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

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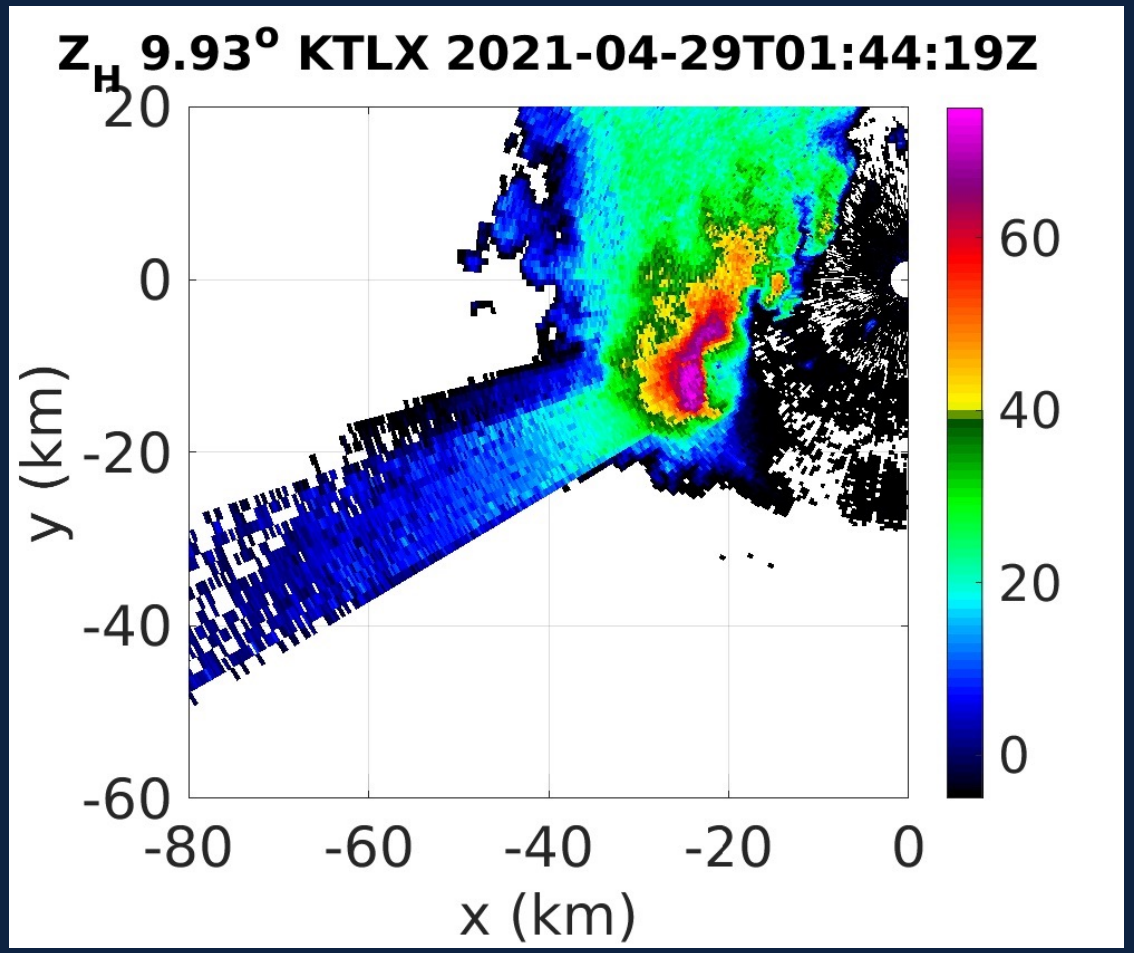
Three-Body Scattering Signature (TBSS; Zrnić 1987)

