Hail Size Determination from Three-Body Scatter Spikes Using Dual-Pol Radar

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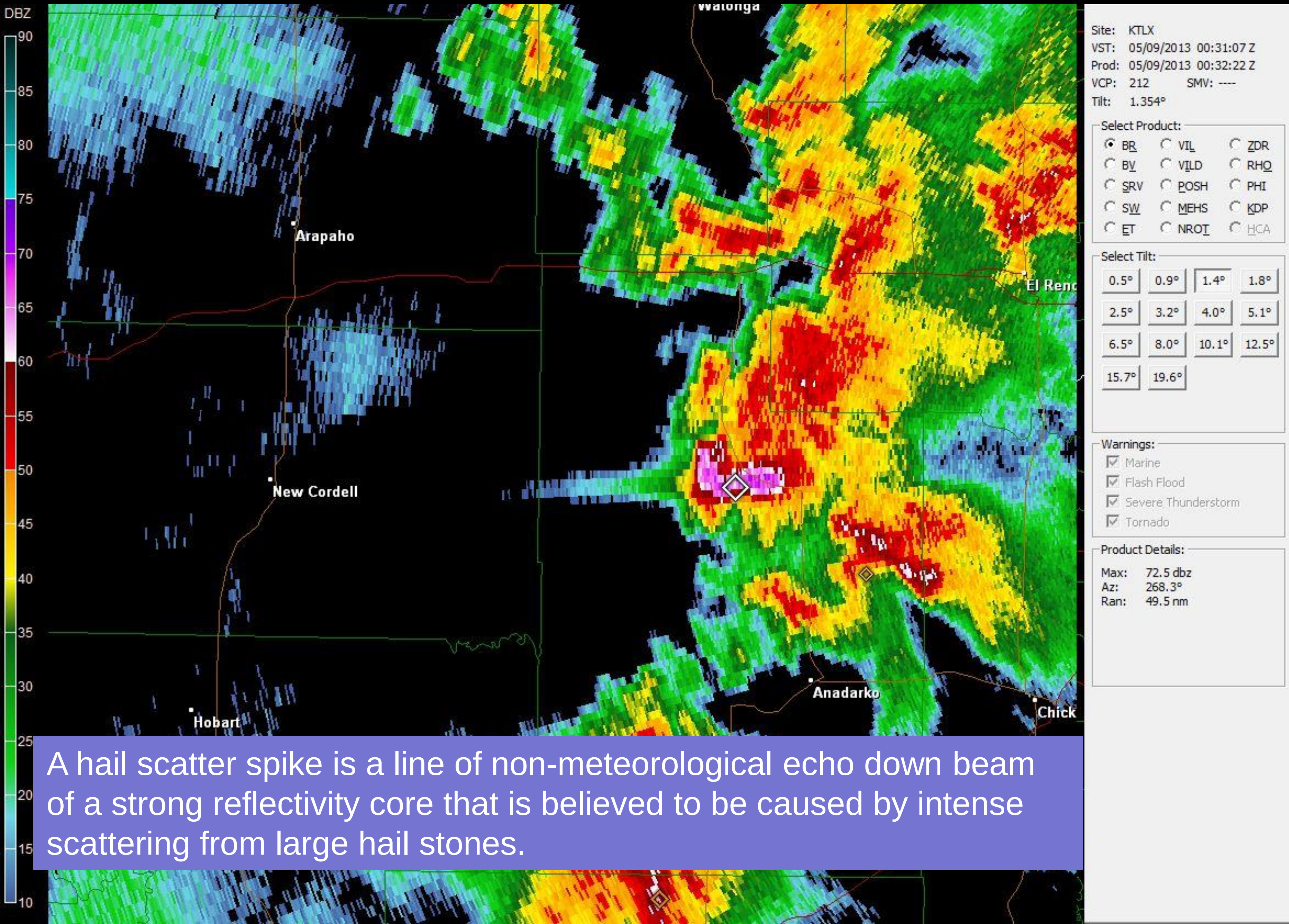
Example of a “good” scatter spike. Hail of 2” verified, GR2 software indicated 3”.

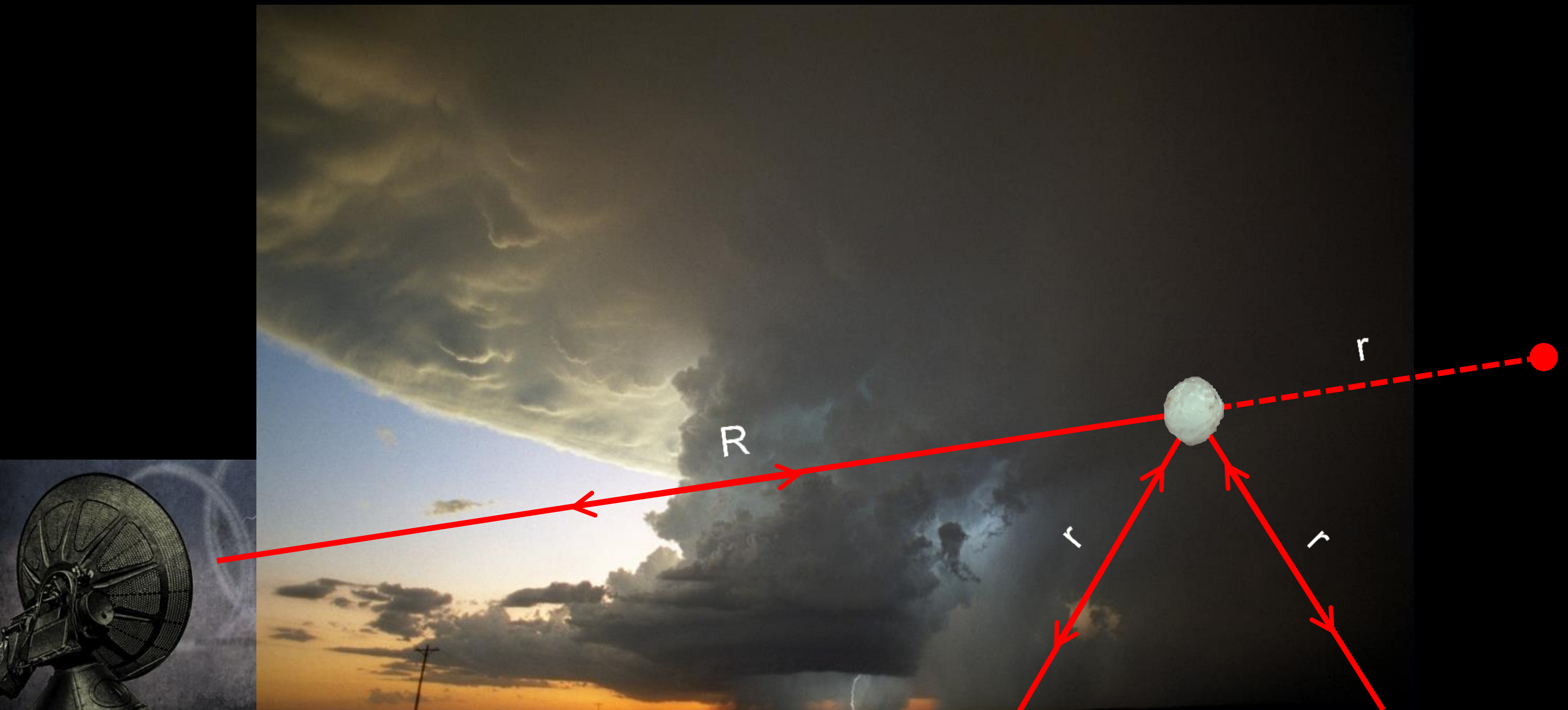


A hail scatter spike is a line of non-meteorological echo down beam of a strong reflectivity core that is believed to be caused by intense scattering from large hail stones.

