A Radar-Based Assessment of the Detectability of Giant Hail

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“Severe” Hail

1 inch diameter (25 mm)

“Significant” Hail

2 inch diameter (51 mm)

“Giant” Hail

4 inch diameter (102 mm)

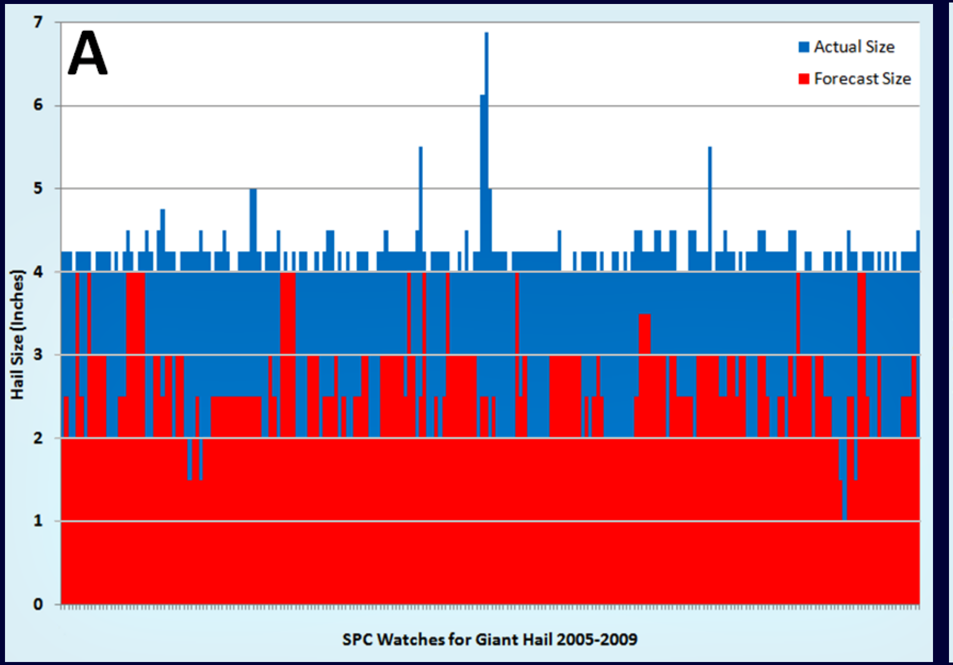
Overview

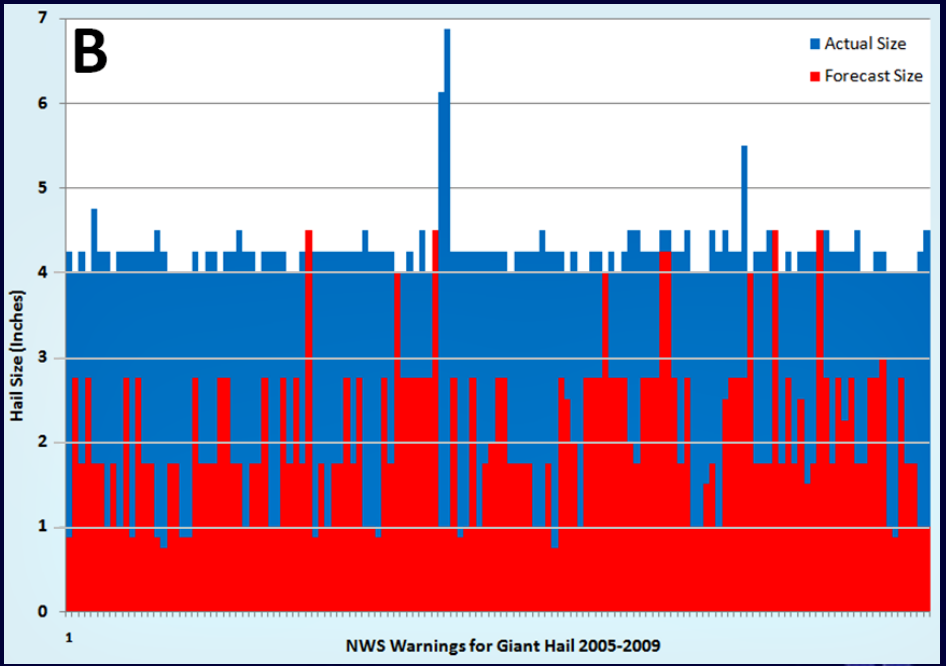
- Giant hail infrequent phenomenon – less than 1% of US hail reports
- Likely underrepresented in Storm Data (rural areas, lack of widespread aggressive spatial verification)
- **These high-end events have potential to cause *extreme damage* to property and a *substantial threat to exposed life***
- IWT partners take action when giant hail imminent (‘severe’ not equal)

Where are we operationally?

- Operational prediction of giant hail (*size in general*) has been challenging
- **Need to determine the predictability/detection of giant hail -and- if possible, improve advanced recognition of these events**
- Sample benefits from investigating known upper threshold hail reports
- **Identify radar-based signatures** of giant hail producing storms

Forecasted Maximum Hail Size (2005-09)





SPC Watches

Predicted 4.00+ in. prior to report (**8%**)

Avg. underestimated size: **1.66 in.**

NWS Warnings/SVS

Predicted 4.00+ in. prior to report (**7%**)

Avg. underestimated size: **2.19 in.**

- **23%** NWS warnings forecasted penny-quarter sized hail
- **26%** giant hail events associated with tornado warnings
- Most NWS tornado warnings contained no hail size information
- NWS tendency to use golfball or baseball (1.75 or 2.75 in.) to convey ‘large hail’

Watch Product

THE NWS STORM PREDICTION CENTER HAS ISSUED A TORNADO WATCH FOR PORTIONS ABC.

TORNADOES...**HAIL TO 4.0 INCHES IN DIAMETER**...THUNDERSTORM WIND GUSTS TO 70 MPH...AND DANGEROUS LIGHTNING ARE POSSIBLE IN THESE AREAS.

Warning Product

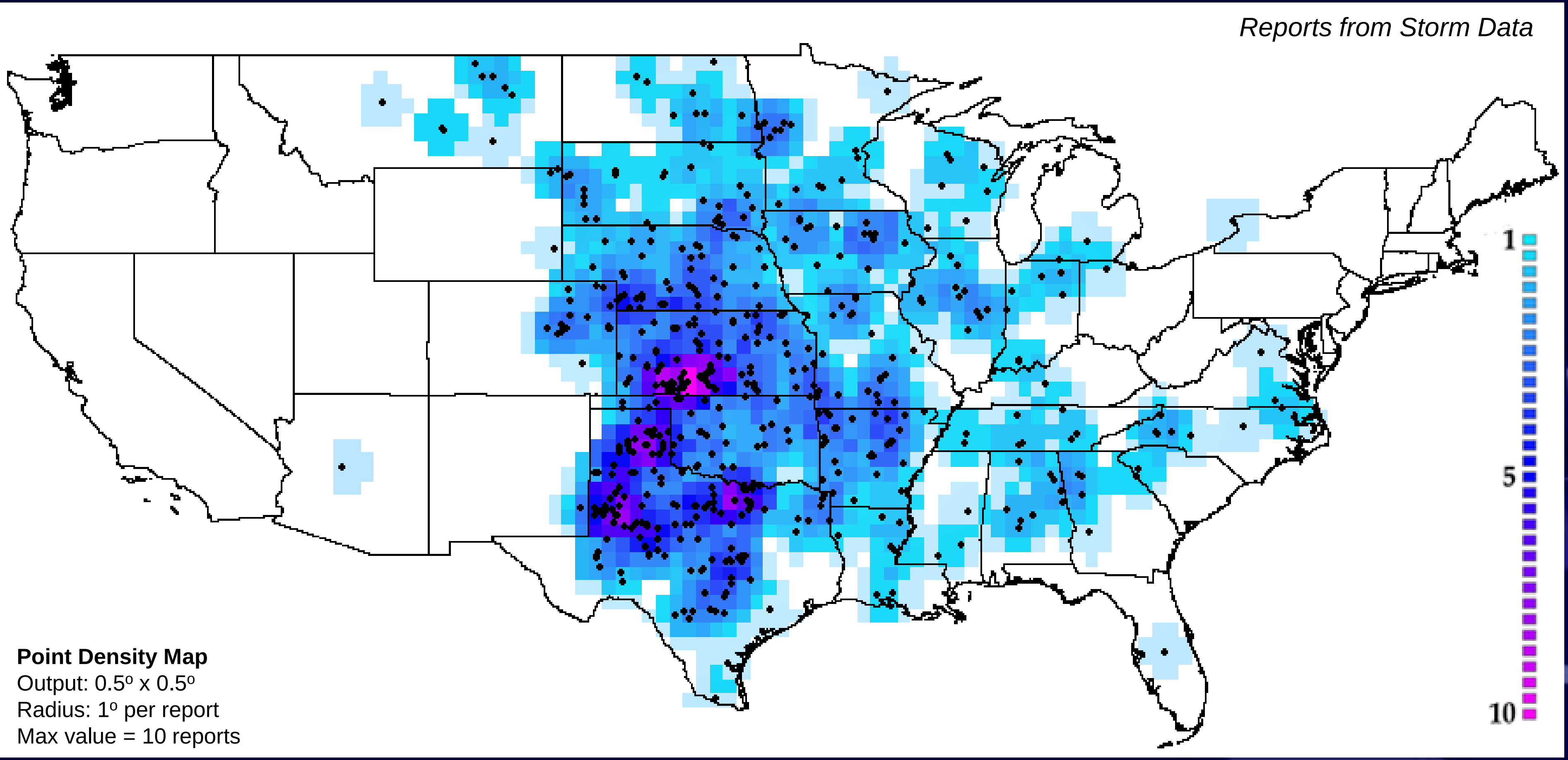
* AT 800 PM CDT...NATIONAL WEATHER SERVICE DOPPLER RADAR INDICATED A SEVERE THUNDERSTORM **CAPABLE OF PRODUCING GRAPEFRUIT SIZE HAIL.**

LARGE DESTRUCTIVE HAIL WILL OCCUR WITH THIS STORM. FOR YOUR SAFETY MOVE INDOORS NOW...AND STAY AWAY FROM WINDOWS.

