products in this course, here's a quick "roadmap" for the lesson. First, we will discuss the Lightning Probability product. Second, we will discuss the Lightning Density product. And we will finish up with the Lightning Jump product.

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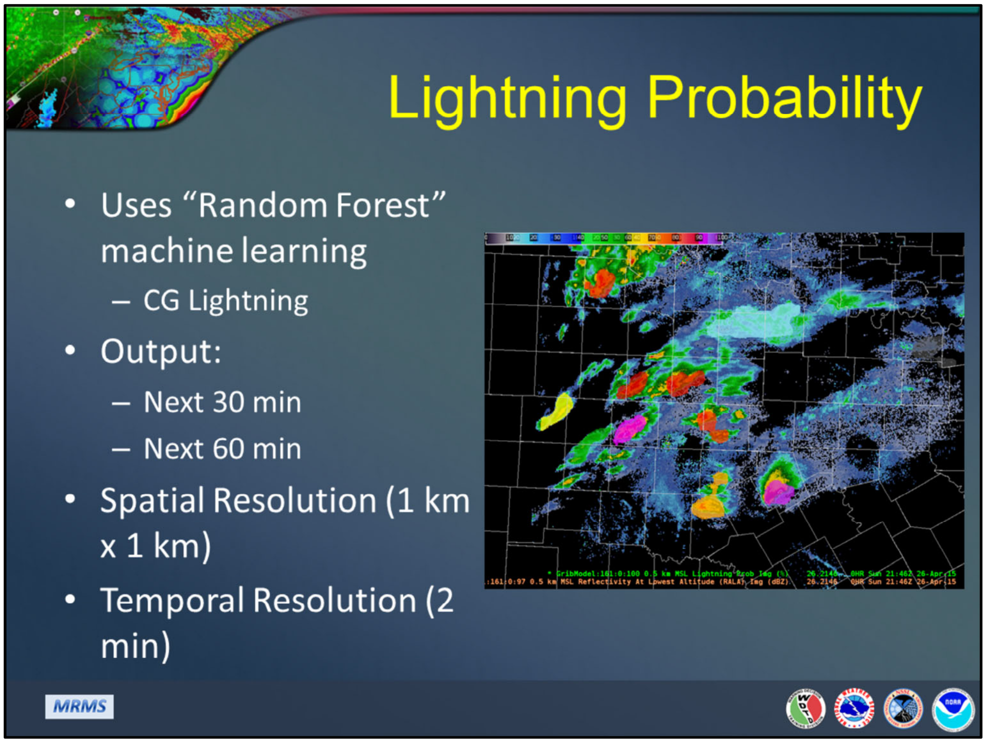


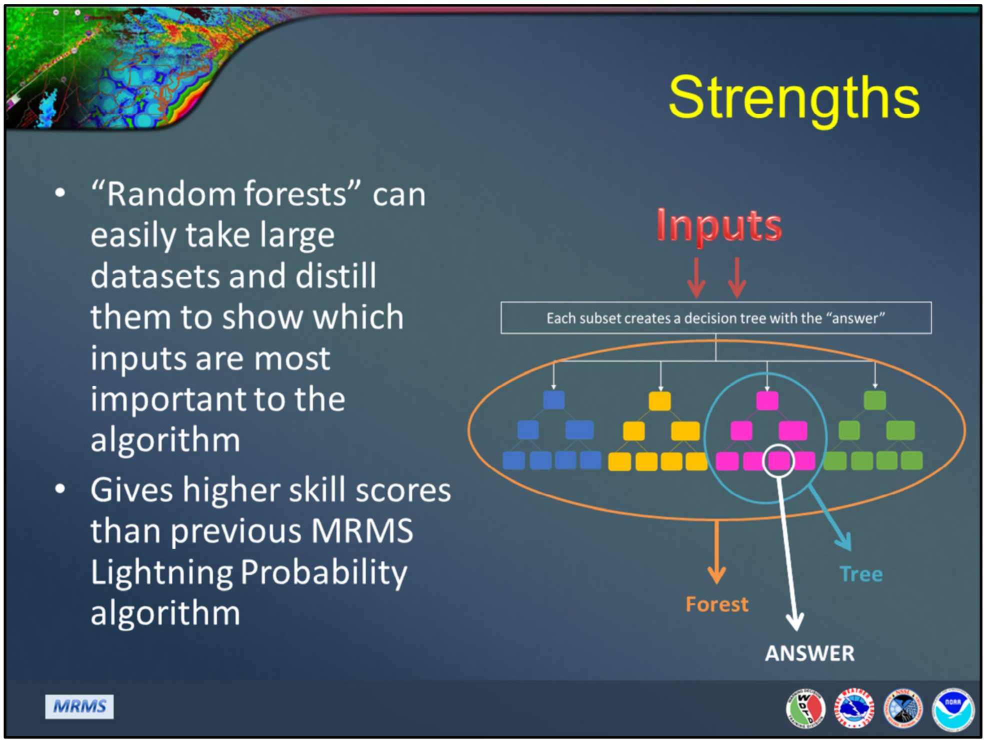
First up is Lightning Probability.

The lightning probability product uses a "random forest" machine learning algorithm to determine the probability of cloud-to-ground lightning.

LEAVE THIS OUT OF NARRATION: (The algorithm was trained over the CONUS domain using over 1.5 million storms from 72 randomly selected days from June 2014 – June 2015, and was validated by 24 days during the same June 2014 – June 2015 time period.)

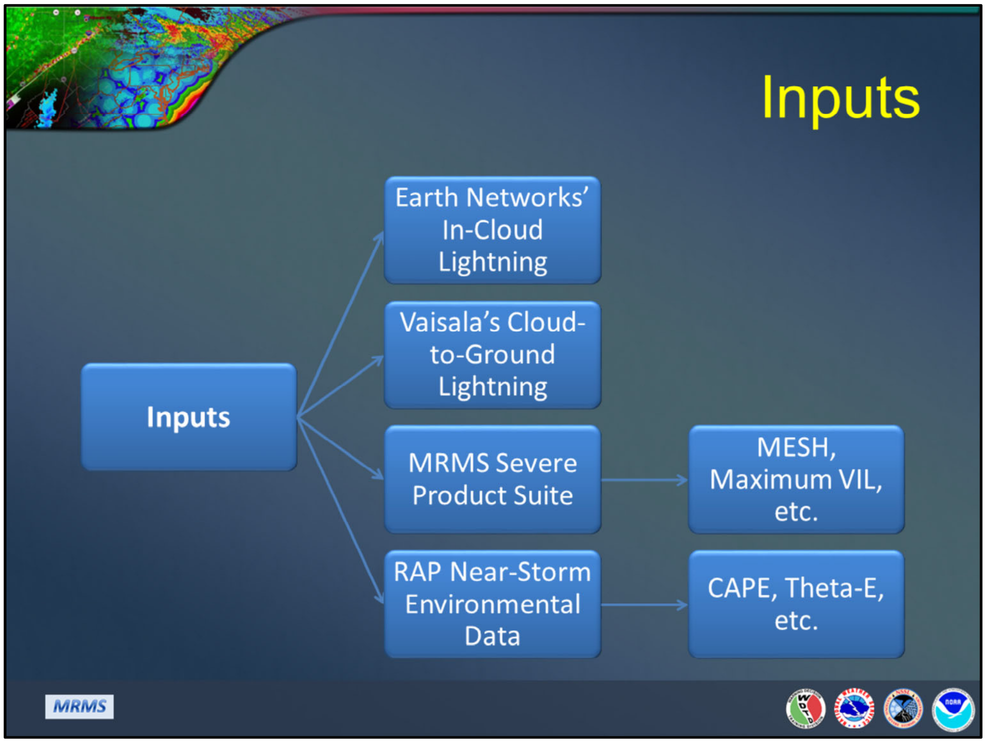
There are two output products: Lightning Probability Next 30 Minutes and Lightning Probability Next 60 minutes. The products are displayed as polygons, colored by their respective probability levels.

The output resolution is 1 km x 1 km, updated every 2 minutes.



The major strength of using "Random forests" is that they can easily take large datasets and create decision trees, then look through the forest and find the most important "trees", or inputs, to the algorithm. The less-important inputs are removed from the algorithm entirely.

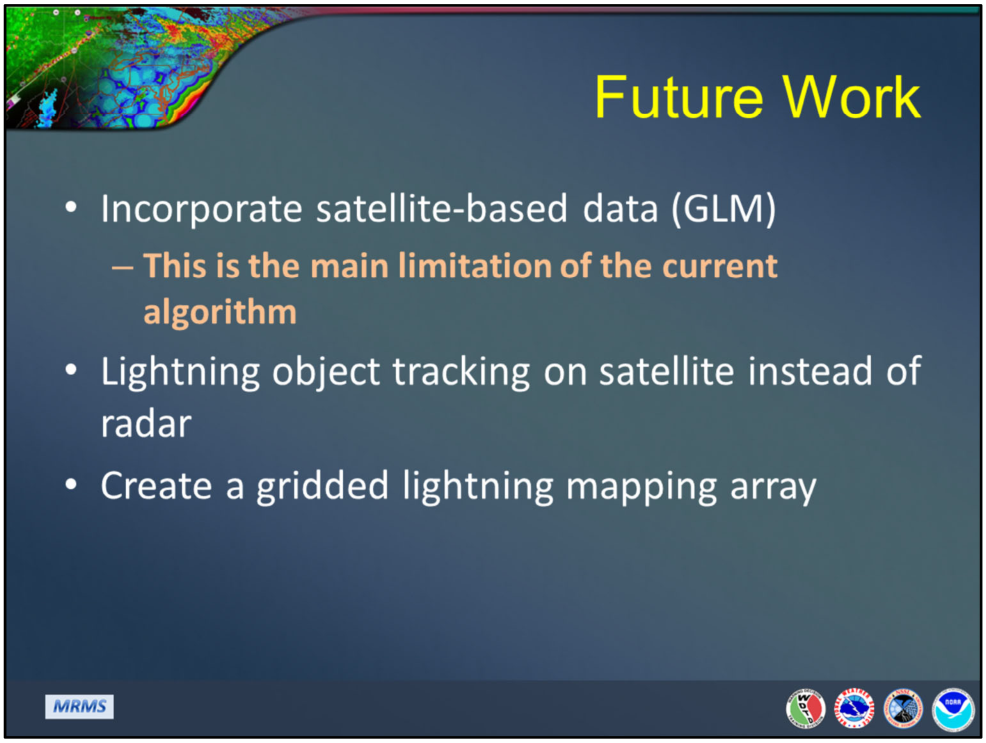
Another strength of this method is it gives higher skill scores than the previous MRMS Lightning Probability algorithm.



Next, we will discuss the storm based inputs that were used to train the random forest algorithm. These inputs include:

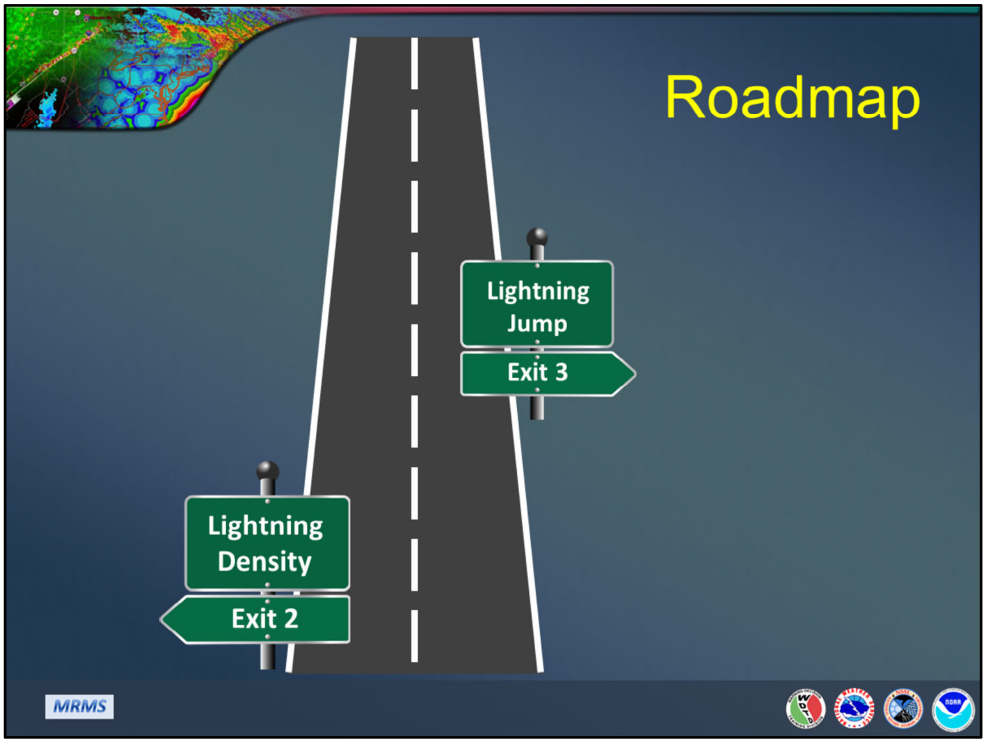
Earth Network's In-Cloud Lightning, Vaisala's Cloud-to-Ground Lightning, MRMS Severe Product Suite (including MESH, Maximum VIL, etc.), and RAP Near-Storm Environmental data including CAPE, Theta-E, etc.

More information about these and other statistically insignificant inputs can be found in the resources tab.



Future work to improve the probability of CG lightning products include:

- Incorporate satellite-based data like the geostationary lightning mapper. The exclusion of satellite-based data is the main limitation of the current algorithm.
- Lightning object tracking on satellite instead of radar, and
- Create a gridded lightning mapping array



Next, we'll take Exit 2 and talk about the Lightning Density product.

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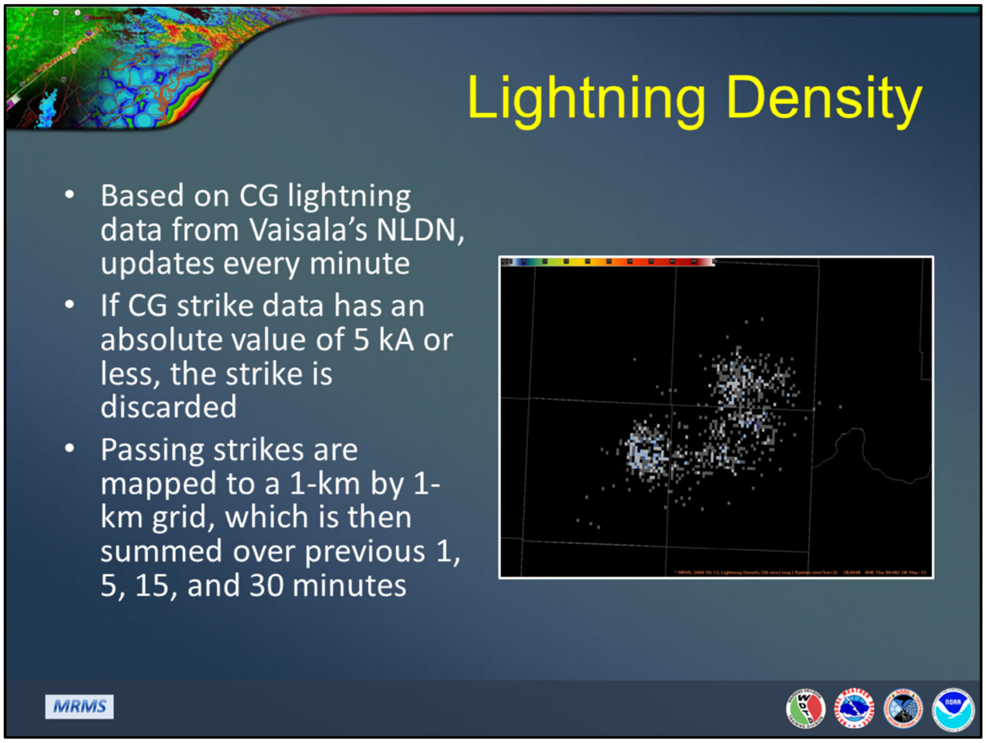

The Lightning Density products are based on cloud-to-ground (CG) lightning data from Vaisala's National Lightning Detection Network (NLDN), and updates every minute.

If the CG strike data has an absolute value of 5 kA or less, the strike is discarded since research has shown most NLDN CG strike data below this threshold are likely to be intra-cloud (IC).

Passing strikes are mapped to a 1-km by 1-km grid, which is then summed over the previous 1, 5, 15, and 30-minute durations to derive each additional density product.

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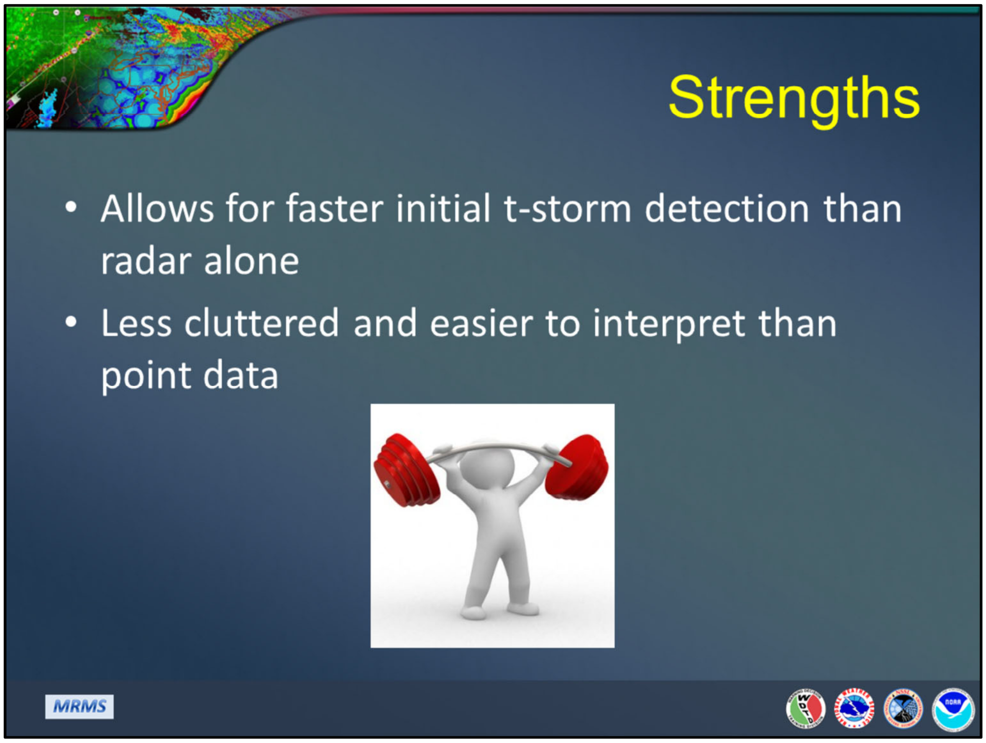

Some of the strengths of lightning density include: 1) It often allows for faster initial thunderstorm detection than radar alone and 2) the lightning density grid is often less cluttered and easier to interpret than point lightning data.

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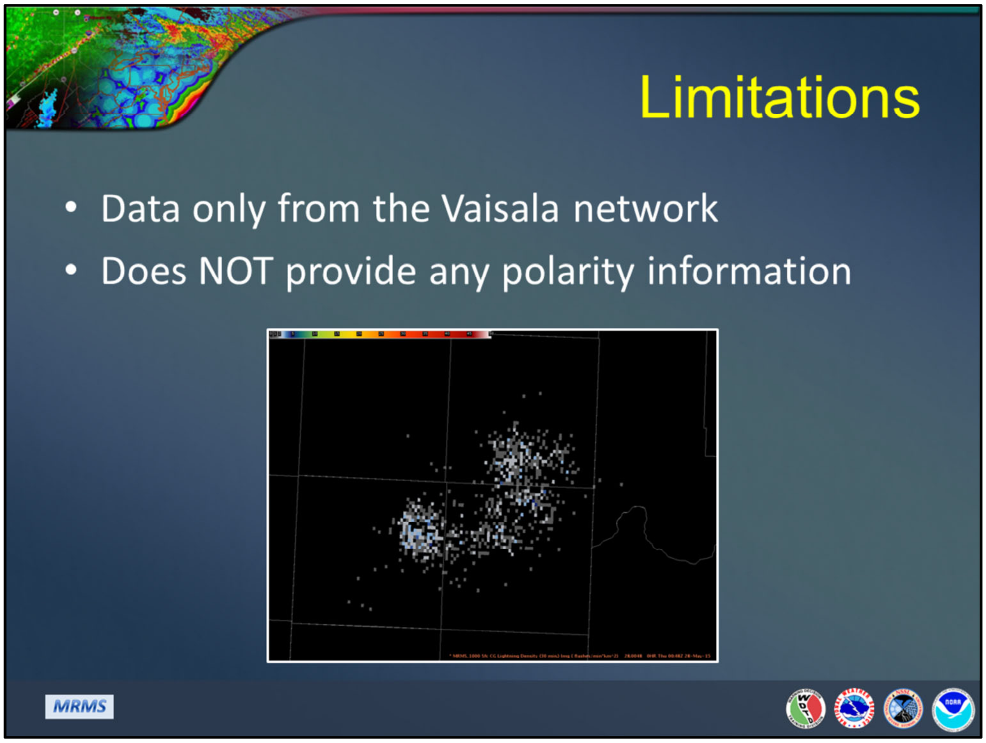
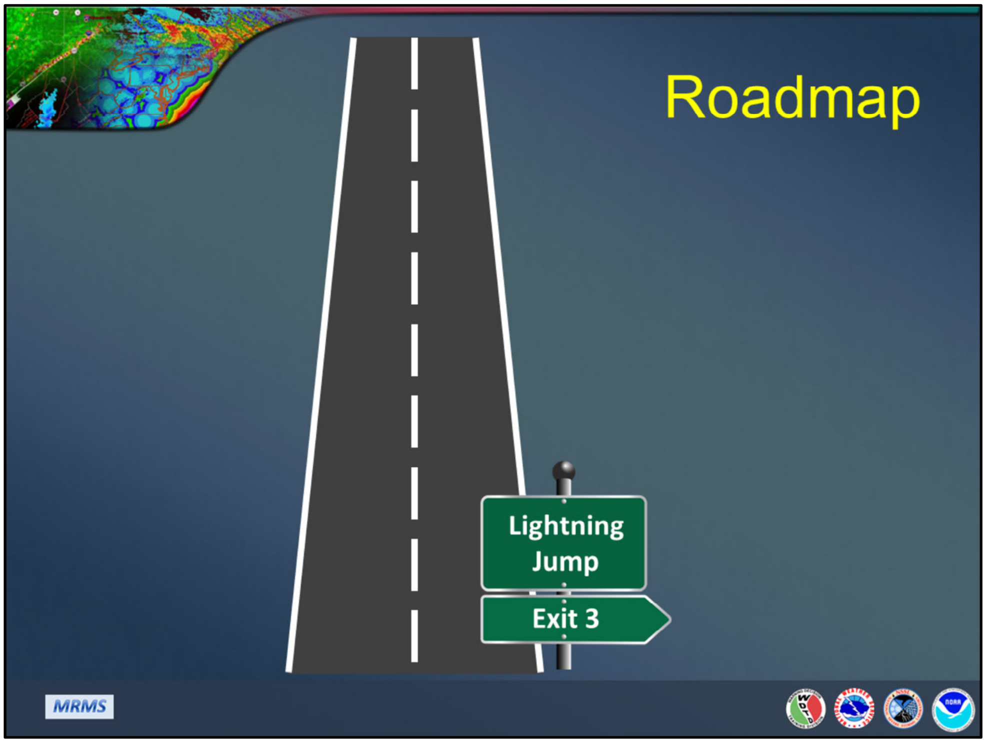


There are multiple sources of lightning CG data, but the lightning density product only uses data from the Vaisala NLDN. Additionally, some research has shown some correlations with polarity information and possible severe weather phenomena, but the Lightning Density product does not delineate CG polarity. The NLDN plots in AWIPS can show you polarity information, but those graphics are harder to read.