Hail Spike Conceptual Diagram

Hail spikes result from a triple scattering mechanism. Radar energy is first scattered from hail stones at a range *R* from the radar in all directions. Some of this scattered energy is scattered a second time from ground targets below the hail. Some of this double scattered energy will scatter a third time off of the same hail targets back to the radar.

With a hail stone a distance R from the radar, the radar will present any ground targets from a reflecting ring on the ground a distance *r* from the hail stone, as meteorological targets at slant distance *R*+*r*.



Hail spikes were first reported in 1986.

Wilson, J. W., and D. Reum, 1986: The hail spike: Reflectivity and velocity signature. Preprints, *23rd conference on Radar Meteorology*, Snowmass, CO, Amer. Meteor. Soc. 62-5.

They have been though of as a somewhat rare phenomenon, however, two recent developments in the performance of the 88D has greatly increase the number of these signatures being reported:

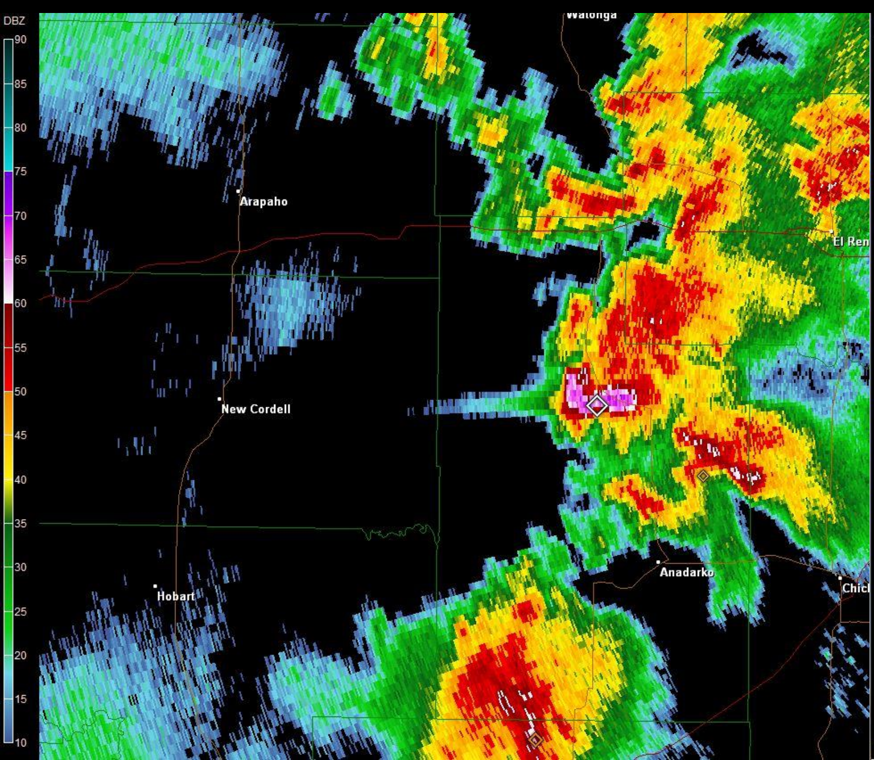
1. Implementation of super-res, or azimuthally over-sampled data collection has made the spikes clearer and easier to see.

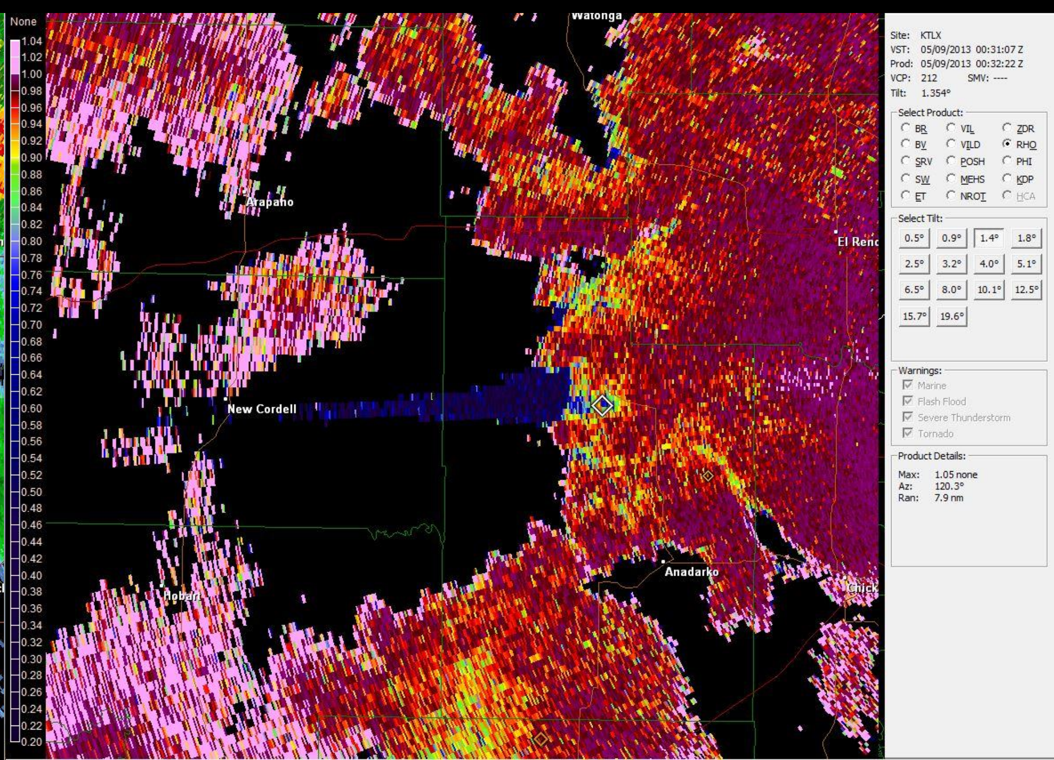
2. Implementation of dual-pol radars (correlation coefficient data, in particular) now allows multiple-scatter signatures to be easily found.

Seeing artifacts from multiple-scattering are now a common occurrence.

