Analysis of Three-Body Scattering Signatures for Use in Hail Size Estimation

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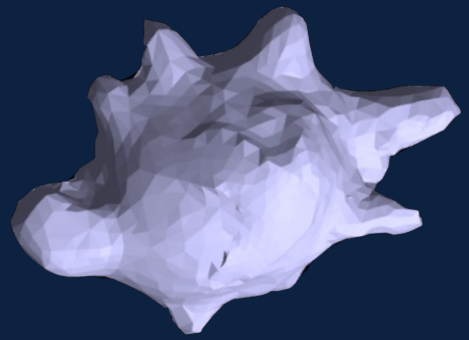
Impacts of Hail

- Hailstorms becoming increasingly significant events

Gargantuan hailstone that fell in Hondo, Texas, on April 28, 2021. (Image/PSURadarMeteorology)

△ Largest hailstone



8 in
(2010, Vivian, South Dakota, USA)

△ Surface Fall Speeds

Hailstone (1.5 in)

~25 m/s

Hailstone (4 in)

~40 m/s

Impacts of Hail

- Hail severity commonly associated with hail size

Marginally Severe

≤ 1 in

Significantly Severe

≥ 2 in

Giant-to-gargantuan

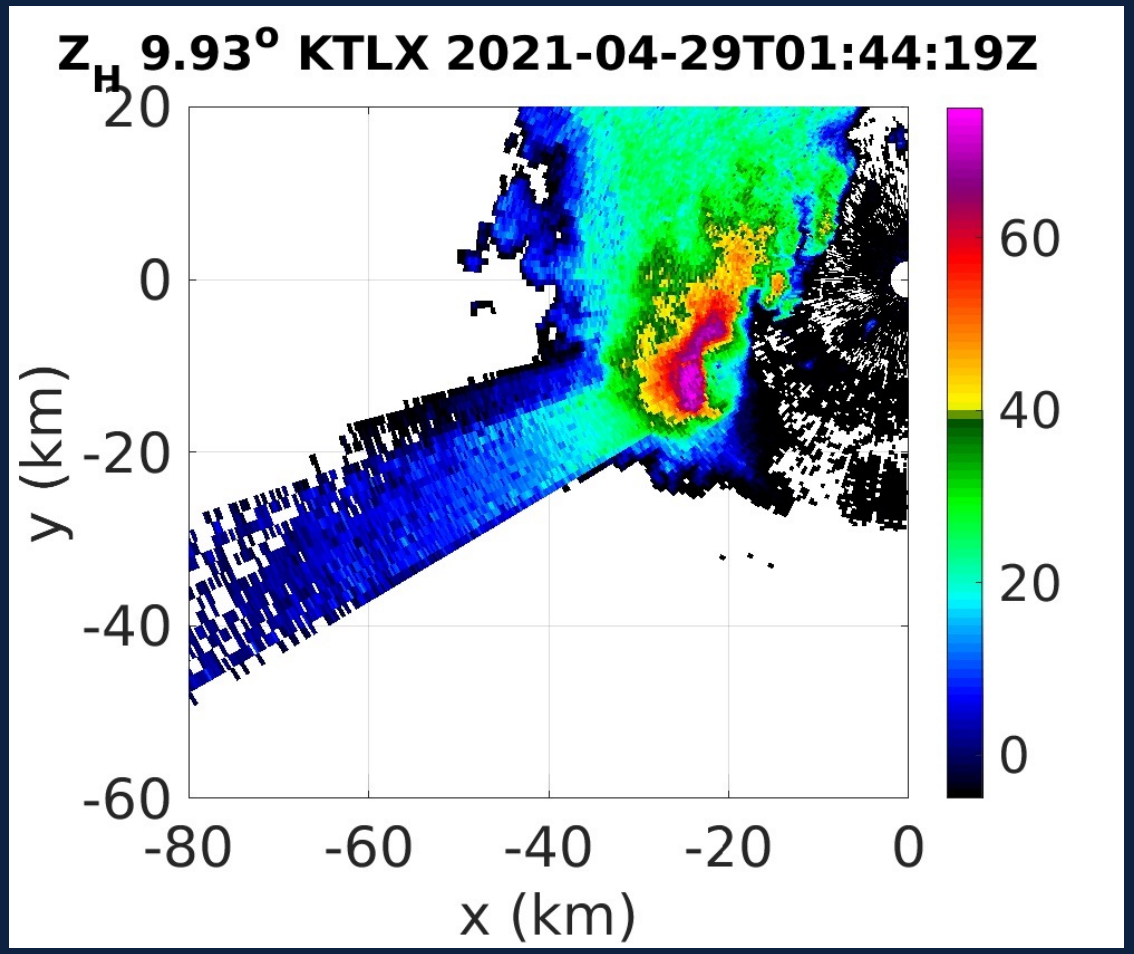
$\geq 4 - 6$ in

Radar & Hail Detection

