Z-R Relationships Inferred from Rain Drop Size Distributions in Different Types of Rain Systems over Gulf of Mexico Coast

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Research Questions/Objectives:

- The primary objective of this study is to analyze and compare rain drop size distribution (DSD) variations across different types of precipitation, including warm rain, cold fronts, thunderstorms, and tropical storms. This work aims to assess the validity of the current Z-R relationship assumptions in radar-based precipitation estimates and its distinct variation between multiple different types of precipitation. Emphasis is placed on the estimation of the limits of K-Band radar reflectivity, specifically in the condition of high volumes of larger rain drops (>2mm) and heavy rain, since Mie scattering may lead to non-linear scattering response to the large hydrometeor particles. This research contributes to the broader goal of improving spaceborne radar precipitation estimates and further understanding of precipitation processes by addressing these questions.

Instrumentation:

Parsivel Disdrometer
- Uses a laser beam to measure the size and fall velocity of rain drops passing through.
- Provides detailed DSD data, such as drop count and diameter.
- Can detect rain drops with a diameter of 0.2 mm to 8mm.
- High resolution data measurements in intervals short as 1 second.

Tipping Bucket Rain Gauges
- Records accumulated rainfall by counting the number of bucket tips.
- Provides ground-data for validating the disdrometer and MRR-Pro estimates.
- Installed since May 2023.

Micro Rain Radar (MRR-Pro)
- A vertical pointing radar operating at K-Band (24 GHz) to observe different types of precipitation at different altitudes.
- Profiles vertical precipitation properties such as reflectivity, doppler velocity, and derived rain rate.
- Captures variations in DSD's, with limitations in heavy rain due to signal attenuation and Mie scattering on large raindrops.

Methodology:

- Rainfall data were collected from the Parsivel disdrometer, MRR-Pro, and the Tipping bucket rain gauges located at Texas A&M University-Corpus Christi. The MRR-Pro profiled vertical variations of reflectivity, velocity, and rain rate and the Parsivel disdrometer presented a surface level raindrop size distribution (DSD). The tipping bucket rain gauges measured the accumulated rainfall to provide validation to the MRR-Pro and Disdrometer. Time series plots were created to show rainfall rate intensities across different instruments during different types of rain events. Drop size distribution plots were created from disdrometer data with raindrop diameter and concentration. Z-R relationships were constructed from the MRR-Pro and Disdrometer data to compare the accuracies of radar-based rainfall estimates across different types of precipitation.

Table 1. Comparison of Z-R Relationships and Total Rain Accumulation Across Different types of precipitation

Cases	Type	Z-R Relationship (MRR-Pro @ 105 m ASL)	Z-R Relationship (Disdrometer)	Total Rain Accumulated (mm)			
				MRR-Pro	Disdrometer	Gauge A	Gauge B
08-22-23	Tropical Storm (Harold)	$Z= 74.44 * R^{0.88}$	$Z= 333.15 * R^{1.40}$	279.94	74.37	101.75	99.08
11-13-23	Thunderstorm	$Z= 149.92 * R^{1.38}$	$Z= 337.26 * R^{1.35}$	197.47	32.44	52.58	55.12
01-24-23	Cold Front	$Z= 47.22 * R^{1.01}$	$Z= 295.69 * R^{1.47}$	40.49	1.74	N/A	N/A
04-10-24	Warm Rain	$Z= 207.23 * R^{1.13}$	$Z= 462.72 * R^{1.34}$	6.22	1.56	2.29	2.29

- MRR-Pro rain rates overestimate the total rain accumulation by a factor more than 3; likely due to the wrong Z-R relationships built in the factory software.
- Parsivel disdrometer underestimates the total rain compared to the rain gauges, possible due to the sensitivity limit on the raindrops bigger than 0.2 mm.

Summary:

- There is a significant variability in drop size distribution (DSD) from four different types of precipitation such as warm rain, tropical storms, cold fronts, and thunderstorms.
- While the tropical storm and convective system displayed larger drops and higher rain rates, the cold front and warm rain displayed smaller drops and lower rain rates.
- Z-R relationships ($Z= a*R^b$) vary in different precipitation types, the constants a and b adjusted to each different type of rainfall event are comparable to the literature.
- The Z-R relationship built in the MRR-Pro factory software significantly overestimates the rain rate in general. However, due to Mie scattering, MRR-Pro underestimates the heavy rain with the large raindrops (e.g. tropical storm and some warm rain cases).
- Disdrometer underestimate the rain rate compared to rain gauges, especially for systems with small raindrops, such as cold front cases.
- Rain gauges gain a delayed information compared to the instantaneous rain rate collected by radar and disdrometer. Therefore, they are not suited for point-by-point comparisons but provide solid references of total rain accumulations.
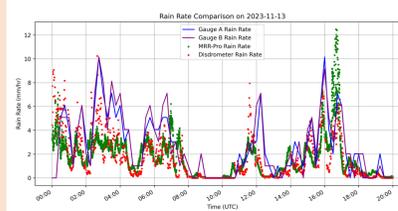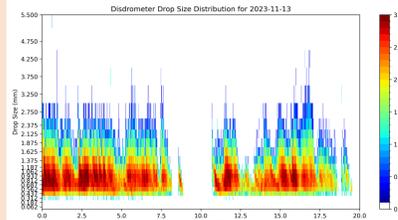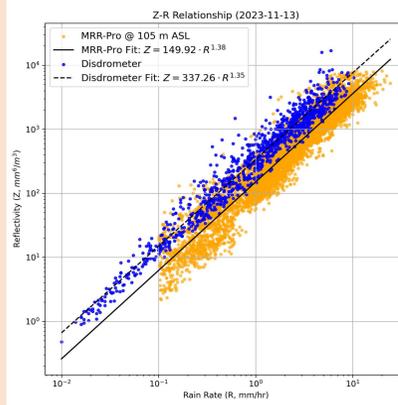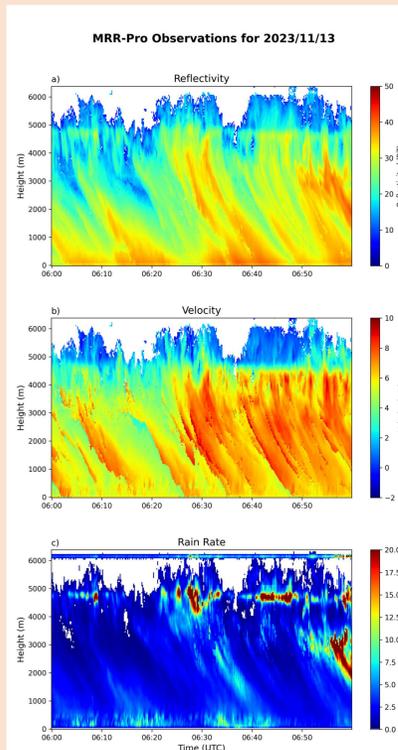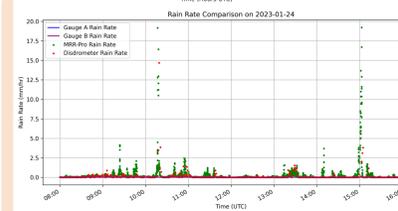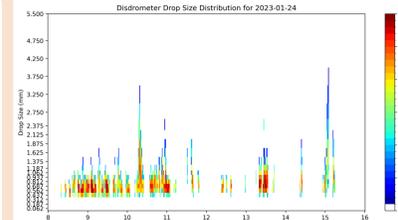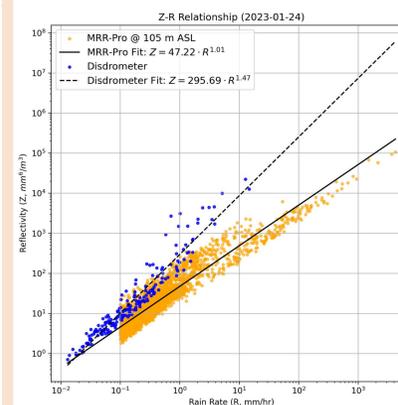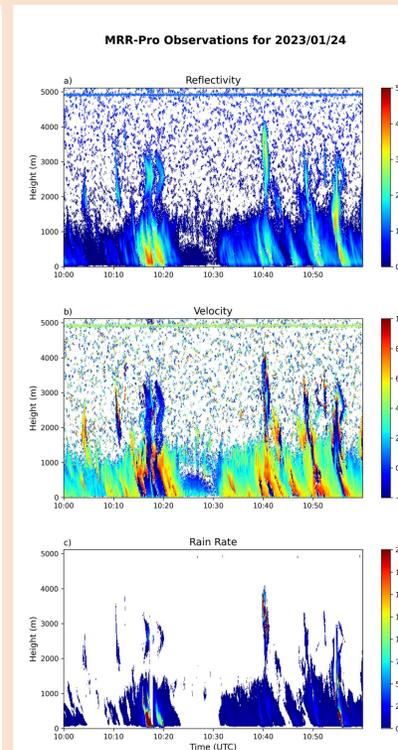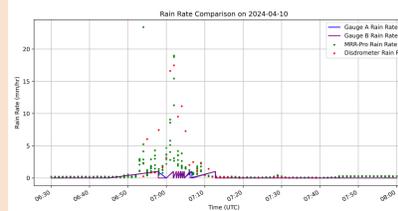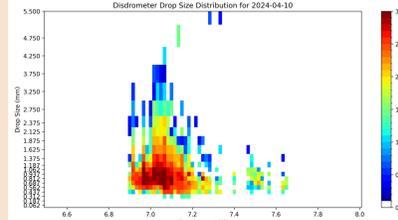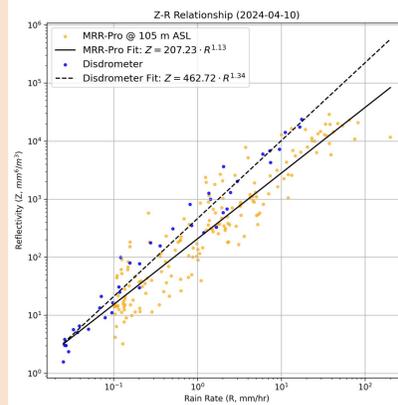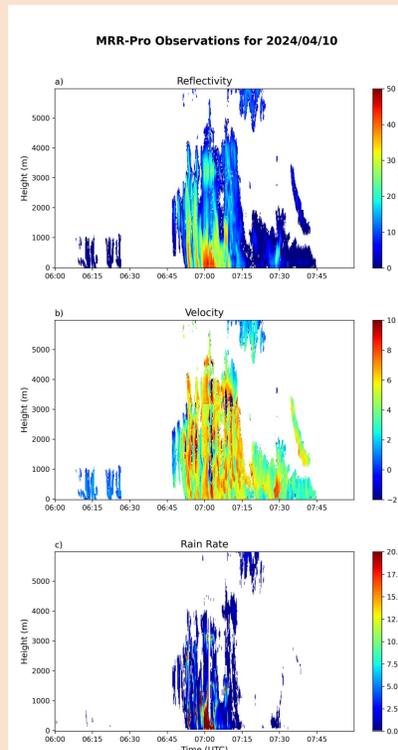