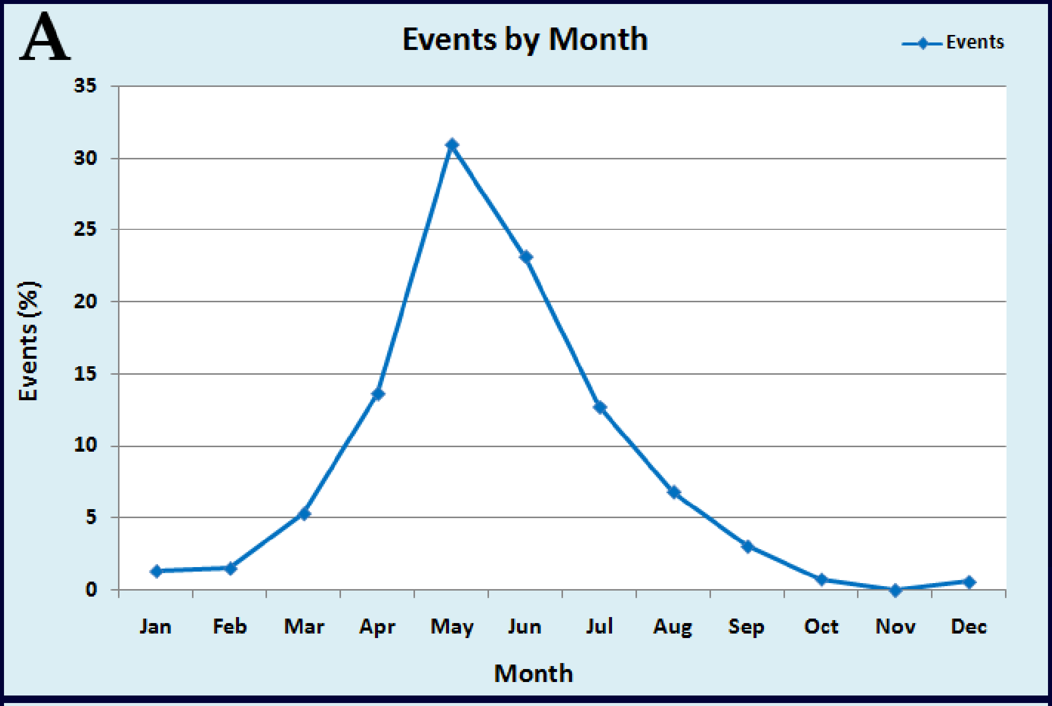
LAT...LON 3966 9579 3966 9601 3977 9598 3979 9597 3983 9578
TIME...MOT...LOC 2315Z 272DEG 14KT 3973 9591
WIND...HAIL 60MPH 4.00IN

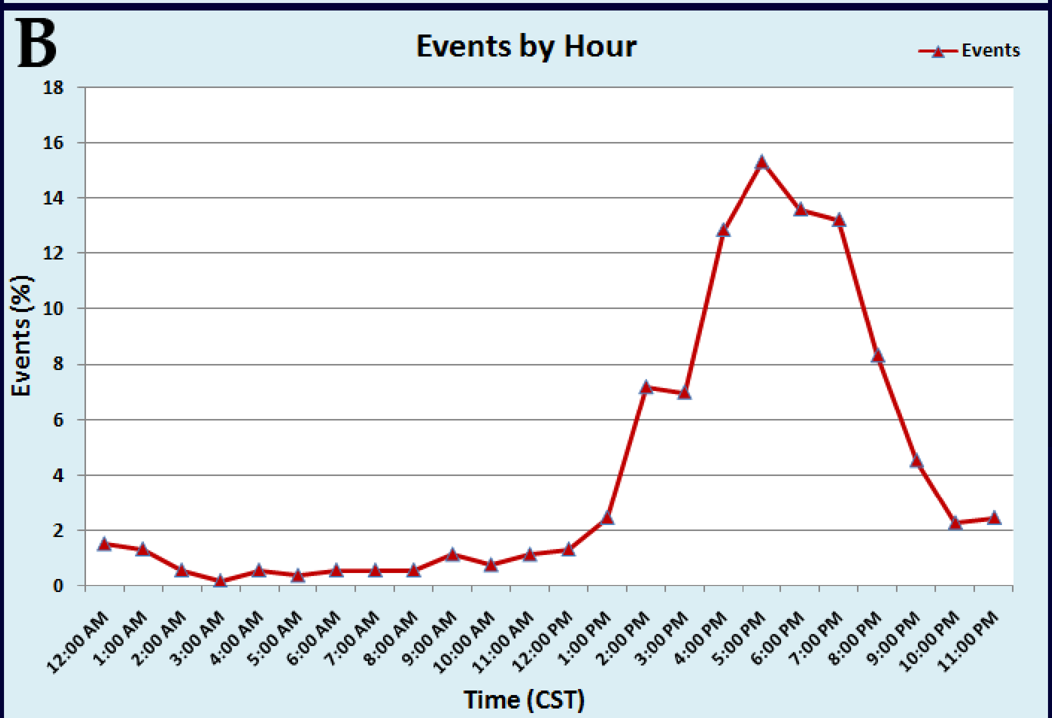
Giant Hail Reports
1 January 1995 – 31 December 2009

Domain: Contiguous United States



4.00+ in. Hail Climatology





Events by Month

80% April–July
54% May and June

Reports by Hour

82% 2–9:59 PM CST
55% *4–7:59 PM CST*

Methodology *(very abbreviated)*
WSR-88D Radar Data

568 *Storm Data* reports from 1 Jan 1995 to 31 Dec 2009

➢ 1-2 radar sites nearest to lat/lon report utilized

➢ Examined data **15 minutes prior** to and **5 minutes post** report time

➢ QC Storm Data report times and location
• time frequently incorrect (*24% cases*)…correction scheme applied

➢ Cases removed when reports > 185 km or < 30 km from radar

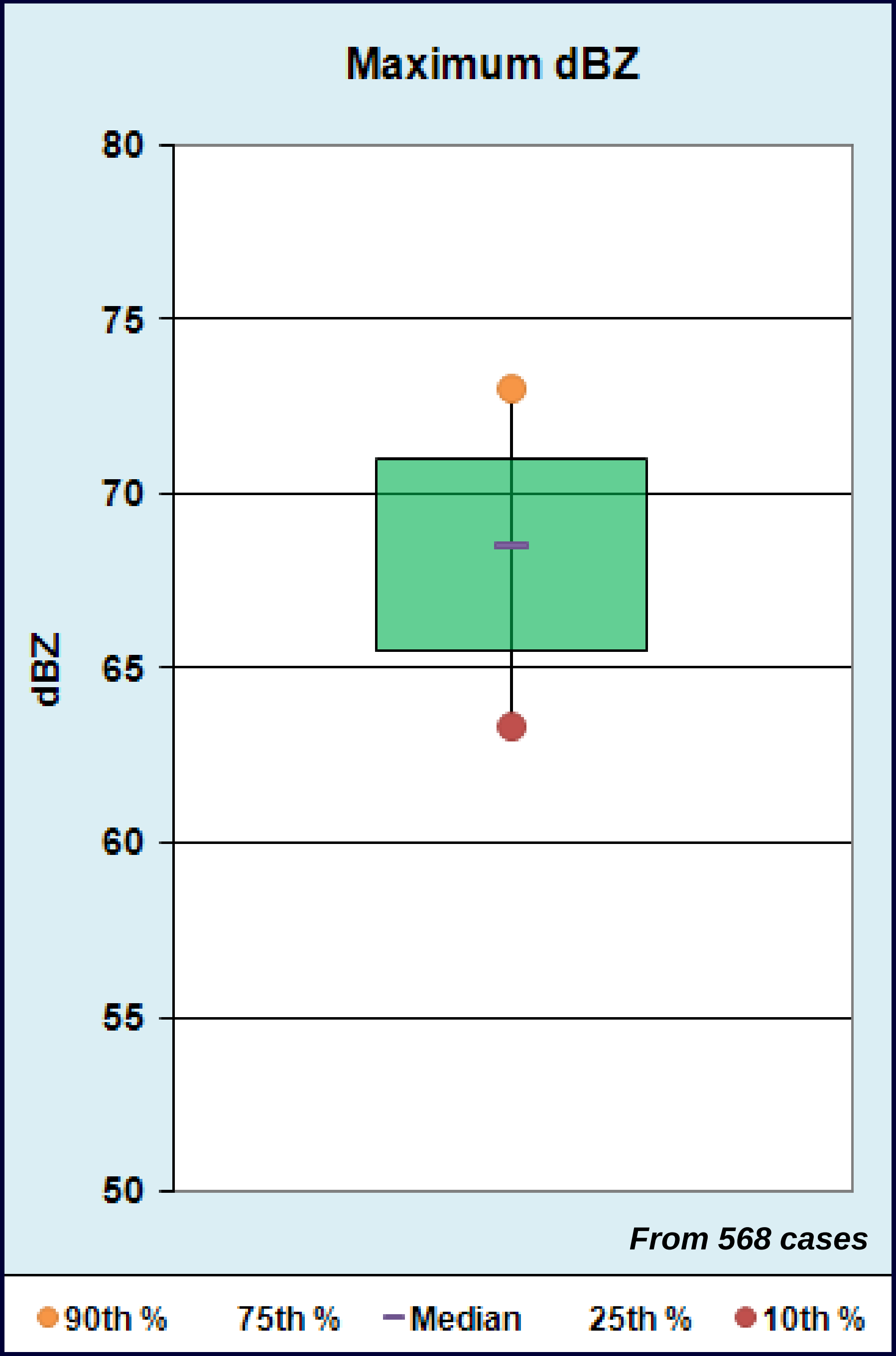
➢ Radar data interpolated, then paired with NARR environmental data

Comparison Database

Giant vs. Golfball-Hen Egg Sized Hail
Storm Data vs. SHAVE

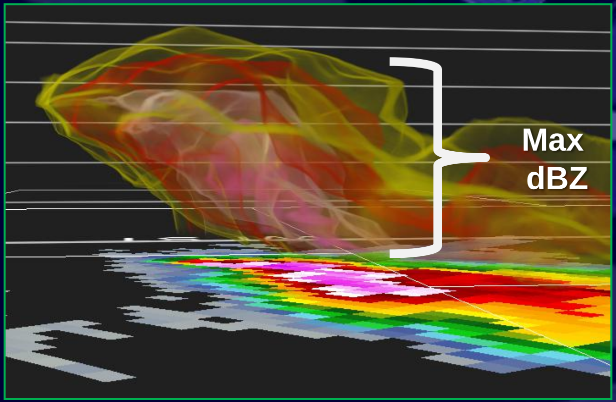
Analysis performed on 174 additional cases

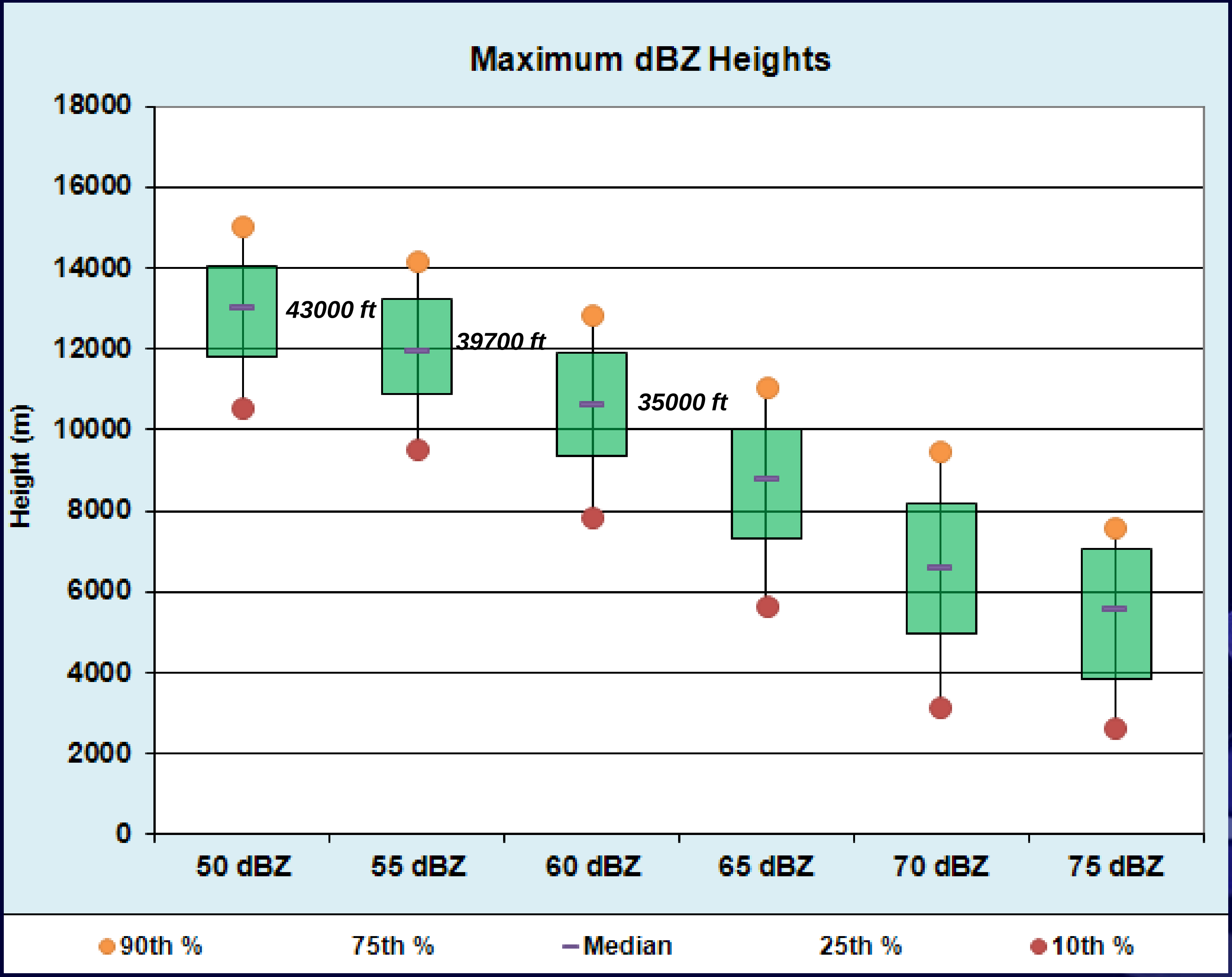
- 67 GBHE reports (*Storm Data*)
- 28 Giant Hail reports (SHAVE)
- 79 GBHE reports (SHAVE)