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



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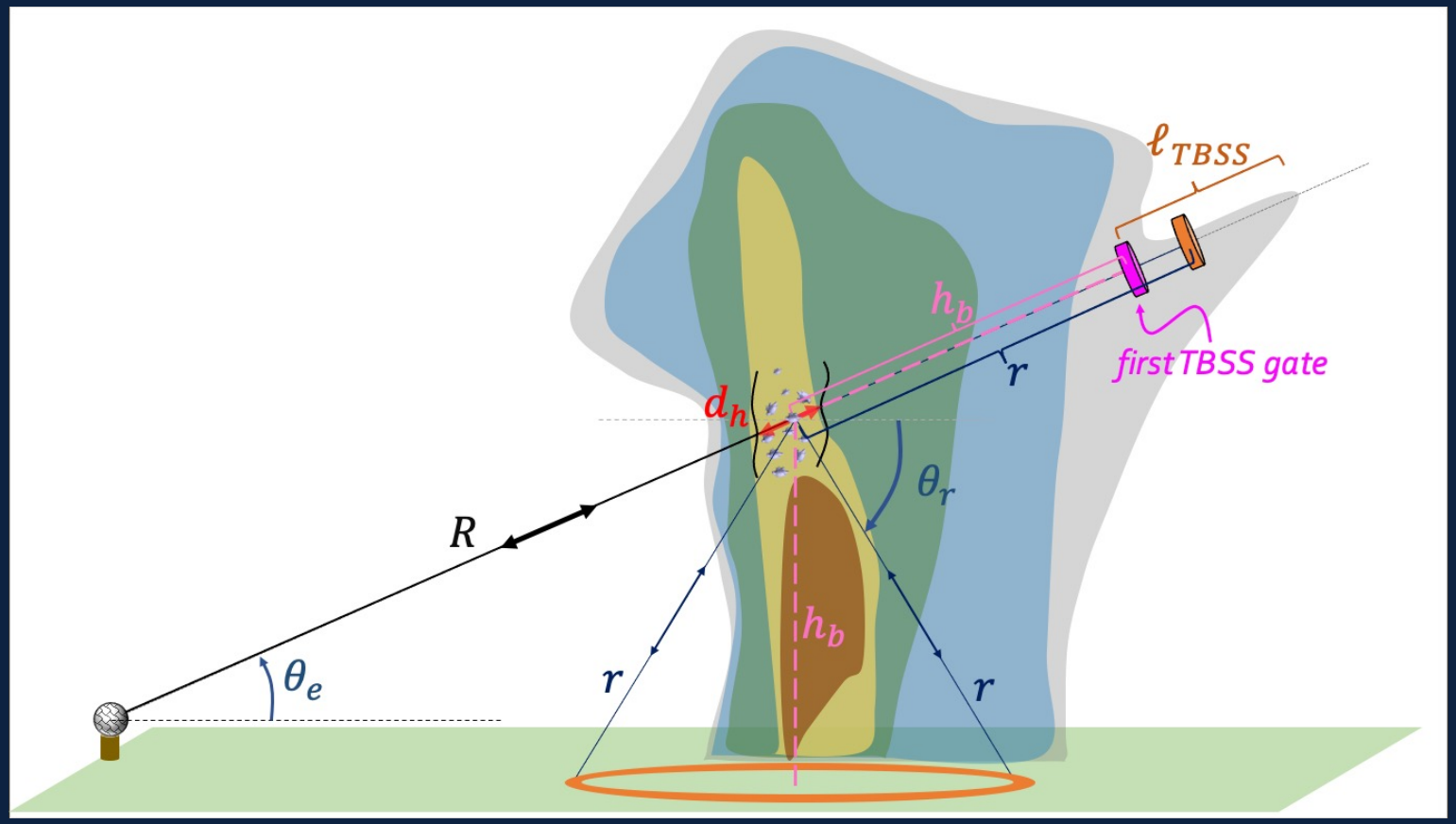
Schematic of Three-Body Scattering Signature

TBSS is EM radiation scattered:

(1) from high-reflectivity core to the ground,

(2) from the ground back to the high-reflectivity core, and then

(3) from high-reflectivity core back to radar antenna.



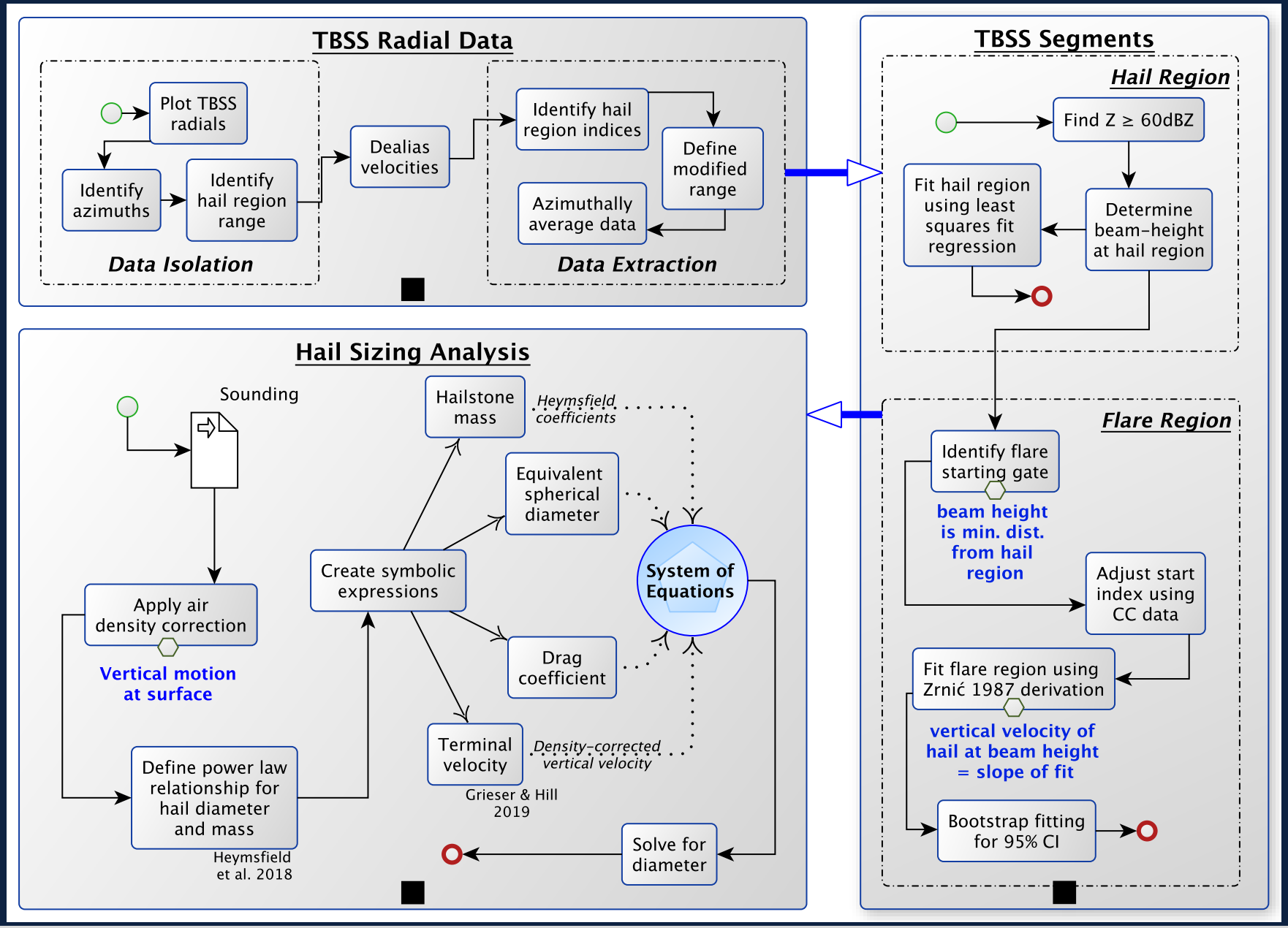
(VanAlstine & Kumjian 2024, in preparation)