Finally, we will take the last exit, Exit 3, and talk about the Lightning Jump product.

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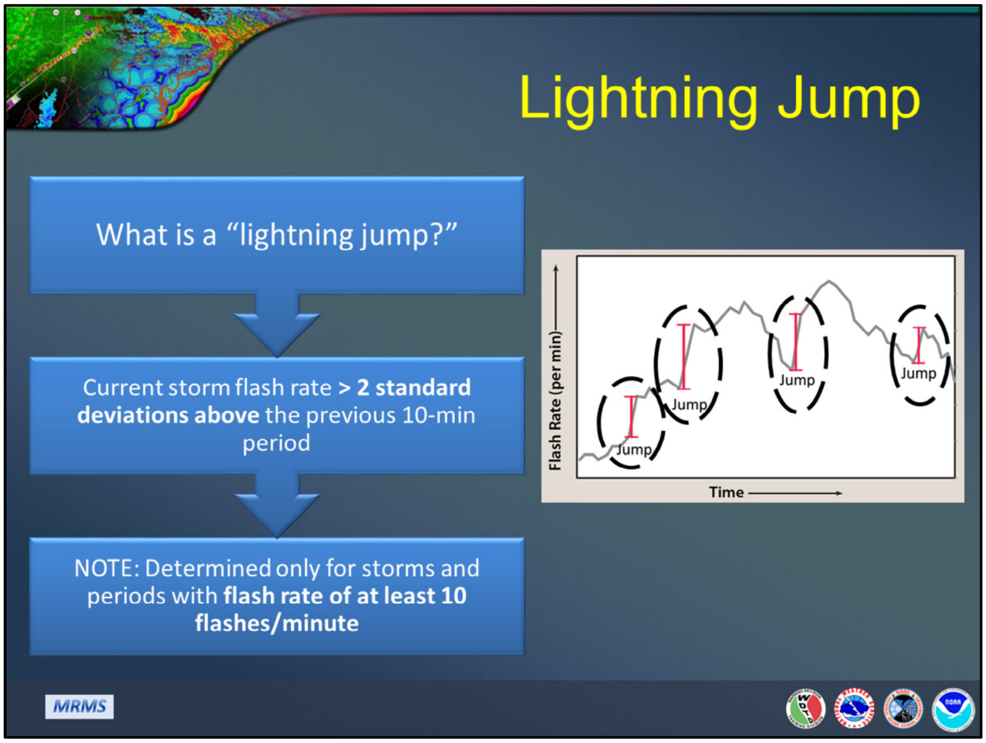

So, what exactly is a "lightning jump?"

A "lightning jump" occurs when the current storm flash rate is greater than twice the standard deviation of the previous 10-min period.

Within the lightning jump products, this is determined only for storms and periods containing a flash rate of at least 10 flashes per minute. This is done in order to reduce false alarms of the algorithm associated with initial storm growth and to remove flash rates typical of non-severe activity.

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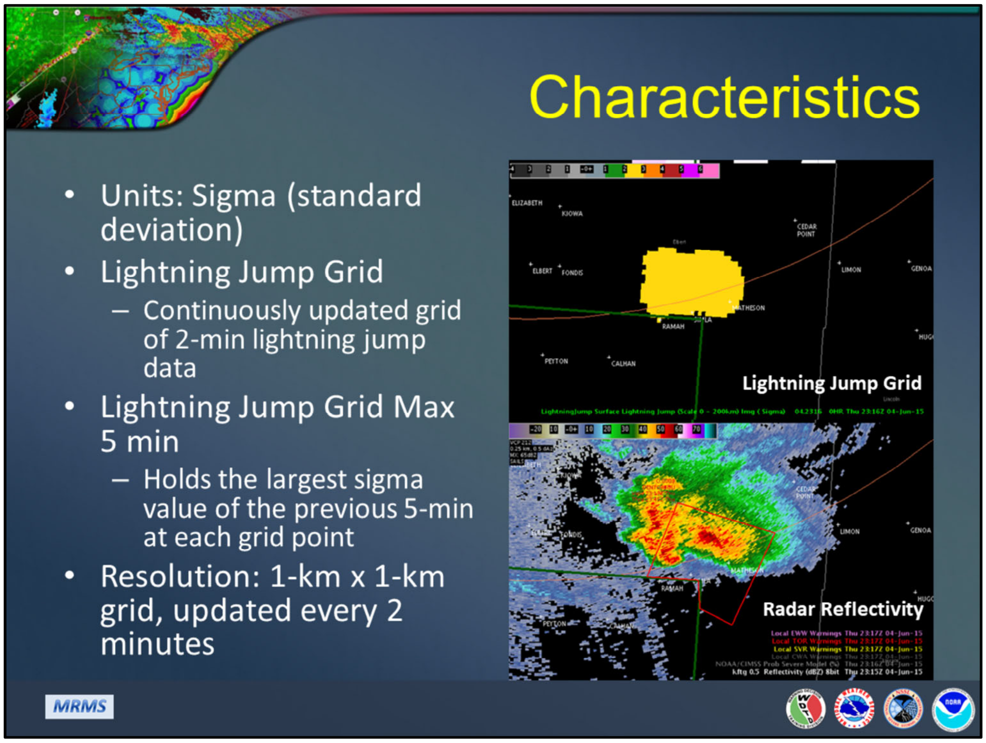


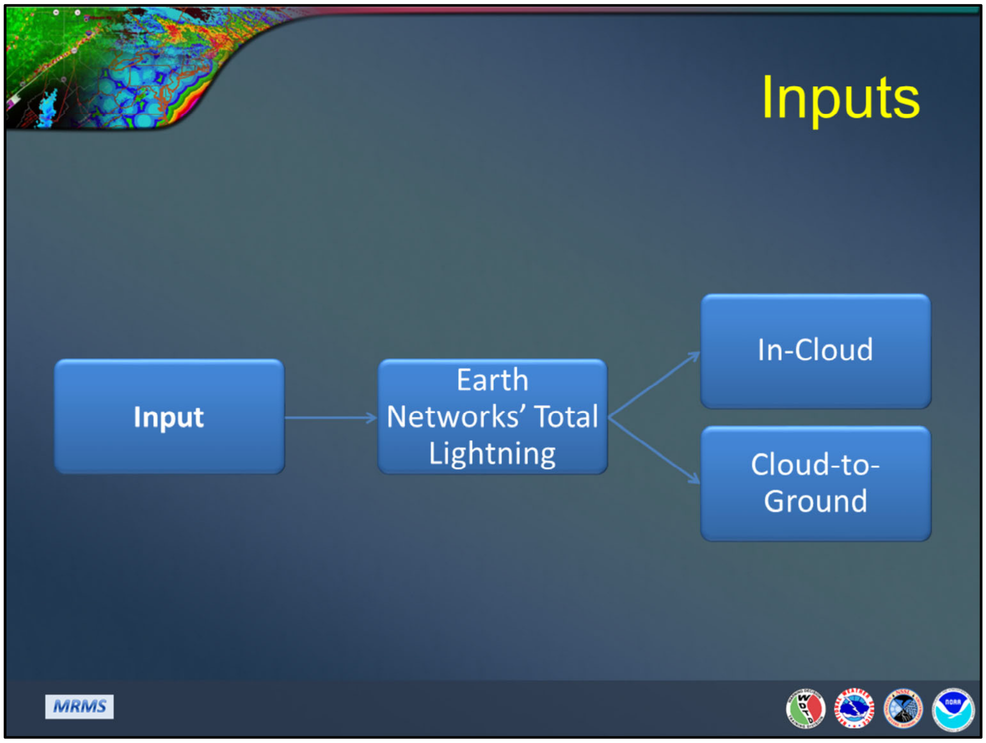
In 2019, the National Severe Storms Lab released the Lightning Jump product. It is important to point out that the units of the lightning jump product are sigma (which is otherwise known as the standard deviation). Keep this in mind when we discuss the outputs and limitations.

There are two outputs to the lightning jump product: Lightning Jump Grid, and Lightning Jump Grid Max 5 minutes.

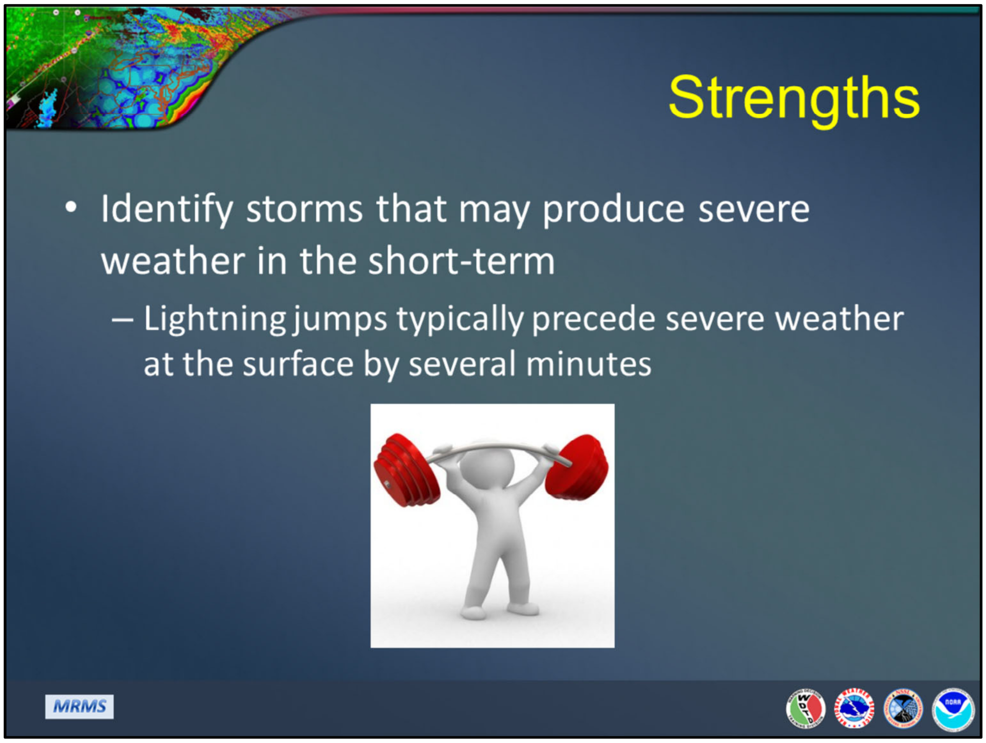
The Lightning Jump Grid is just as it sounds, a continuously updated grid of 2-minute lightning jump data, which is the sigma (aka the standard deviation) of the current storm flash rate compared to the previous 10-minute period.

The Lightning Jump Grid Max 5 minute holds the largest sigma value of the previous 5 min at each grid point; this product was developed based on forecaster feedback in NOAA's Hazardous Weather Testbed to ensure forecasters did not miss jump events and to provide a cleaner visualization during looping.

The output resolution is on a 1 km x 1 km grid, updated every 2 minutes.



This implementation of the lightning jump algorithm uses the Earth Networks Total Lightning (In-cloud and cloud-to-ground) for calculation of the lightning jump.



The strength of the lightning jump product is it can help identify storms that may produce severe weather in the short-term. Rapid increases in lightning flash rate, or "lightning jumps," are coincident with pulses in the storm updraft and typically precede severe weather at the surface by several minutes.

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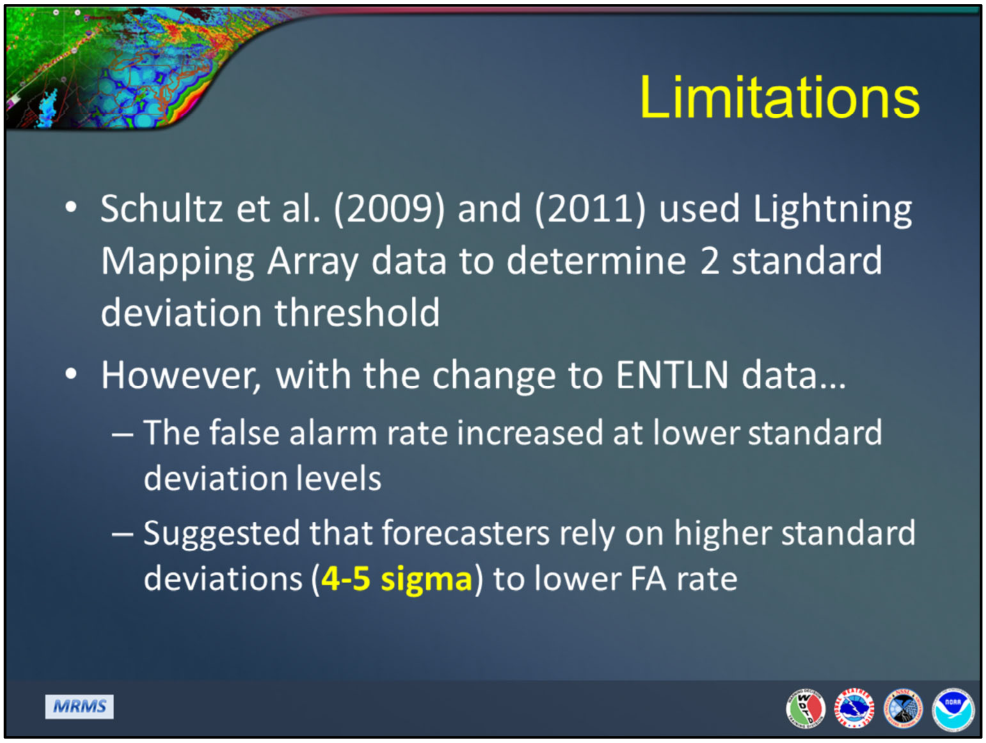
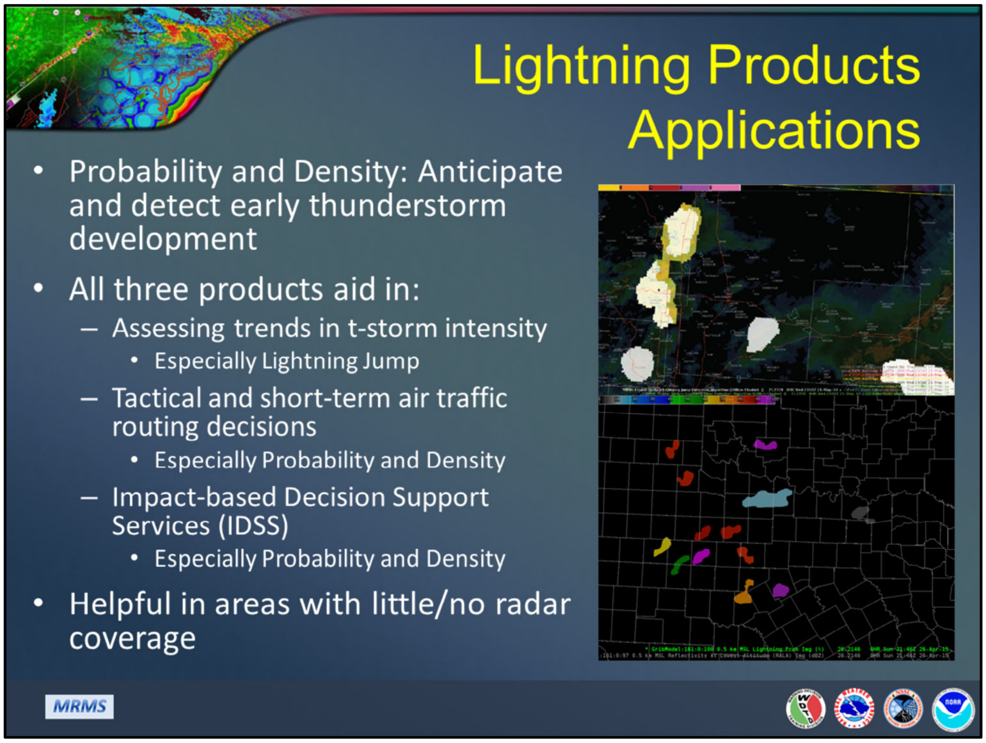
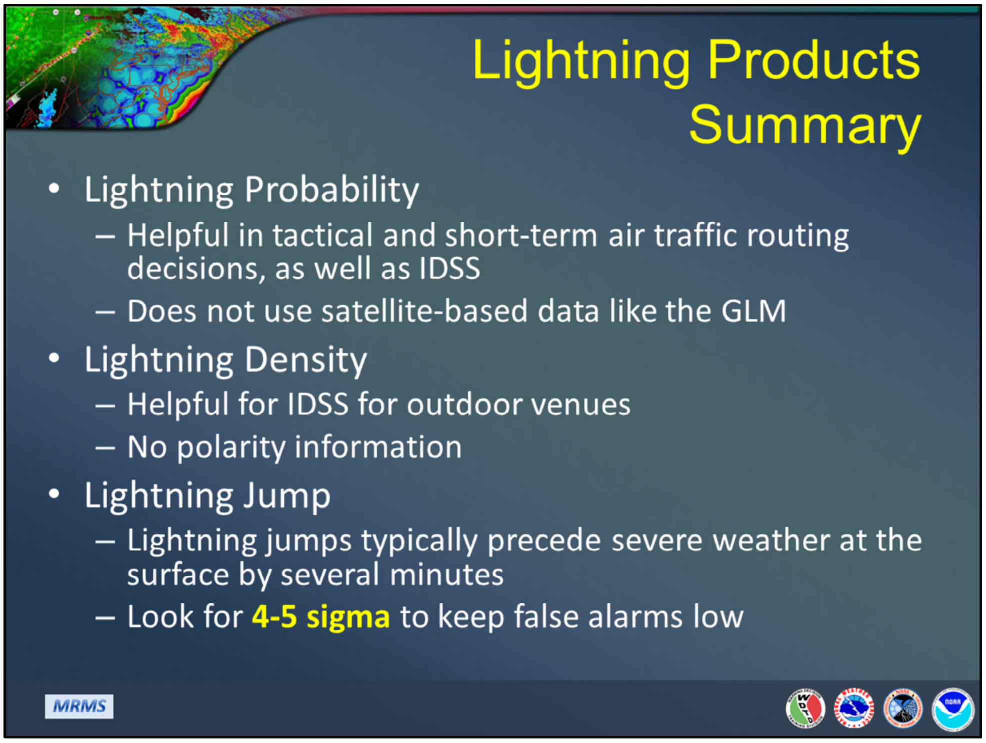


In the Schultz et al. (2009) and (2011) studies, Lightning Mapping Array Data was used to determine the 2 standard deviation threshold.

However, with the change to Earth Networks Total Lightning Network data for the lightning jump product, the false alarm rate increased at lower standard deviation levels, including at the 2 standard deviation level. Therefore, it is suggested that forecasters rely on higher standard deviations, likely 4-5 sigma, for a lower false alarm rate.



Now, let's discuss the applications of the MRMS lightning products.
A couple of product-specific applications are that the Lightning Probability and Density products are useful for anticipating and detecting early thunderstorm development.
All three products can help assess trends in thunderstorm intensity. For example, as we mentioned, lightning jumps typically precede severe weather at the surface by several minutes.
All 3 products can also be used for tactical and short-term air traffic routing decisions, and
They can be useful while providing impact-based decision support services (IDSS) for outdoor venues and events.
Specifically, the lightning probability and density products are helpful in both tactical and short-term air traffic routing decisions, as well as with IDSS. The probability product is useful because it provides a lightning forecast, rather than just an observation of lightning. Also, the lightning density product often allows for faster initial thunderstorm detection than radar alone.
Since these products were developed within MRMS, they are all particularly helpful in areas with little-to-no radar coverage.



Here is a quick summary for each of the products:
Lightning Probability
-Helpful in tactical and short-term air traffic routing decisions, as well as IDSS
-Does not use satellite-based data like the GLM
Lightning Density
-IDSS for outdoor venues
-No polarity information
Lightning Jump
-Lightning jumps typically precede severe weather at the surface by tens of minutes
-Pay attention to 4-5 sigma
Next up will be the quiz!