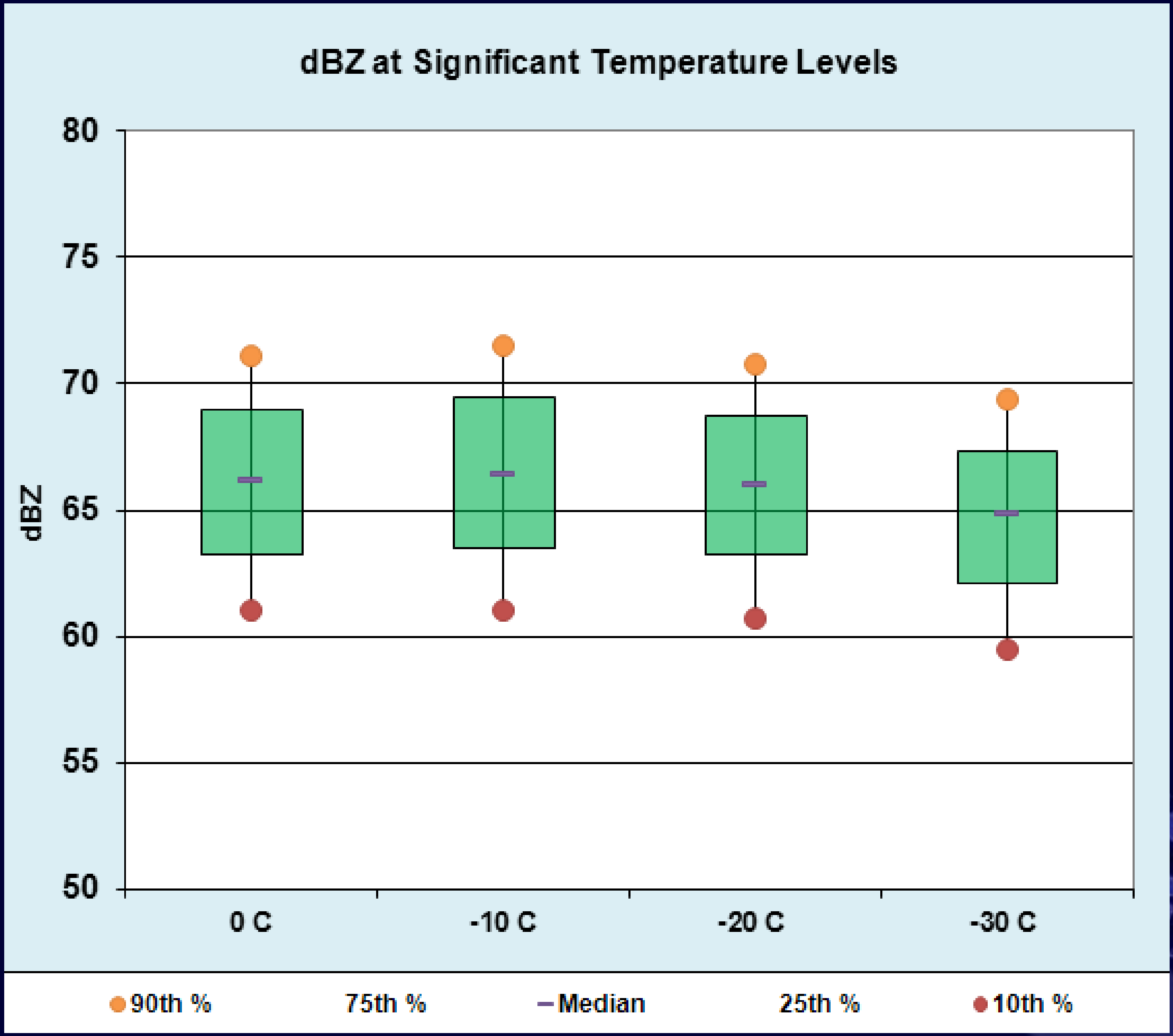
- **Max column reflectivity > 66 dBZ *(Median 69 dBZ)***
- '*Extreme*' dBZ values ≠ giant hail
- Upgrade to super resolution increased the potential for higher reflectivity values to be identified than with the legacy resolution
- 65% of cases max reflectivity ≥ 75 dBZ occurred within the two years of super resolution data (17% of the database)

Max reflectivity values within the storm column will be greater than the 15-year average