Utility of TBSS to estimate hail size?

Zrnić (1987) theory:

Hailstone fall speed increases monotonically with size (e.g., Heymsfield et al. 2018)

HYPOTHESIS: The Doppler velocity in TBSS is related to hailstone 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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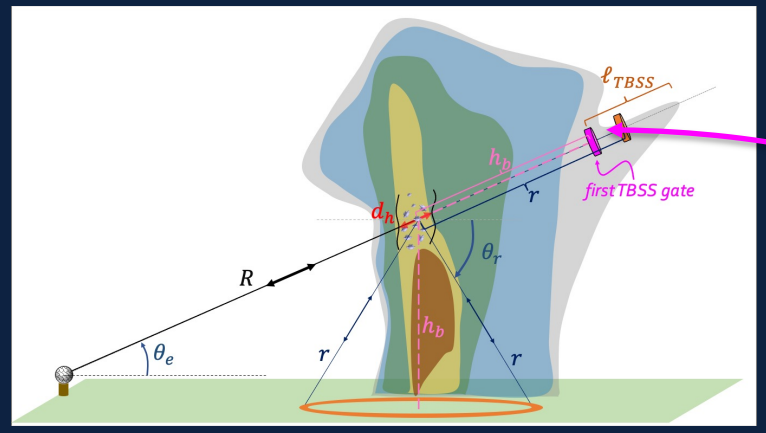
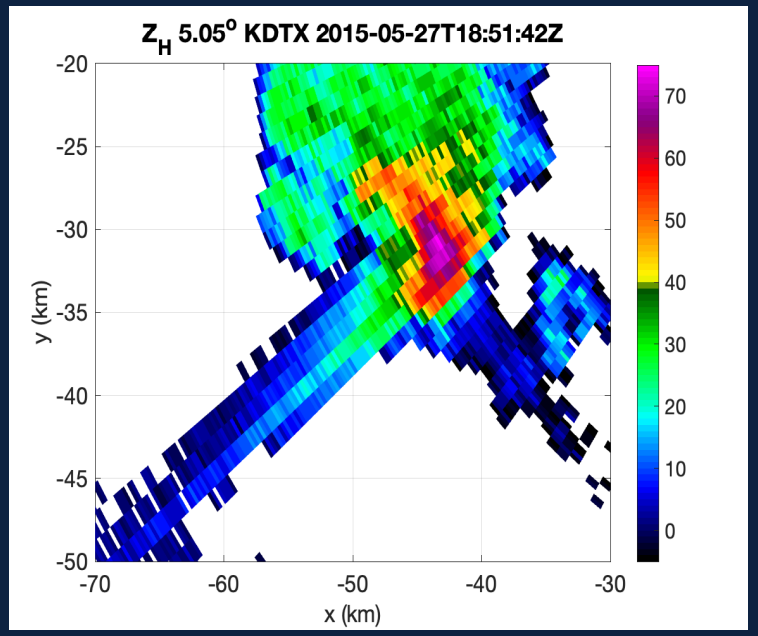
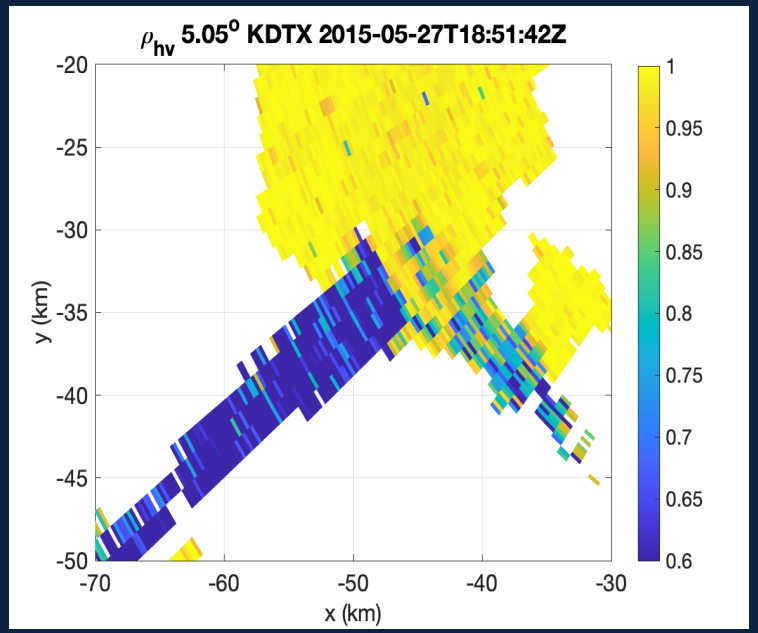
Detroit, Michigan