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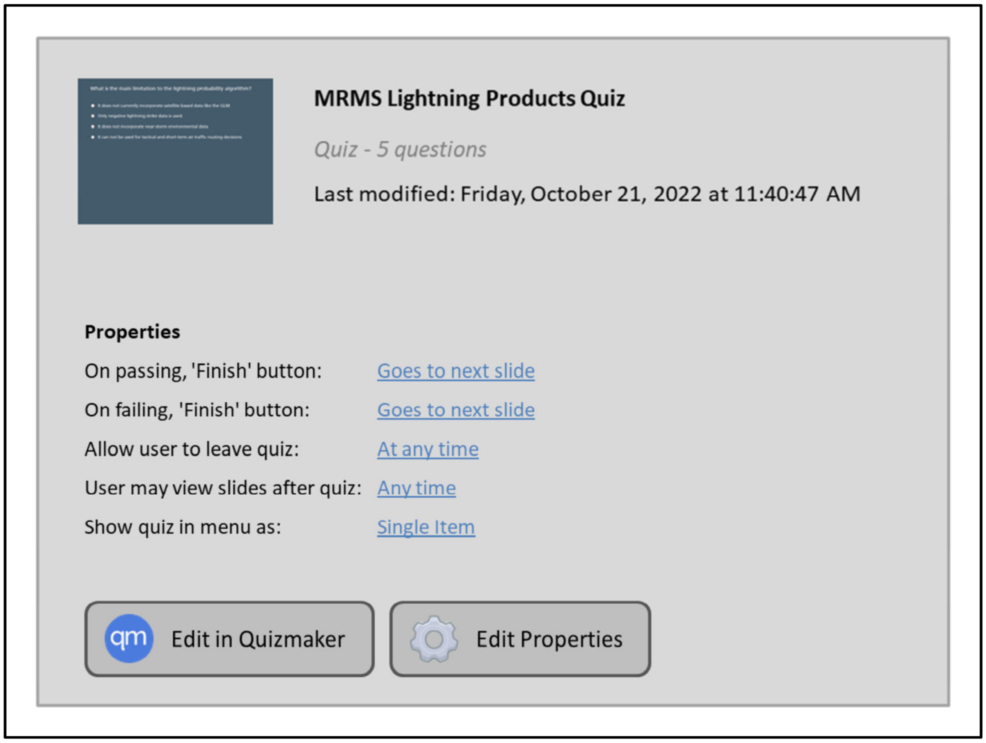
MRMS Lightning Products Quiz
Quiz - 5 questions
Last modified: Friday, October 21, 2022 at 11:40:47 AM
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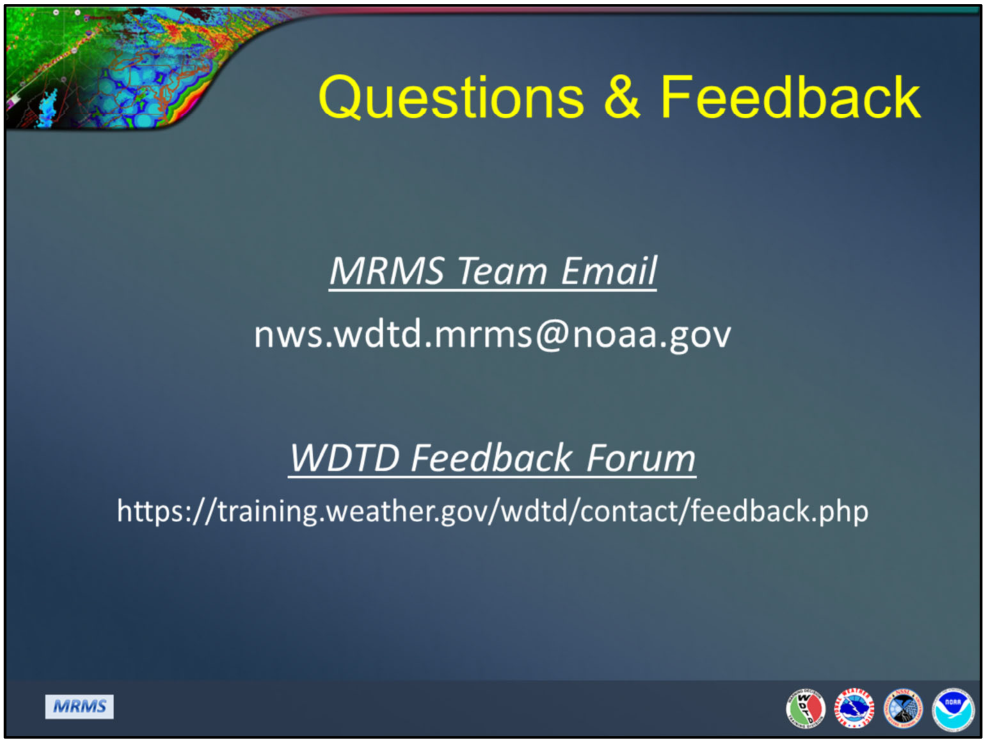

Thanks for completing this module on MRMS Lightning Products. If you have any questions or feedback concerning this module, please feel free to contact us at the addresses listed.

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Hi, my name is Jill Hardy, and welcome to the Hydro Products Overview lesson. This module will give an introduction to the MRMS quantitative precipitation estimation (or QPE) related products, as well as the quality control steps used to create them.

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Course Completion Info

Tabs - 4 Tabs (Including Introduction)

Last modified: Wednesday, November 23, 2022 at 1:45:33 PM

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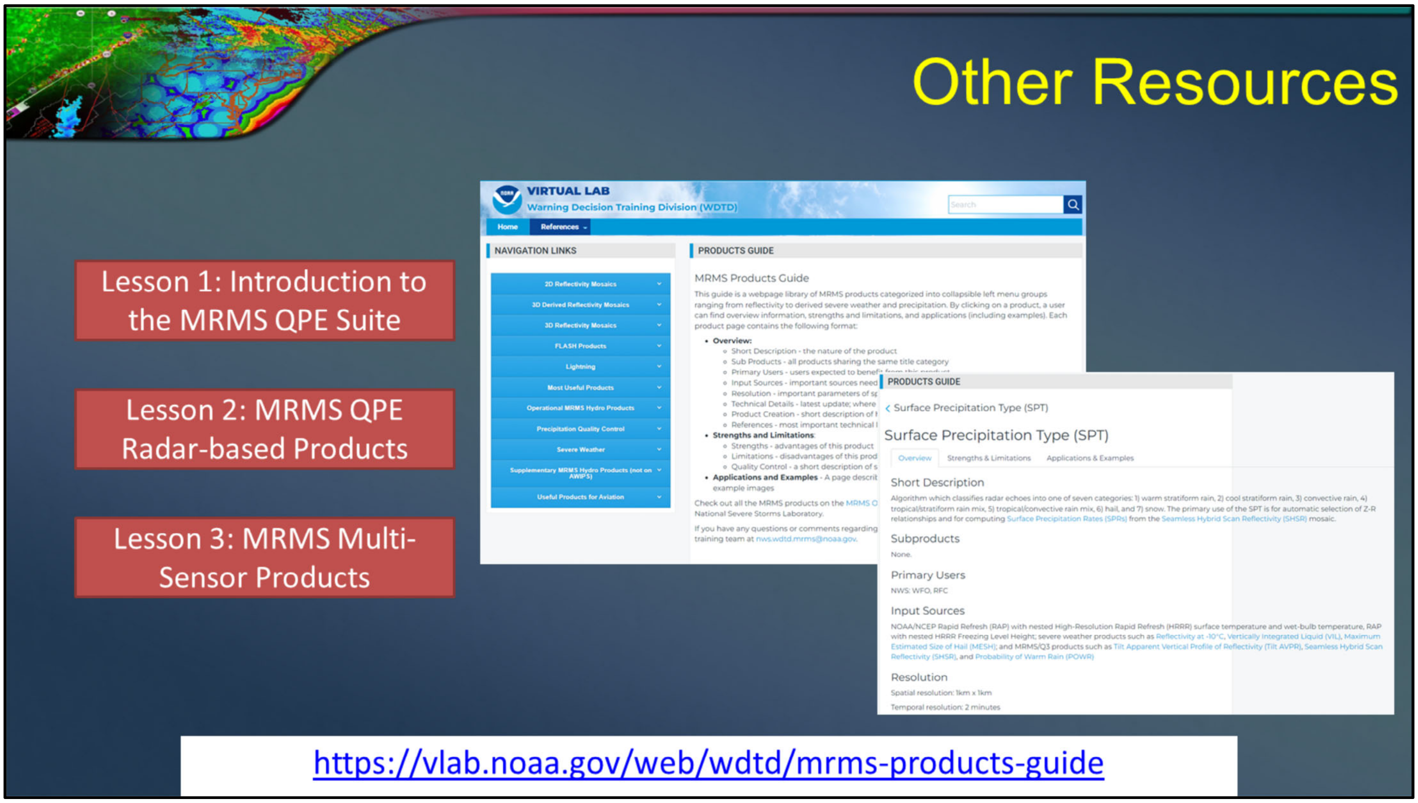


As the name implies, this lesson is meant to be a brief overview of the MRMS hydro products available in AWIPS. If you want more detailed explanations, please refer to the full Hydro Products Course, which contains three lessons that delve deeper into everything introduced here.

Additionally, there is useful reference material on the VLab, including strengths and limitations of each product, resolution information, applications, and examples. The link provided here does not require log-in to view.

Okay, let's get started…

Learning Objectives

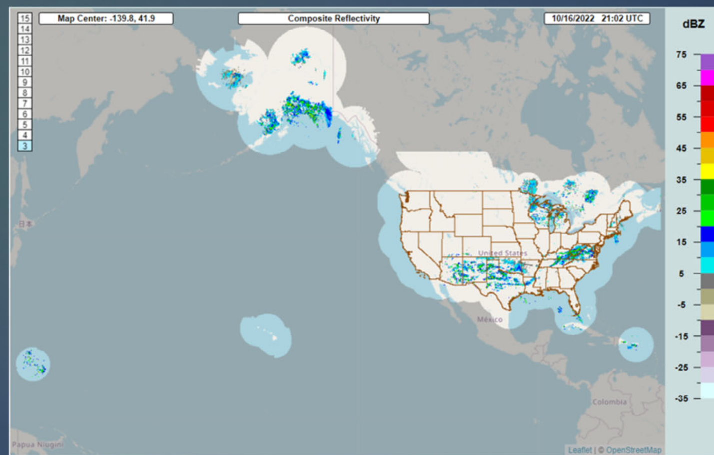
At the end of this lesson, students will be able to:

1. Define what is unique about the MRMS QPE product suite
2. Identify the three main inputs
3. Identify the quality control steps used to create the reflectivity-based QPE products
4. Identify the rain rate relationships used within the Surface Precipitation Rate product
5. Identify the differences between the radar accumulation products
6. Identify the purpose, strengths, limitations and applications of the Multi-Sensor QPEs

Here are the learning objectives for this lesson. When you have finished reading them, please move onto the next slide.

What is the MRMS QPE suite?

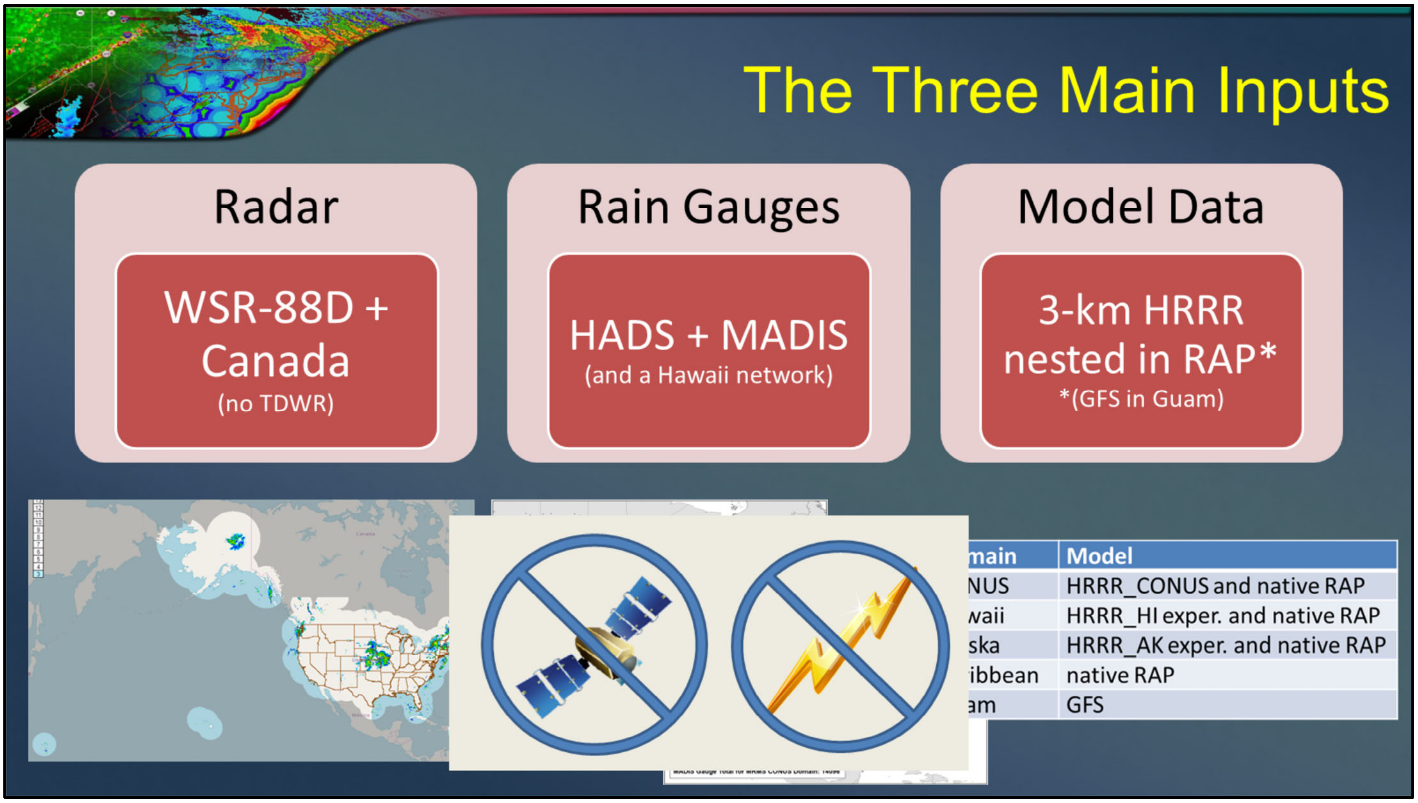
- Multi-radar: CONUS and OCONUS radar networks
- Multi-sensor: created with radar, gauge, and model data
- Resolution
  - Temporal: up to 2 minutes
  - Spatial: up to 1-km x 1-km
- Purpose: Aids in monitoring and warning for floods and flash floods; support hydrological modeling



--As you are probably familiar with at this point, MRMS stands for multi-radar/multi-sensor. In the QPE suite of products, the term "multi-radar" encompasses the radar networks within the CONUS domain, as well as the different radars within the OCONUS sites, as seen in the image on the right. The "multi-sensor" component is highlighted by using a variety of inputs to create the QPE products. These will be discussed on the next slide.

--The highest resolution in the QPE suite is 2-minute temporal resolution, and 1-km by 1-km spatial resolution, although not every product is this spatiotemporal resolution. In particular, all of the gauge-related products are a minimum of one-hourly.

--The ultimate purpose of the QPE suite is to aid in the monitoring and warning for floods and flash floods, and to support further development of hydrological modeling.



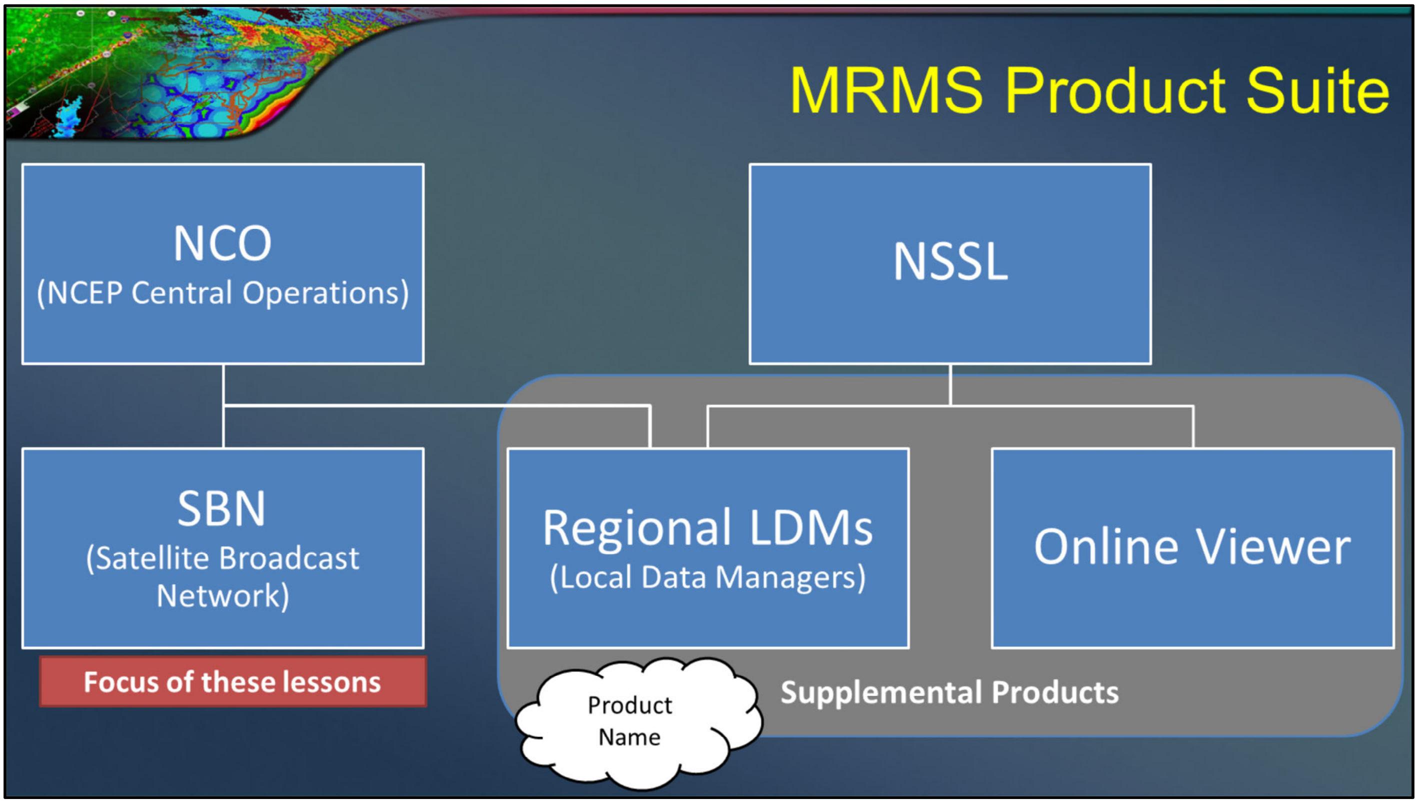
--The QPE system has three main inputs that are used to create the majority of its products.

--Radar data comes from the national network of WSR-88D radars, as well as the Canadian network. However, there are NO Terminal Doppler Weather Radars.

--Rain gauge data primarily comes from the HADS (or Hydrometeorological Automated Data System) gauge network, as well as from MADIS (or the Meteorological Assimilation Data Ingest System). The more gauge data, the better, because it provides valuable ground validation used for bias-correction of precipitation estimates.

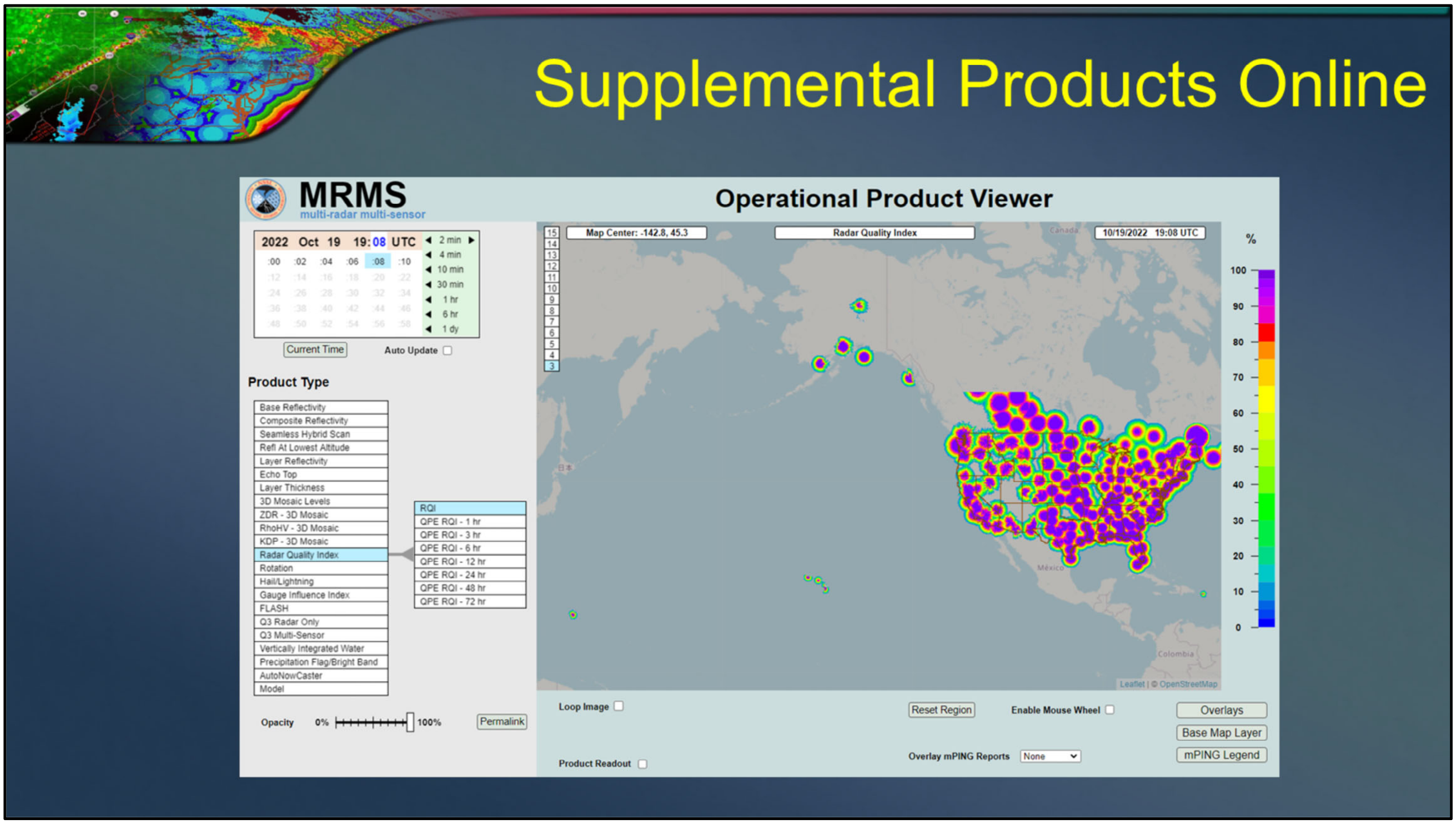
--Finally, model data comes from the 3-km HRRR, nested within the 13-km RAP domain. The HRRR is used in most locations, and the RAP model is used anywhere the HRRR does not reach. There are some deviations, so here's a summary table for all domains. These models provide environmental data that is incorporated into several QC steps, as well as directly into some products.