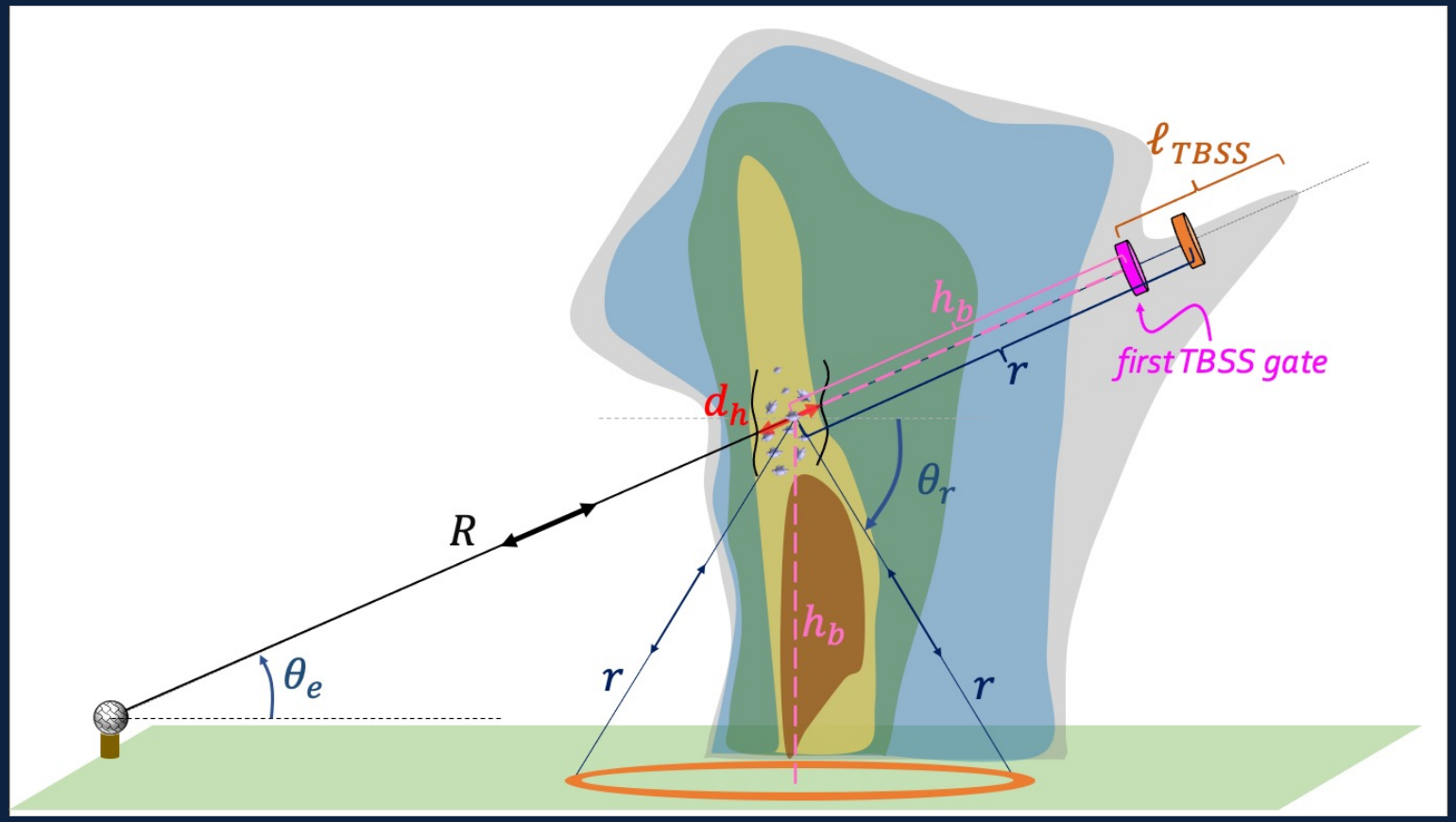
- Radar highly effective in hail detection
- Dual-polarization enhances observation data
  - Scatterers shape, size, and physical composition
- Radar-based hailstone size determination a challenge
  - Roughness / irregular shape
  - Orientation from collisions
  - Nonuniform beamfilling

Three-Body Scattering Signature (TBSS; Zrnić 1987)

- Weak reflectivity “spike” or “flare”
- Colloquially referred to as “hail spike”
- Often used to infer the existence of severe hail for NWS forecasting

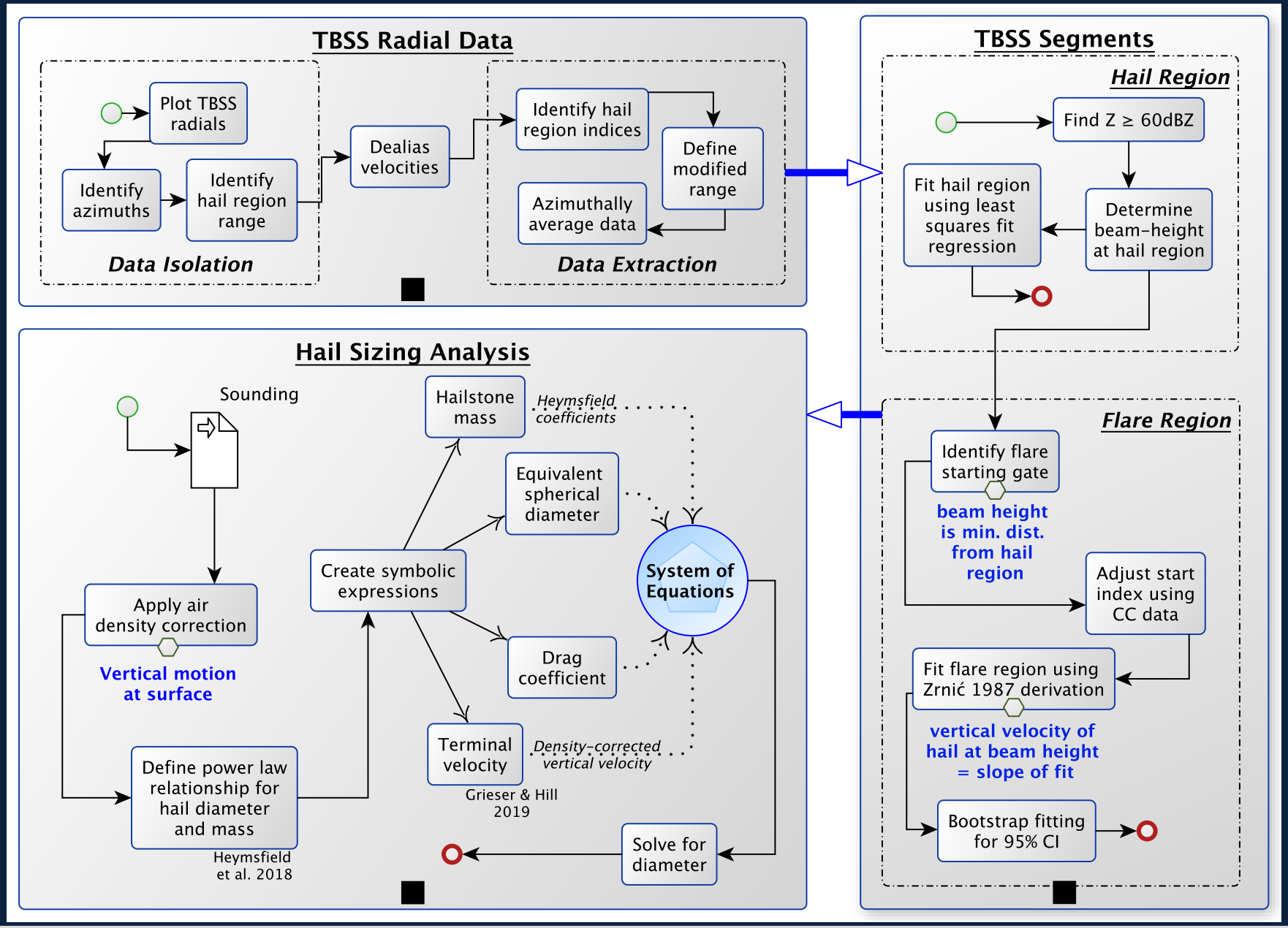


Schematic of Three-Body Scattering Signature



(VanAlstine & Kumjian 2022)

Utility of TBSS to estimate hail size?