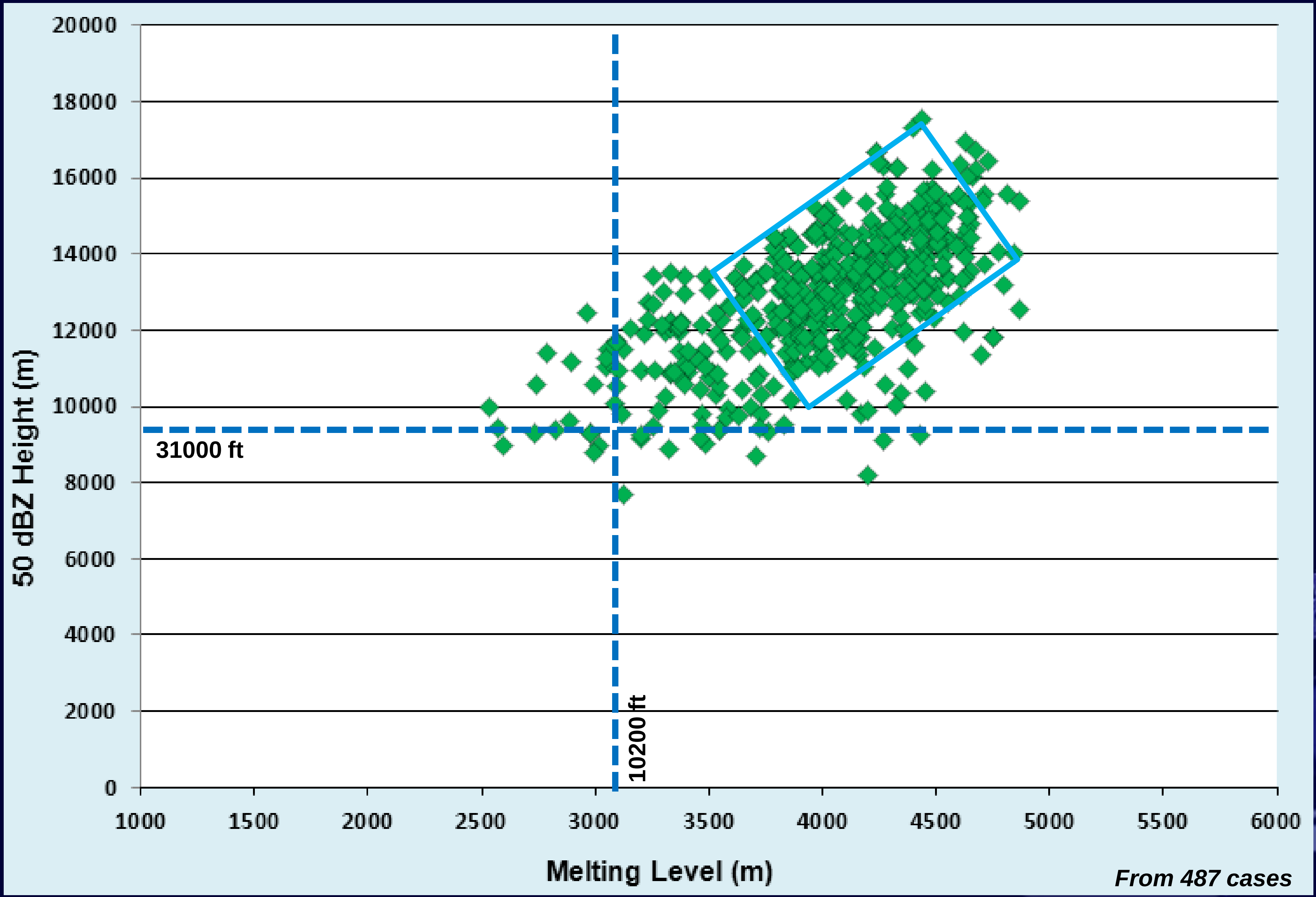


# of cases: 487 532 552 449 220 26



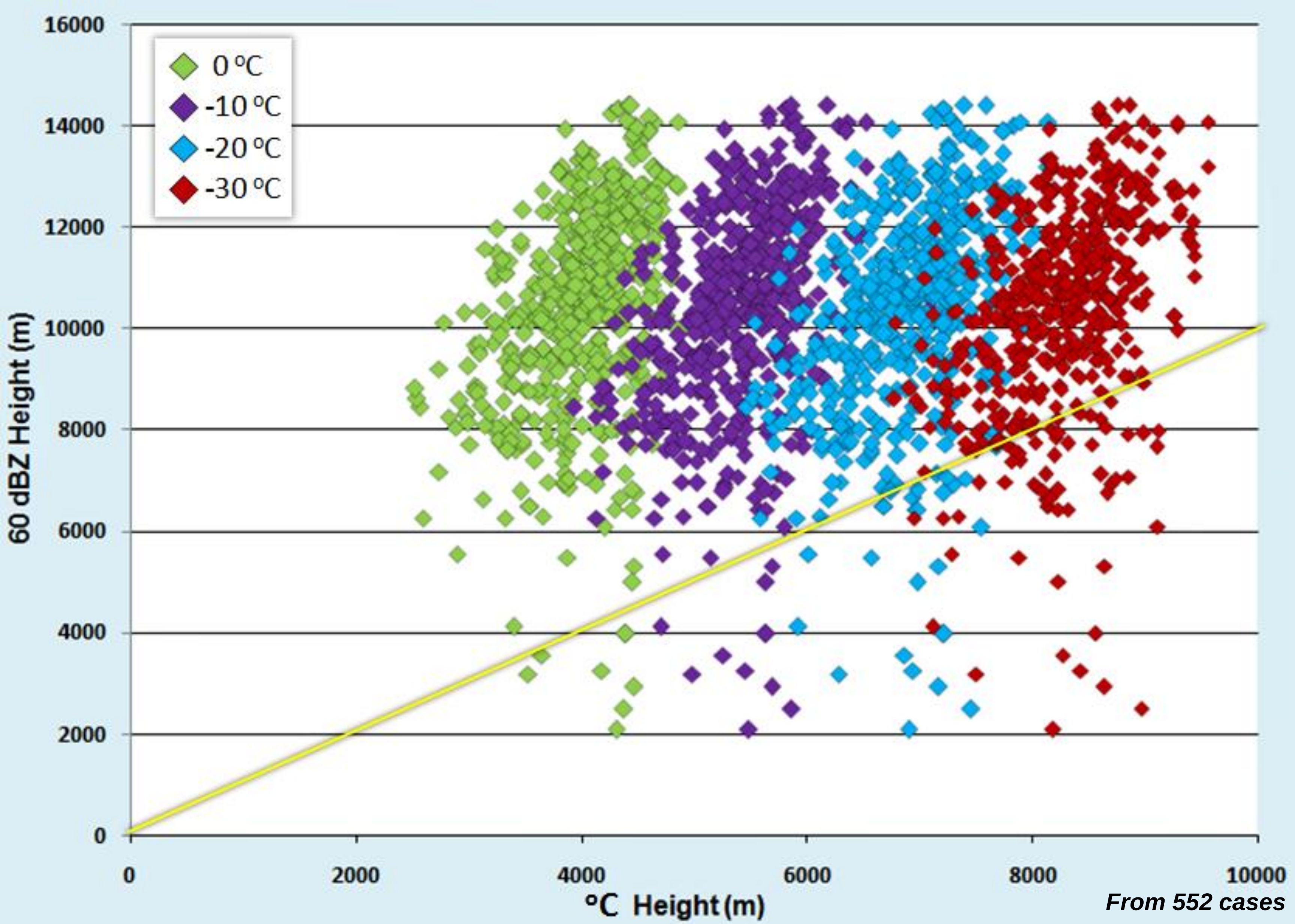
# of cases:* *563* *568* *567* *564

Hail Growth Zone > 60 dBZ
(Median: 66 dBZ)



• Tight clustering of reports, general increase in 50 dBZ echo height as 0 °C level increases

• Function of updraft strength / hail residence time

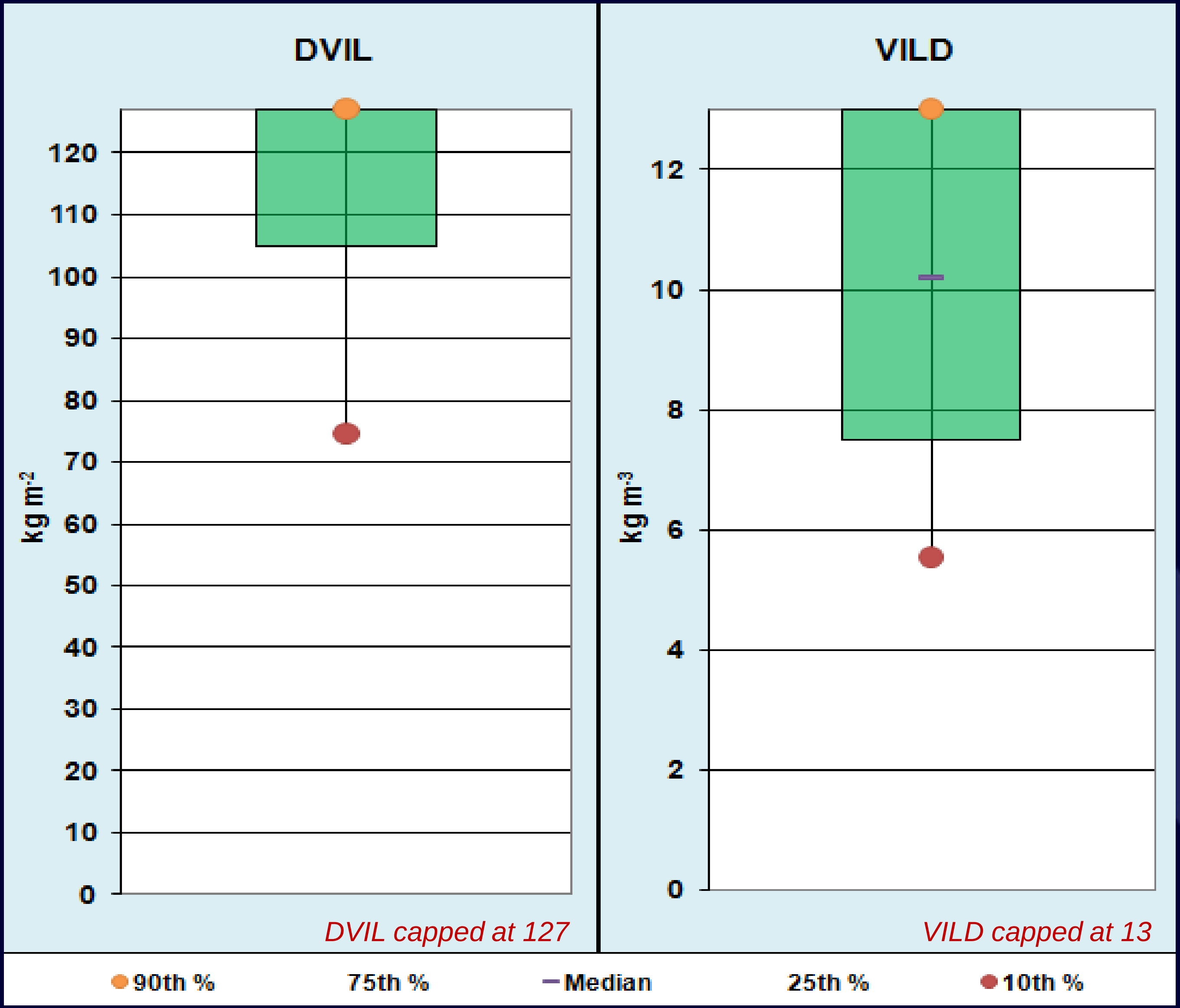


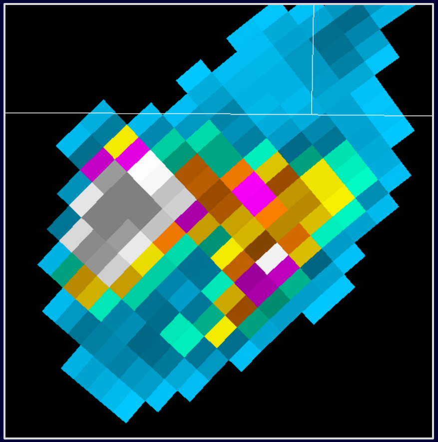
60 dBZ height relationship with environmental temperatures

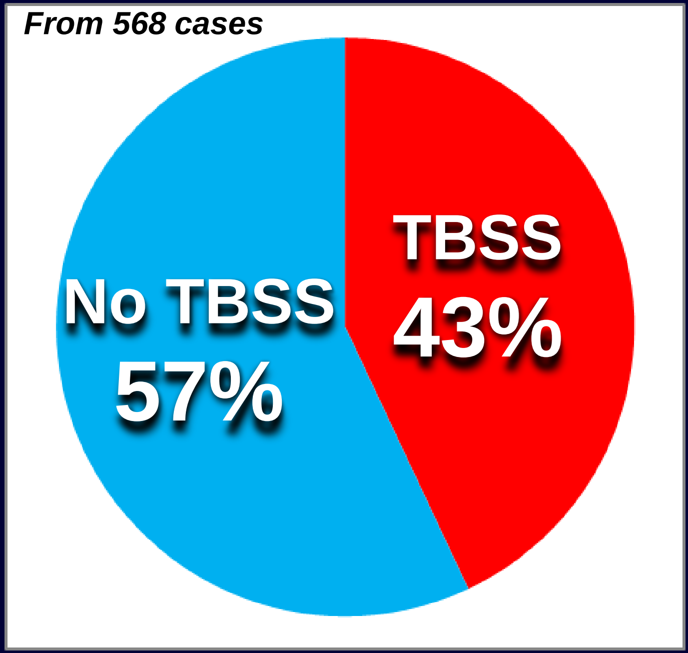
• 60 dBZ height well above hail growth zone per identity line of constant height

Digital VIL and VIL Density

- Documented issues correlating legacy VIL/VILD to hail size
- **DVIL > 105 kg/m^{-2}** and **VILD > 7 kg/m^{-3}**







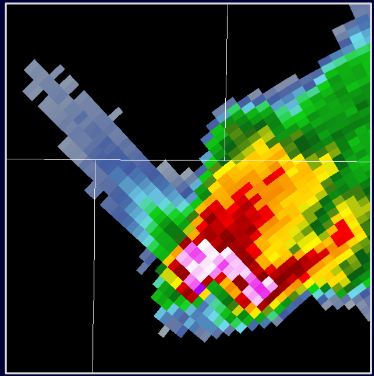
Three-Body Scatter Spike

• Radar microwave scattering artifact associated with large hydrometeors frequently considered good signal for "large hail" (NOAA WDTB 2002)