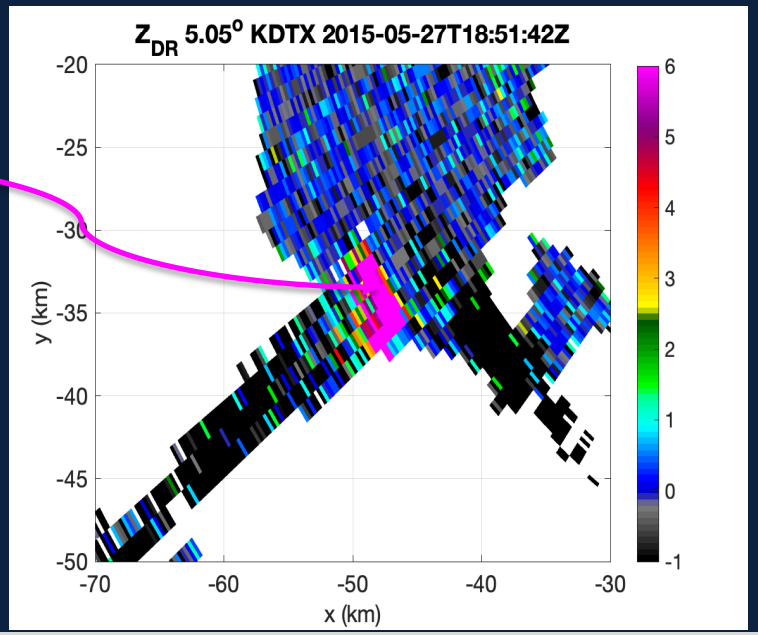
2015 – 05 – 27

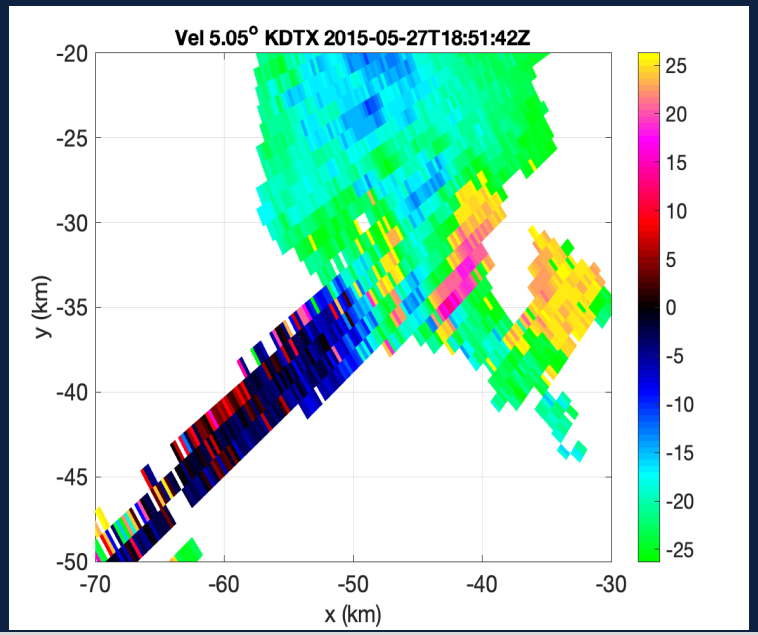
Reports of 2-5 cm hail.











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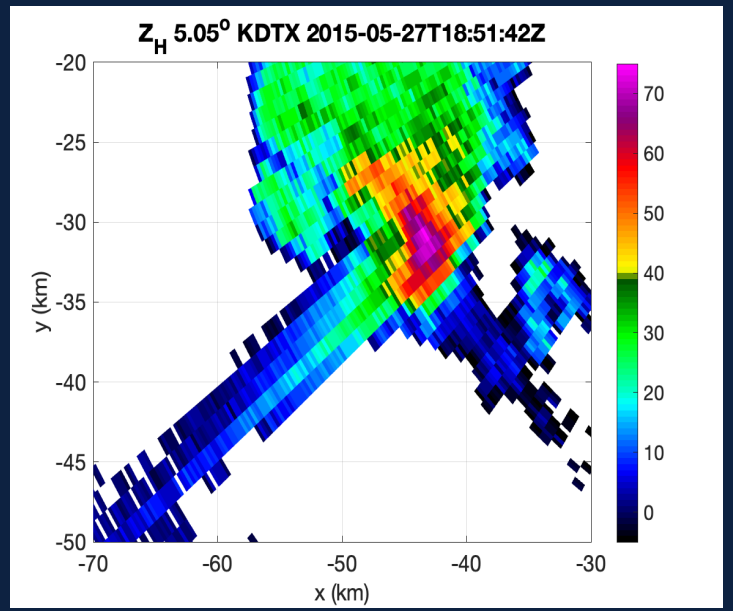