TBSS Radial Data
Plot TBSS radials
Identify azimuths
Identify hail region range
Data Isolation
Dealias velocities
Identify hail region indices
Define modified range
Azimuthally average data
Data Extraction
TBSS Segments
Hail Region
Find Z ≥ 60dBZ
Determine beam-height at hail region
Fit hail region using least squares fit regression
Flare Region
Identify flare starting gate
beam height is min. dist. from hail region
Adjust start index using CC data
Fit flare region using Zrnić 1987 derivation
vertical velocity of hail at beam height = slope of fit
Bootstrap fitting for 95% CI
Hail Sizing Analysis
Sounding
Apply air density correction
Vertical motion at surface
Define power law relationship for hail diameter and mass
Heymsfield et al. 2018
Create symbolic expressions
Hailstone mass
Heymsfield coefficients
Equivalent spherical diameter
Drag coefficient
Terminal velocity
Density-corrected vertical velocity
Grieser & Hill 2019
System of Equations
Solve for diameter

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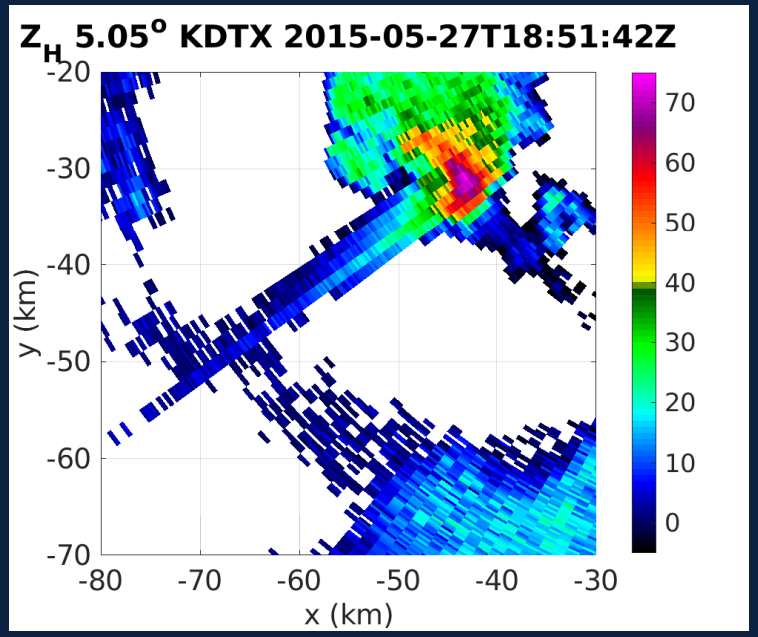
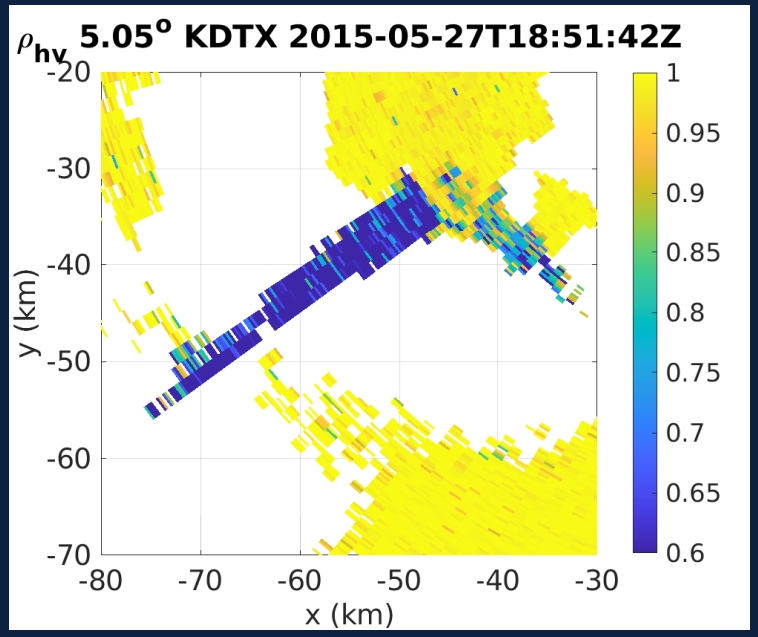
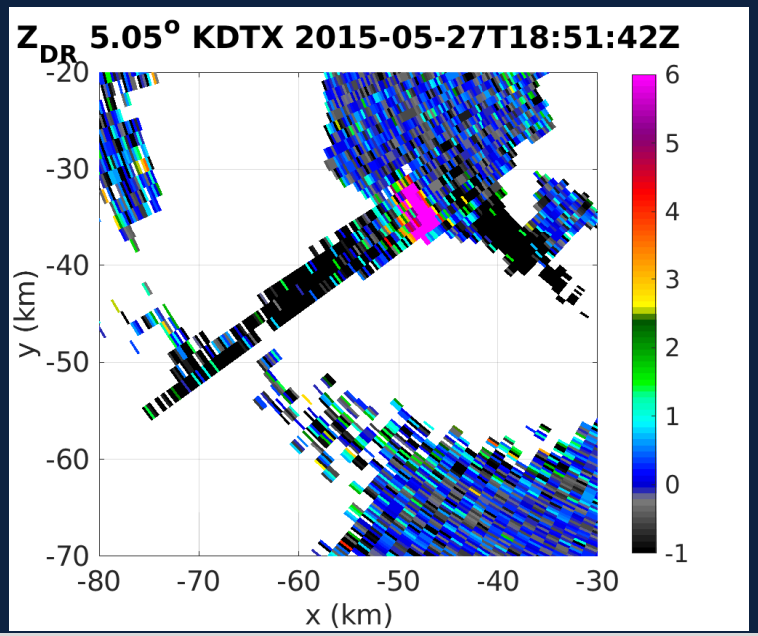
Detroit, Michigan