--While lightning and satellite data are used in some of the MRMS severe products, it is important to know they are not incorporated into any of the precipitation products at this time.



NSSL supports and develops a very extensive suite of products. However, only a handful of them can fit on the SBN feed into AWIPS. These SBN products will be the focus of these lessons. But regional LDM feeds can supplement the SBN list. So in AWIPS, you may see even more products than what these lessons cover. Additionally, NSSL supports an online viewer you can use. We'll talk more about that in a minute.

But we think some of these supplemental products are quite useful. So throughout these lessons, you'll see little cloud bubbles with product names. These clouds will highlight some of the products you may have access to via other pipelines.



Speaking of other pipelines, here is the MRMS operational product viewer, linked in the Resources. The Operational Viewer has every product that NSSL supports for operational usage, including both SBN and LDM feeds. And the archive goes back a couple years. So it can come in handy for looking at supplemental products in real-time, or for case study analysis after the fact.

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SBN-Supported Products

Radar-based Products	Multi-Sensor Products
Surface Precipitation Type (SPT)	Multi-Sensor QPE (Pass 1) (1, 3, 6, 12, 24, 48, 72-hr)
Surface Precipitation Rate (SPR)	Multi-Sensor QPE (Pass 2) (1, 3, 6, 12, 24, 48, 72-hr)
QPE – Radar Only (1, 3, 6, 12, 24, 48, 72-hr)	

Alright, so this table shows the products that we will be discussing in this course. There are two main types of products: radar-based and multi-sensor. All of these products are provided in AWIPS through the SBN, and therefore, are the most operationally-supported. So let's begin!

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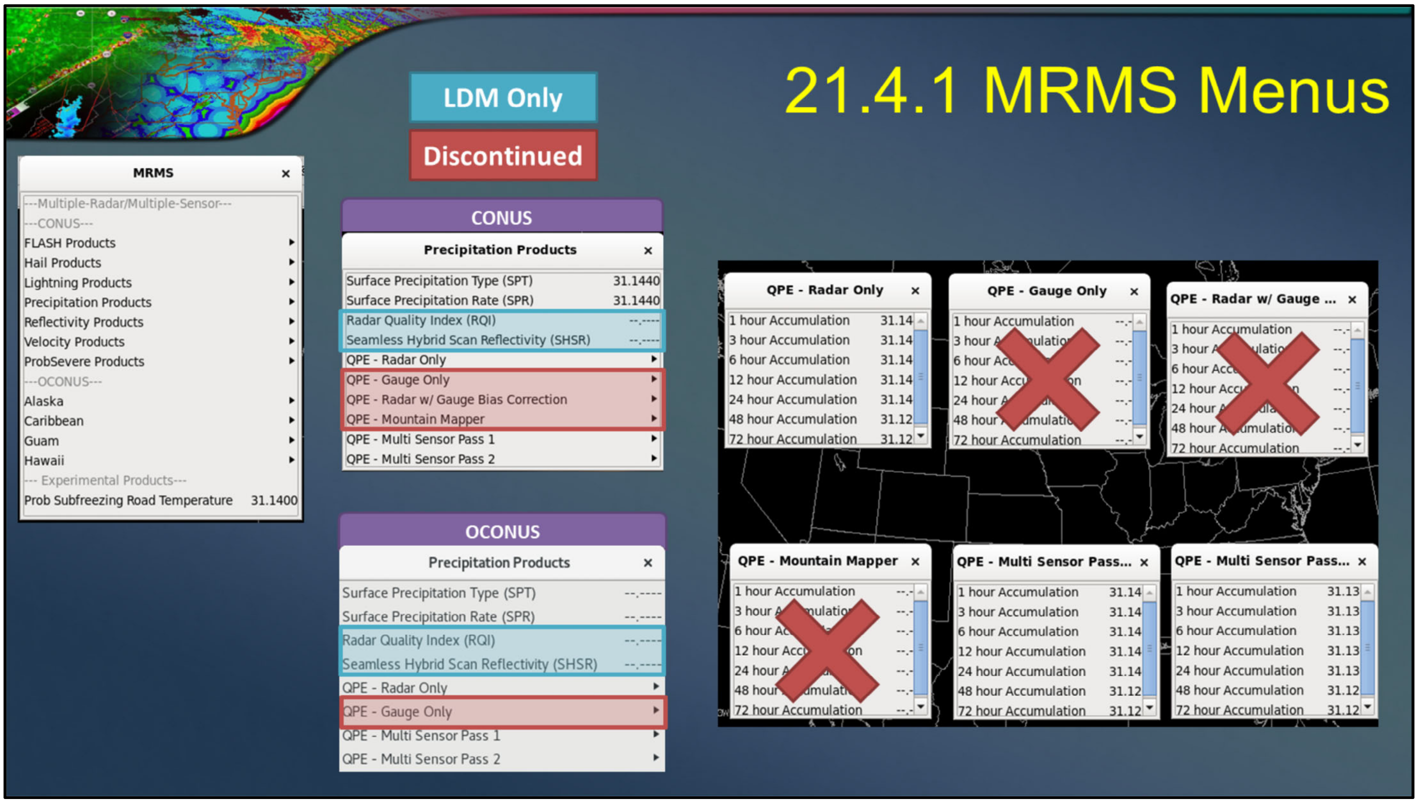
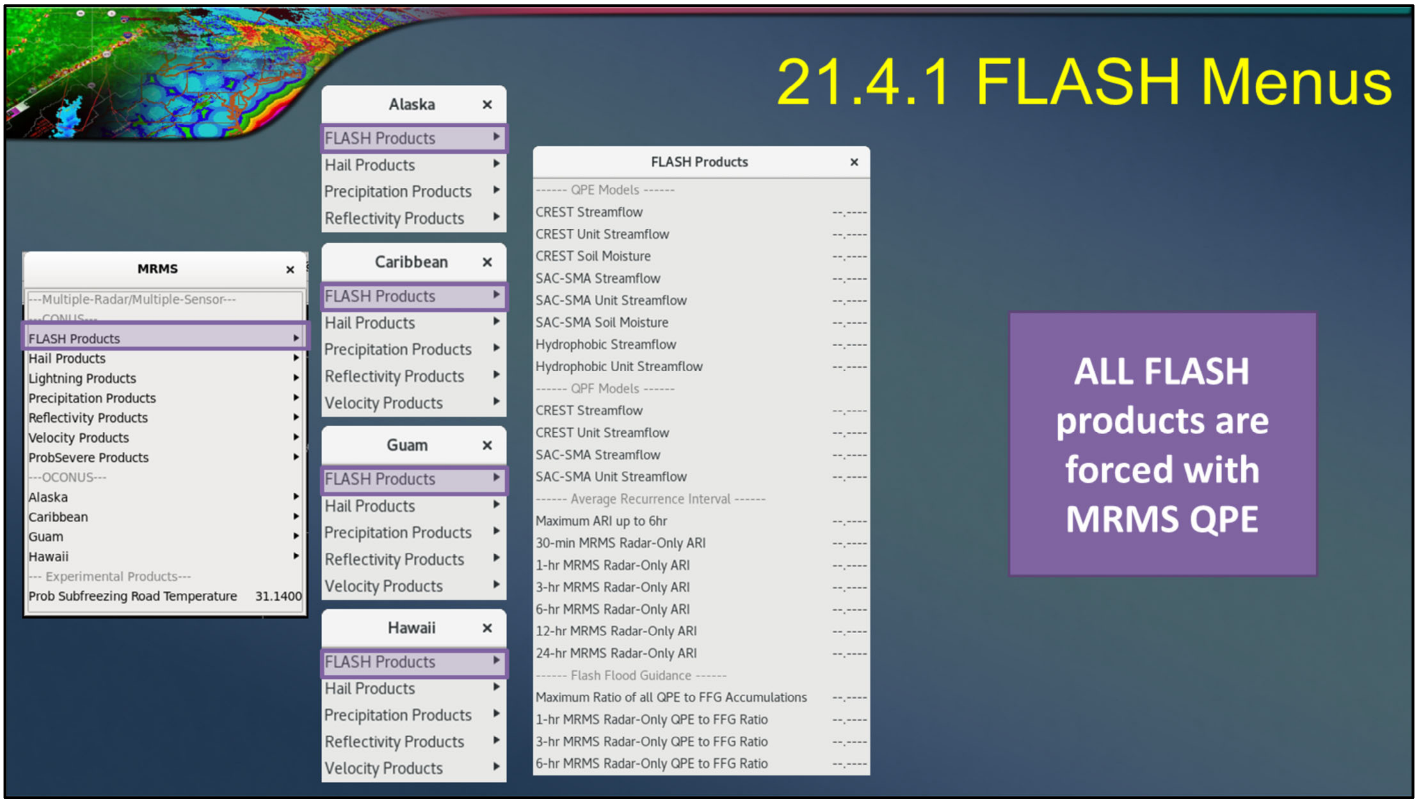


In AWIPS, MRMS has its own menu, as shown here, complete with CONUS and OCONUS sub-menus. For the Precip products, here are the CONUS and OCONUS sub-menus. There are a couple things to note:
--For one, several of the non-SBN products are still listed in the menu. Specifically, the ones highlighted here. If your office is pulling them in via LDM, these products may populate. Otherwise, they will be empty.
--Second, some discontinued products are still listed, unfortunately. They're highlighted here. These will never populate because the products are not being distributed by NSSL.
--With that, here are the individual product menus with all their different durations.



A quick note: FLASH products also appear in the MRMS menu, and all of the OCONUS sub-menus. We will not talk about FLASH in this course; however, it is important to know that all FLASH products are forced using MRMS QPE. So just remember that MRMS and FLASH are joined at the hip. Knowing your MRMS QPE output and biases can help you better interpret what you're seeing from all your FLASH products.

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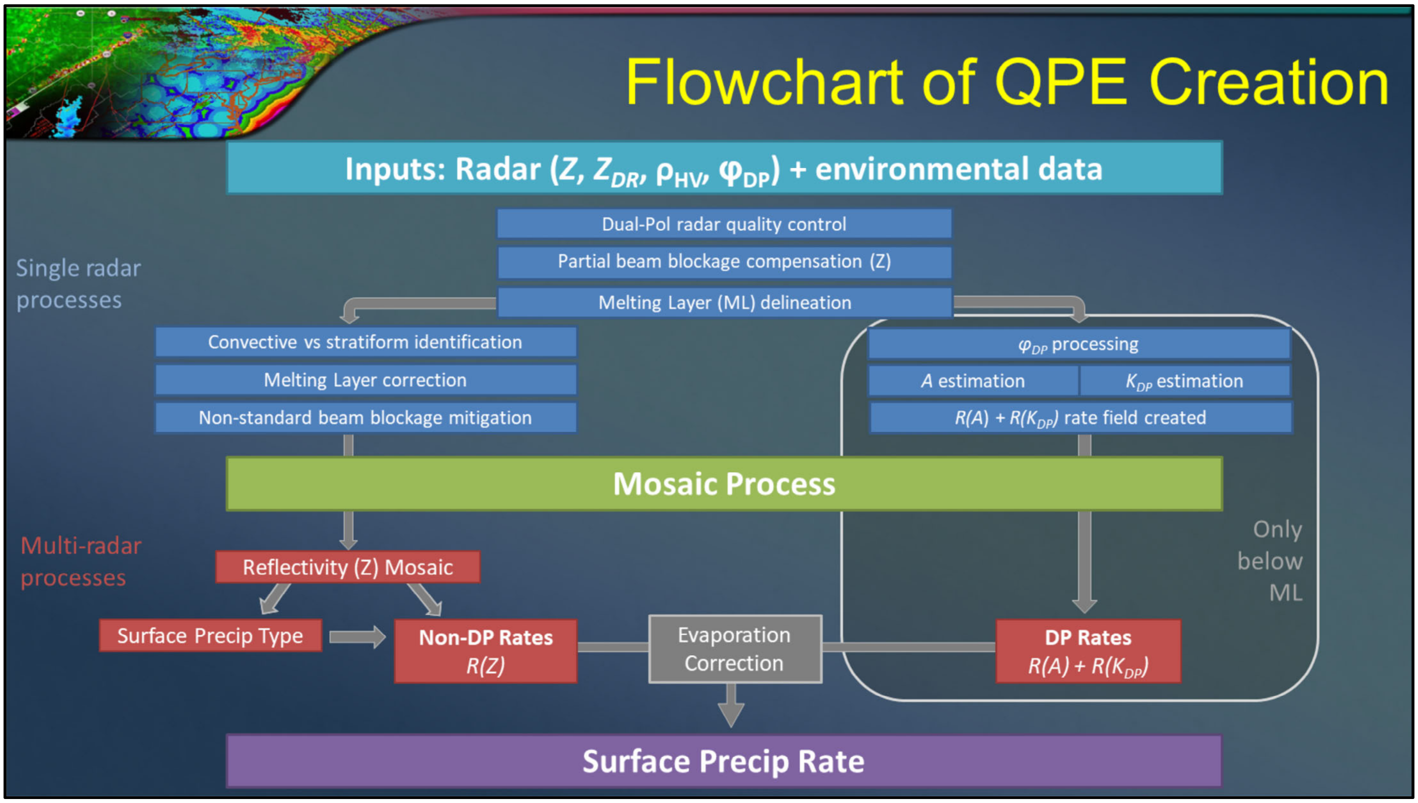
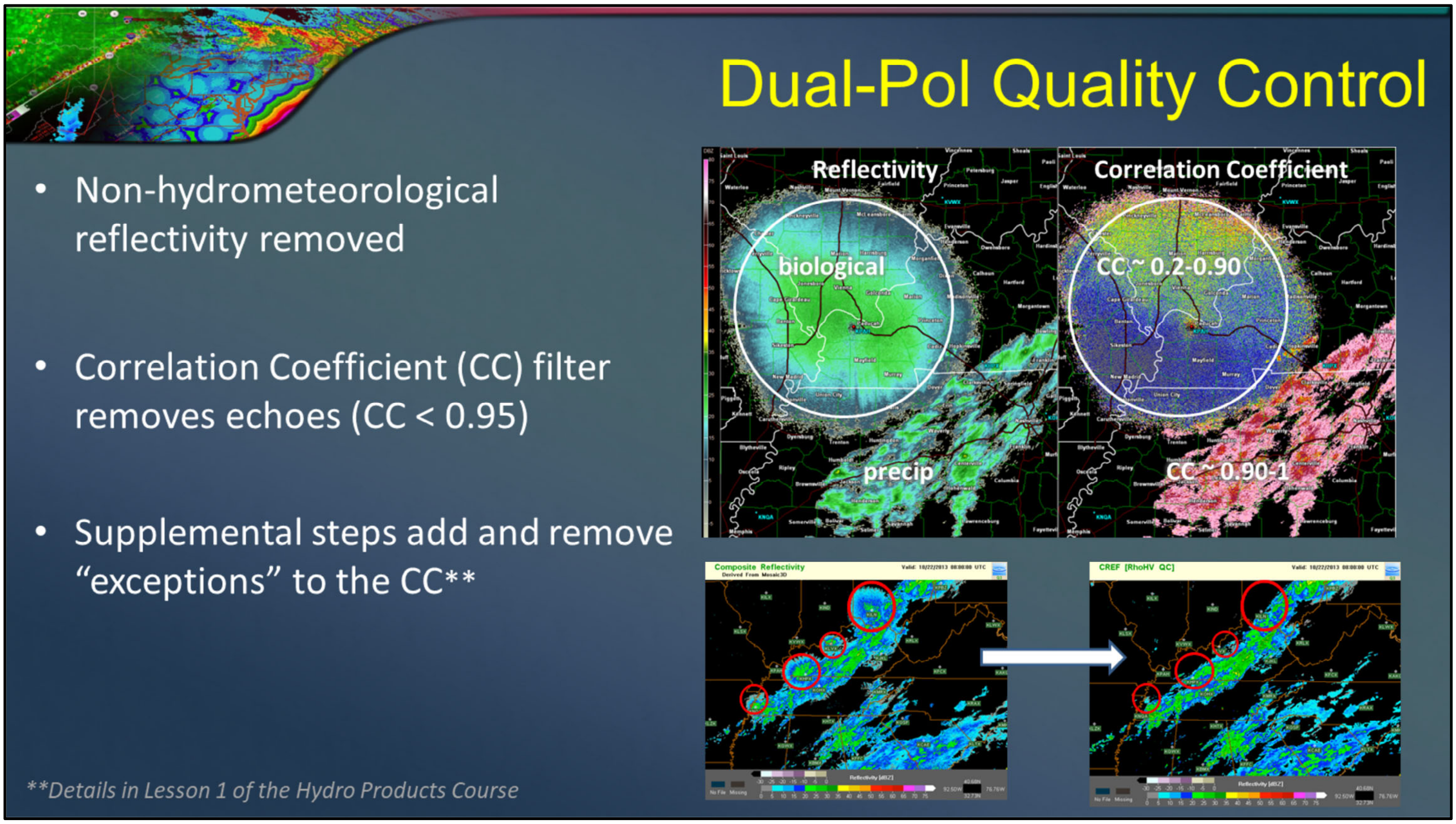


Here is the flowchart for QPE creation. The ultimate goal is to create the Surface Precip Rate product – at the bottom – which feeds into almost every other product in the suite. So we'll take the rest of this lesson to run through each of these steps. So let's start with the big picture.

To create the Surface Precip Rate, the algorithm begins with raw radar data plus some environmental data that helps identify temperature heights. This data then runs through a series of quality controls to help filter non-hydrometeorological data, compensate for partial beam blockage, and identify the melting layer heights. Then, the algorithm diverges for data within and above the Melting Layer versus below the Melting Layer. Below the Melting Layer, rain rates that use Dual-Pol moments are preferred, so processing is done to create those DP rates. But within and above the Melting Layer, only reflectivity is used and it requires additional quality controls before it can be turned into R(Z) rain rates. Ultimately, the two mosaics are merged – and an evaporation correction applied – to create the Surface Precip Rate product.

So let's begin with the quality control steps that all the data undergoes.

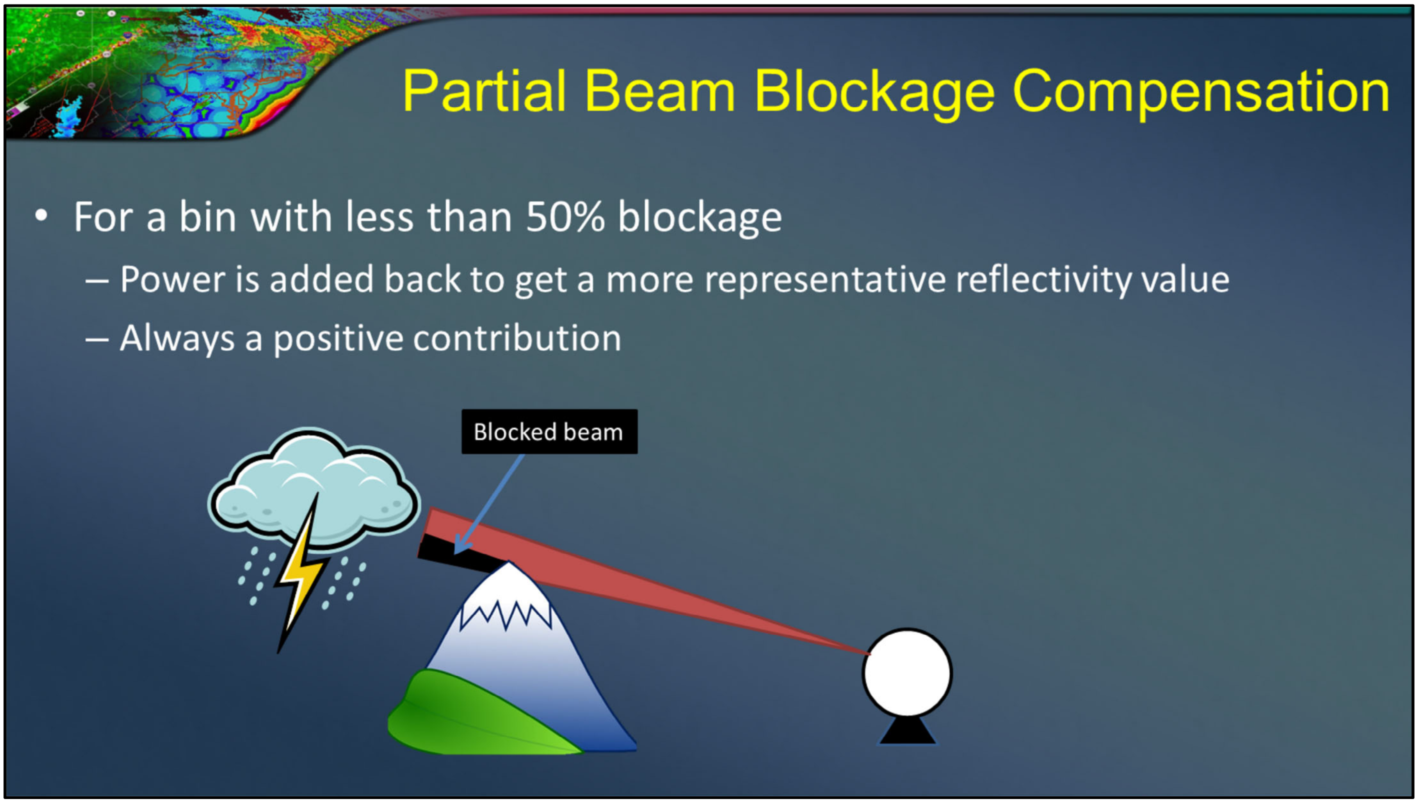


--The dual-pol quality control removes non-hydrometeorological echoes from each volume scan of reflectivity.