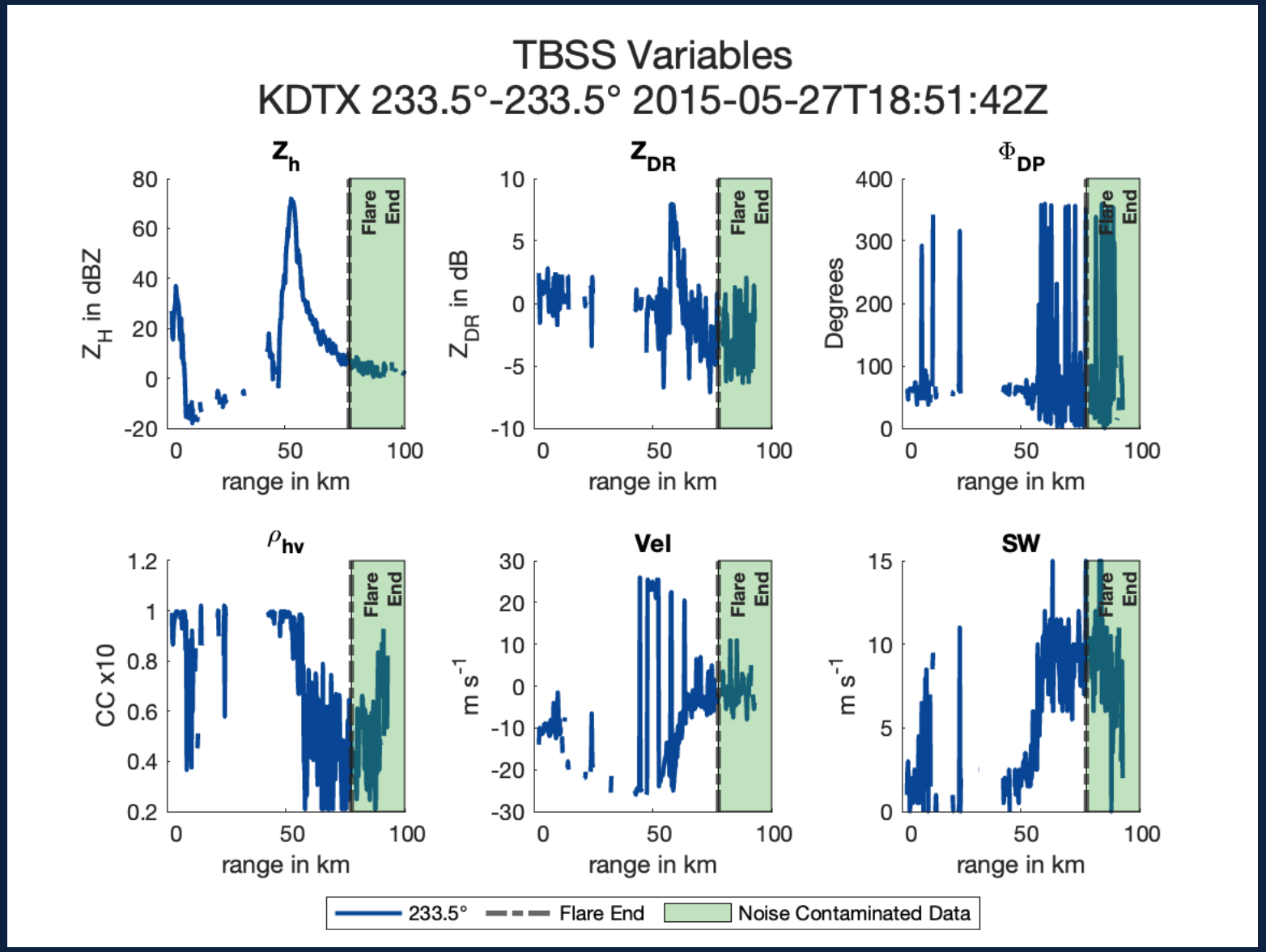

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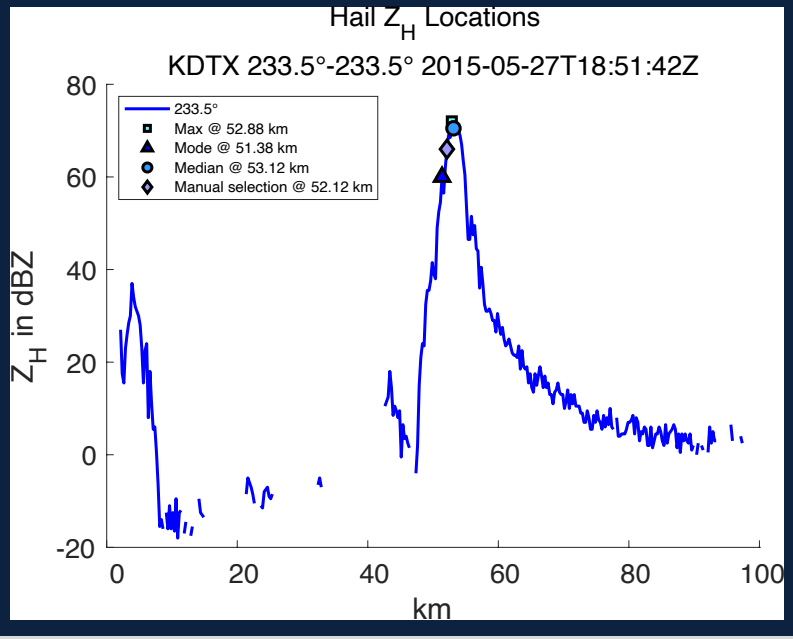