Occasionally…

• Downrange echoes masked TBSS signature

• TBSS existed outside the 15/5 study period

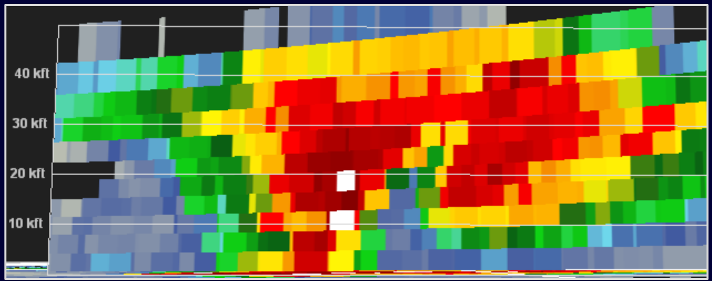


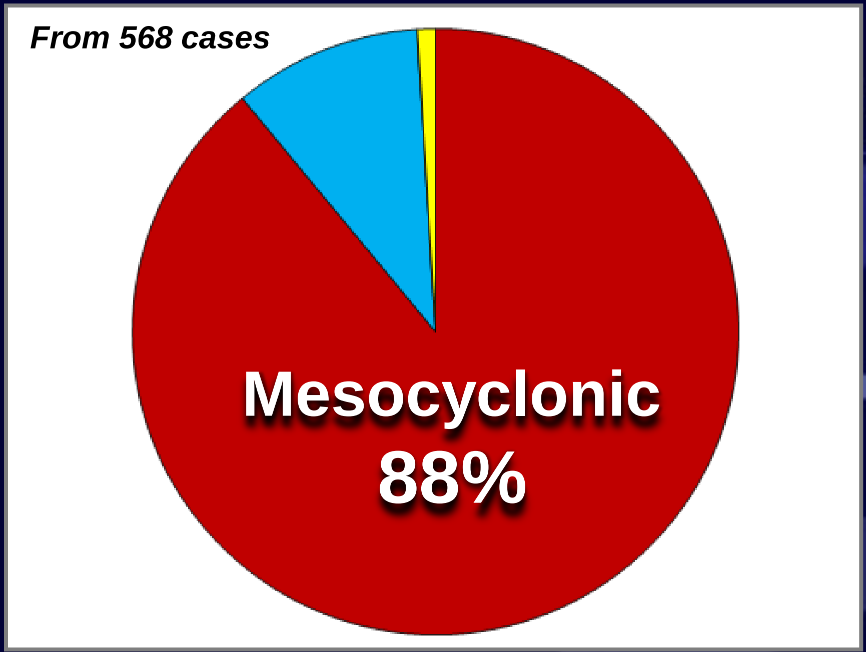
Structure Characteristics

99% reports associated with isolated or embedded supercells

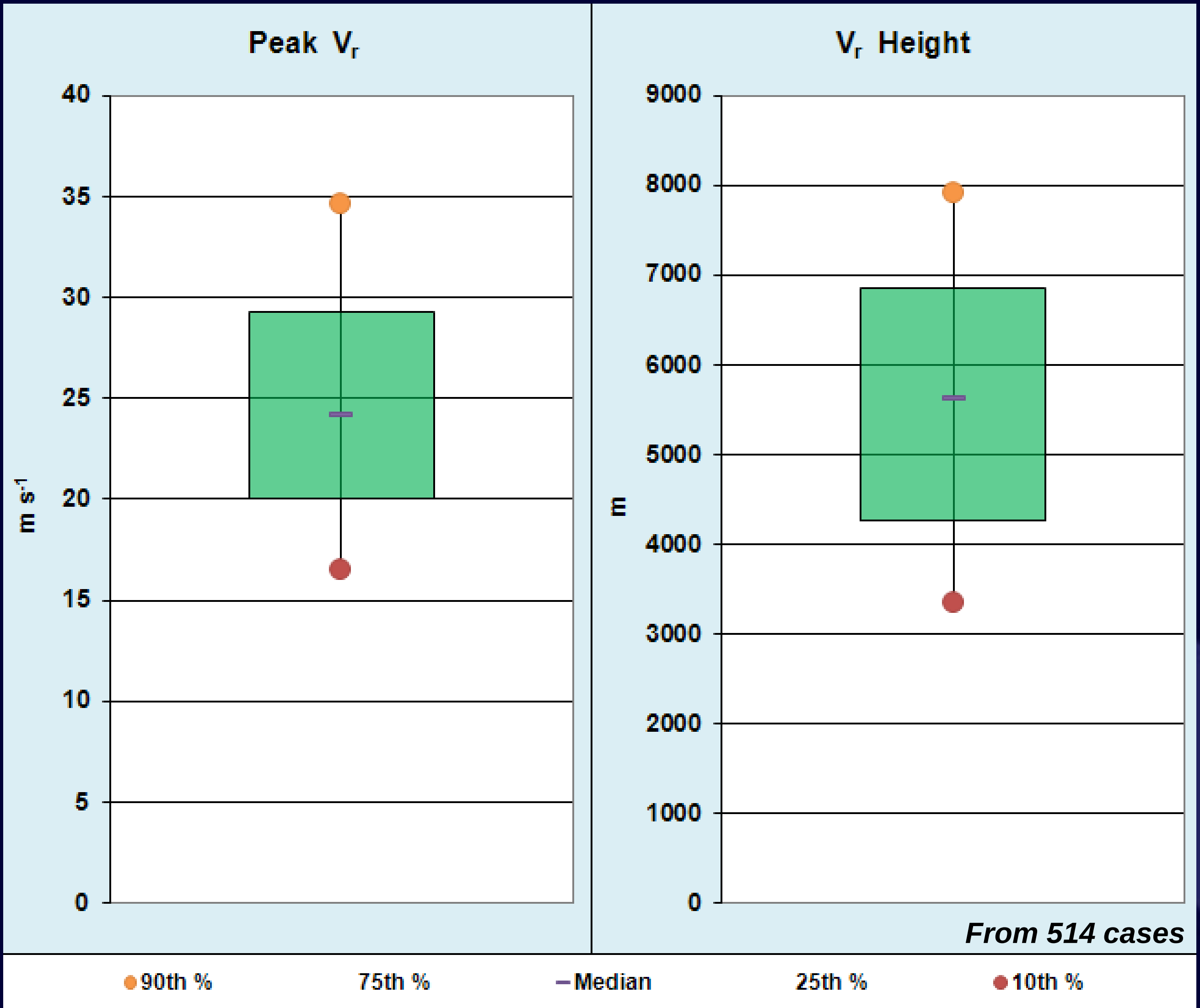
• Persistent mid-level mesocyclone

• Presence of BWER





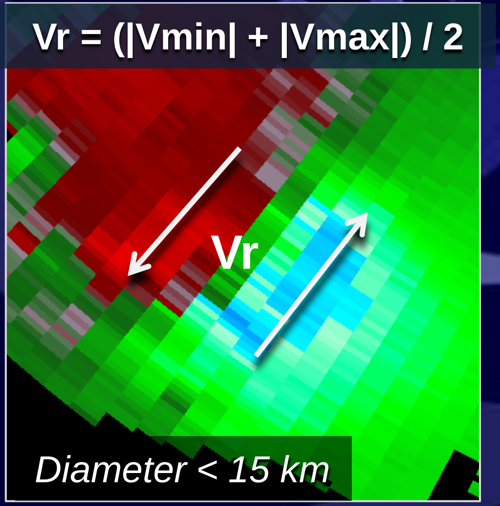
Rotational Velocity

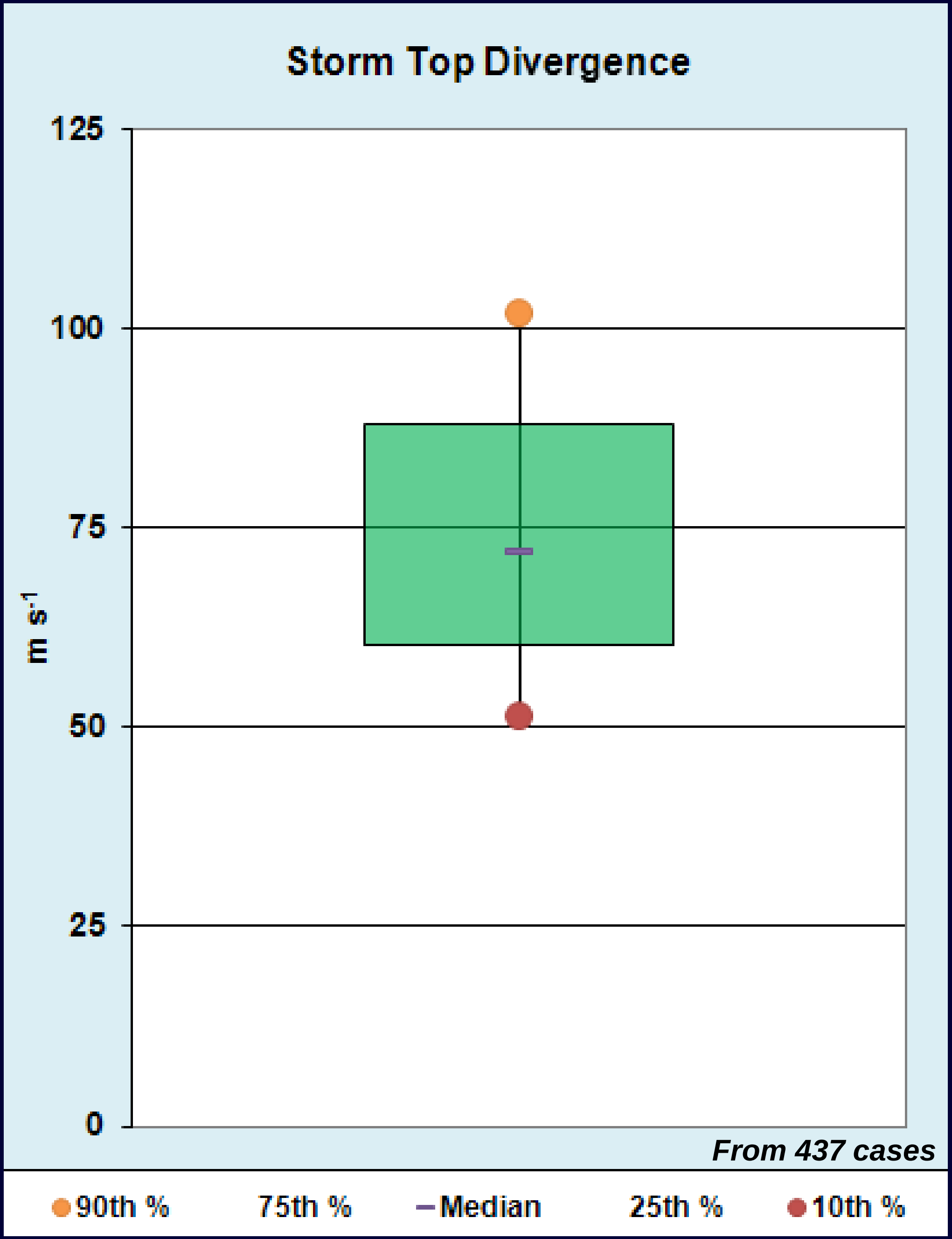


Moderate/Strong Mesocyclone

V_r > 40 kts (*Median 47 kts*)

- Vertical pressure gradient forces induced by rotation within storm can lead to significant updraft accelerations (greater than CAPE alone) and maintain supercell structure
- Creates a favorable growth trajectory within specific regions of the updraft with preferred vertical motions and fallspeeds.
- Likely plays a vital role in potential for giant hail production (when other parameters exist)