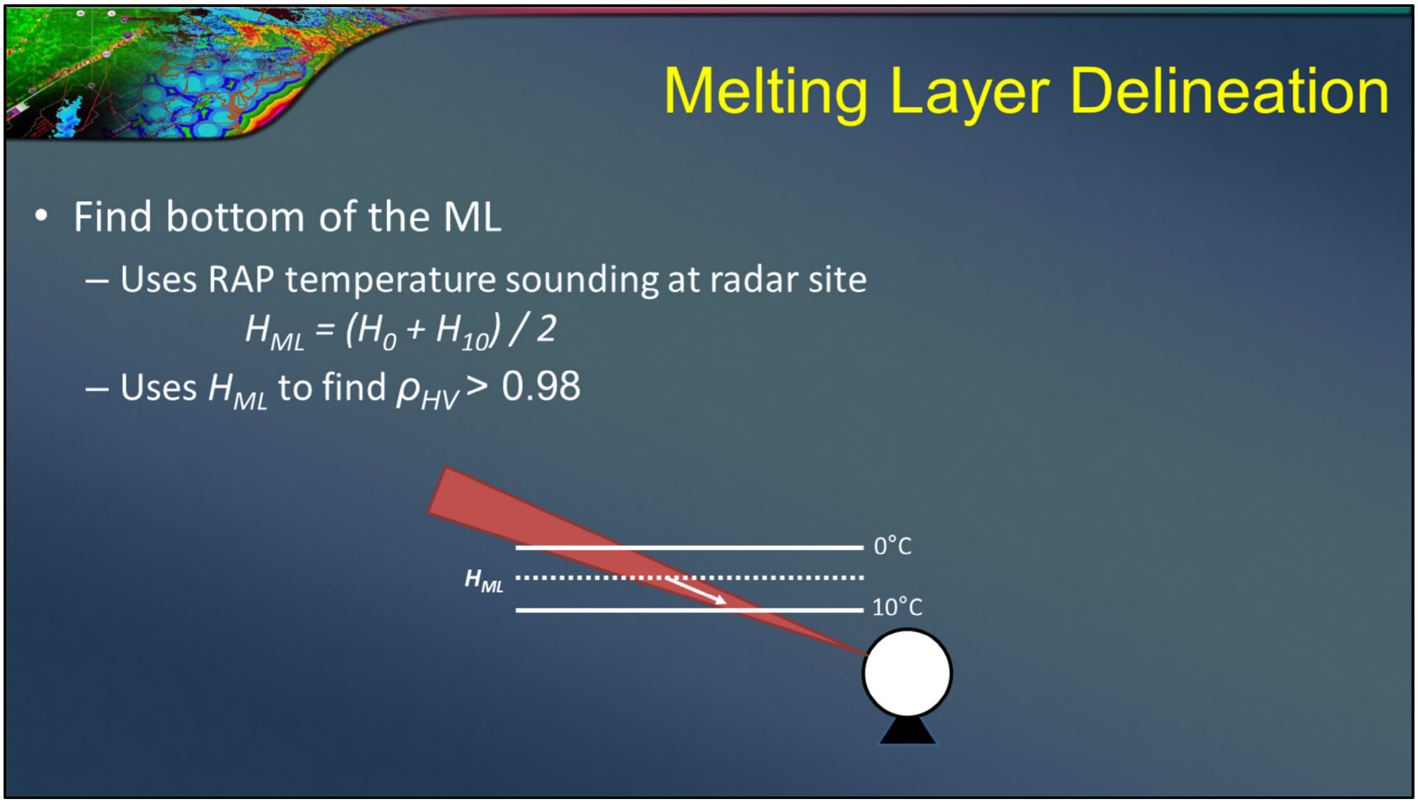
--The main filter in this algorithm is the correlation coefficient filter that removes all echoes below 0.95. While this is a very aggressive initial reflectivity-removal threshold, the algorithm has a number of subsequent steps to reintroduce or further remove reflectivity.

--On the right is an image of the KPAH radar showing a strong biological bloom signature near the radar, as well as precipitation echoes to the SE. Notice how low CC values exist in the bloom area, generally well below 0.95. However, the precipitation region is returning values generally above 0.95.

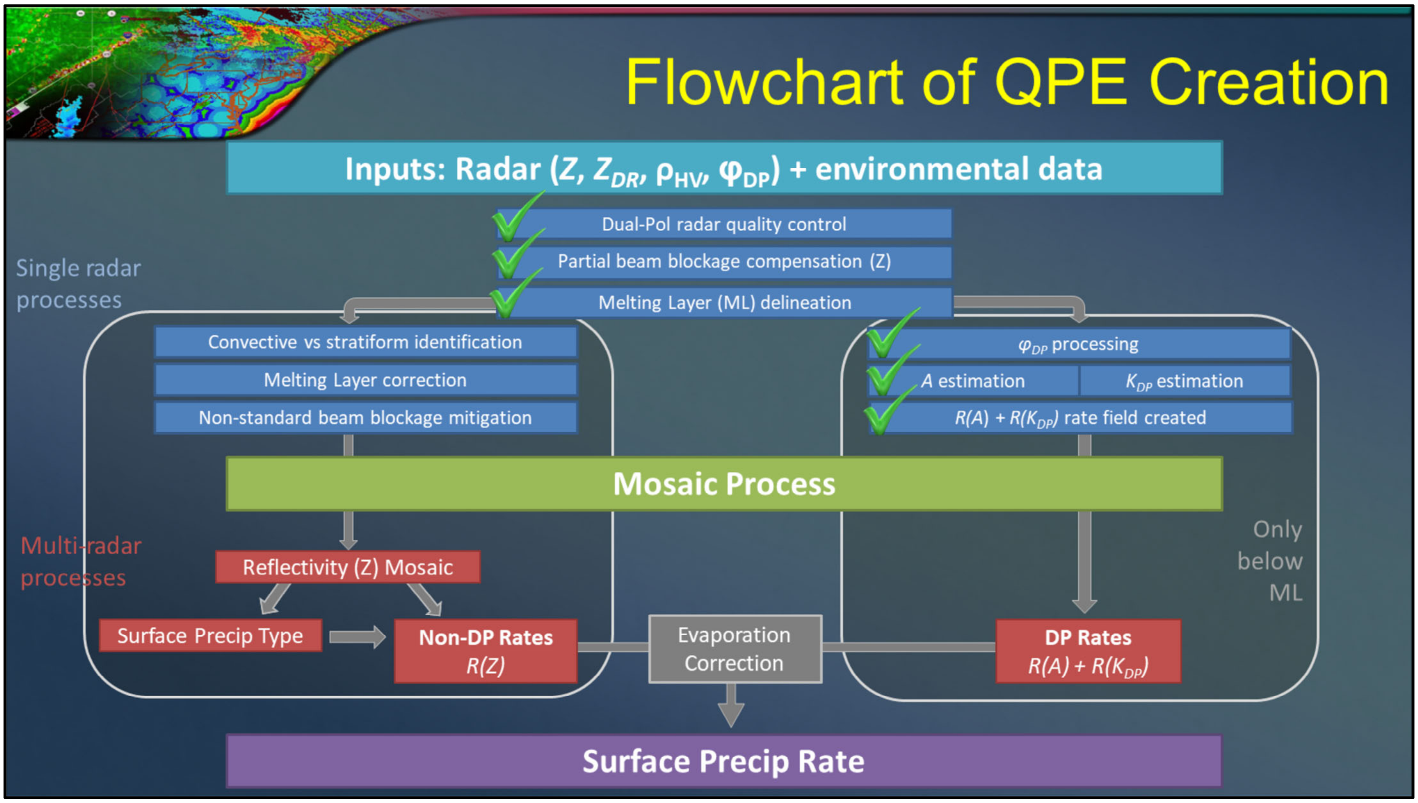
--MRMS uses these CC signals to remove reflectivity in the bloom region, while maintaining the precipitation to the SE of the radar. Below is an example showing what the reflectivity field may look like after the blooms have been removed by the filter.



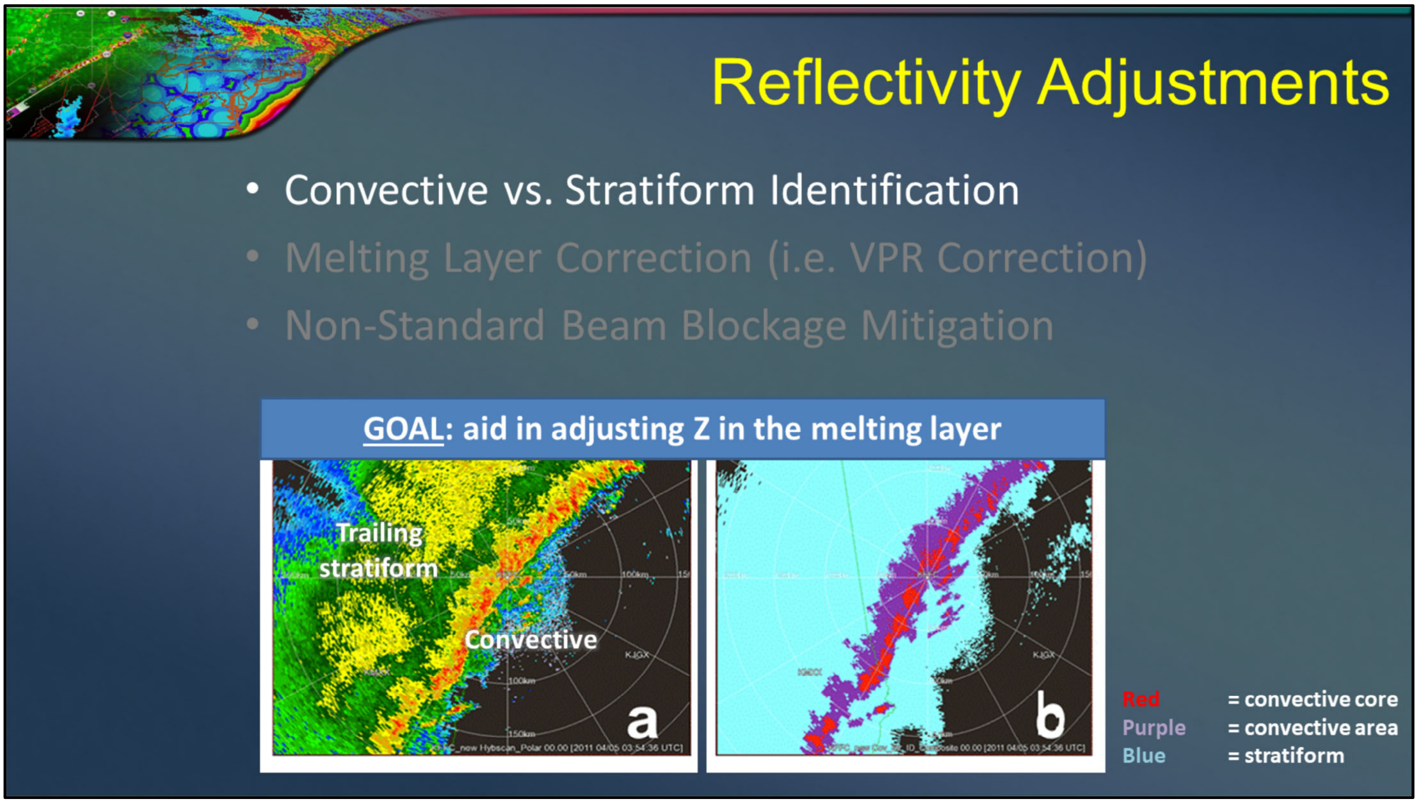
--Next is the Partial Beam Blockage Compensation. This step takes any radar bin that is blocked by 50% or less, and adds power back into its reflectivity total, in order to get a more representative value.



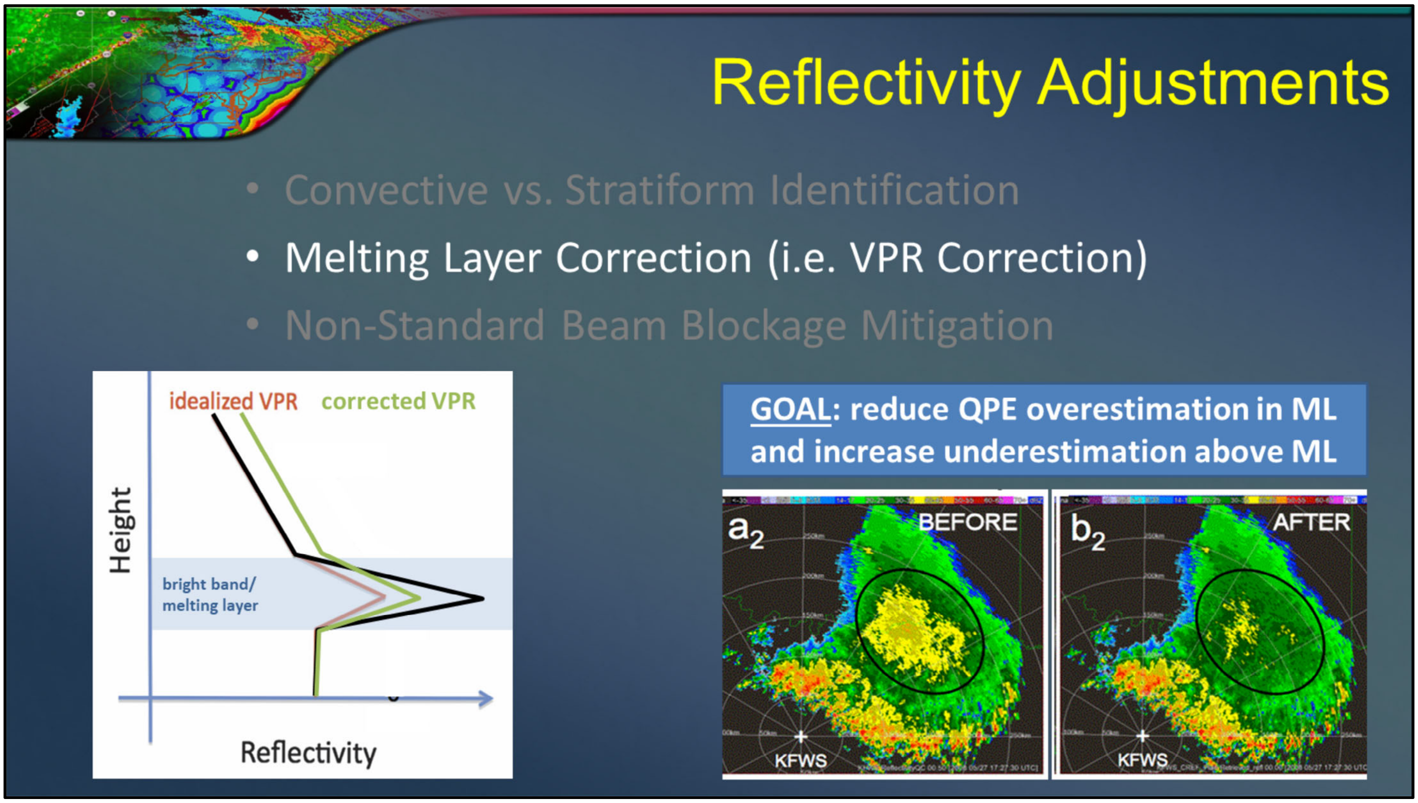
For DP rain rates to be effective, they can only be used in pure rain areas. Therefore, identifying the bottom of the melting layer is important. The algorithm does this using RAP temperature sounding data at the location of the radar. It finds the heights of the 0 degree and 10 degree isotherms and averages them. It then uses that height as the initial point in the radial to focus a search towards the radar for the first gate where correlation coefficient is greater than 0.98, denoting uniform precip.



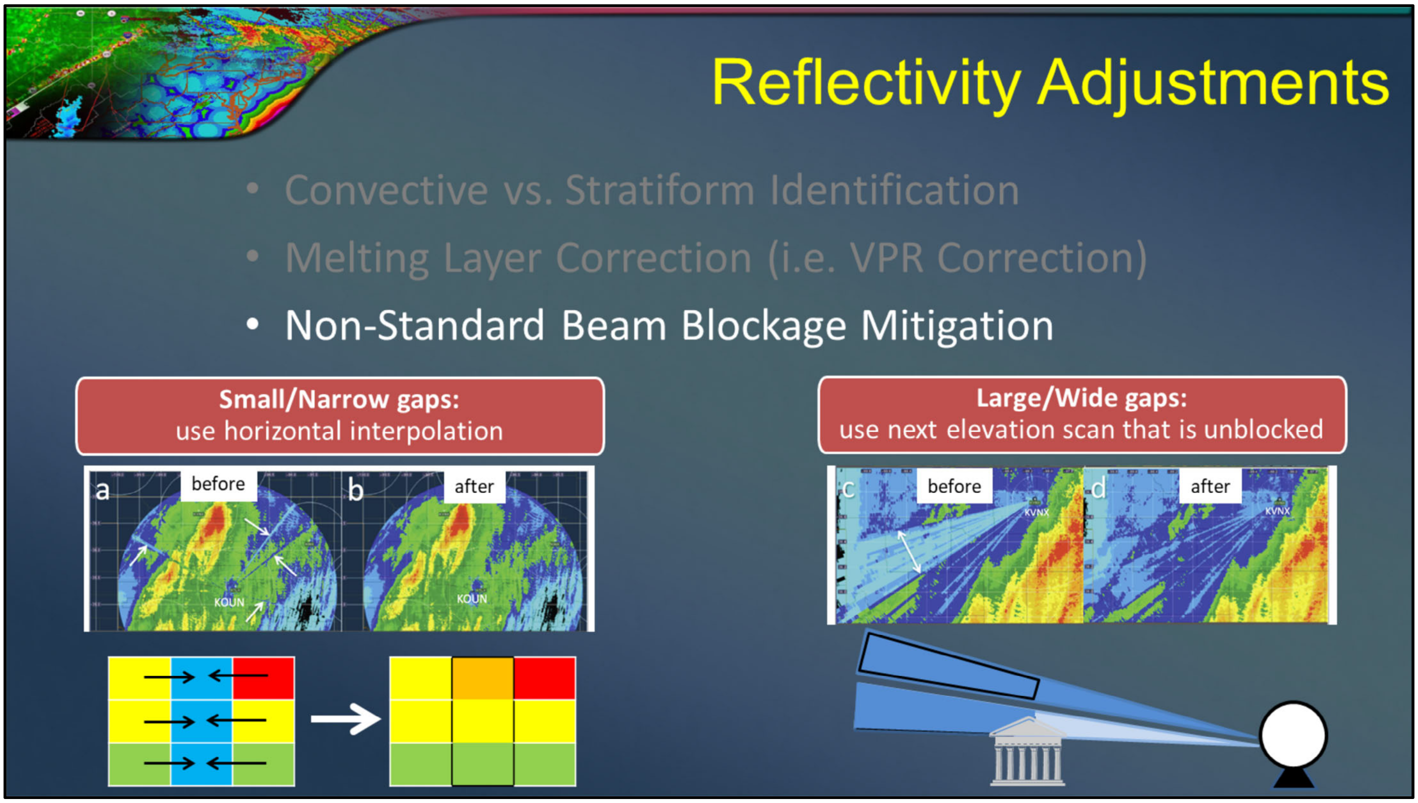
Alright, so once the bottom of the melting layer is established, the algorithm diverges. On the left is the "old school" way MRMS creates rain rates. It only uses reflectivity and adjusts it via multiple methods. On the right, is the "new school" method using Dual-Pol parameters. The reason for the split is because Specific Attenuation, or A, is only valid in pure rain classes. So it can only be used below the Melting Layer. In areas where hail or ice is present, KDP is used as a supplement. These steps are FAR too complicated to get into here, so I'm just going to include the relevant papers in the Resources and…godspeed. So instead, let's talk a little about the reflectivity adjustments made on the left side.



Just as the name sounds, this step defines each radar bin as either convective or stratiform.
--It uses the model height levels, VIL, and range dependency of radar sampling to classify the pixels.
--The purpose of the convective/stratiform identification is to aid in adjusting reflectivity values in the melting layer, which will be discussed on the next slide.



--Once the precip type is classified, the next step is to apply corrections for biases in the "bright band", or the melting layer. This layer can cause QPE overestimation because melting ice particles may appear to the radar as big drops, and thus, get falsely assigned higher reflecitvities in the region.
--A vertical profile of reflectivity (or VPR) correction is used in affected stratiform regions, as well as ice regions above the BB. Saving the details for Lesson 1 of the Hydro Products Course, in general, the VPR, as shown on the left, samples the elevated reflectivities in the bright band, and then, applies an algorithm to reduce the values in these areas.
--The images on the right show a "before and after" instance for an MCS. The BB is likely causing higher reflectivities in the areas that are circled. However, after the correction, the bright banding is significantly reduced.



--Finally, there is the non-standard beam blockage mitigation. The first process (the partial beam blockage) accounted for instances when there was beam blockage associated with known features that block the radar beam (for example, mountains). However, reflectivity fields may still have non-standard beam blockage issues (like, trees and buildings) that are not accounted for in the digital elevation models. That's where this adjustment comes in!

--For small or narrow gaps, like the images on the left, the gaps are filled using horizontal interpolation. MRMS averages the two bins on either side to get the middle value.

--For large or wide gaps, like the images on the right, a horizontal interpolation is not ideal because interpolating over a broad region may not be very representative of what is occurring. Instead, the next elevation scan up that is unblocked is used. This replaces all values in the lower, blocked region. In this case, the dark blue values would be extrapolated to the lower tilt.