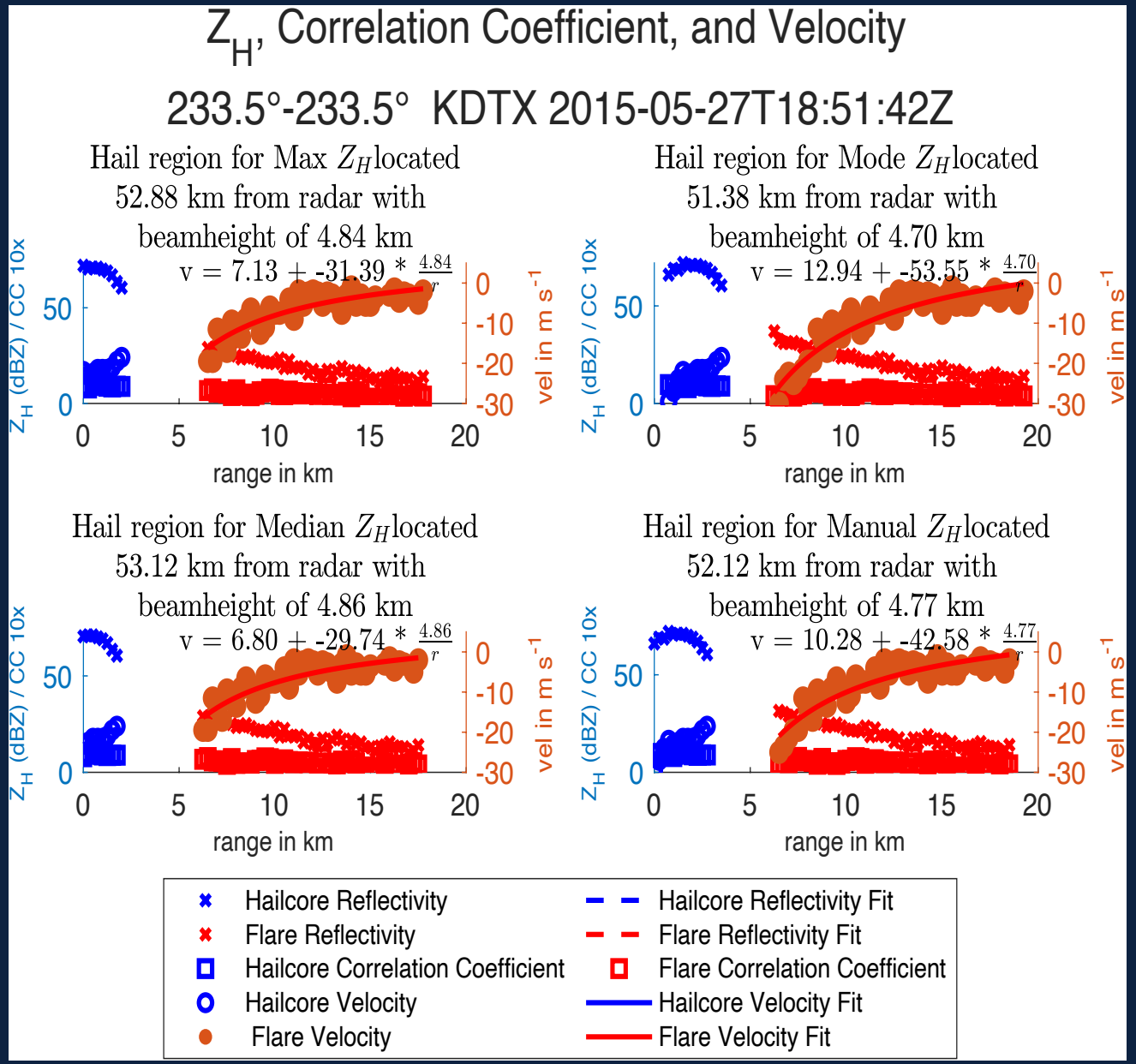

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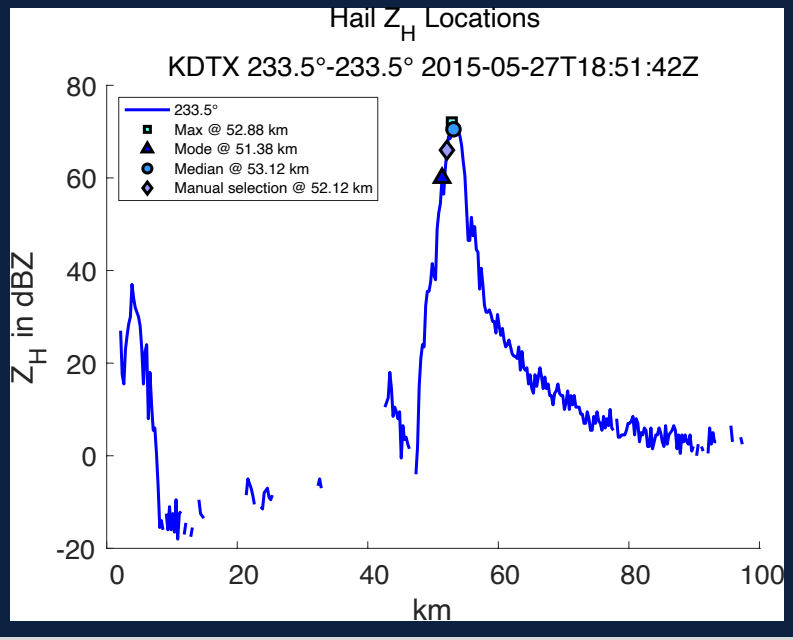