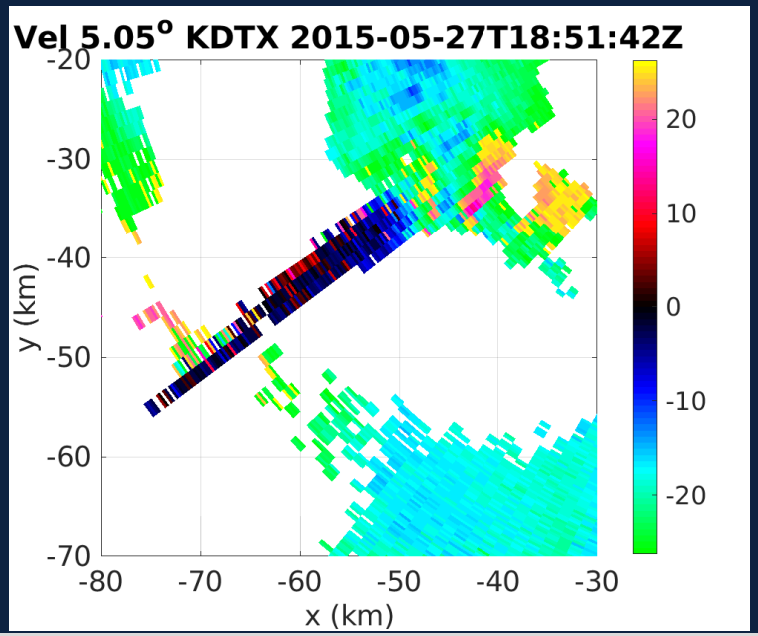
2015 – 05 – 27

Marginally Severe ≤ 1 in.









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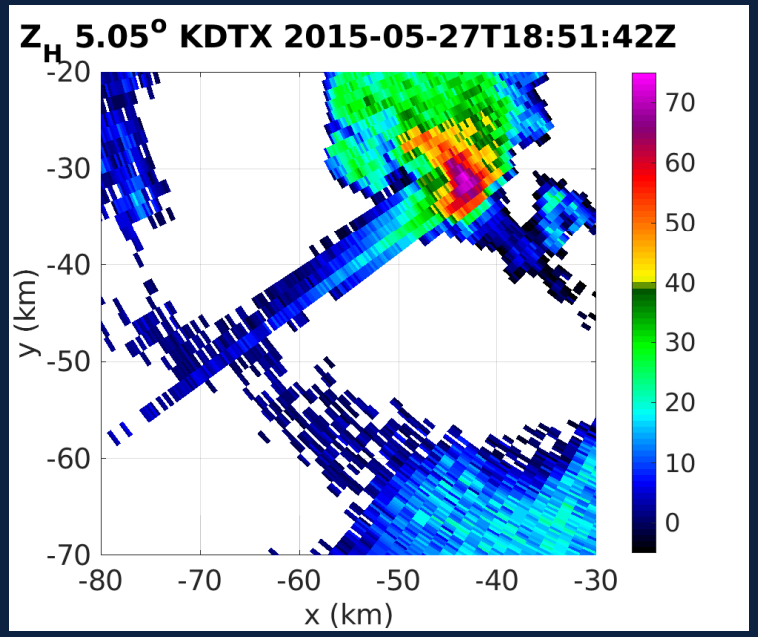
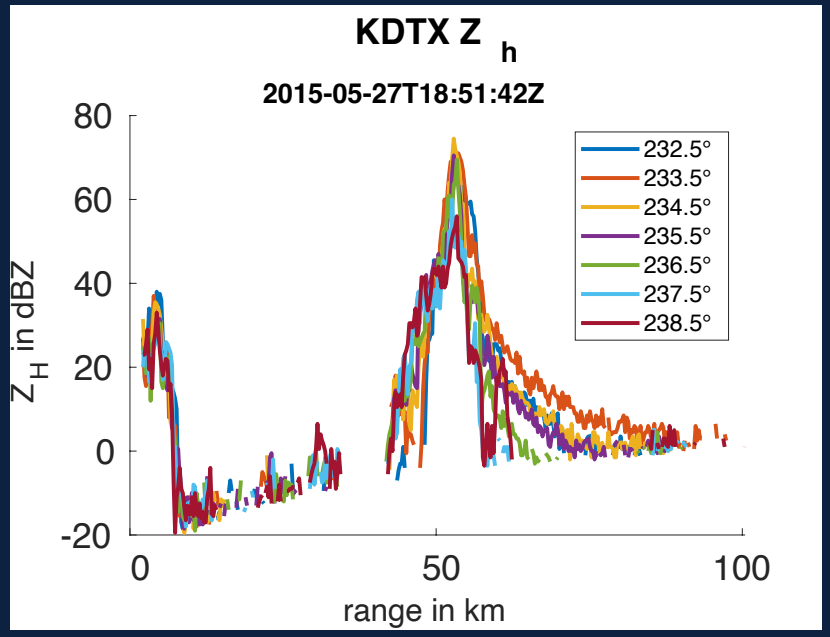
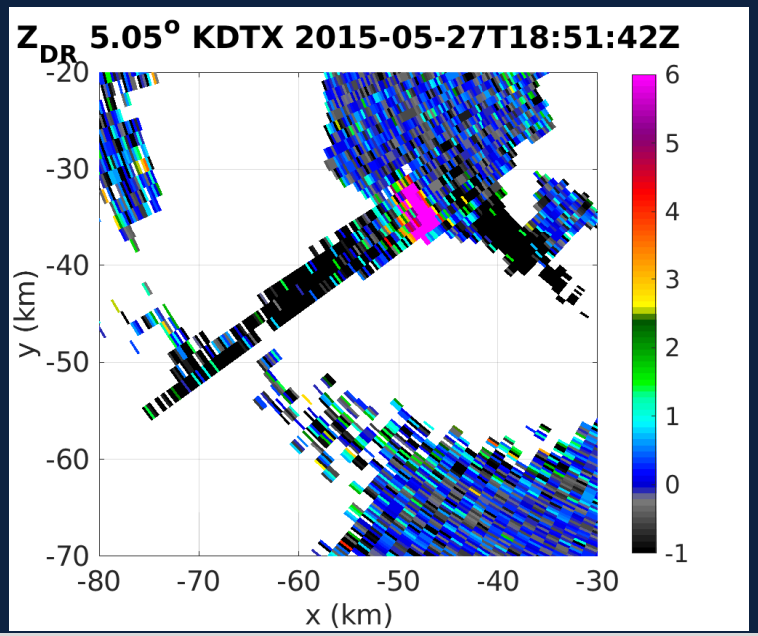
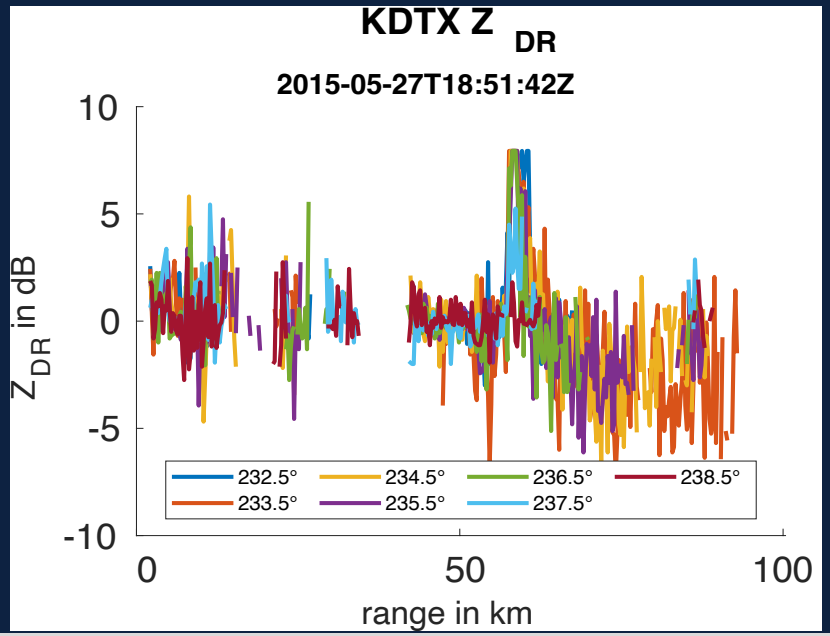
2015 – 05 – 27