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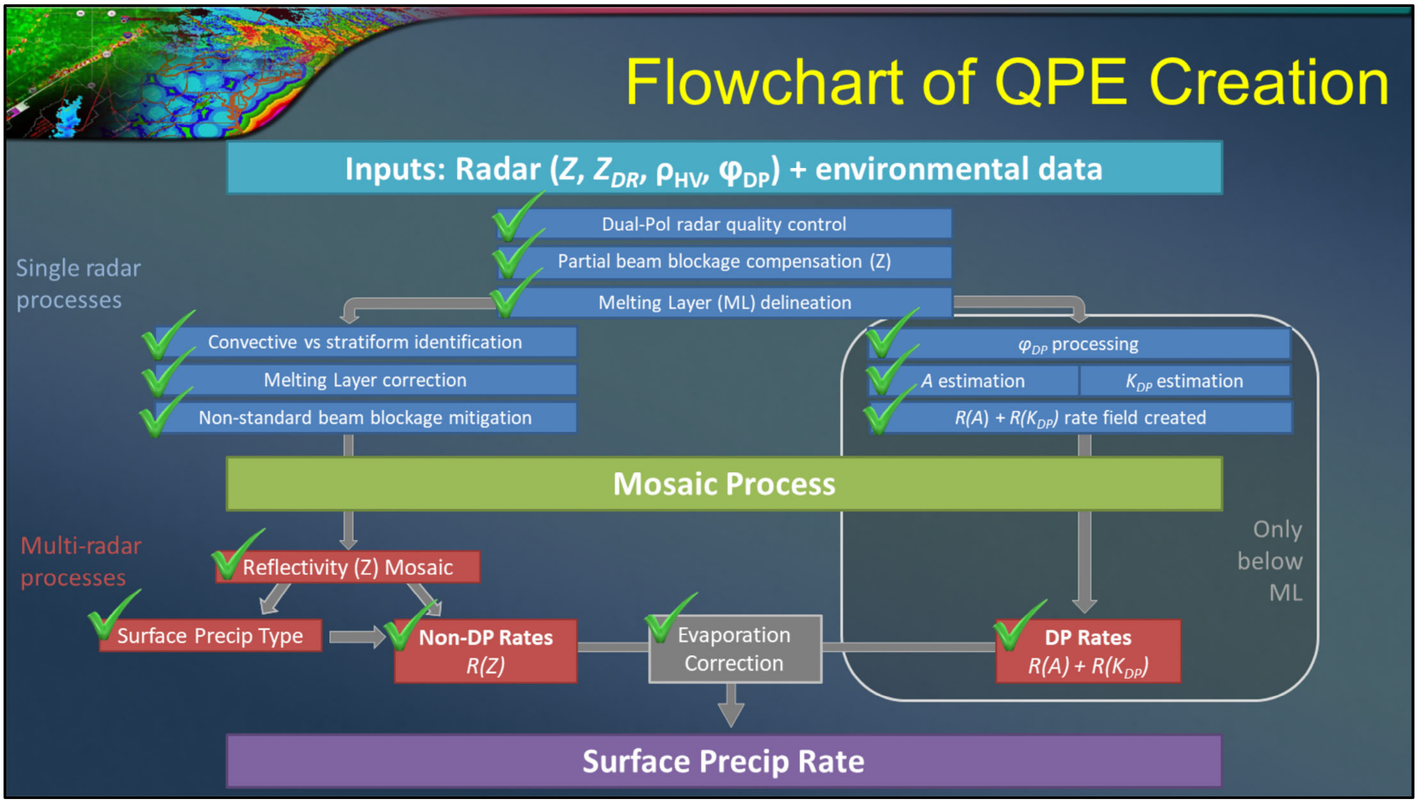
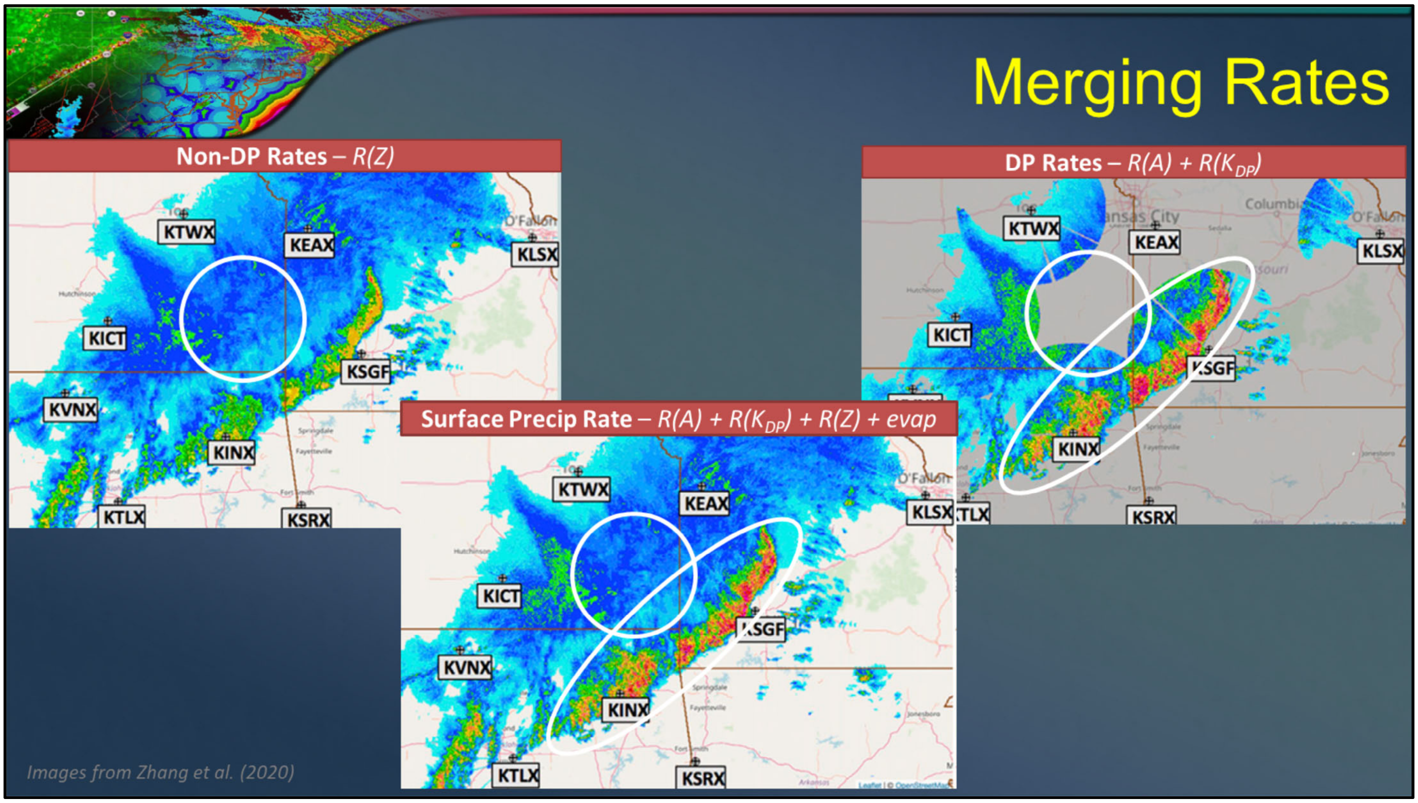


Now that the single-site radar reflectivity has been filtered using the Dual-Pol QC and then adjusted for blockage and bright-band effects, the next step is to combine the radars into a mosaic. We will not cover the details of this here, but the algorithm uses logic that considers radar quality, as well as distance and height weighting to get the final reflectivity at each grid point. At this point, we have a mosaic of reflectivity on the left and a mosaic of DP rates on the right. To turn the reflectivity mosaic into rates, we have to create the Surface Precip Type product. But the final non-DP rate field is created by assigning Z-R relationships based on the precip type at each pixel. Then the reflectivity mosaic is used with those Z-R relationships to create the rainfall rate itself. Finally, the two rate products are merged into one mosaic and an evaporation correction applied. Let's see how this looks on the next slide.



So we begin with the two separate mosaics. Notice how the DP Rates in the upper right have a much shorter range around each radar. This is due to the rates only being calculated below the melting layer. On the other hand, the non-DP rates have a much broader reach since they can be calculated throughout the radar coverage. But once they're merged together, the DP rates are prioritized when they are available, and the non-DP rates fill in the gaps. Notice how the leading convective line mimics the DP rates. But just behind it, in the DP gap, the stratiform region mimics the non-DP rates.

This shared merger – along with the evaporation correction – makes the Surface Precip Rate product a robust radar-only product that feeds into many other products.

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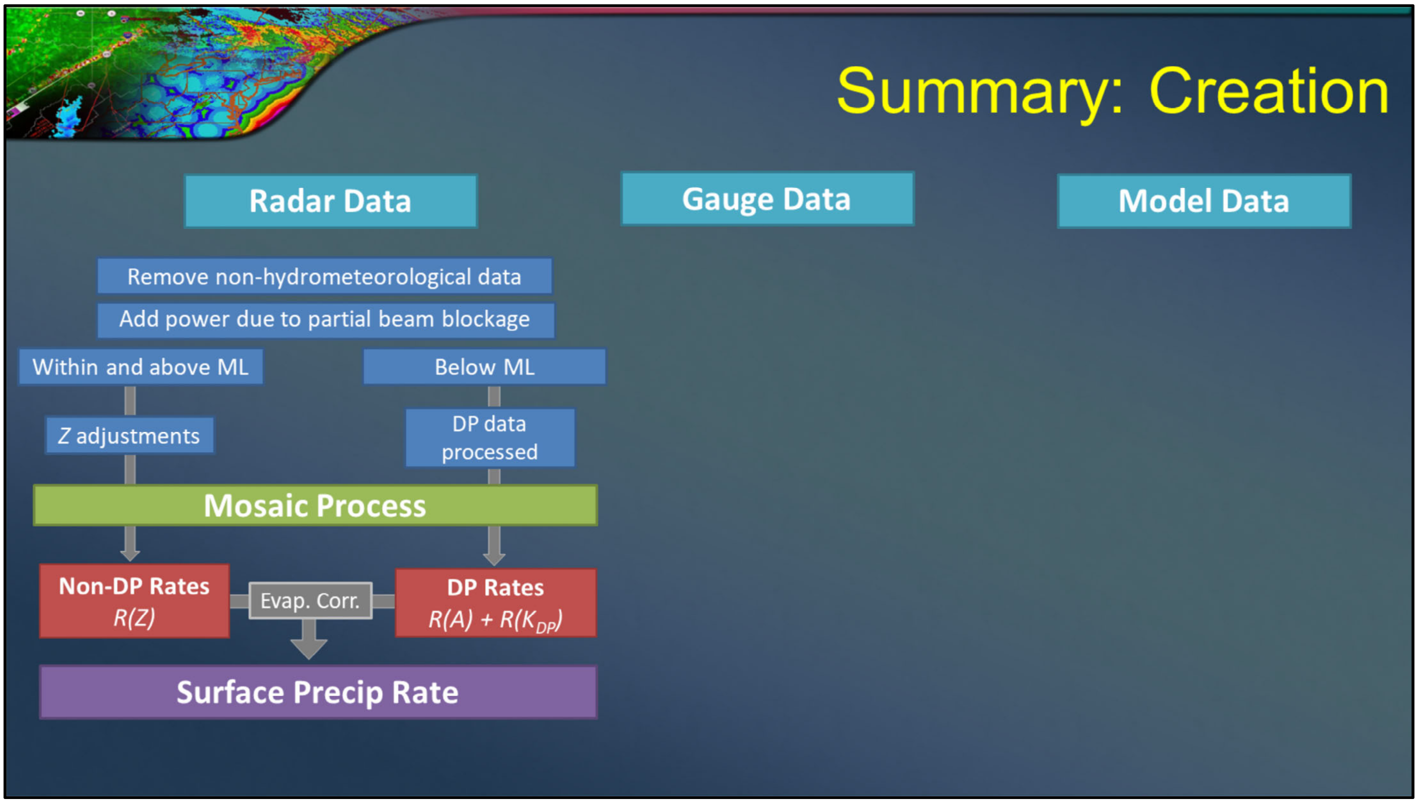

--In summary, the MRMS QPE suite is a set of mosaicked products, created from a variety of inputs.

--Those three main inputs are: radars from the WSR-88Ds and the Canadian network, gauges from the HADS and MADIS networks, and model data from the RAP with nested HRRR.

--The radar data is the core of the system, and it goes through some immediate quality control steps including: the removal of non-hydrometeorological reflectivity and adding power back due to partial beam blockage.

--From there, rain rates based on DP parameters are calculated below the melting layer, while rain rates within and above the melting layer are calculated from heavily-adjusted reflectivity data.

--These separate rate products are then merged – and have an evaporation correction applied – to become the flagship Surface Precip Rate product.

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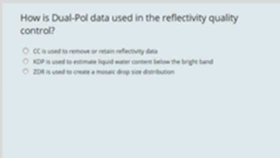

Overview Recap 1

Quiz - 3 questions

Last modified: Wednesday, December 14, 2022 at 2:36:39 PM

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User may view slides after quiz:	Any time
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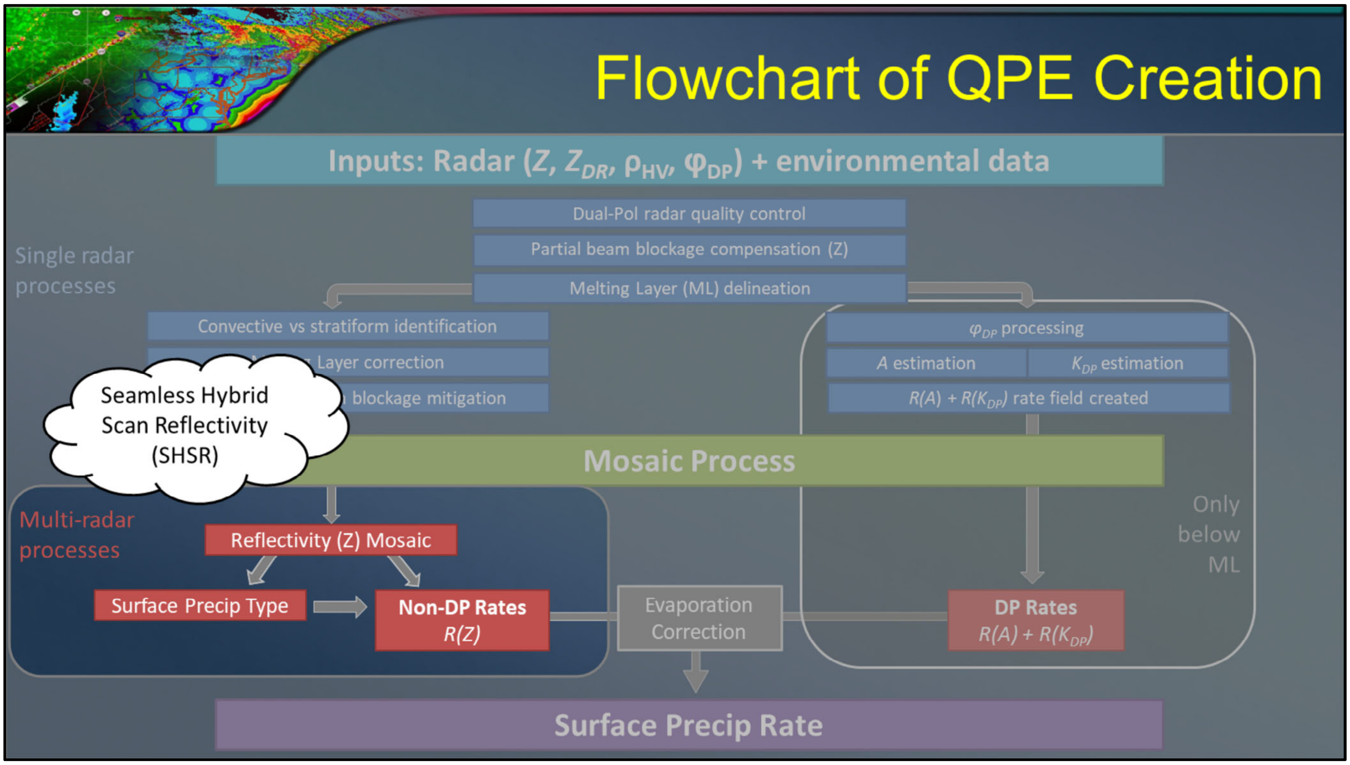

We went through all of the steps leading to the Surface Precip Rate. However, we kinda glazed over how the Surface Precip Type feeds into the product. So let's begin there.

As a reminder, within and above the melting layer, we focus on reflectivity – or Z – based rain rate relationships. Therefore, after the mosaic process, we start with a quality-controlled reflectivity mosaic called the Seamless Hybrid Scan Reflectivity. This product is used both within the Surface Precip Type product to help define various precip types, as well as the within the non-Dual-Pol rate product as the reflectivity value for the rate calculations.

The Surface Precip Type is also used here to determine which rain rate relationship to assign each point.

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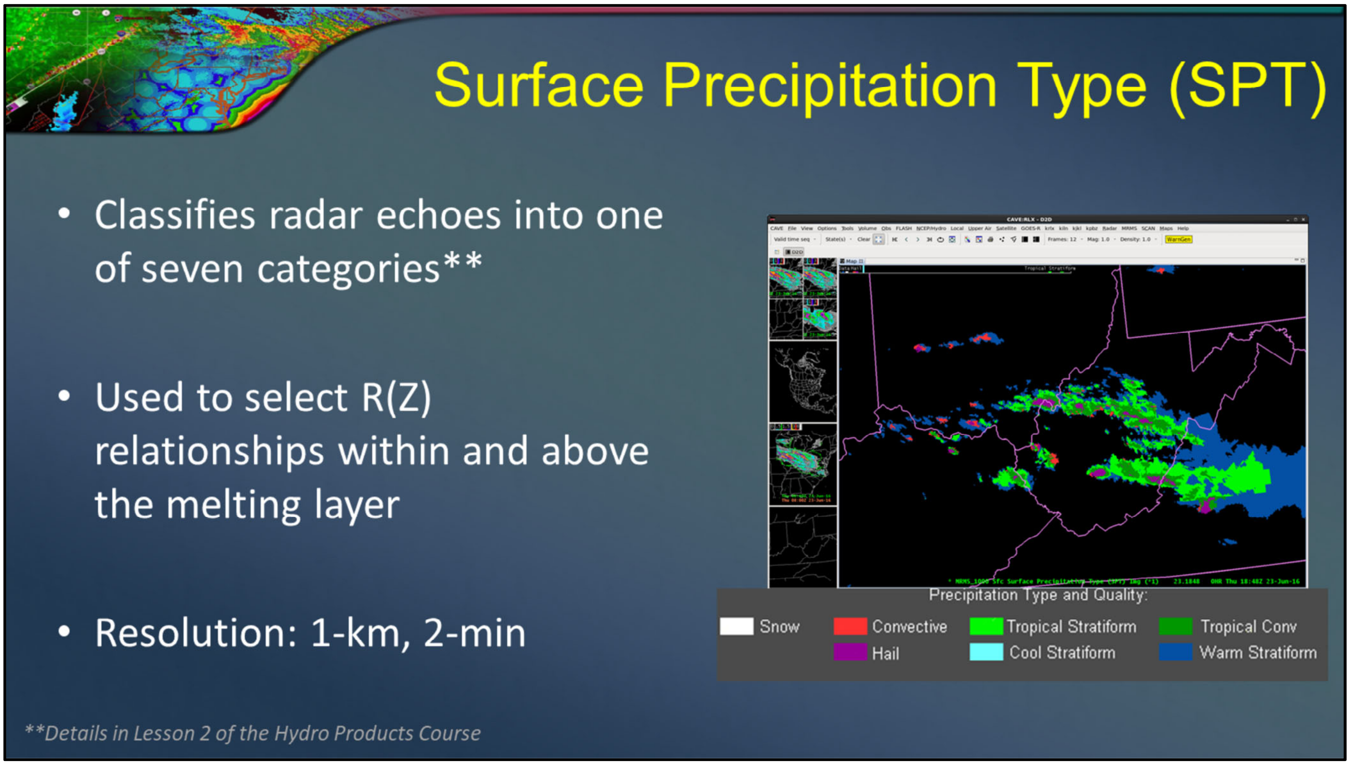


So the Surface Precipitation Type (or SPT) product is an algorithm that classifies radar echoes into one of seven categories, as shown on the right.

Its primary use is for the selection of Z-R relationships in order to compute the non-Dual Pol rates at each point within and above the melting layer.

The image on the right is an example of the SPT product. You can see how there are little pockets of convective and hail pixels embedded in a broader stratiform system.

Non-Dual-Pol Rain Rate Relationships

Purpose: used within and above the melting layer

Surface Precip Type	Z-R Relationship	Rate Cap
Warm stratiform rain	$Z = 75R^{2.0}$ when $Z < 40$ dBZ	1.9 in/hr
Cool stratiform rain	$Z = 200R^{1.6}$ when $Z \geq 40$ dBZ	
Convective rain	$Z = 300R^{1.4}$	4.1 – 5.9 in/hr
Hail	$Z = 300R^{1.4}$	2.1 – 5.9 in/hr
Snow	$Z = 75R^{2.0}$	none
Tropical Stratiform	Weighted mean: $Z = 250R^{1.2} / \beta^{1.2}$, $Z = \max\{75R^{2.0}, 200R^{1.6}\}$	varies, up to 8.7 in/hr
Tropical Convective	Weighted mean: $Z = 250R^{1.2} / \beta^{1.2}$, $Z = 300R^{1.4}$	

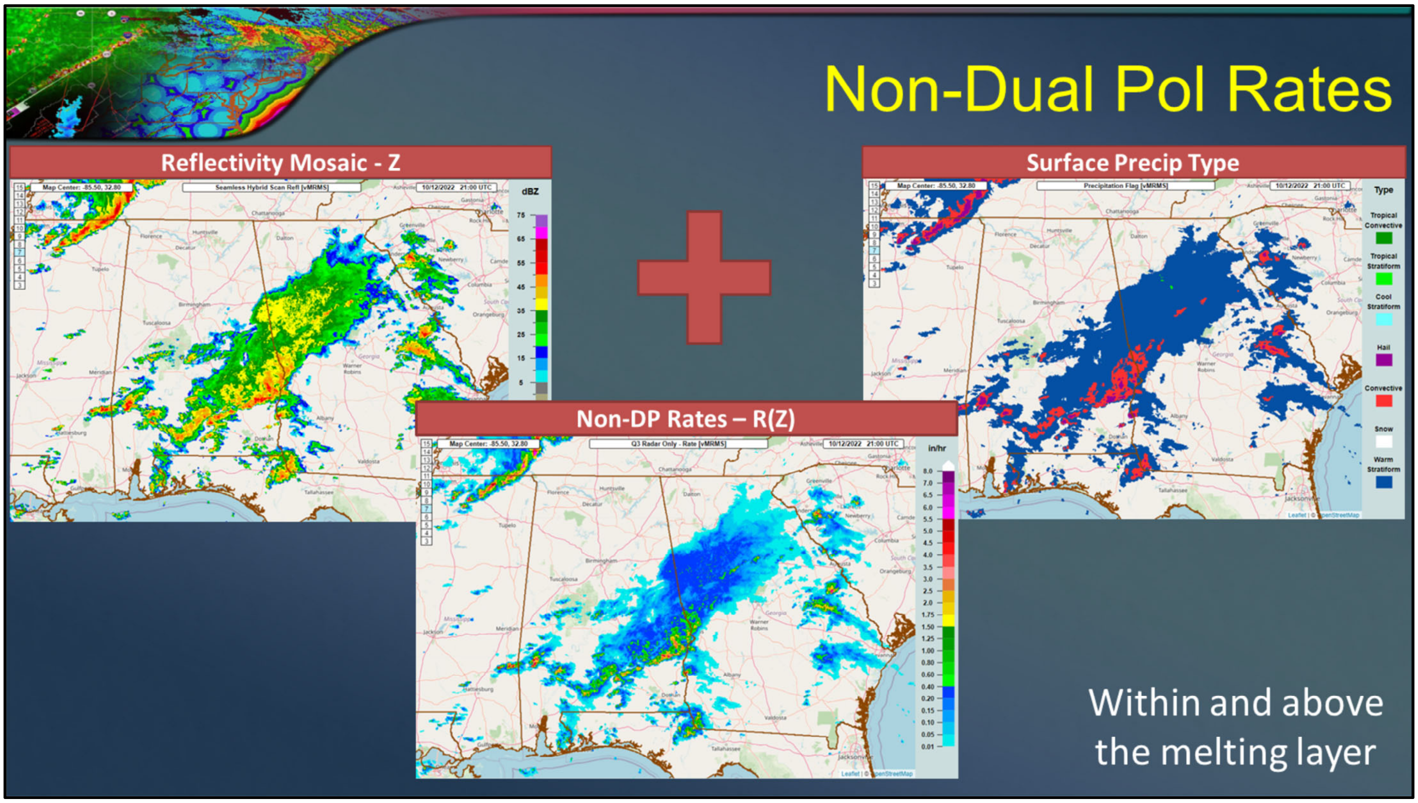
***Details in Lesson 2 of the Hydro Products Course*

β increases in tropical environments

Tropical Rain Probability

Here is a table of the Z-R relationships used for each of the Surface Precip Types. Remember that these rates are only used within and above the melting layer where Dual-Pol relationships are not valid.