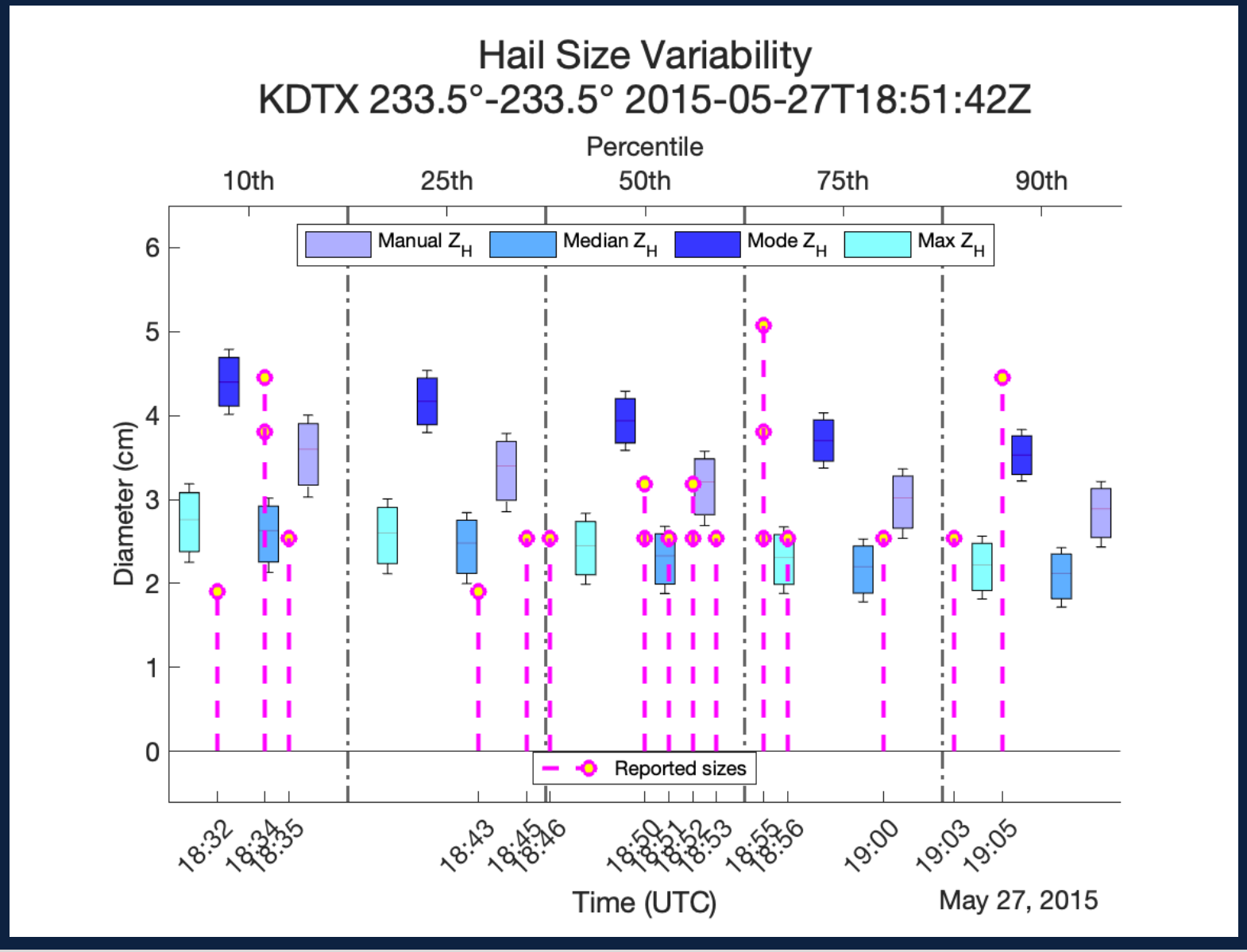

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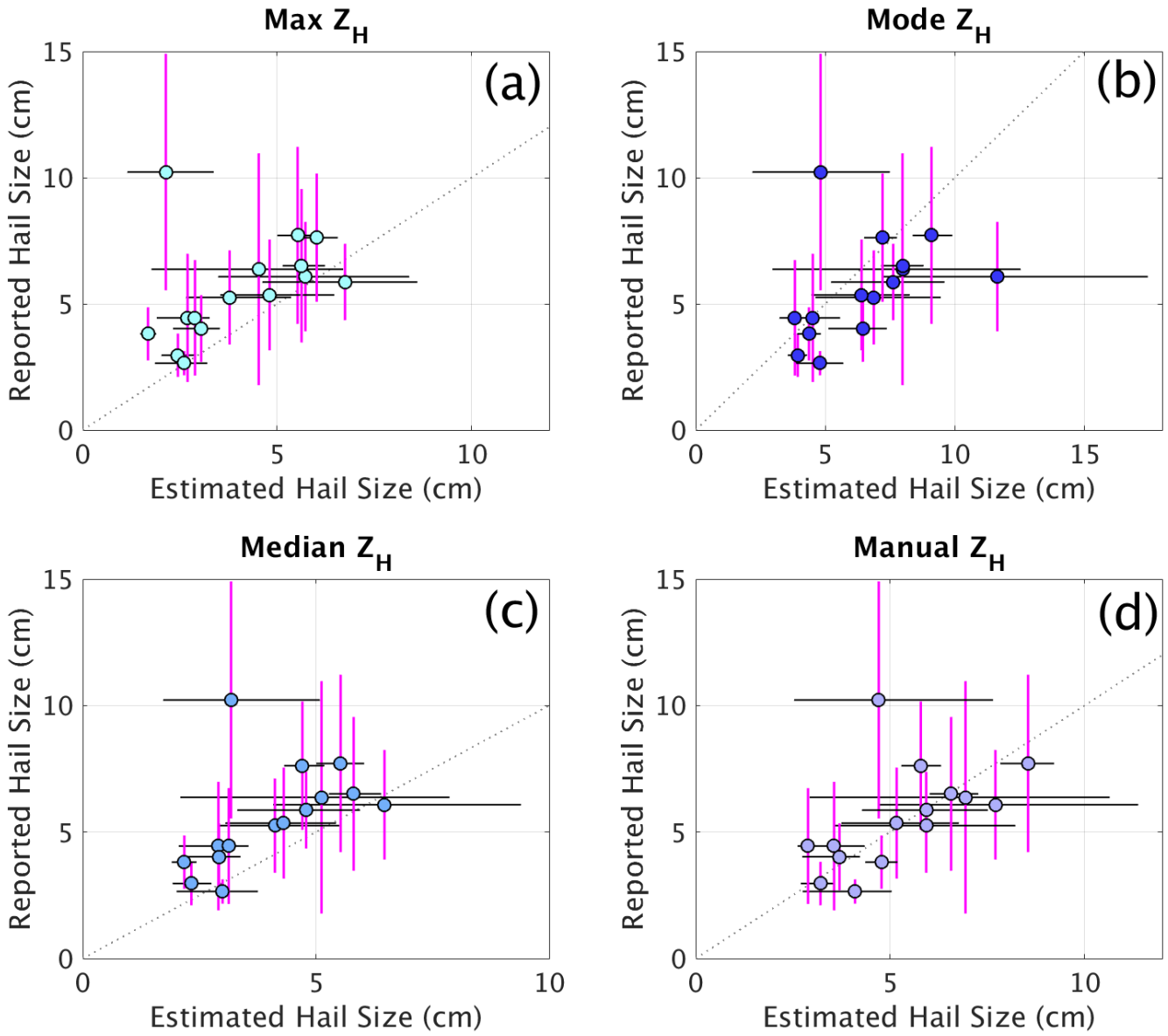
Max Z_H
(a)
Reported Hail Size (cm)
Estimated Hail Size (cm)
Mode Z_H
(b)
Reported Hail Size (cm)
Estimated Hail Size (cm)
Median Z_H
(c)
Reported Hail Size (cm)
Estimated Hail Size (cm)
Manual Z_H
(d)
Reported Hail Size (cm)
Estimated Hail Size (cm)

Key Takeaways

- Does it work?
  - moderate correlation (~0.4 to 0.6, depending on choice of Z_H location) between estimated hail size and mean reported hail size
  - technique works well in revealing when the average reported hail size will be larger
- Limited by scattering physics
- Fitting procedure is a least-squares regression of Doppler velocity data in h/R space
  - Less confidence are introduced when the fitting is challenged by:
    - greater variance in the Doppler velocity data
    - a limited number of data points to which a line can be fit
    - Precipitation contamination in flare

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