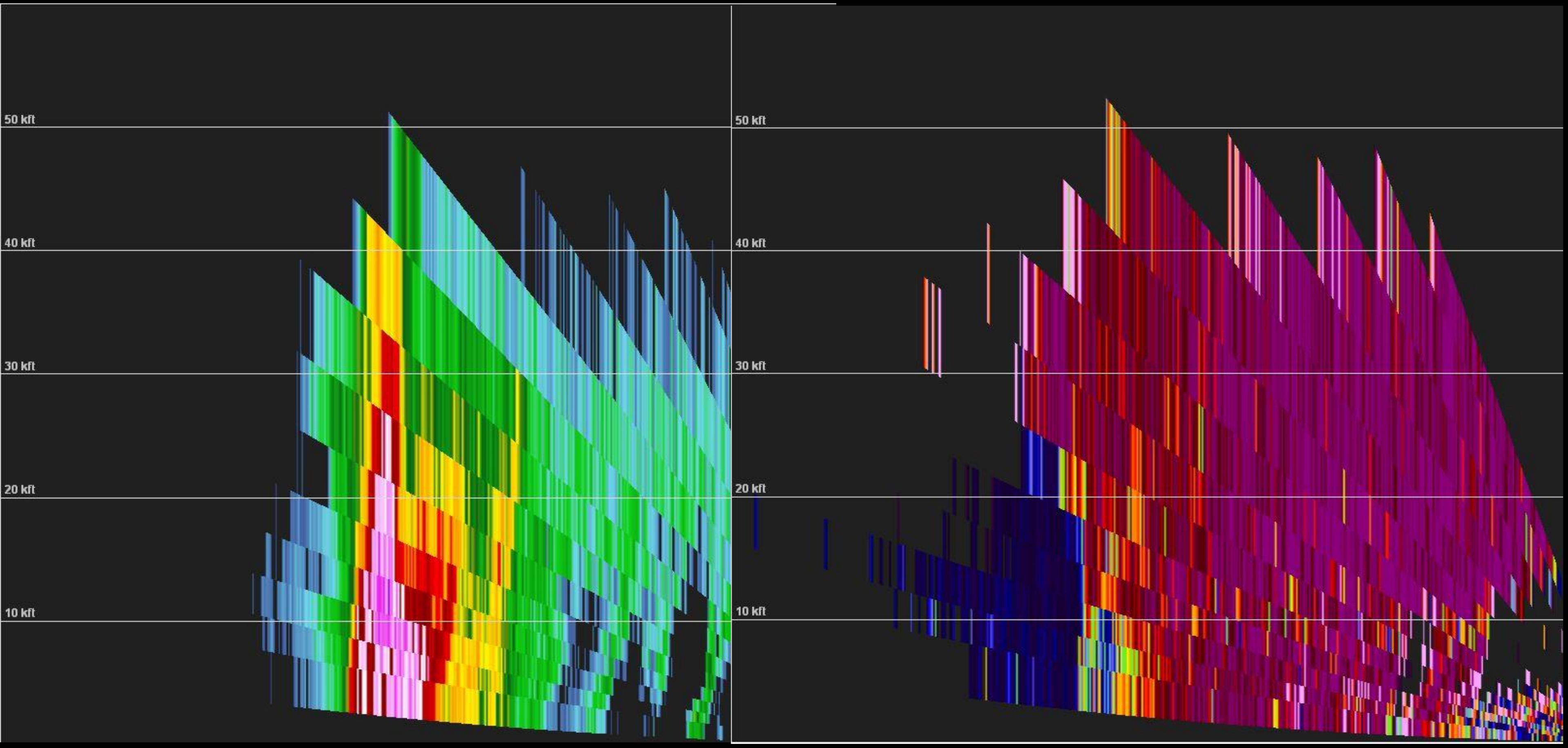
The left figure shows the previous example of a “good” spike in reflectivity, and the right figure shows the correlation coefficient (CC) data at the same time.

A greatly reduced CC to around 0.5 is a universal feature of these artifacts.