Note some of the similarities:
--For instance, both Warm and Cool Stratiform types use the same logic, so there's virtually no difference between them.
--Convective rain and Hail also use the same equation, just with different rate caps.
--And finally, the Tropical types are both weighted means of the equations shown, with the top equation being the Tropical Z-R. Note the coefficient beta here. Beta increases in more tropical environments, such as hurricane months and coastal areas.
--Additionally, the weighted mean is a function of the Tropical Rain Probability, formally the Probability of Warm Rain. Details are in Grams et al. (2014) in the Resources.



So to recap so far, the reflectivity mosaic plus the Surface Precip Type are used to calculate the non-DP rain rates within and above the melting layer. So now let's take a look at the logic used below the melting layer.

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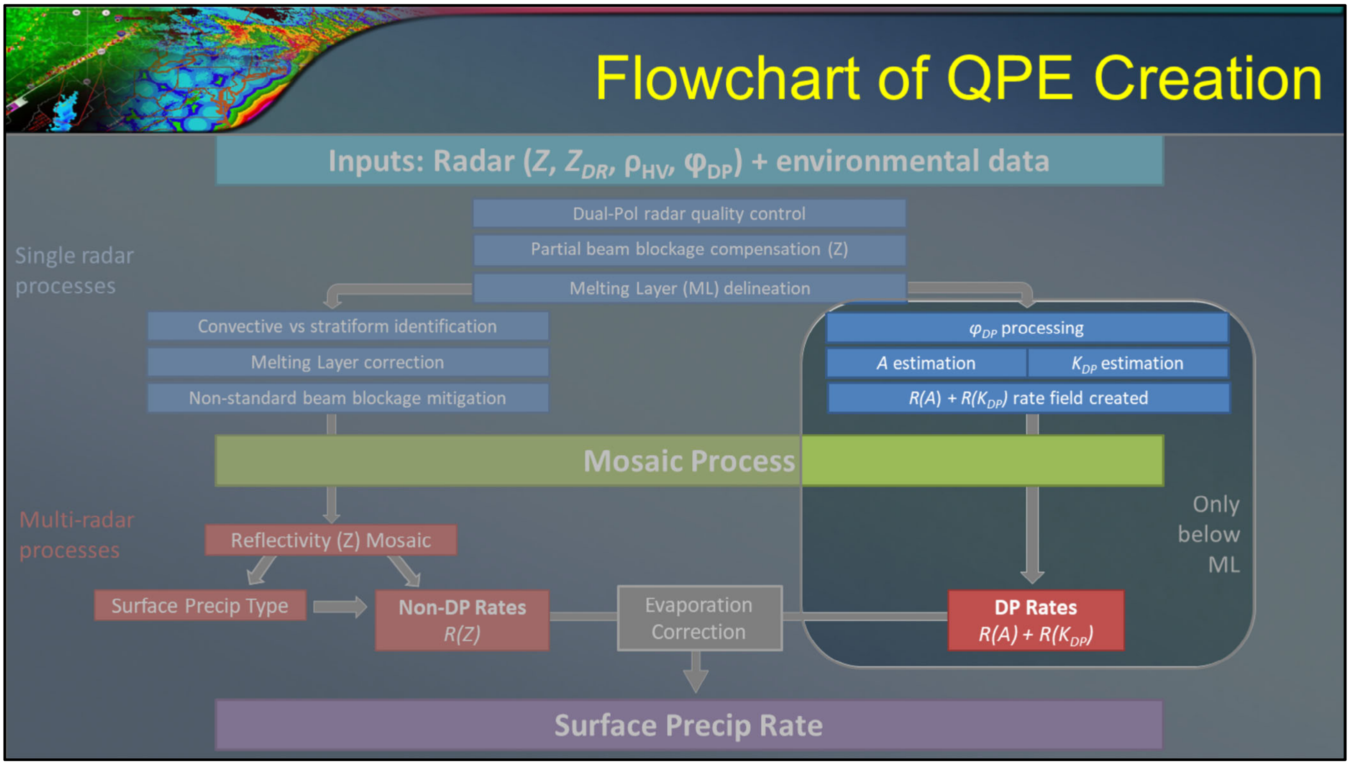

Below the melting layer, the MRMS algorithm favors Dual-Pol parameters, such as specific attenuation (A) and specific differential phase (KDP). These go through various processing and mosaicking to become the Dual-Pol rates we use in the Surface Precip Rate.

So let's first look at why they are advantageous for rainfall estimation.

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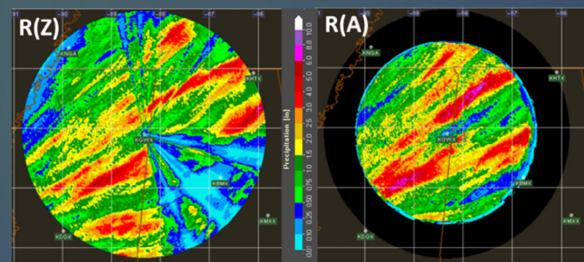
Advantages of R(A)

- Less sensitive to drop size distribution variabilities in S-band
- Immune to:
  - Calibration errors in Z and Z_{DR}
  - Partial beam blockage
  - Attenuation
- Higher resolution than $R(K_{DP})$
- Beats all other relationships for low-to-moderate rain rates



In areas of pure rain, using specific attenuation for rain rate relationships has several advantages over other variables.
--For one, it is less sensitive to drop size distribution variabilities in S-band radars.
--It's also immune to calibration errors in Z and ZDR, partial beam blockage (as seen here), and attenuation.
--And it has a higher resolution than R(KDP) because it doesn't need to be smoothed.

Ultimately, it beats out all other rain rate relationships for low-to-moderate rain rates, making it the preferred option in areas of pure rain. (Ryzhkov et al., 2022)

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Uses of R(KDP)

- Immune to:
  - Radar Miscalibration
  - Attenuation
  - Dry Hail
- Overestimates in areas of water-coated hail and melting graupel
  - Different multipliers can be used (based on CC)
- Noisy in areas of weaker echoes (where Z < 30-40 dBZ)
  - Limited to areas of heavy rainfall + hail

In areas that are not pure rain, specific attenuation is not valid. Instead R(KDP) is used because it is also immune to radar miscalibration and attenuation, but more importantly, it's immune to dry hail. So it is a great substitute in these areas.

However, in areas of water-coated hail or melting grapuel, R(KDP) can overestimate. In order to mitigate this, different multipliers can be used based on correlation coefficient. You'll see those details on the next slide.

R(KDP) can also be noisy in areas of weaker echoes, so its use is limited to areas of higher reflectivities indicating heavy rainfall mixed with hail.

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Dual-Pol Rain Rate Relationships

Purpose: used below the melting layer

Conditions		Rain Rate Relationship	Rate Cap	Applications
Z < 48 dBZ	Below the bottom of the ML	$R = 4120A^{1.03}$ (if φ_{DP}_span ≥ 3°)	7.9 in/hr	Pure, steady rain (i.e. no ice, hail)
		max{ R(A) , R(Z) } where R(Z): $Z = 75R^{2.0}$ (east of 105W) $Z = 200R^{1.6}$ (west of 105W)	varies	Very light, sporadic, stratiform rain
48 ≤ Z < 50 dBZ		Weighted mean of R(A) and $R(K_{DP})$ (linear weight of function of Z)	varies	---
Z ≥ 50 dBZ		$R = 29\lvert K_{DP}\rvert^{0.770}$ (CC < 0.97) $R = 44\lvert K_{DP}\rvert^{0.822}$ (CC ≥ 0.97)	4.9 in/hr 6.9 in/hr	Areas of potential hail & heavy rain
---	50 km transition zone from bottom of ML	Weighted mean of R(A) and R(Z) where R(Z) is based on SPT	varies	---
---	Above the bottom of the ML	R(Z) where R(Z) is based on SPT	see previous slides	Within & above the ML

Okay, so now that we better understand R(A) and R(KDP), let's look at the Dual-Pol rain rate logic in MRMS.

The first thing to notice is that the table is broken up by conditions that are dependent on reflectivity and the melting layer. Since R(A) is best in pure, steady rain, it is solely used below the melting layer, as well as constrained to lower reflectivities. But R(A) can have issues in areas with very light or sporadic rain because the total attenuation signal in these areas can be too small to calculate an accurate R(A) estimate. If that's the case, the maximum rate is given between R(A) and the stratiform Z-R.

R(KDP) is more immune to hail, so it is used in areas with high reflectivity below the melting layer where there's potential hail and heavy rain. Notice the correlation coefficient condition to help alleviate overestimates in non-uniform areas.

Finally, within or above the melting layer, the algorithm defaults back to being based on the Surface Precip Type at each pixel, as discussed earlier.

There are a couple areas where weighted means are applied, mainly in transition zones between the reflectivity and melting layer conditions. And this is simply to help the QPE field not look so abrupt when changes in rain rate relationships occur.

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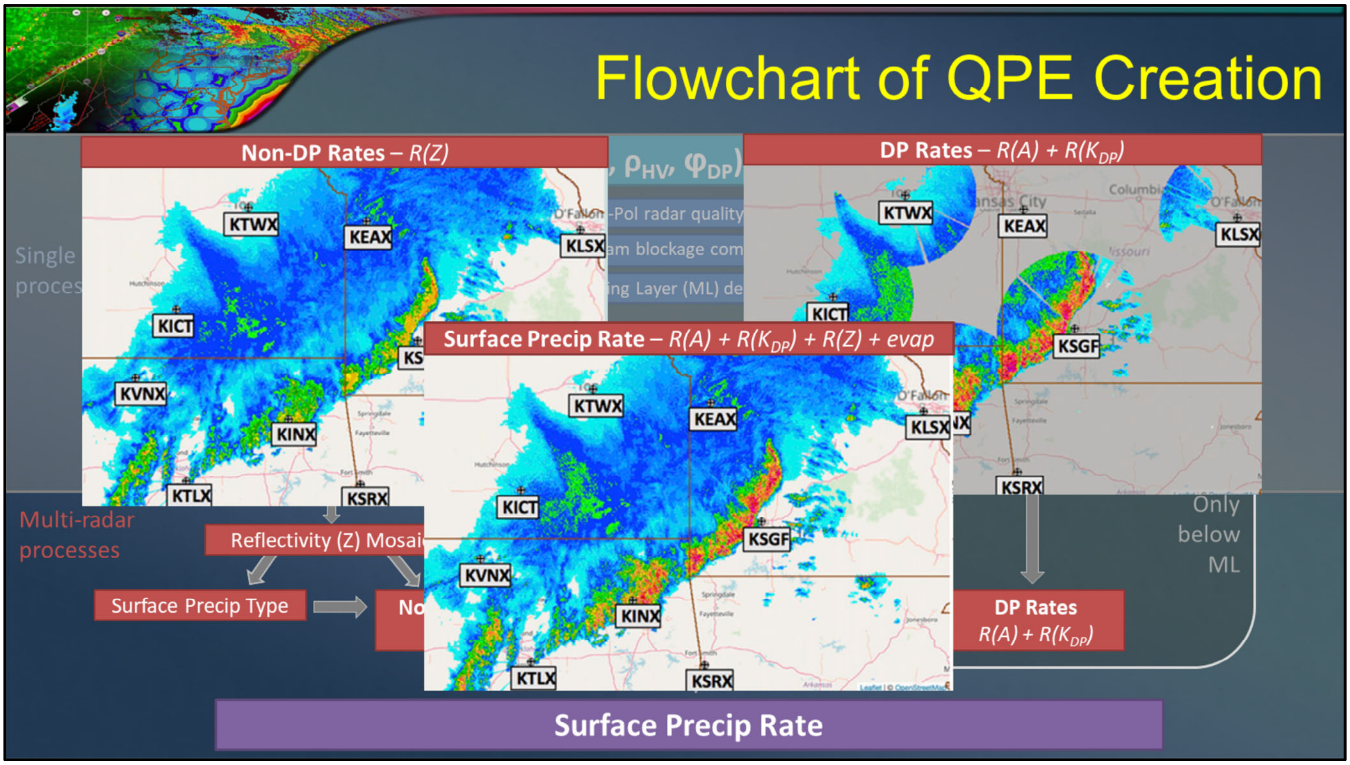
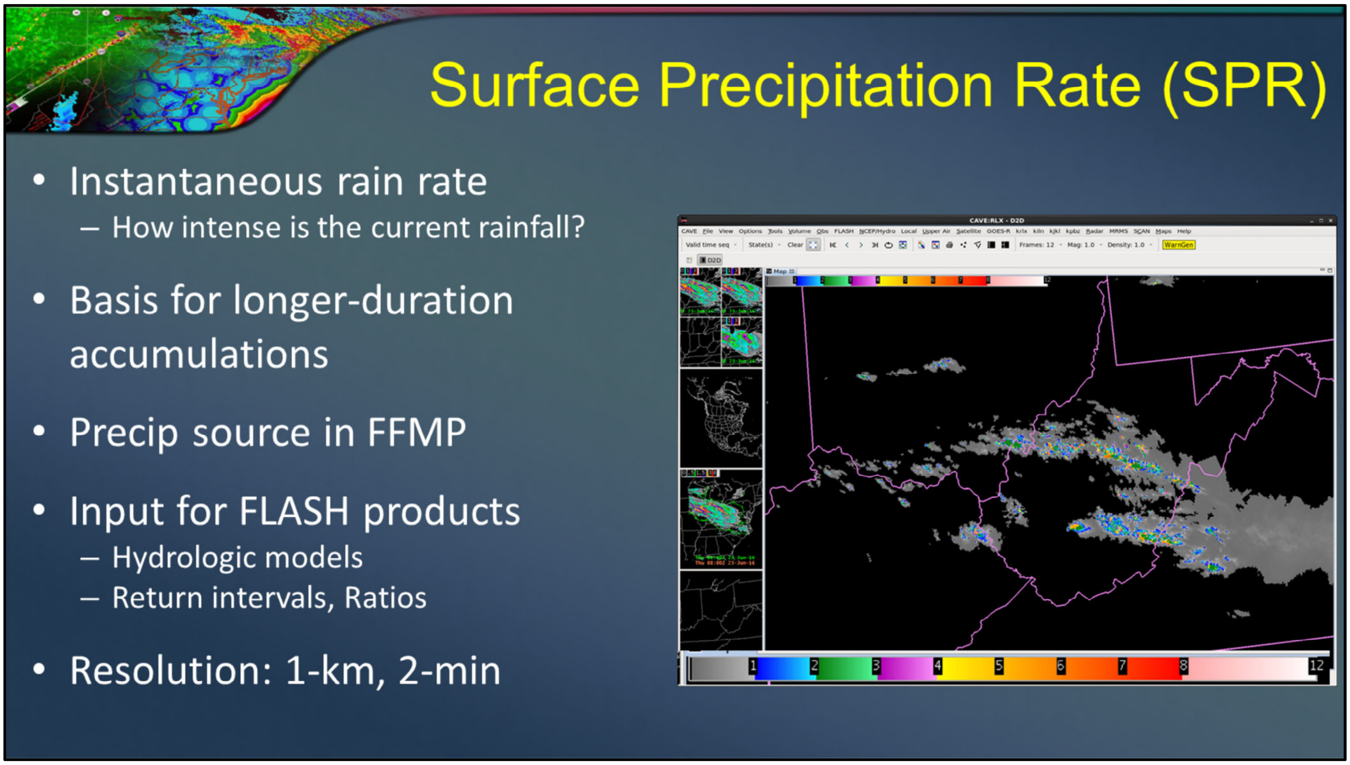


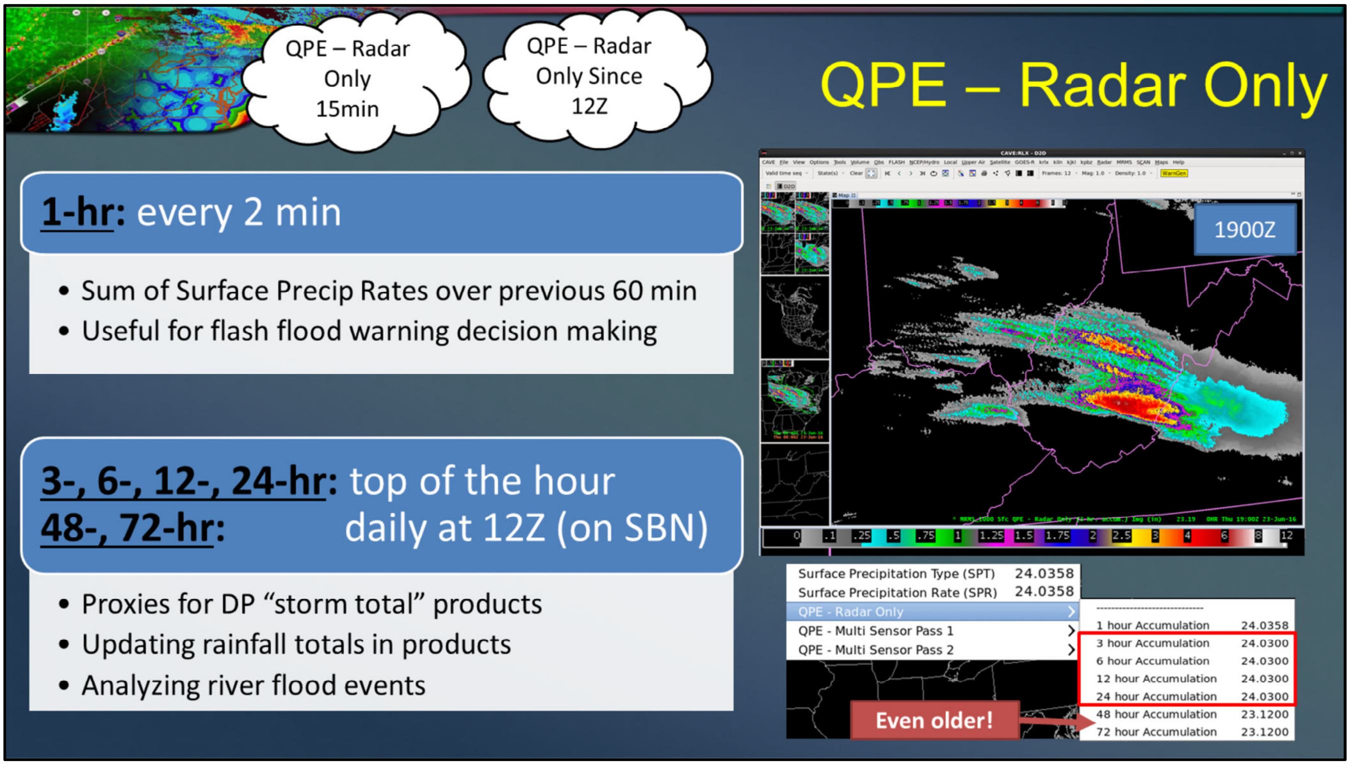
So just to summarize, we end up with a mosaic of non-DP rates used within and above the melting layer and a mosaic of DP rates only valid below the melting layer. They're merged and run through an evaporation correction to ultimately create the Surface Precip Rate product.



The Surface Precip Rate product is a flagship MRMS QPE product and is the foundation of many other products.

--One essential concept to understand is that this is an instantaneous rain rate product. By itself, it can be interpreted as how intense the current rainfall is.
--Integrated over time, it is the basis of longer duration accumulation products.
--It is a precip source in FFMP, and should be considered alongside your other options.
--And it is also the QPE input to most FLASH products, including the hydrologic models, return intervals (or ARIs) and QPE-to-FFG ratios.

--And since it updates every 2 minutes, it has the fastest update time of any precip source available in AWIPS.



Directly from the Surface Precipitation Rate product comes the QPE – Radar Only product.

The one-hour accumulation is a summation of the rate product over the previous 60 minutes. This is updated every 2 minutes, as shown by the example on the right which is valid at 1848UTC. Because of its quick update time, this product is useful during flash flood warning decision-making.

The rest of the accumulations are only created every hour, at the top of the hour. Or even less frequently for some of the longer durations. Here is a 3-hour accumulation, and it is valid at 19Z. Applications of the longer duration products include being proxies for the Dual-Pol Storm Total product, for updating current warnings with how much rain has fallen, and for analyzing longer-duration river flood events.

Here is the AWIPS menu for these products. From this, it is easy to see how the update times differ and how that can affect interpretation. In this menu, the longer accumulations are missing almost an hour's worth of data since they were last updated at 3Z, but the latest 1hr accumulation shows that it's now 0358 UTC. So be careful when interpreting the longer-duration products much past the top of the hour, as they will be missing data.

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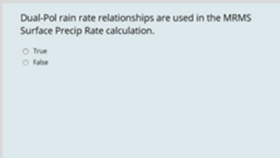
Important Precipitation Products

Radar-based Products	Multi-Sensor Products
Surface Precipitation Type (SPT)	Multi-Sensor QPE (Pass 1) (1, 3, 6, 12, 24, 48, 72-hr)
Surface Precipitation Rate (SPR)	Multi-Sensor QPE (Pass 2) (1, 3, 6, 12, 24, 48, 72-hr)
QPE – Radar Only (1, 3, 6, 12, 24, 48, 72-hr)	

Now we have discussed all of the radar-based products available in the MRMS QPE suite. The next section will be about the multi-sensor products.