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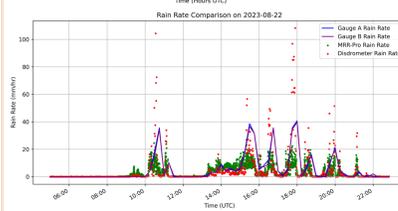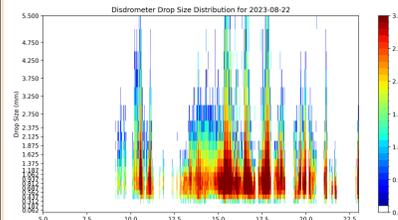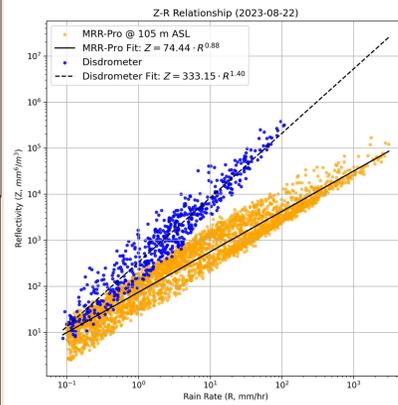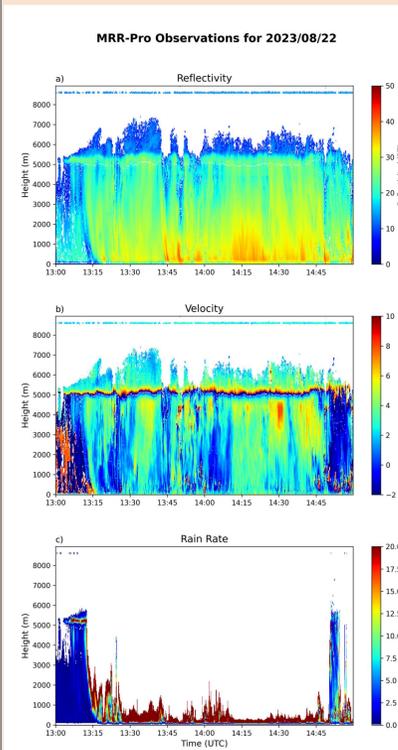
Case 1 Tropical Storm Harold:
Case 2 Thunderstorm:
Case 3 Cold Front:
Case 4 Warm Rain:

- Top two rows shows MRR-Pro reflectivity and doppler velocity derived using the CU Boulder MRR-Pro spectrum algorithm developed by Dr. Christopher Williams. This algorithm uses the clean sky measurements to correct the radar spectrum during the rain events. There are still some background issues to be removed for the winter cold front case.
- Third row shows the rain rate provided by MRR-Pro software. It failed during the tropical storm Harold case.
- Fourth row shows the relationships between the radar reflectivity (Z) to the rain rate (R) with fit lines with equation $Z= a*R^b$. The relationships are derived using the MRR-Pro corrected Z and factory provided rain rates and Parsivel disdrometer DSD and fall velocity information.
- Fifth row shows the Parsivel raindrop size distribution during the four cases. Note that there are big rain drops (> 3 mm) in the tropical storm and the warm rain cases, while MRR-Pro derived lower rain rates.
- Bottom row compares the rain rate derived using MRR-Pro, disdrometer, and two rain gauges. The rain gauges shows delayed peaks compared to other two instantaneous measurements.