Marginally Severe ≤ 1 in.









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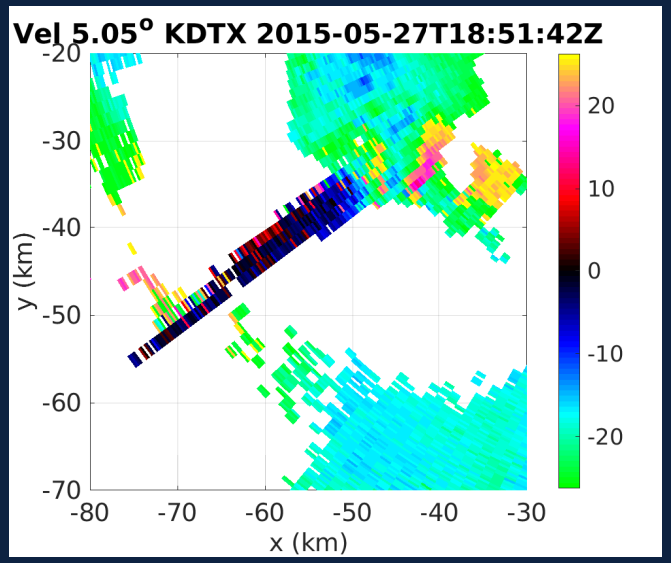
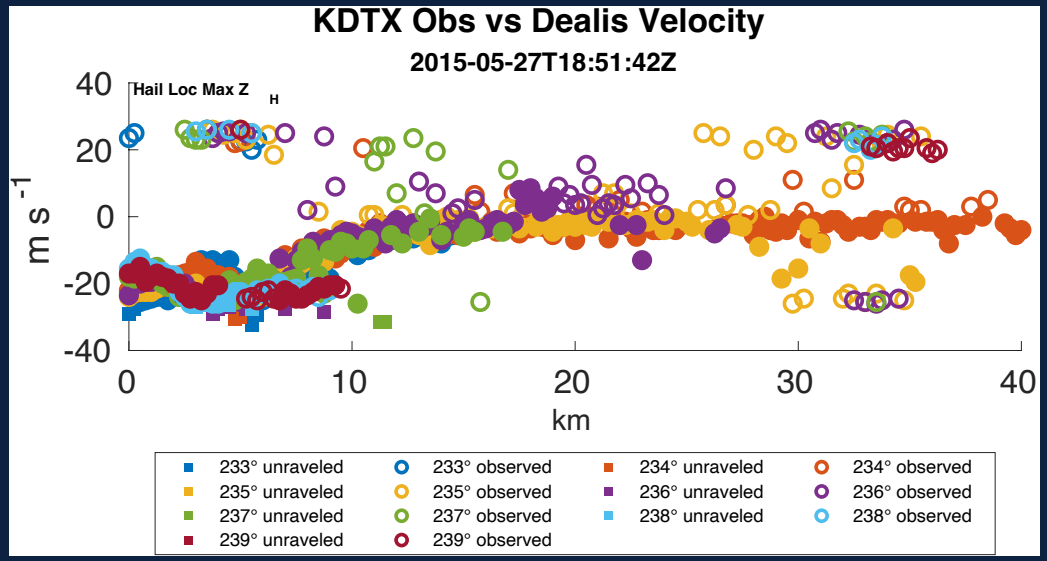
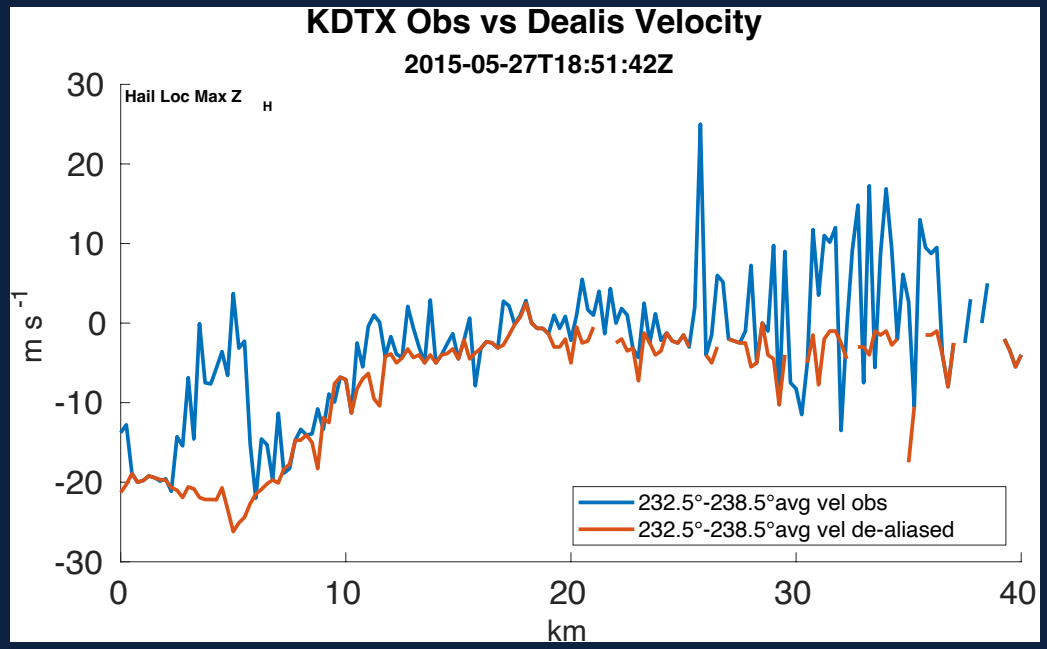
Marginally Severe ≤ 1 in.