Overview Recap 2

Quiz - 3 questions

Last modified: Wednesday, December 14, 2022 at 2:35:44 PM

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Important Precipitation Products

Radar-based Products	Multi-Sensor Products
Surface Precipitation Type (SPT)	Multi-Sensor QPE (Pass 1) (1, 3, 6, 12, 24, 48, 72-hr)
Surface Precipitation Rate (SPR)	Multi-Sensor QPE (Pass 2) (1, 3, 6, 12, 24, 48, 72-hr)
QPE – Radar Only (1, 3, 6, 12, 24, 48, 72-hr)	

At this point in the course, we have covered all of the radar-based products. So let's finish up with the multi-sensor products. As the name implies, these products use several inputs. Their purpose is to supplement radar-based QPEs with other sensors, particularly to gap-fill areas of poor radar coverage.

Since this is the first place we've talked about gauges, let's begin with understanding how gauges get quality controlled in MRMS.

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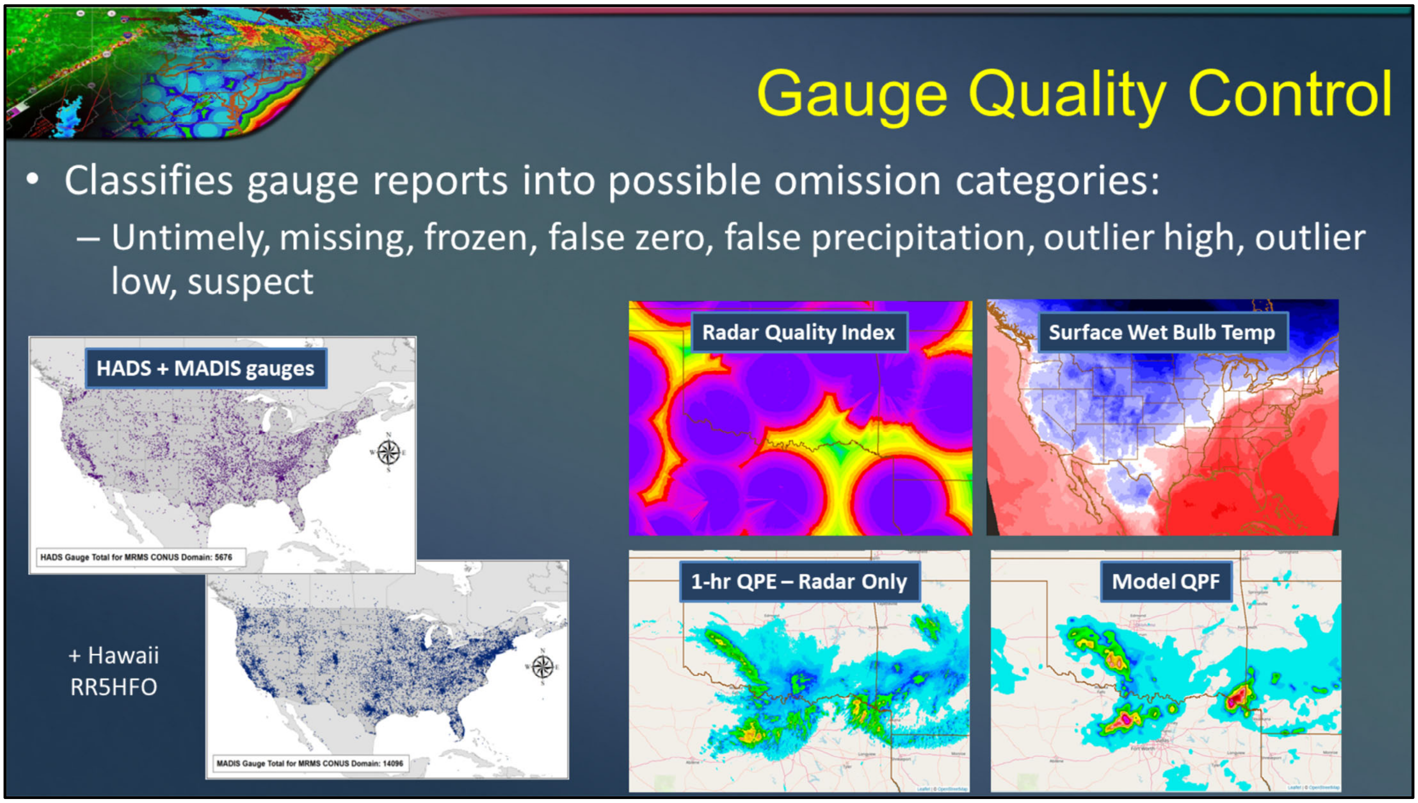

--Each of these products begins from the same foundation, which is the raw gauge data going through the Gauge Quality Control. The algorithm goes through a series of steps to determine if a gauge report falls into one of the categories that could cause it to be omitted in product generation.

--These categories are: untimely, missing data, may be frozen due to winter precipitation, report “false zero” or “false precipitation”, are considered outliers that are either too high or too low, or those that may be deemed suspect.

The QC uses a variety of inputs to go through a decision tree:
--The raw hourly gauge data that is being QC’ed comes from the HADS and MADIS networks.
--The Radar Quality Index provides a measure of current radar quality to determine whether gauge totals can be compared to radar estimates.
--In areas of good radar coverage, one-hour Radar Only QPE is compared to gauges to determine false zeroes, false precips, and outliers.
--Hourly surface wet-bulb temperature helps determine if a gauge is in an environment where it could be deemed frozen.
--And lastly, hourly model QPFs help check gauges that are outside of adequate radar coverage.

The details of this quality control are saved for the VLab reference material.

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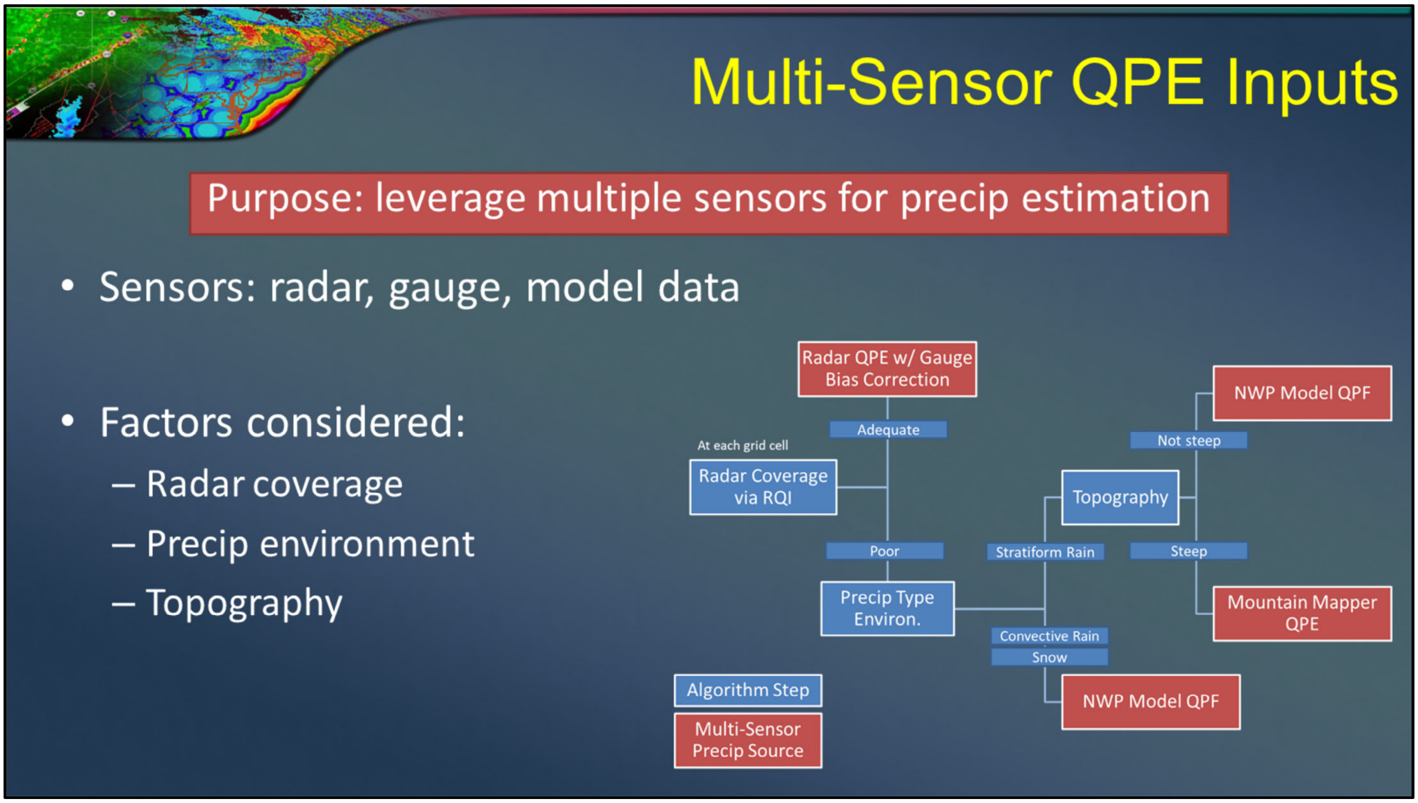

As mentioned on a previous slide, the Multi-Sensor QPE products were created to leverage multiple sensors for precip estimation. The algorithm prioritizes the use of radar, gauge, and model data at each grid cell using factors such as radar coverage, the precip environment, and topography.

On the next slide, we'll briefly cover the strengths and limitations of each of the inputs shown in this flow chart.

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Multi-Sensor QPE Inputs

	QPE – Radar w/ Gauge Bias Correction	Mountain Mapper QPE	NWP Model QPF *(CONUS domain = HRRR_CONUS)*
Definition			
Strengths			
Limitations			

***Details in Lesson 3 of the Hydro Products Course*

Here are the three fields that are mosaicked within the Multi-Sensor QPE. Let's summarize each one.

--The first product, the Radar w/ Gauge Bias Correction, applies a bias correction to the Radar Only accumulation product.

--This product is a good base for the Multi-Sensor QPE because it leverages the spatial coverage of radar data, but adjusts it using direct gauge observations at the surface.

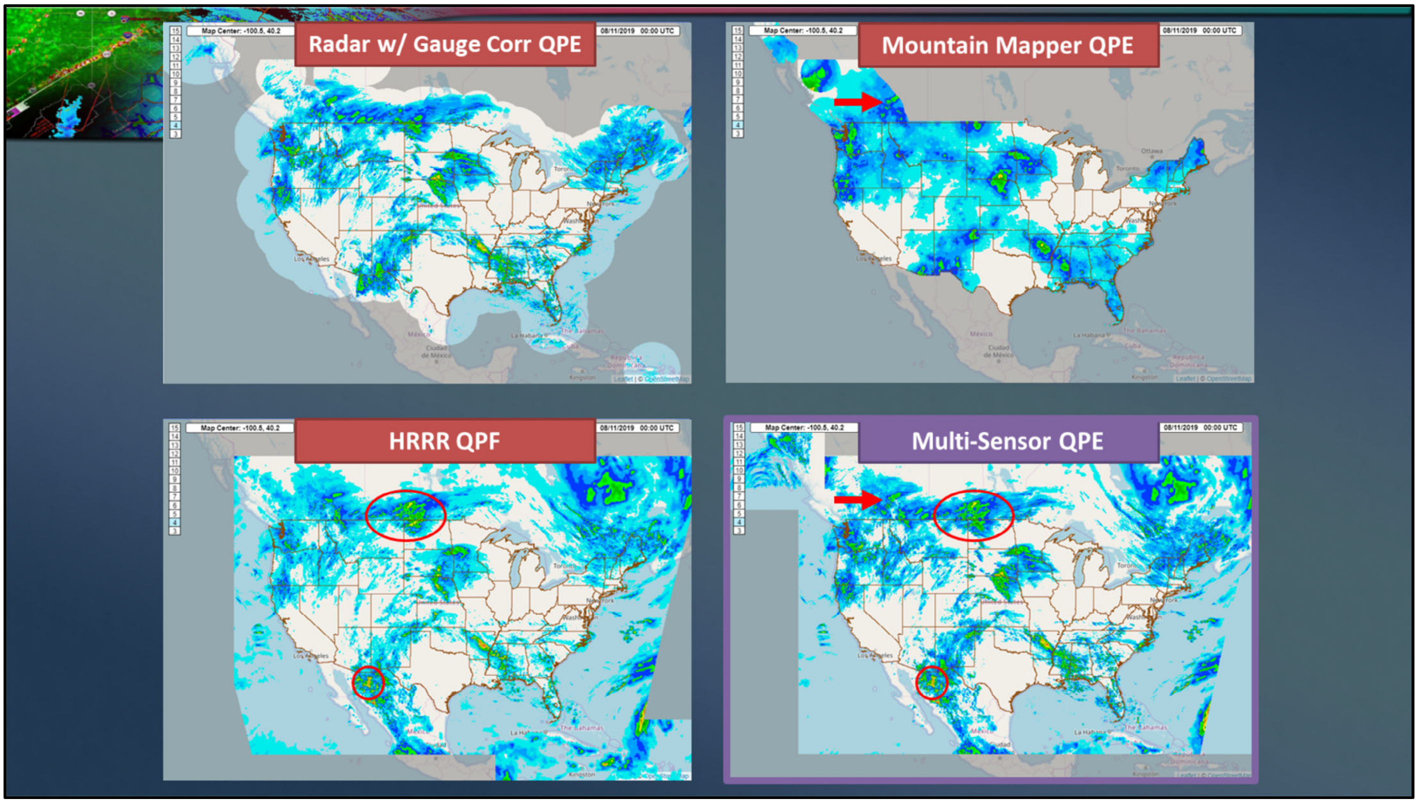
--When radar coverage is poor (based on the RQI product), the Multi-Sensor QPE algorithm turns to the other two options. So let's see how they help in these areas.

--The next solution is the Mountain Mapper QPE. This product is simply a comparison between gauges and gridded hourly precip climatologies. As such, it does not incorporate radar data.

--This is by design since it is meant to help in areas that the first product does not have good coverage. This means it tends to help in complex terrain, particularly along the Pactific coast in the Western U.S.

--Due to its reliance on gauge data, the MM performs poorly for small-scale convective precipitation and winter weather; so it is only applied to stratiform rain. Additionally, when the gauge network is sparse, the interpolation is far-reaching and can cause errors. Finally, when the real-time precip gradient strongly differs from the climatology, large errors can occur.

--Finally, hi-res NWP model QPFs fill in the rest of the gaps that Mountain Mapper does not, which include the snow and convective rain environments, and over the oceans. The main limitation is that QPFs are, by nature, forecasts. Additionally, since they cover the convective regions that the other two do not, this makes their role a lot harder since convective areas are traditionally harder to forecast. Note that the model used varies across domains, so refer to Lesson 3 for more info.



--Here is a side-by-side of all 3 inputs, valid at the same time for a 24-hour accumulation.

--The Radar with Gauge Bias Correction QPE is the base for the Multi-Sensor product. Next, Mountain Mapper, which blends precip climatologies and gauge data, has a much smoother appearance and is limited to areas where the climatology exists. Finally, the high-res model QPF looks similar to the radar-based solution, but adds much more coverage over Canada and the oceans.

--The algorithm takes these 3 pieces and mosaics them into the Multi-Sensor QPE, as seen here. In areas of good radar coverage (which is most of the domain), it is identical to the radar-based input. But in this example, the Mountain Mapper QPE is applied in a few areas, such as north of Idaho. Finally, the model QPF is used in snow regions, as shown here, and in convective regions with poor radar coverage, like here. And you can also easily see how it fills in parts of Canada and the oceans.

--While this example relies heavily on the radar-based solution, the Multi-Sensor QPE can have much more of its domain influenced by the other two inputs, especially in winter months when the radar quality is reduced due to lower melting layers across the country.

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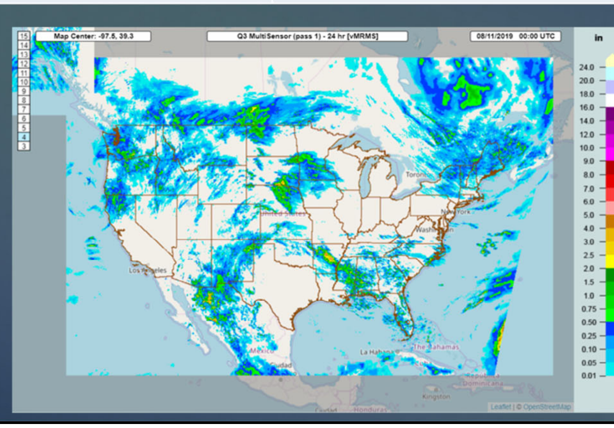
Multi-Sensor QPE

- Temporal resolution
  - hourly, at the top of the hour
- Products
  - 1-, 3-, 6-, 12-, 24-, 48-, 72-hr
- Applications
  - Update rainfall totals in Flash Flood Statements
  - Compare with previous hours' Radar Only QPE to get a sense of real-time biases in Radar Only QPE

Pass 1	Pass 2
20-min latency *(Ex: QPE valid at 01:00 UTC is released at 01:20 UTC)*	60-min latency *(Ex: QPE valid at 01:00 UTC is released at 02:00 UTC)*
Includes 10% of gauges	Includes 60% of gauges



It has a spatial resolution of 1-km by 1-km, has an hourly temporal resolution, and is created at the same accumulations as the Radar Only QPE.

The Multi-Sensor QPE was implemented as two products: Pass 1 and Pass 2. The differences are summarized in the table.

Even though the low temporal resolution and associated latencies hamper their use in flash flood warning decision-making, the Multi-Sensor products still have some applications. For one, they can be used to update rainfall totals in Flash Flood Statements. Additionally, you can directly compare previous hours' Radar Only QPEs to the Multi-Sensor products to get a sense of real-time biases in Radar Only QPE. Simple time-matching can help you quickly perform this comparison.

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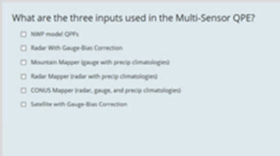

Overview Recap 3

Quiz - 4 questions

Last modified: Wednesday, December 14, 2022 at 2:39:25 PM

Properties

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User may view slides after quiz:	Any time
Show quiz in menu as:	Single Item

Edit in Quizmaker

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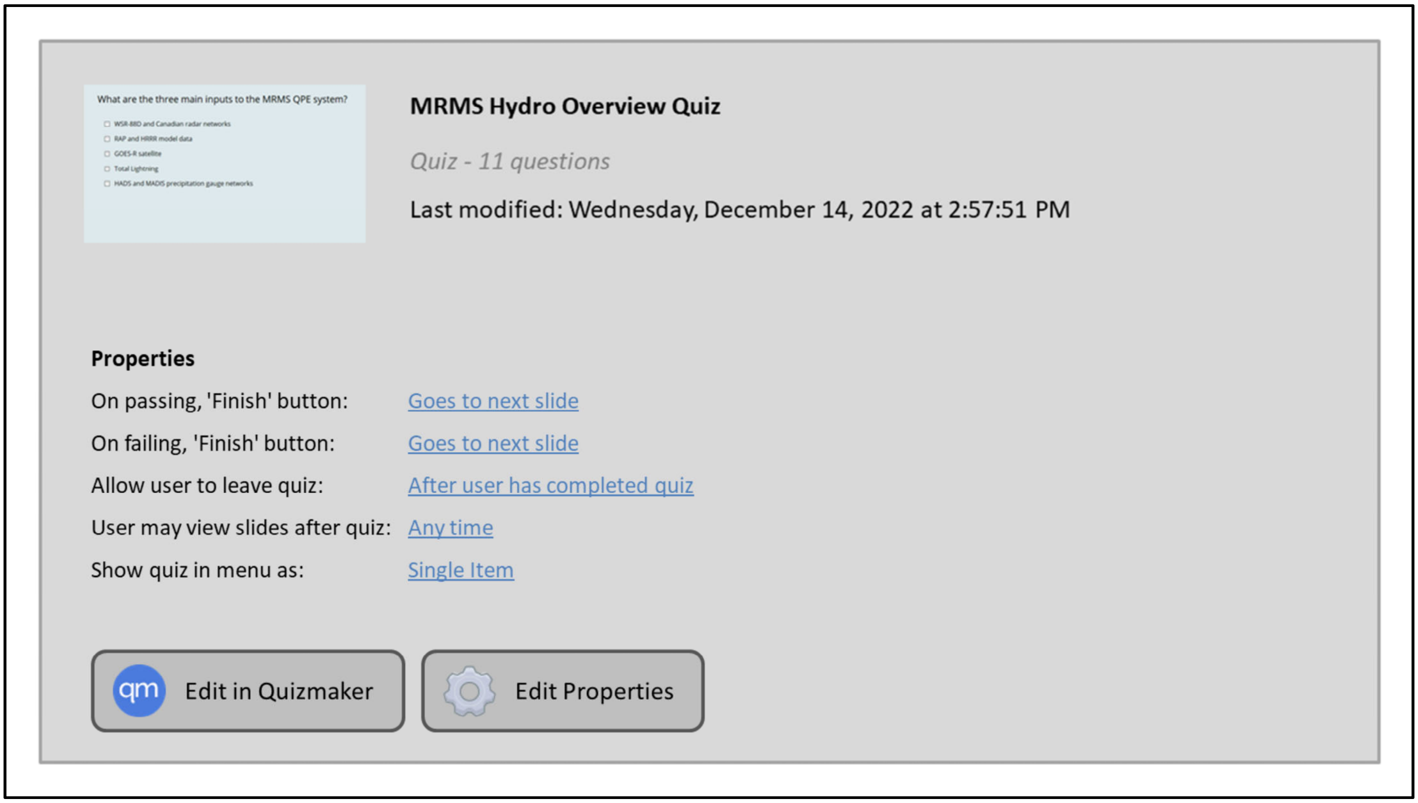
Important Precipitation Products

Radar-based Products	Multi-Sensor Products
Surface Precipitation Type (SPT)	Multi-Sensor QPE (Pass 1) (1, 3, 6, 12, 24, 48, 72-hr)
Surface Precipitation Rate (SPR)	Multi-Sensor QPE (Pass 2) (1, 3, 6, 12, 24, 48, 72-hr)
QPE – Radar Only (1, 3, 6, 12, 24, 48, 72-hr)	

--Alright, now we have covered all of the products available in the MRMS QPE suite.

--Don't forget there is A LOT more reference material available on the VLab, so check that out if you ever need to brush up on this content. The link is provided in the Resources tab.

--When you are ready, move onto the next slide to take the quiz and receive credit on the LMS.


What are the three main inputs to the MRMS QPE system?
WSR-88D and Canadian radar networks
RAP and HRRR model data
GOES-R satellite
Total Lightning
HADS and MADIS precipitation gauge networks
MRMS Hydro Overview Quiz
Quiz - 11 questions
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