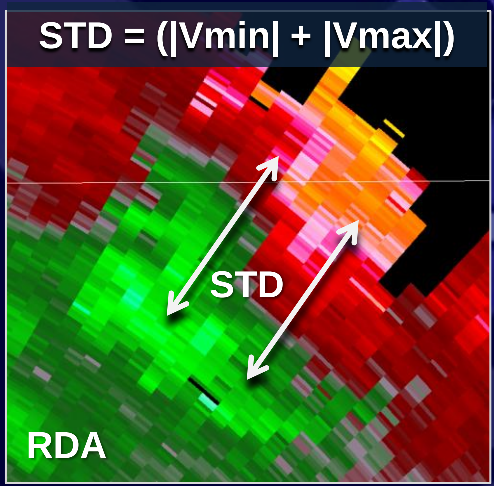
Storm-Top Divergence

- Strong divergent flow at summit of convection

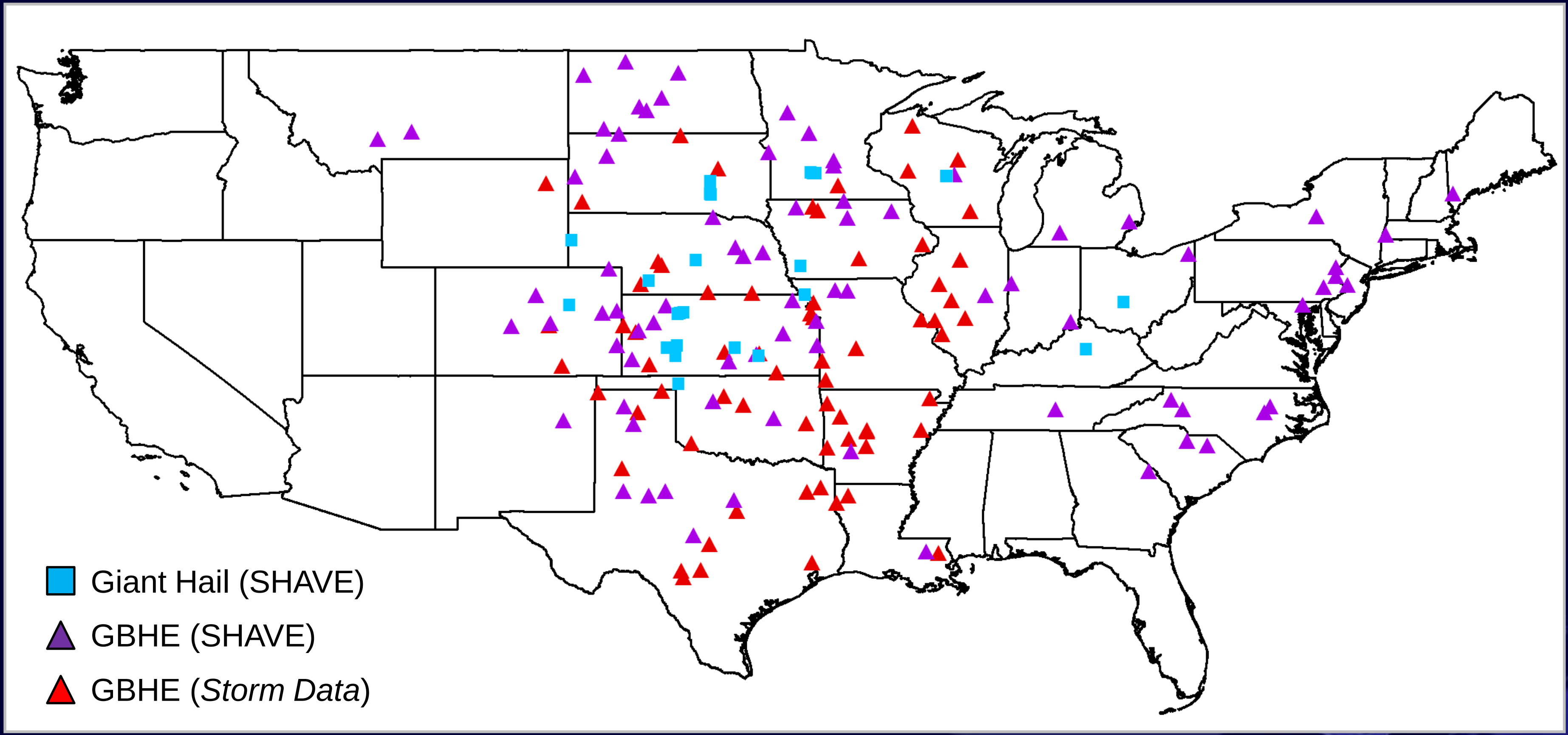
STD > 120 kts

(Median 140 kts)

STD should be considered a good proxy of updraft strength that may suggest the potential for giant hail.



Comparison: *Giant Hail vs. Large Hail*



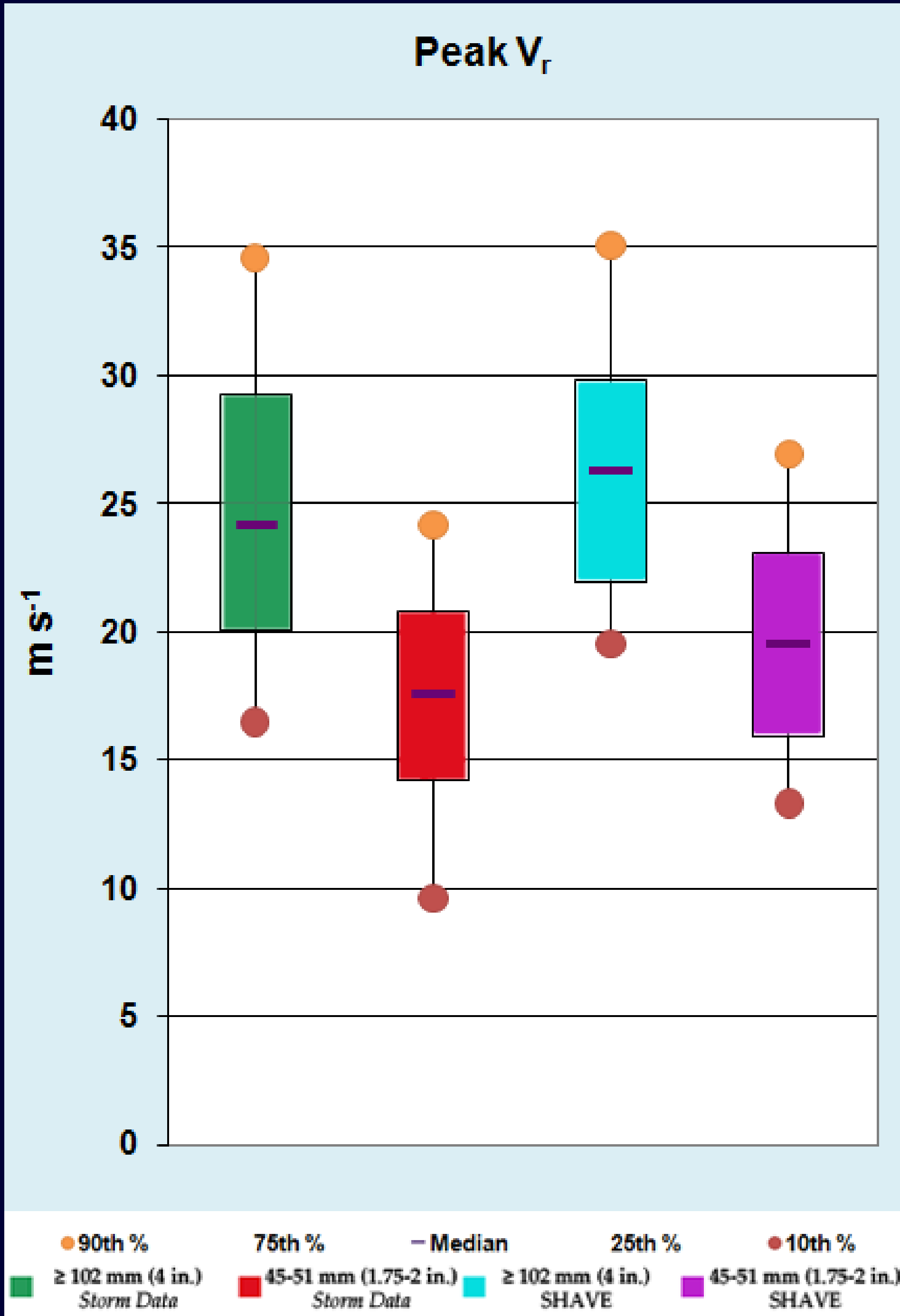
Determine whether unique signals were distinguishable for giant hail

Giant Hail vs. Golfball-Hen Egg-sized Hail [GBHE] (1.75-2.00 in.)

- Same methodology applied to database

Cases removed if hail > 2.00 in. was reported within 250 km of the storm.

- 81% GBHE reports associated with supercells



Comparison:
Giant Hail vs. Large Hail

Rotational Velocity

Vr = (|Vmin| + |Vmax|) / 2

Median V_r values

Storm Data

47 kts *(Giant)*

33 kts (GBHE)

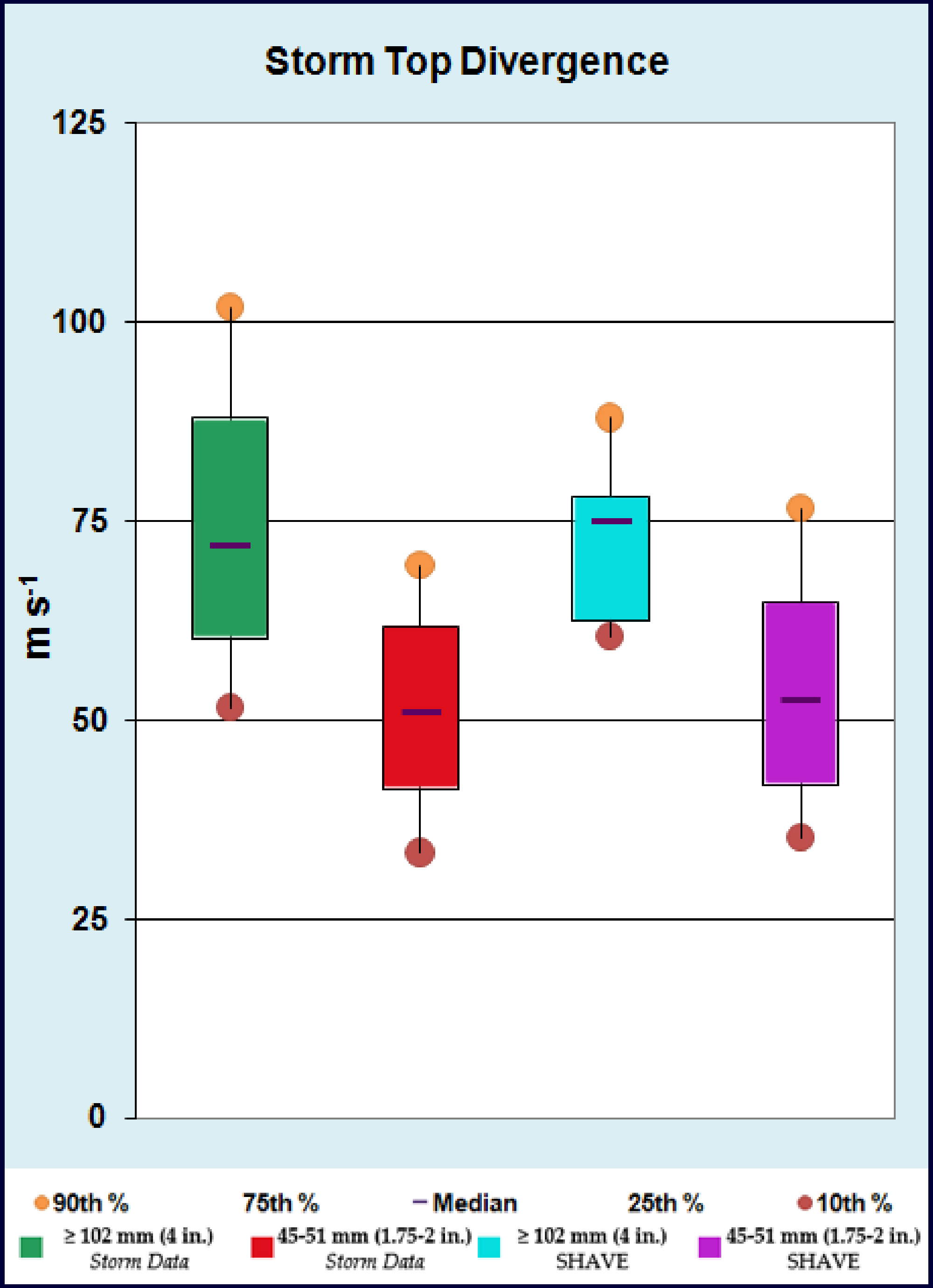
SHAVE

50 kts (Giant)

37 kts (GBHE)

Null hypothesis Student's t-test conducted

Statistically significant
at the 99% confidence level



Comparison: *Giant Hail vs. Large Hail*

Storm-Top Divergence

STD = (|Vmin| + |Vmax|)

Median STD values

Storm Data

140 kts (*Giant*)

99 kts (GBHE)

SHAVE

146 kts (Giant)