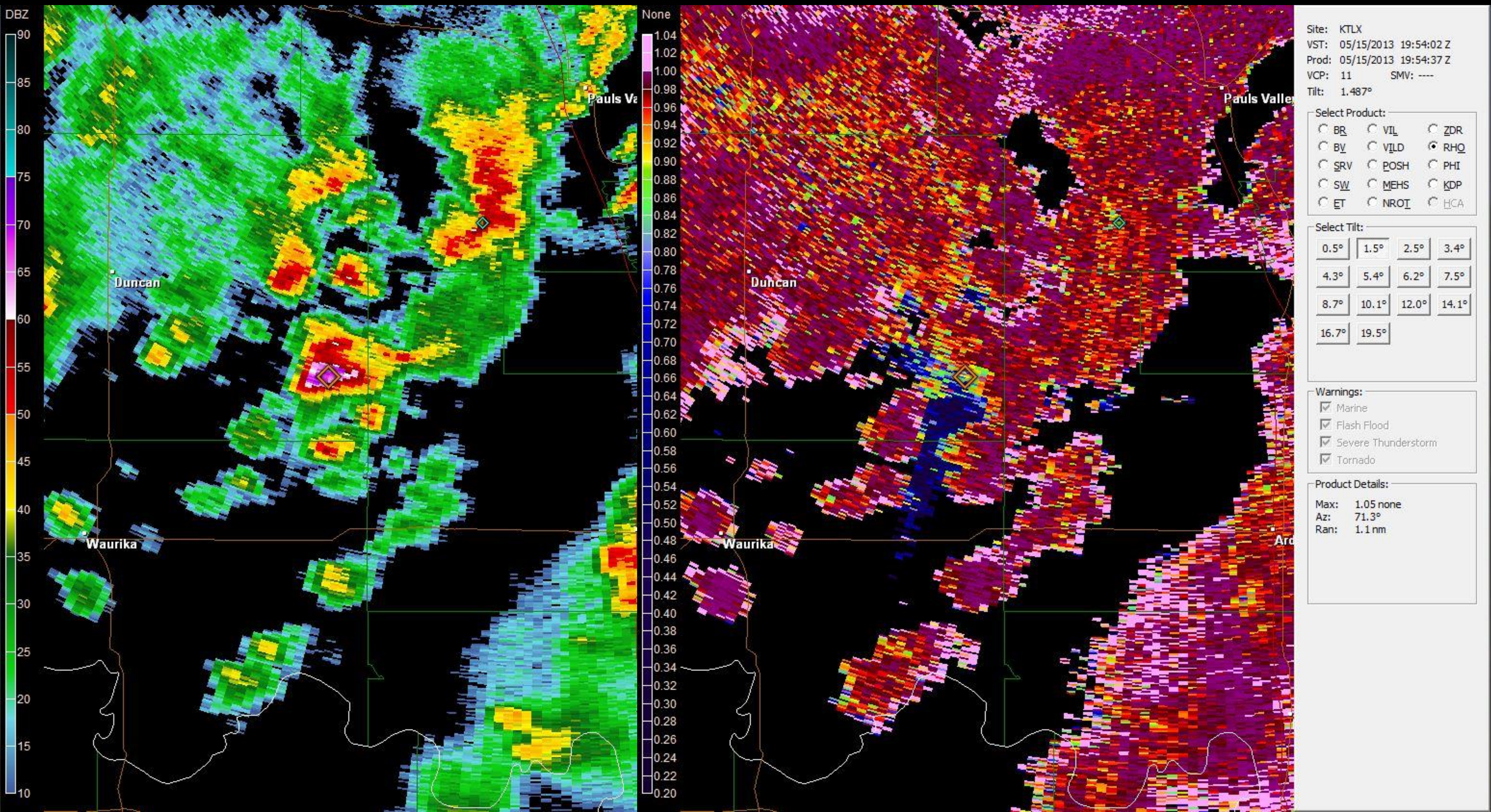




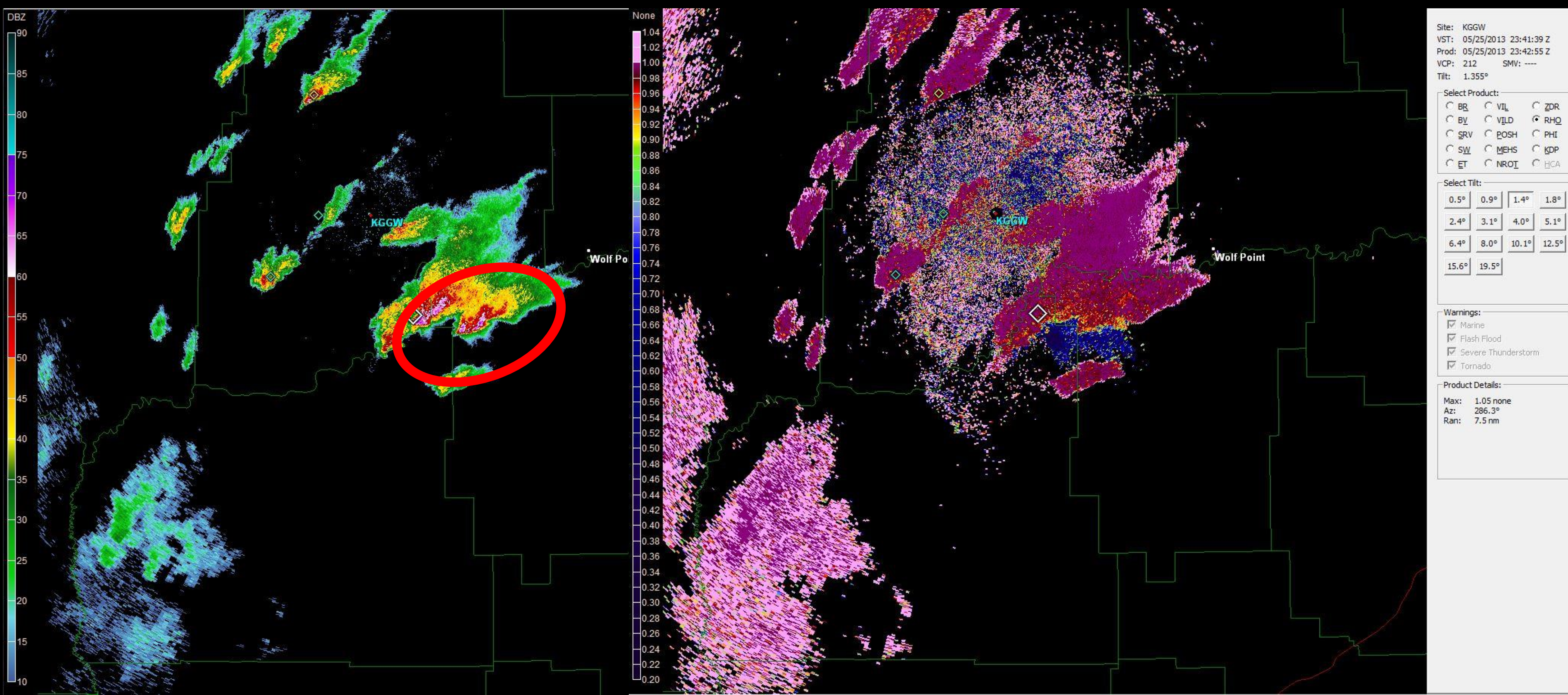
Same storm in RHI cross-section.



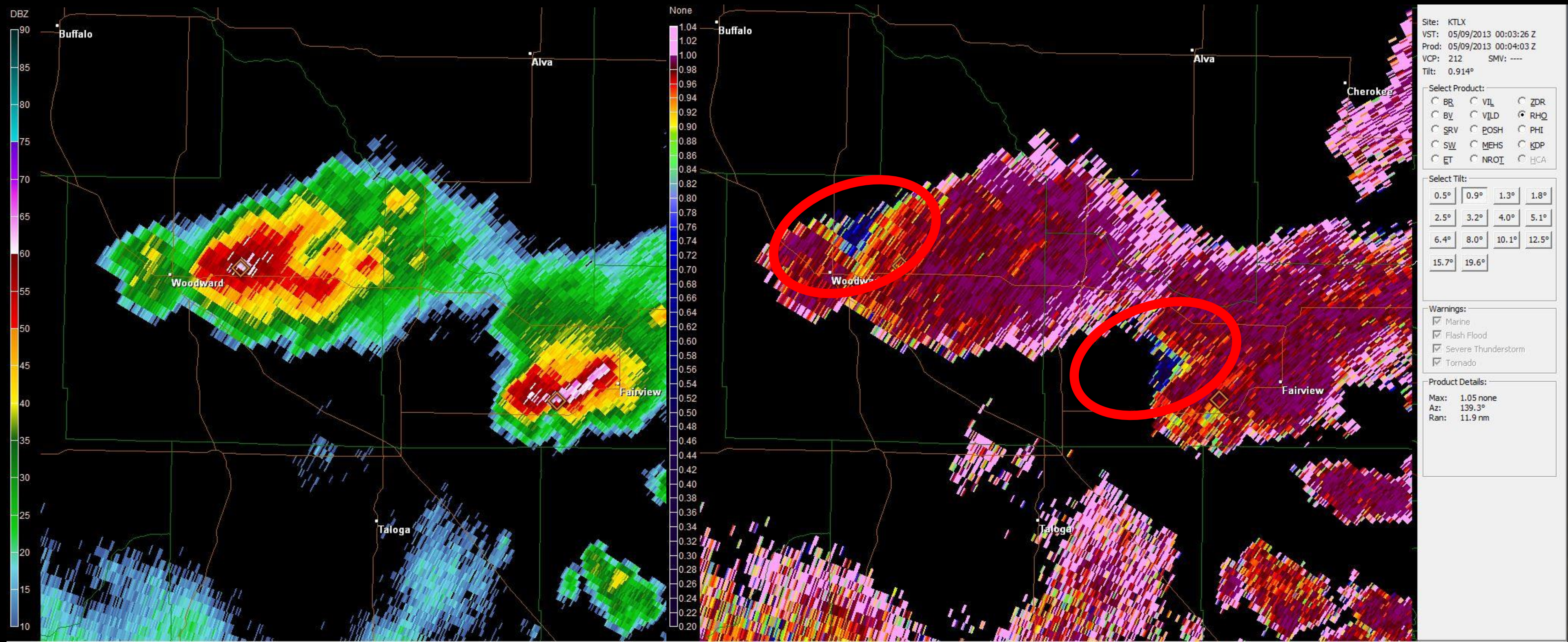
Another example of a “good” spike, which is not so noticeable in Z, due to a lot of other echo around the spike; but it is rather obvious in CC.