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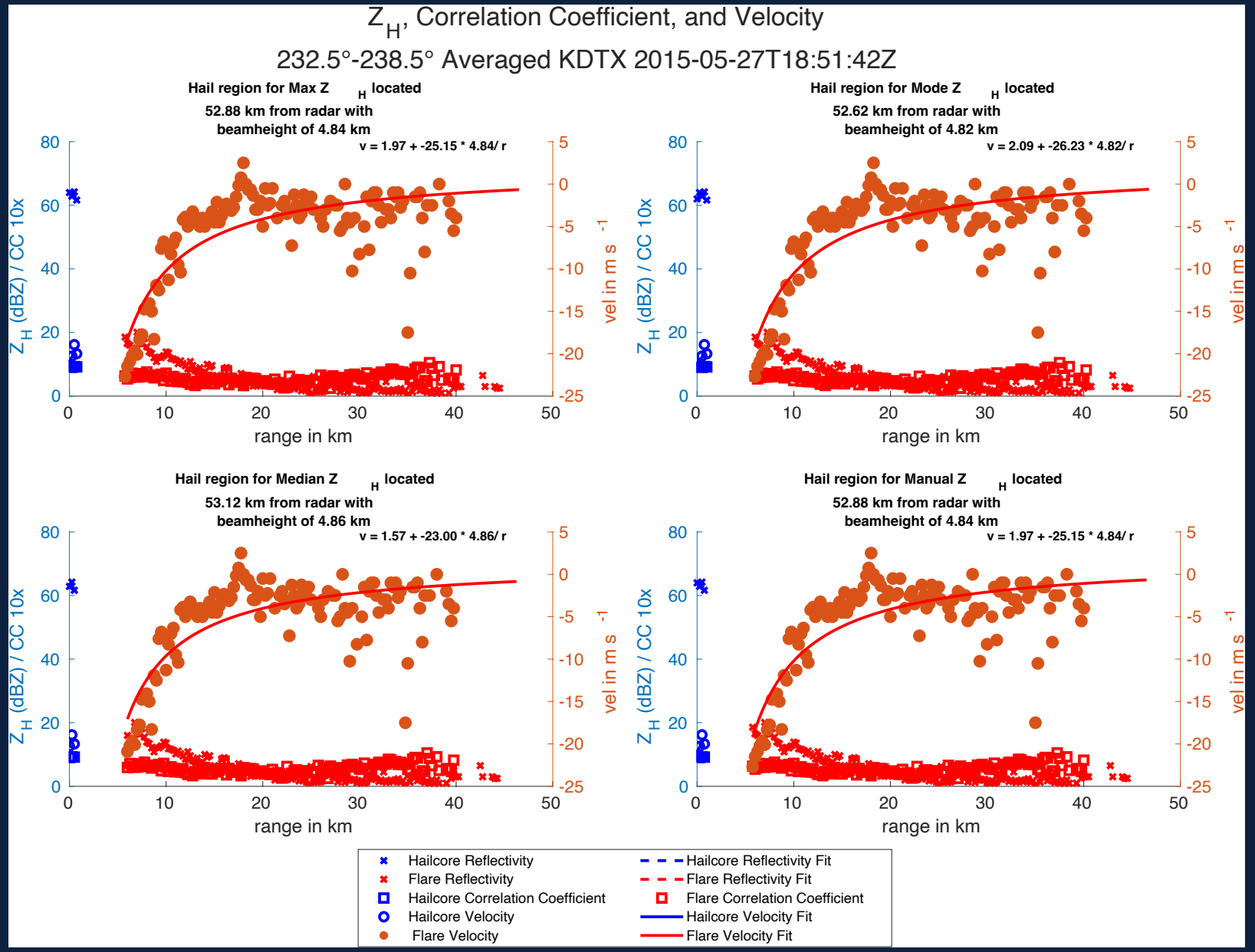
2015 – 05 – 27

Marginally Severe ≤ 1 in.



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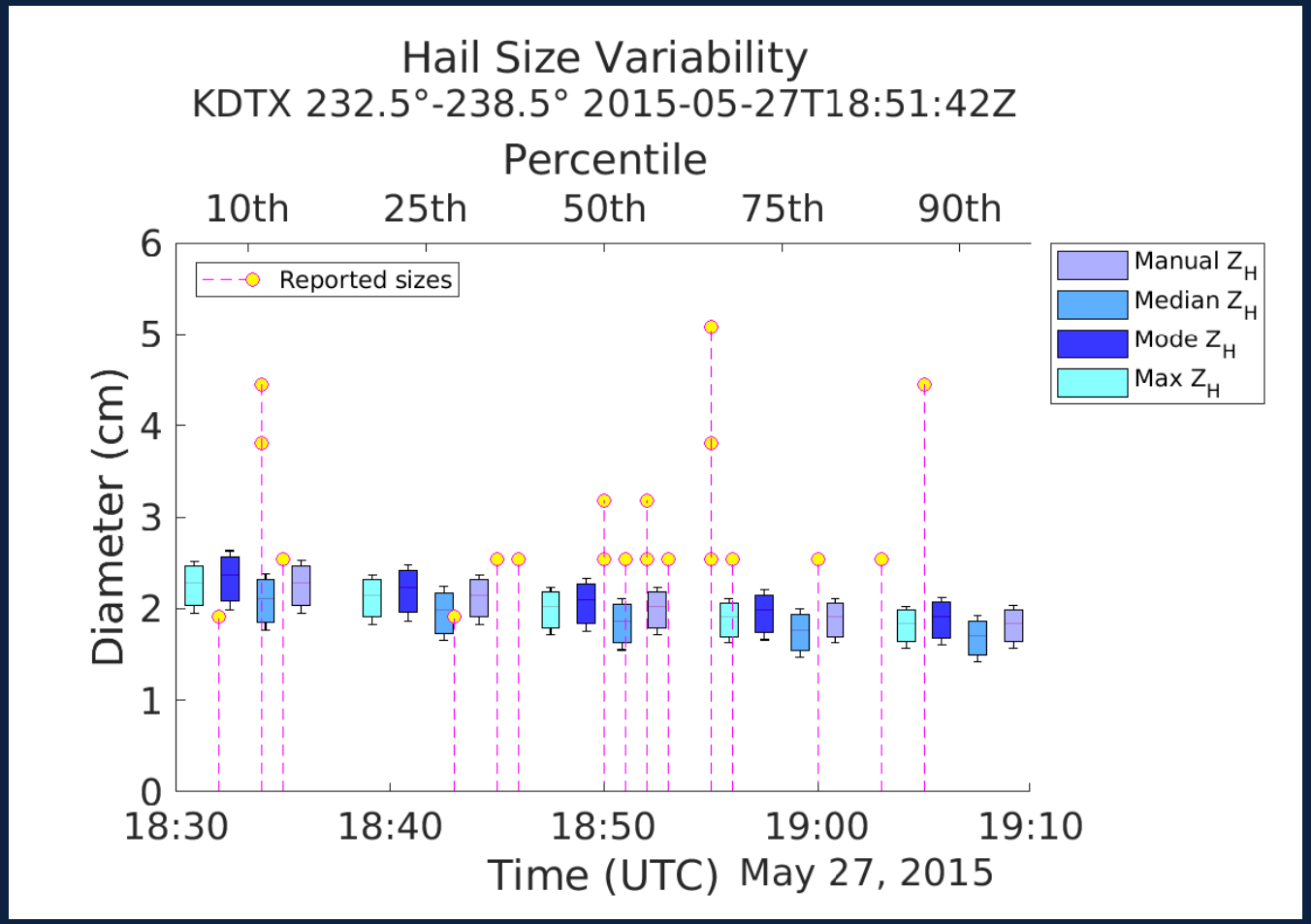
Marginally Severe ≤ 1 in. (2.54 cm)