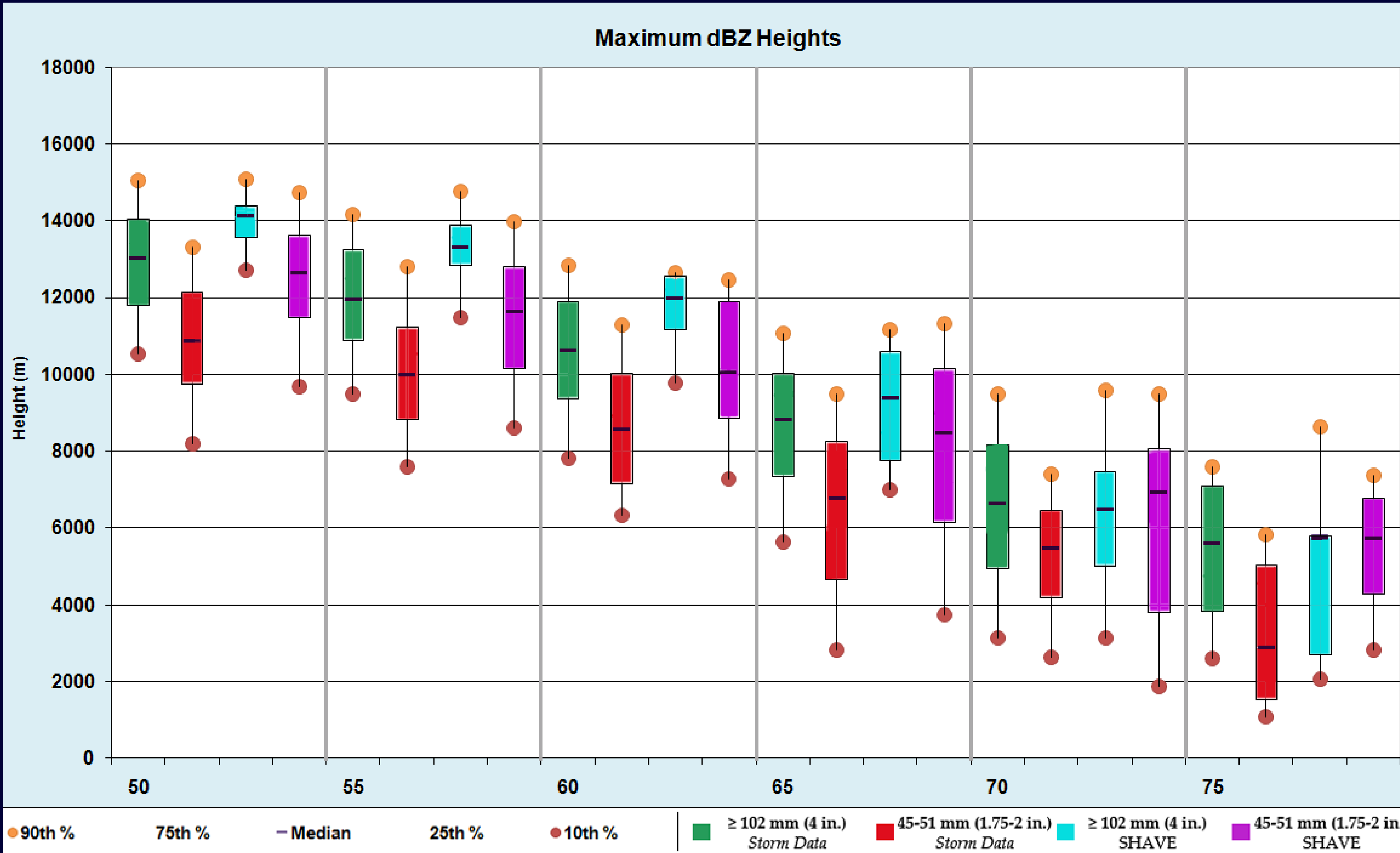
101 kts (GBHE)

Null hypothesis Student's t-test conducted

Statistically significant

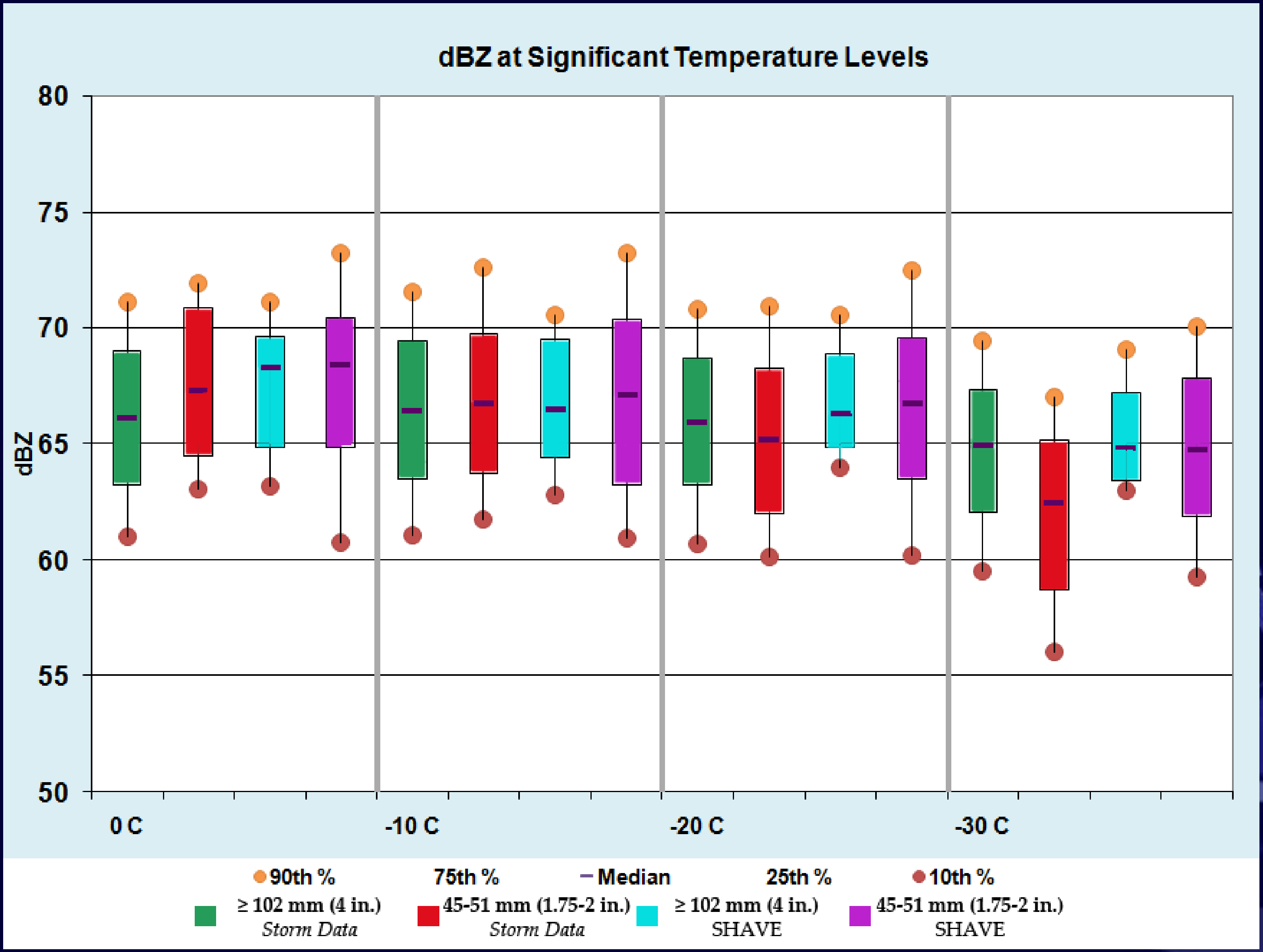
at the 99% confidence level

Comparison: *Giant Hail vs. Large Hail*



Giant hail events frequently contained greater reflectivity heights for 50, 55, 60 dBZ
Relative to the time of year [May-Aug GH (74%) GBHE (60%)]

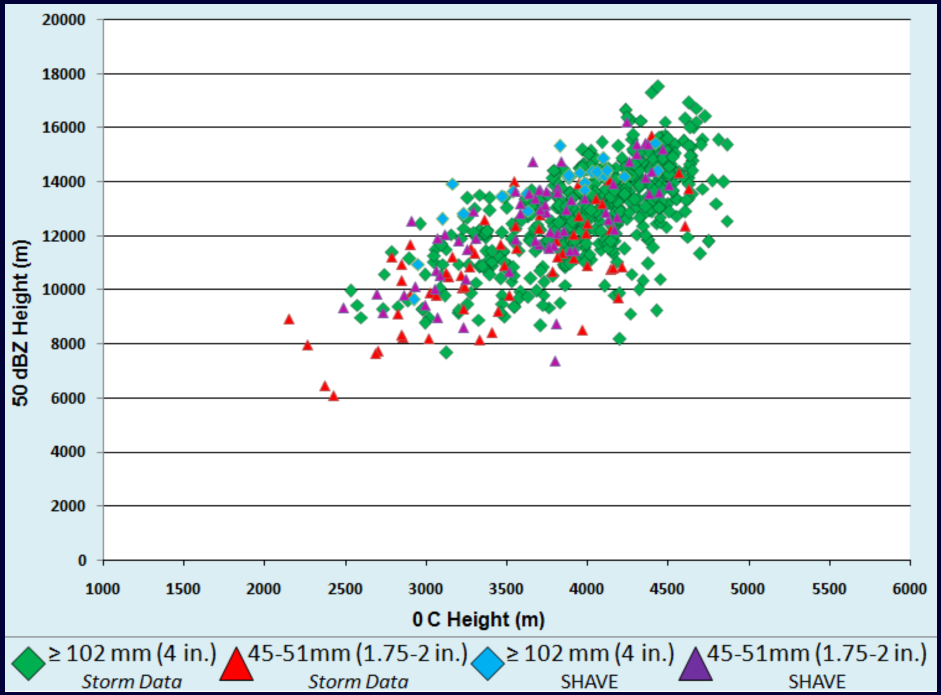
Comparison: *Giant Hail vs. Large Hail*



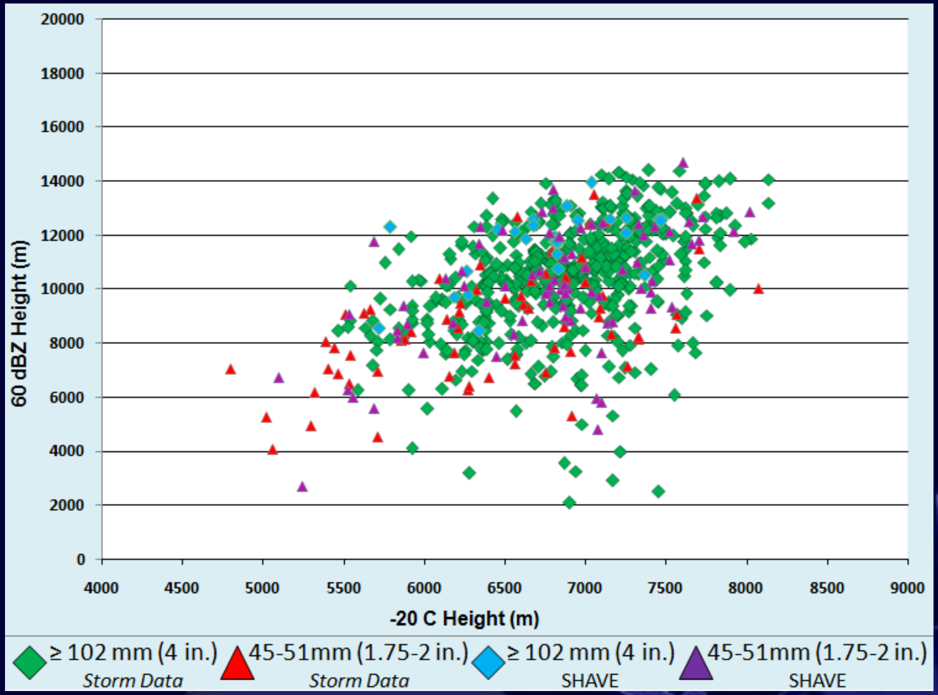
Significant overlap / poor discriminator of giant hail
Should still expect ~65 dBZ present through hail growth zone