Example of several "moderate" spikes, which are marginally noticeable in Z, but very clear in CC.



A couple “weak” spikes, which can not be identified in Z at all, but which have low CC down beam of strong reflectivity cores which have GR2 large hail indications.



Given the much expanded ability to detect multiple scattering from intense reflectivity cores, and the association of such artifacts with large hail, can these artifacts be used to reliably identify severe hail for the purpose of issuing a warning?

Severe hail is hail of 1” in size or larger.

At one time, it was believed that a scatter spike was a sure sign of severe hail. However, cases of scatter spikes with no severe hail, or even no hail verified at all, have caused people to doubt this.

Zrnic et al. (2010) developed the theoretical underpinnings of relating hail size to scatter spikes:

Zrnic, D., G. Zhang, V. Melnikov, and J. Andric, 2010:
Three-Body Scattering and Hail Size. *J. Appl Meteor. Climatol.,* **49**, 687-700.

Unfortunately, Zrnic et al. cast grave doubt on the utility of scatter spikes.

The radar cross-section of the ground is important theoretically, and is generally not accurately known. The type of hail (wet, dry, spongy) and the size distribution function of the hail also need to be known, and are not well-characterized.

More importantly, the function to invert scatter spike intensity to hail size is non-unique, providing several possible hail sizes for the same spike.

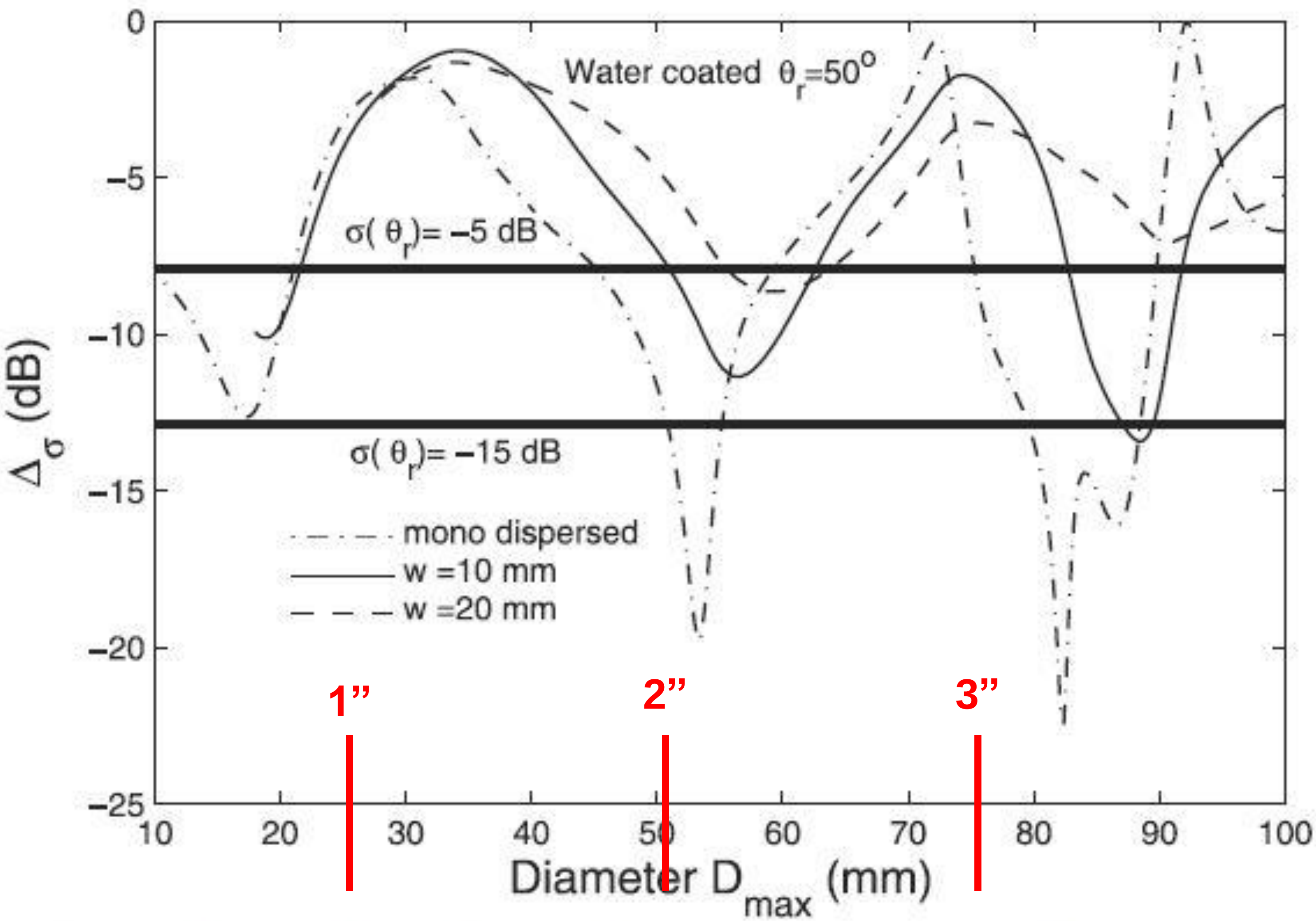


FIG. 3. Size functions for a uniform distribution of water-coated hail. On the abscissa are the diameter of monodispersed hail and the maximum diameters of hailstones that have a uniform distribution 10 and 20 mm wide. The forward-scattering angle is 50°.

From Zrnic et al. (2010) for WET HAIL. In this example, hail could have been .5”, 2”, or 3.5”.

However, Zrnic et al., also found that for dry hail, there is a much simpler size function with mostly unique solutions, at severe hail sizes.