Est. Hail Sizes for Hail Regions & Mass-Diameter Power Fit					
	10th	25th	50th	75th	90th
Max ZH	2.28	2.15	2.02	1.91	1.84
Mode (ZH ≥ 60 dBZ)	2.37	2.23	2.10	1.98	1.91
Median (ZH ≥ 60 dBZ)	2.11	1.98	1.86	1.76	1.70
Manually Selected	2.28	2.15	2.02	1.91	1.84



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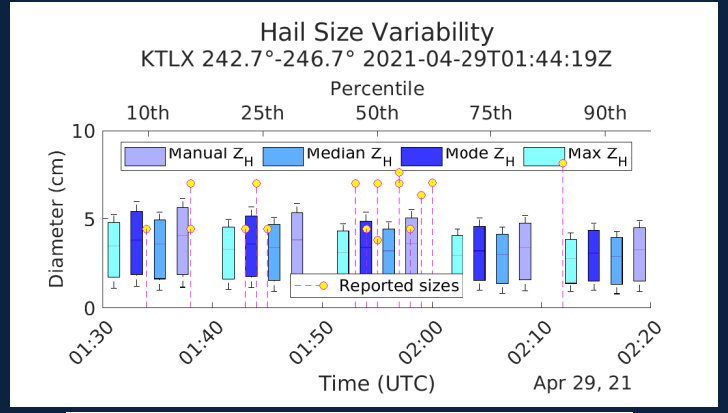
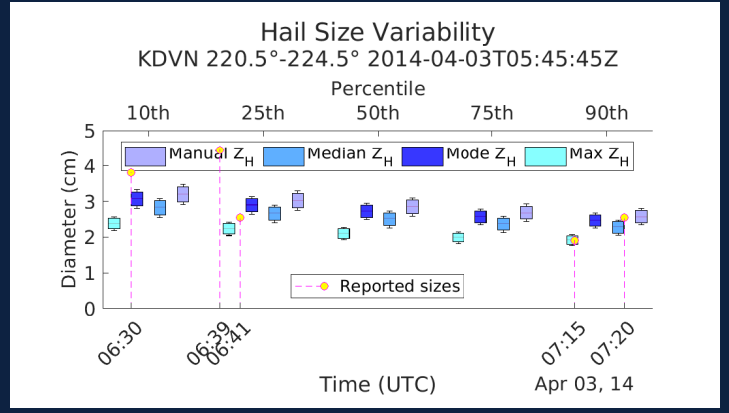
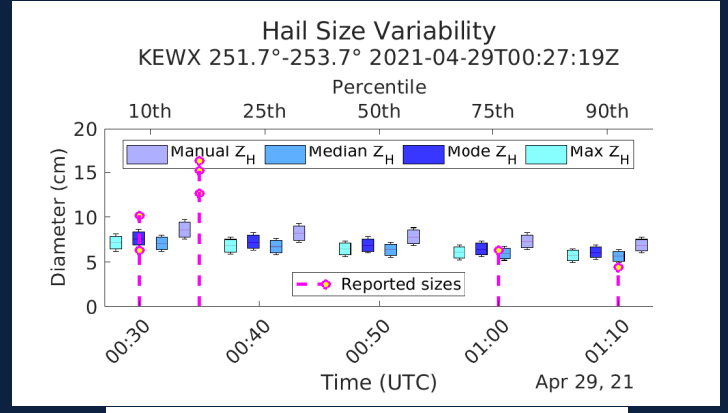
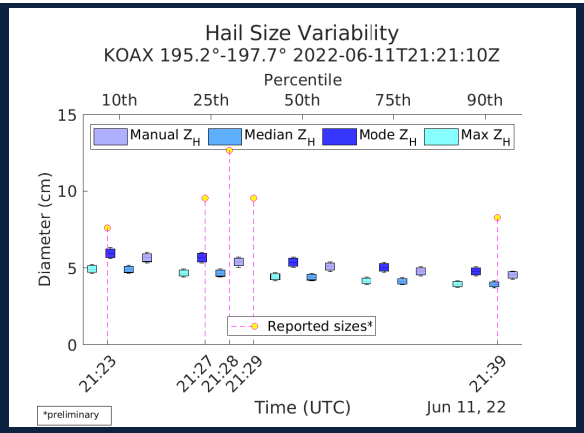
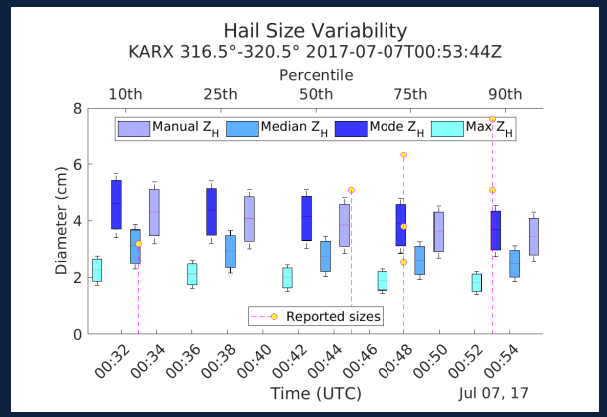
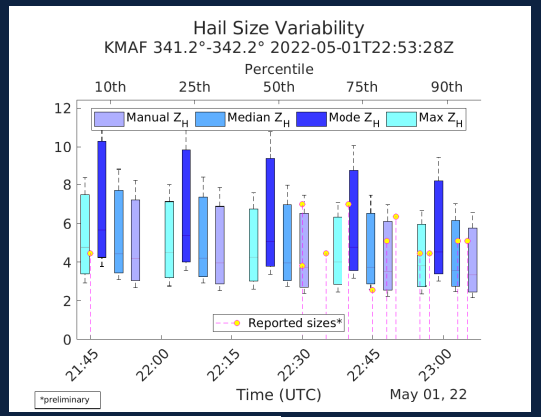