Comparison: *Giant Hail vs. Large Hail*

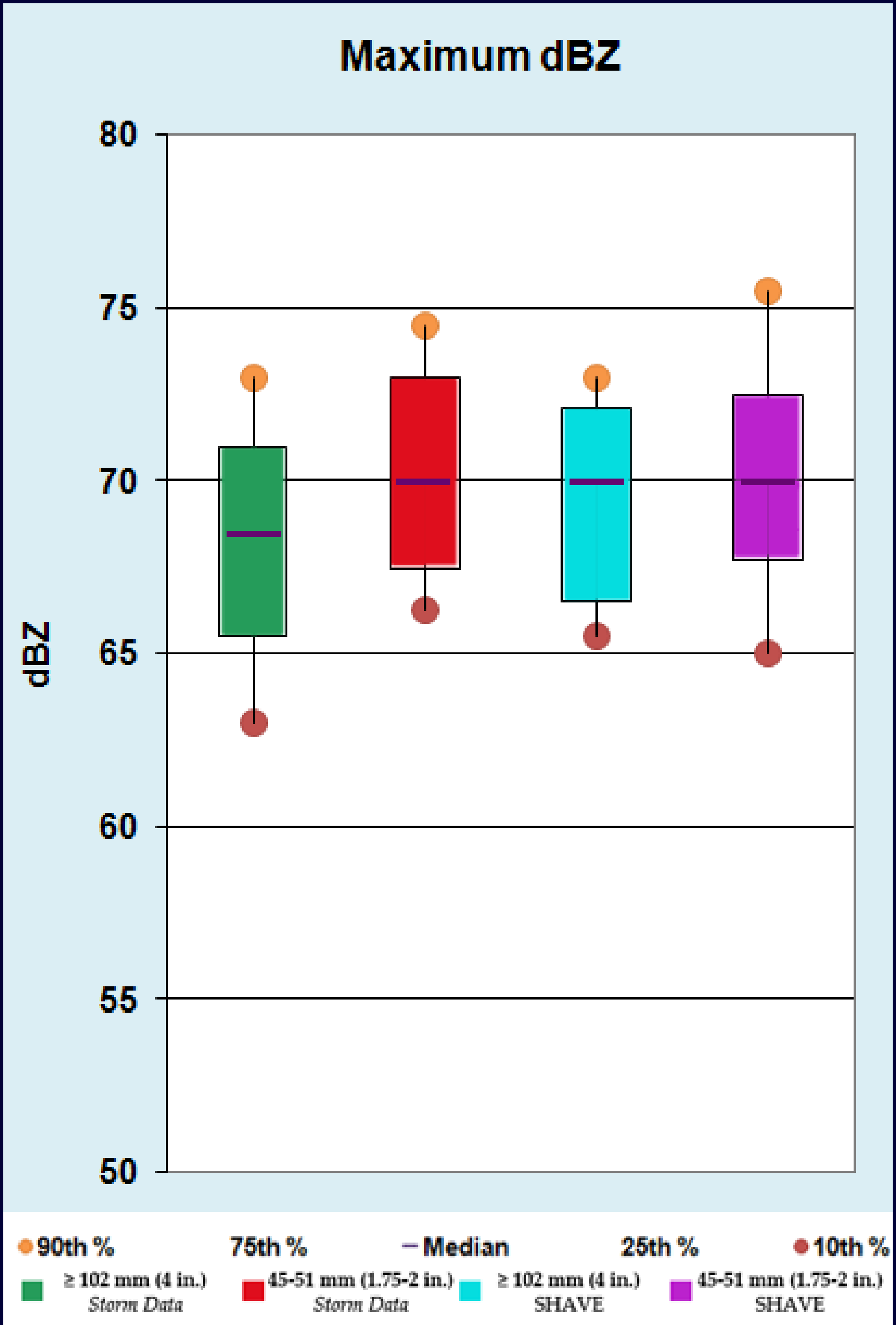
50 dBZ height vs. 0 °C



60 dBZ height vs. -20 °C



Unreliable relationship to discriminate between hail sizes



Comparison: *Giant Hail vs. Large Hail*

Maximum dBZ

Median values

Storm Data

68.5 dBZ (*Giant*)*

70 dBZ (GBHE)

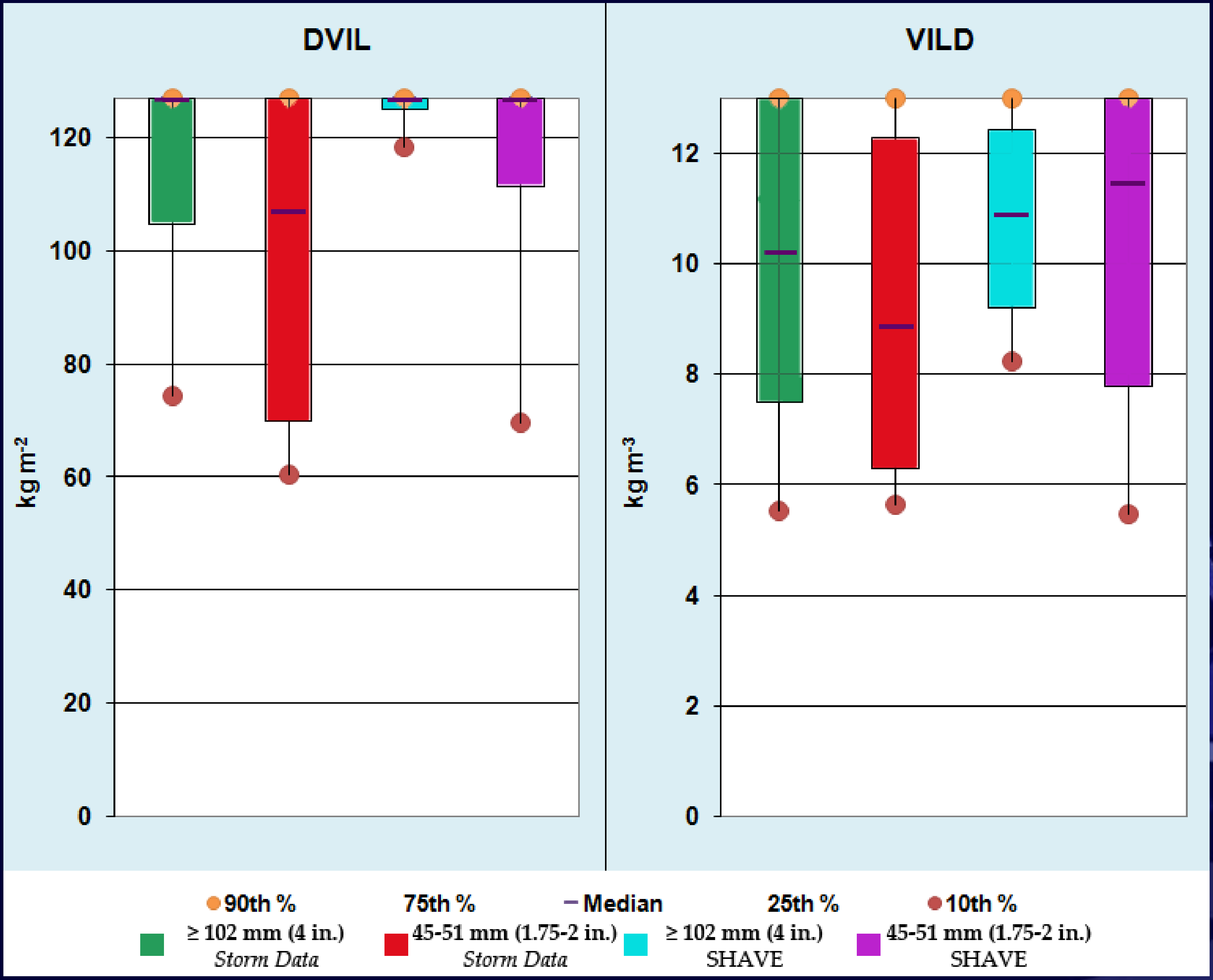
SHAVE

70 dBZ (Giant)

70 dBZ (GBHE)

*Legacy resolution artifact

Comparison: *Giant Hail vs. Large Hail*



Summary

Results from the radar analysis successfully identified operational signals that distinguished storms more favorable for generating giant hail:

- ~**99%** of the giant hail convection was classified as supercellular, with well-organized storm structure.
- Peak rotational velocity (V_r) of the mid-level mesocyclone was typically found to be 39 to 56 kts, with a median value of **47 kts**.
- Maximum storm-top divergence (STD) was frequently observed to be 117 to 171 kts, with a median value of **140 kts**.
- V_r and STD values for giant hail versus smaller GBHE hail sizes were **statistically significant** to the 99% confidence level. (Greatest promise identifying storms capable of hail ≥ 4.00 in.)
- Overlap in values for reflectivity in the hail growth zone.
- Seasonal dependency for maximum reflectivity heights.
- Maximum reflectivity, TBSS signatures, and VIL-based products showed little to no skill in discriminating hail sizes.

Signals should increase advanced recognition and confidence to the potential of giant hail during short-term warning operations.

EJSSM Publication Forthcoming

September 2011

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A Radar-Based Assessment of the Detectability of Giant Hail

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ABSTRACT

The occurrence of giant hail, defined as hail ≥ 102 mm (4.00 in.) in diameter, is a relatively rare phenomenon, accounting for less than 1% of all hail reports in the United States. Despite the infrequent nature of these events, hail of this magnitude has the potential to cause extreme damage to property and a substantial threat to exposed life. The short-term prediction of these events has been challenging. Since 2005 when giant hail occurred, only 7% of convective warnings and severe weather statements issued by the National Weather Service (NWS) accurately predicted a maximum hail size ≥ 102 mm prior to the report, with an average underestimated size error of 55.6 mm (2.19 in.).

The objectives of this study are to determine the detectability of giant hail in convective storms and to improve advanced recognition of these events during NWS warning operations. A total of 568 giant hail reports gathered over a 15-year period from 1 January 1995 through 31 December 2009 throughout the contiguous United States served as the primary database for the research. Weather Surveillance Radar-1988 Doppler (WSR-88D) data and North American Regional Reanalysis (NARR) environmental data were collected for each case. Several radar signatures were examined to assess their utility in discriminating storms more favorable for giant hail. It was found that 99% of the storms were supercells with well-organized structure, with giant hail producing storms characterized by median values of rotational velocities of 24 m s^{-1} (47 kts), storm-top divergence of 72 m s^{-1} (140 kts), and 50 dBZ and 60 dBZ echo heights of 13100 m (43000 ft) and 10600 m (34800 ft) respectively. VIL-based products, maximum reflectivity within the storm, and reflectivity within the preferred hail growth zone showed little to no skill in discriminating between giant hail and smaller hail sizes.

1. Introduction

One of the biggest challenges to the operational community remains the ability to accurately predict specific maximum hail sizes in real-time warning operations. The NWS defines "severe hail" as a hail stone with a diameter ≥ 25.4 mm (1.00 in.) and utilizes this size as the threshold to issue severe thunderstorm warnings. The term "significant hail" has become synonymous with hail ≥ 51 mm (2.00 in.) in diameter (Hales 1998), and the Storm Prediction Center (SPC) explicitly forecasts the potential for hail of this magnitude in the day 1 convective outlook product. "Giant hail", defined by Knight and Knight (2001) as hail ≥ 102 mm (4.00 in.) in diameter, is a relatively rare phenomenon, but has the potential for extreme economic and societal impacts. One of the more notable

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