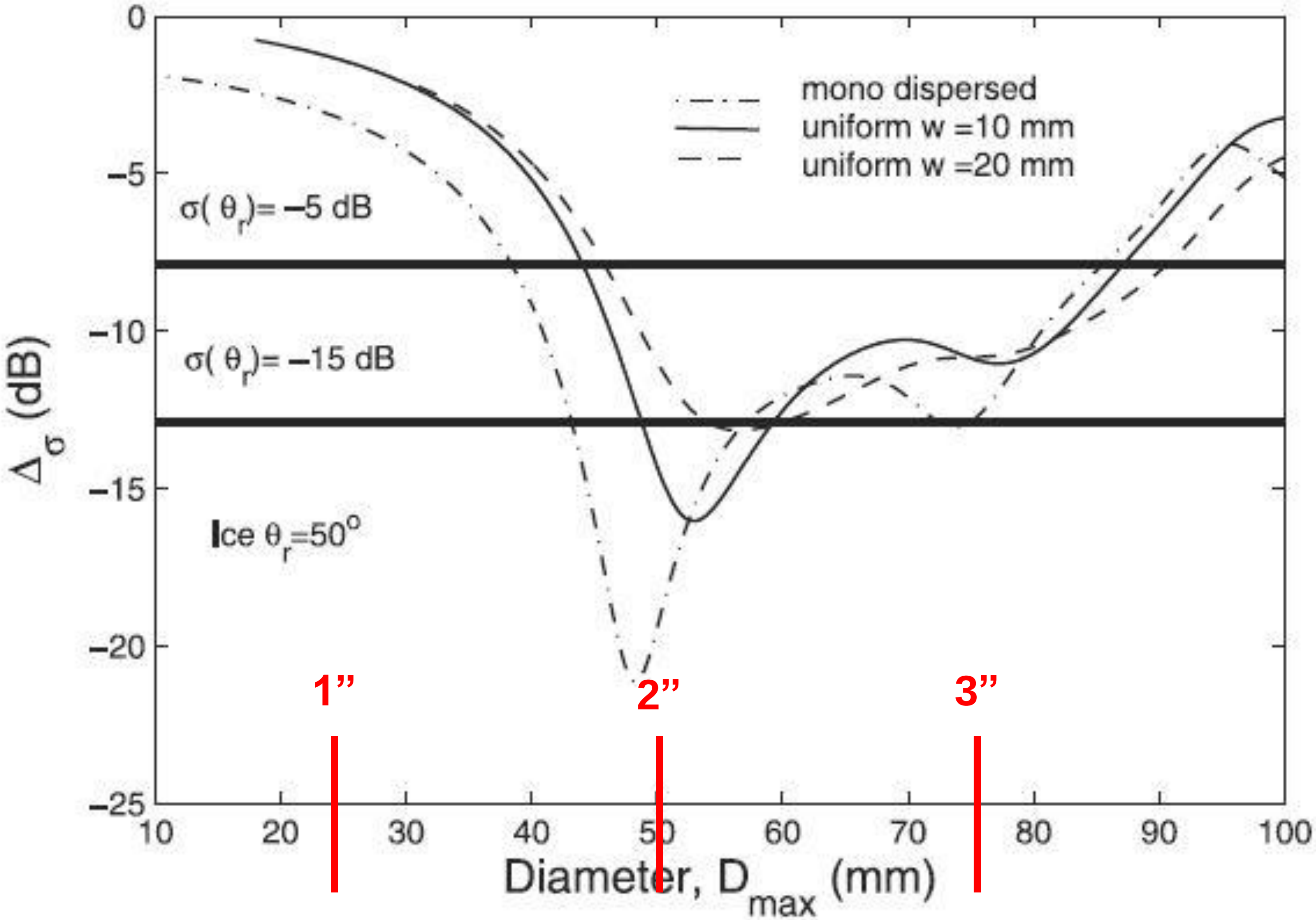


FIG. 5. Size functions for a monodispersed and two uniform distributions of dry hail. The abscissa indicates the diameter of monodispersed hail and the maximum diameters of hailstones that have a uniform distribution 10 and 20 mm wide.

From Zrnic et al. (2010) for DRY HAIL, implying the strongest spikes for hail around 2” in size, and minimal spikes for hail below 1”.

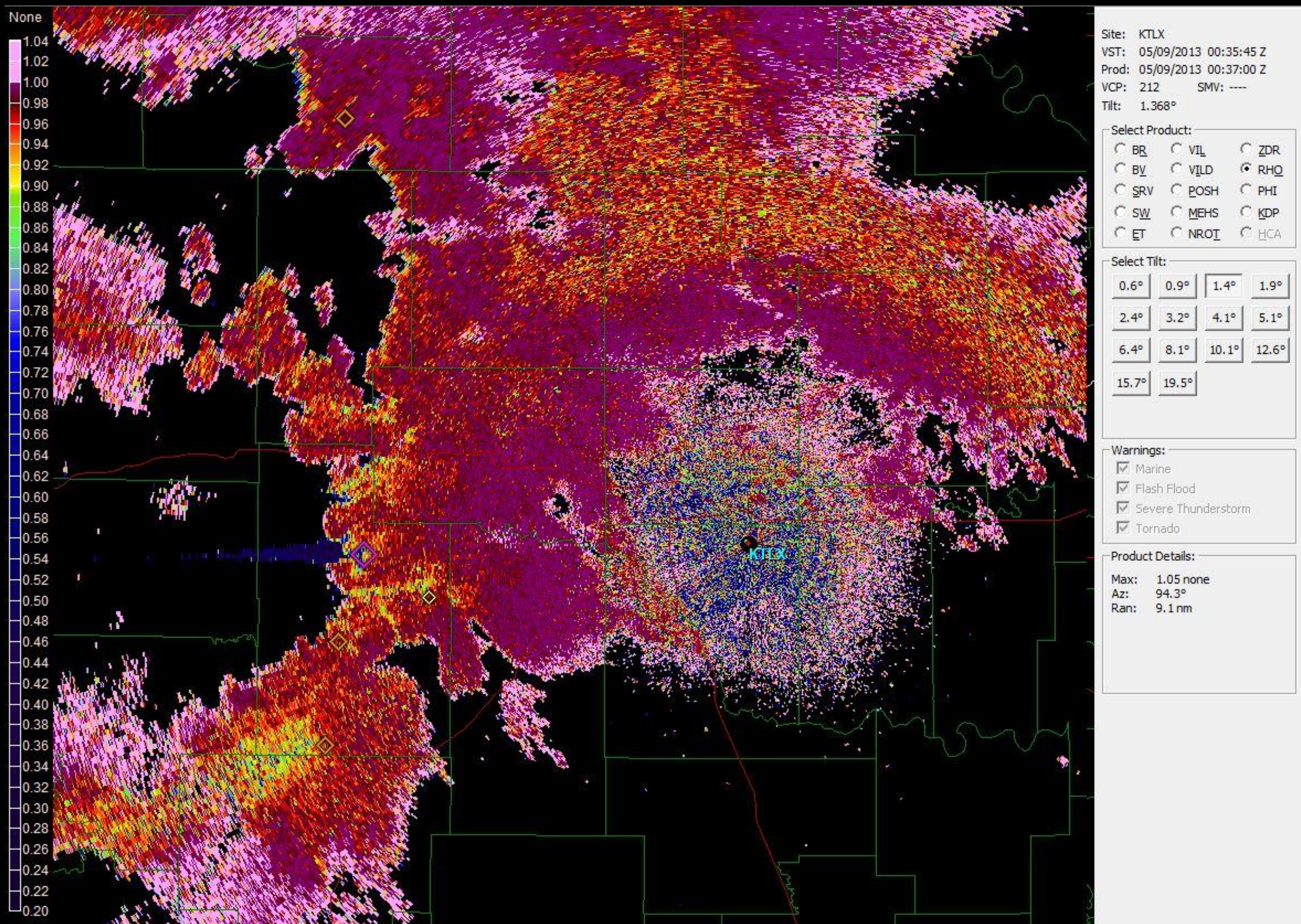
So, if we restrict ourselves to dry hail, there might be some hope in using hail spikes.