Hail Size Variability
KTLX 242.7°-246.7° 2021-04-29T01:44:19Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes
Time (UTC)
Apr 29, 21

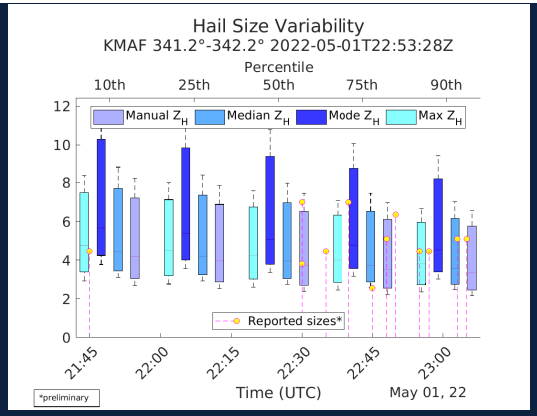

Hail Size Variability
KDVN 220.5°-224.5° 2014-04-03T05:45:45Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes
Time (UTC)
Apr 03, 14

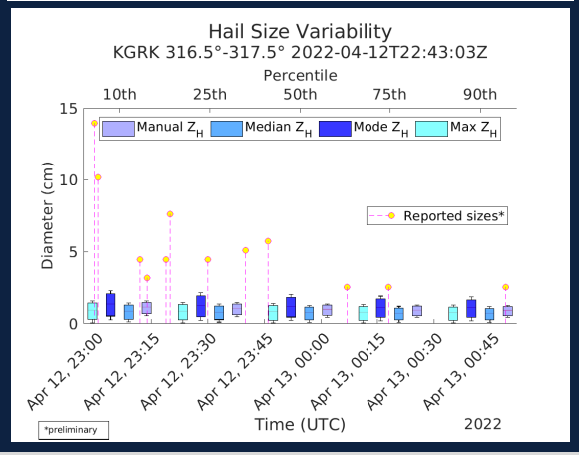

Hail Size Variability
KEWX 251.7°-253.7° 2021-04-29T00:27:19Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes
Time (UTC)
Apr 29, 21

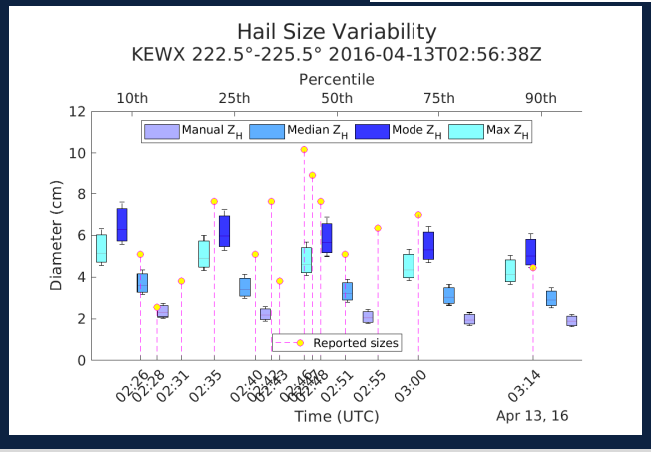

Hail Size Variability
KOAX 195.2°-197.7° 2022-06-11T21:21:10Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes*
*preliminary
Time (UTC)
Jun 11, 22

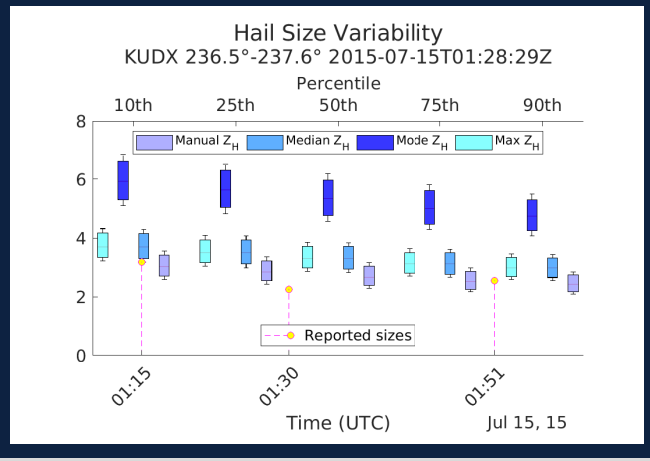

Hail Size Variability
KARX 316.5°-320.5° 2017-07-07T00:53:44Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes
Time (UTC)
Jul 07, 17


Hail Size Variability
KMAF 341.2°-342.2° 2022-05-01T22:53:28Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes*
*preliminary
Time (UTC)
May 01, 22


Hail Size Variability
KMAF 341.2°-342.2° 2022-05-01T22:53:28Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes*
*preliminary
Time (UTC)
May 01, 22


Hail Size Variability
KGRK 316.5°-317.5° 2022-04-12T22:43:03Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes*
*preliminary
Time (UTC)
2022


Hail Size Variability
KEWX 222.5°-225.5° 2016-04-13T02:56:38Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes
Time (UTC)
Apr 13, 16


Hail Size Variability
KUDX 236.5°-237.6° 2015-07-15T01:28:29Z
Percentile
10th 25th 50th 75th 90th
Manual Z_H Median Z_H Mode Z_H Max Z_H
Diameter (cm)
Reported sizes
Time (UTC)
Jul 15, 15

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Scratch

- Forecasting and detecting hail size remains a challenge
- Radar is highly effective tool in hail detection