As it happens, most storms with hail have both dry and wet hail, with dry hail expected above the melting layer (ML), and wet hail below.

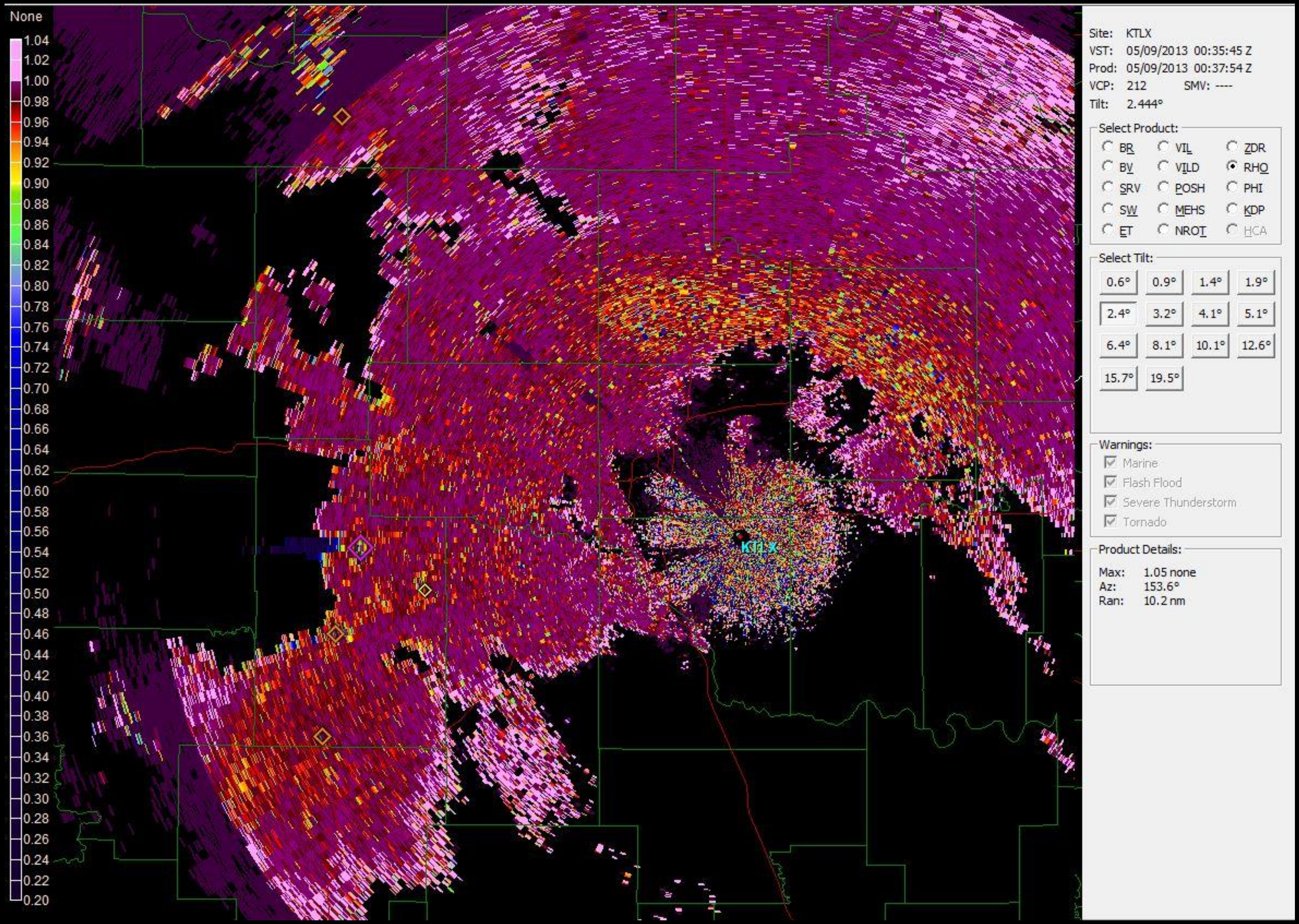
There are 3 ways to discriminate dry from wet echo:

Use KDP (which is sensitive to liquid water)
Use CC (which is depressed in the ML)
Use a sounding from the nearest RAOB or model analysis.

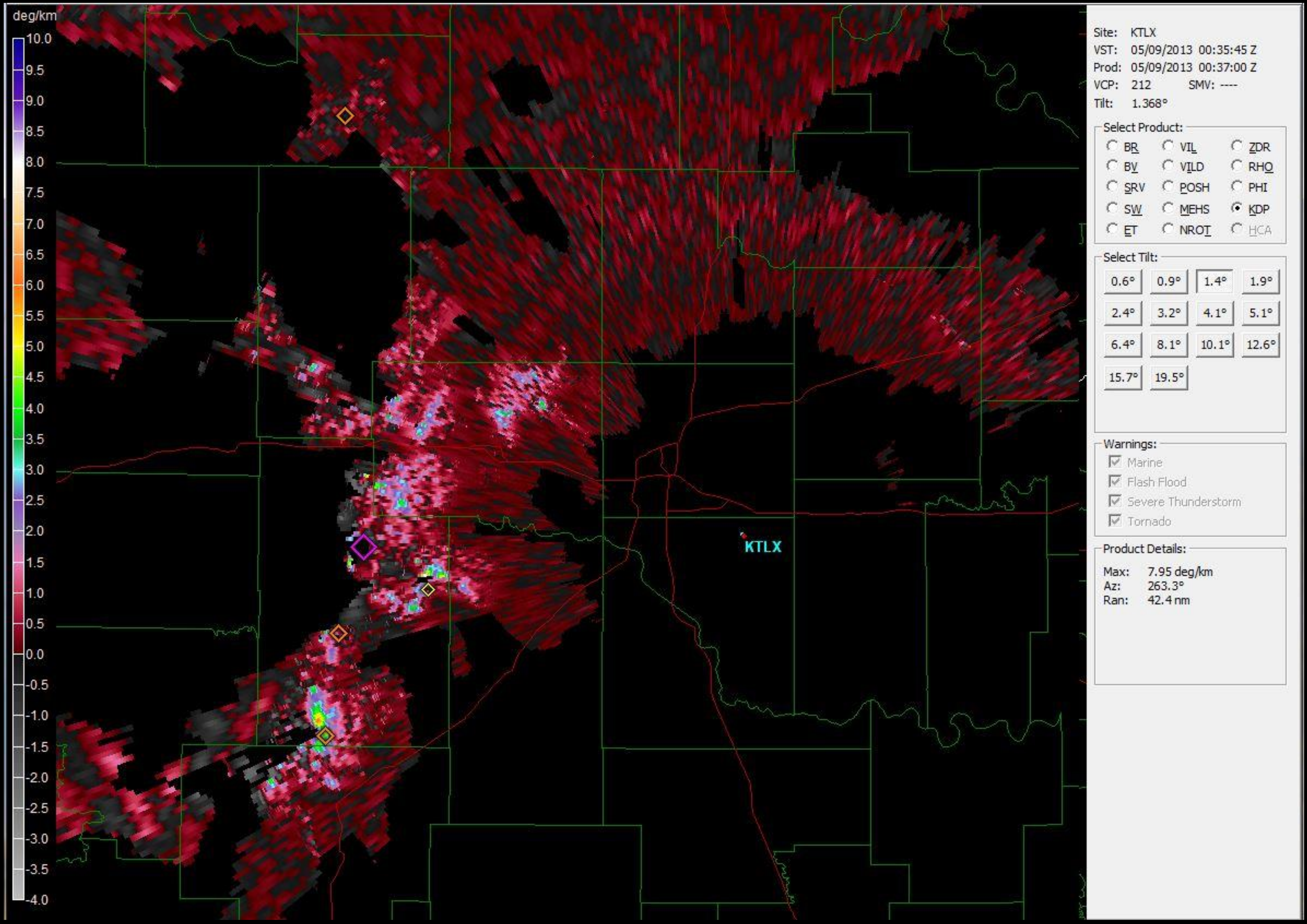
From the “good” spike case earlier, the CC data shows the reflectivity core was in the melting layer. The melting layer shows as a band of low CC in the .9 to .95 range.



However, for the next tilt up, we still have a scatter spike, from a core above the ML.



KDP from same case also works to directly show areas with liquid, though the product tends to be very noisy. The easiest approach is probably to just use a sounding for knowledge of the ML height.



Hail verification is problematic for various reasons. Many storms probably have severe hail that goes unverified; and verification size is often exaggerated.

If we only examine cases where severe hail verified (the easiest thing to do), then if “better” hail spikes tend to occur with the larger hail, then the concept probably has some value.

Examined storms with verified hail (from Storm Data) for 40 separate storms, from May through August 2013 with 88D data from the KGGW radar (9 days) and KTLX radar (8 days).

The protocol was to examine each storm for evidence of multiple scattering, primarily by examining CC at all tilts, and to classify and such spikes as:

NONE, WEAK, MODERATE, or STRONG

The multiple scattering had to originate from a reflectivity core that was above the ML, or it would be classified as “NONE”.

Reported hail sizes ranged from 0.75” to 3”.

The ML varied from 9200’ to 16000’.

RESULTS

Quality of Spike	Average Verified Hail Size
None (N=13)	1.2”
Weak (N=13)	1.3”
Moderate (N=12)	1.7”
Strong (N=2)	1.8”

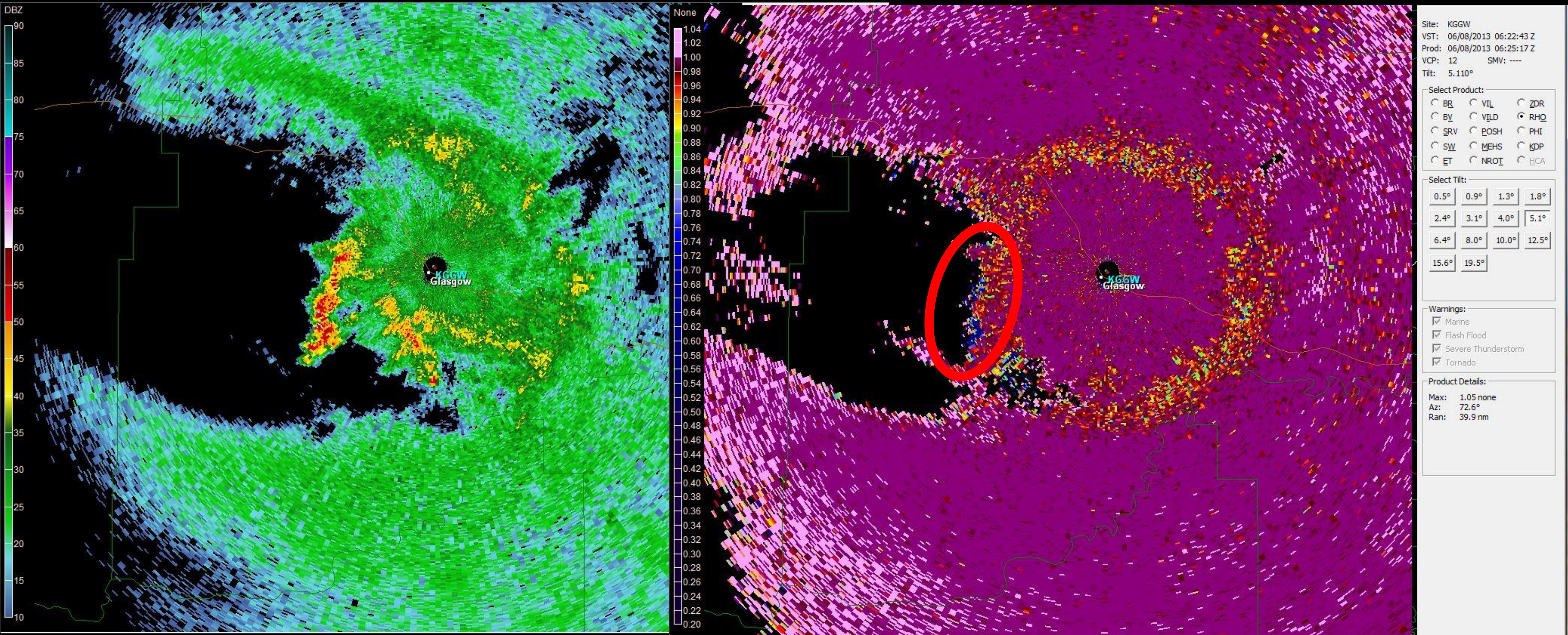
68% of the cases had a scatter signature above the ML, and only 2 cases with scatter below the ML were classified as “NONE” for no spike above the ML.

All 6 cases of 2”+ hail had either a MODERATE or STRONG spike above the ML.

We also found 1 case of weak multiple scatter from heavy rain (as predicted by Zrnic et al).

This case had 1.2” of rain in a short period of time, with no hail.

Note that echo is in the ML.



SUMMARY

Prior to the advent of dual-pol data, you could find scatter spikes in 30% of severe hail cases. Using dual-pol CC data, you can now find some scatter in 70% of severe hail cases, and “MODERATE” or “STRONG” spikes in 40% of such cases.

Quality of scatter spike does scale with hail size, with stronger spikes being associated with larger hail.

Theoretically, hail spikes are only useful for the part of the storm containing dry hail, though we have not found many actual cases where this discrimination was necessary to eliminate false positives.

RECOMMENDATIONS

Operationally, storms which have a moderate or strong scatter spike above the ML should probably be considered to most likely have severe hail.

Storms with weak evidence of multiple scattering above the ML should be considered severe only if severe hail size is confirmed by some other method.

END