PRECIPITATION IMAGING PACKAGE (PIP): A POTENTIAL INSTRUMENT FOR MEASURING RAINDROPS

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1 Introduction

Rain is crucial for ecosystems, but accurately measuring it across the entire size spectrum remains a scientific challenge. The **Precipitation Imaging Package (PIP),** developed by **Dr. Larry Bliven** at NASA's Wallops Flight Facility, is a camera-based instrument known as a disdrometer. Originally designed to measure snowflakes, the PIP has been used in NASA's winter field campaigns under the **Global Precipitation Measurement (GPM) mission** for nearly two decades, demonstrating reliability, low-maintenance and cost-effectiveness.

Potential for Rain Measurement

The PIP has demonstrated its value in falling snow, but its potential for capturing entire size range of raindrops remains to be explored. This study aims to assess the PIP's capability to accurately measure raindrop size distribution and rainfall through comparing its performance against traditional instruments, such as the laser optical PARSIVEL (PARticle SIze VELocity) disdrometer and Pluvio weighing and tipping bucket gauges.

2 Instrumentation and Data Collection

PIP Features and Capabilities

- High-Resolution Imaging Camera: Captures detailed multi-images of falling particles at **380 frames per second**
- Light Source: Backlights particles, improving image clarity
- Particle Size Detection: Measures diameters ≥ **0.2 mm**
- Field of View: **(64−Deq) x (48−Deq) mm²**
- Depth of Field**: 117/2 x Deq mm**
- Key Measurements: Size, Velocity, Concentration]

PIP Data Collection and Processing

As part of the GPM ground validation program, a unique set of precipitation measuring instruments, including PIP, has been deployed at the University of Connecticut (UCONN) in Storrs, CT (41.809°N, 72.295°W) over the past three winters.

- 2021-22 winter (IMPACTS 2022): PIP data not used as there was no tipping bucket gauges deployed
- 2022-23 winter (IMPACTS 2023): One PIP (PIP 002)
- 2023-24 winter (UCONN 2024): Two PIPs (PIP 002 & PIP 003) were collocated

The first two campaigns were part of NASA's Investigation of Precipitation and Microphysics for Atlantic Coast-Threatening Snowstorms. Reprocessing of the PIP data is ongoing. It has been completed for IMPACTS 2023, with 11 rain events processed in this study. There were 27 rain events during UCONN 2024, with 4 processed so far. This poster focuses on the event of **January 9-10, 2024**, which lasted 15 hours, with 897 minutes of rain and a max rainfall rate of 173.3 mm/h.









Top Right: Precipitation Imaging Package (PIP) at the South Korean Winter Olympics.
Top Left: Location of Field Campaign at the University of Connecticut (41.809°, -72.295°).
Bottom Right: UCONN 2024 Field Campaign Instruments and Trailer Configuration.
Bottom Left: PARSIVEL (Center), Tipping Buckets (Left & Right).

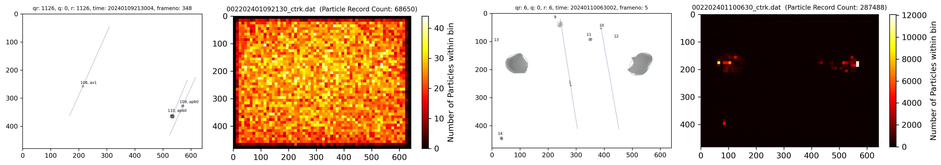
3 Instrumentation and Data Collection

PIP Processing Methods

The original **IMAQ** software tracks particle size and velocity independently. The **Standard** method, the first developed, had uncertainties. To address this, the **AT Terminal** and **AT Observed** methods were introduced to better replicate Standard outputs, using terminal and observed velocities, respectively, with median velocities assigned to frequently observed particles.

The **CNH** software is the latest advancement, allowing simultaneous tracking of size and velocity. This software uses prior motion, aspect ratio, and equivalent diameter to allow more particles to have an identifiable velocity as compared to IMAQ. It enhances accuracy by measuring more particles' fall velocities and applying a threshold.

Percent of Particle Observations with Assigned Fall Speed	
IMAQ	CNH
PIP 002: 23.3 %	PIP 002: 62.8%
PIP 003: 26.1%	PIP 003: 66.3%

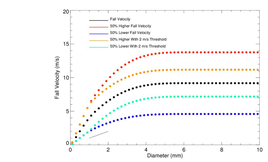


The four images display CNH data from PIP 002, recorded on January 9 and 10. Each snapshot is paired with a corresponding 10-minute heat map average: the first two images are from January 9, while the latter two represent January 10. The January 10 images illustrate an anomaly where stationary particles appear on the camera lens, leading to an overestimation of the particle count.

Four separate processing methods of CNH were examined for this project: **CNH** (base), **CNH Terminal** (with terminal velocity constraints), **CNH ap60** (with additional adjustments), and **CNH ap60 Terminal** (combining adjustments with terminal velocity). These methods offer a comprehensive assessment of PIP performance compared to traditional instruments.

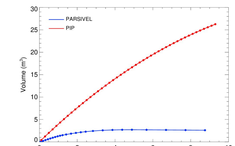
$$(1).\ N(D_{eq,i}) = \frac{1}{TN_f \Delta D_{eq,i}} \sum_{j=1}^{N} \frac{1}{DOF_{i,j} FOV_{i,j}} \qquad (2).\ PR = 6\pi 10^{-4} \int_{D_{min}}^{D_{max}} v(D_{eq}) D_{eq}^3 N(D_{eq}) dD_{eq}$$

The Precipitation Imaging Package (PIP) measures particle size distribution ($N(D_{eq,i})$) as the number of particles per unit volume in 0.2 mm intervals. PIP volume is influenced by the depth of field, field of view, and the number of frames (380 x 60). Integrating this distribution gives the total particle concentration. The precipitation rate (PR) from PIP is based on particle volume, fall velocity, and concentration over 60 seconds, and is expressed in millimeters per hour. The contribution of particles to the precipitation rate within a size bin (RRD) is also expressed in millimeters per hour per millimeter.



Diameter vs. Fall Velocity

Curves apply different criteria (+/- 50% with a maximum deviation of 2 m/s) to assist in filtering out anomalies, specifically used in CNH processing methods.

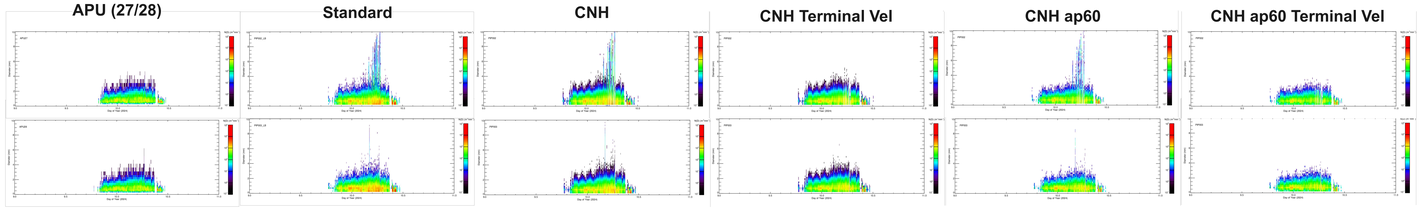


Diameter vs. Volume

PIP consistently measures higher volumes for larger diameters compared to PARSIVEL, demonstrating PIP's greater sampling volume and sensitivity to larger particles.

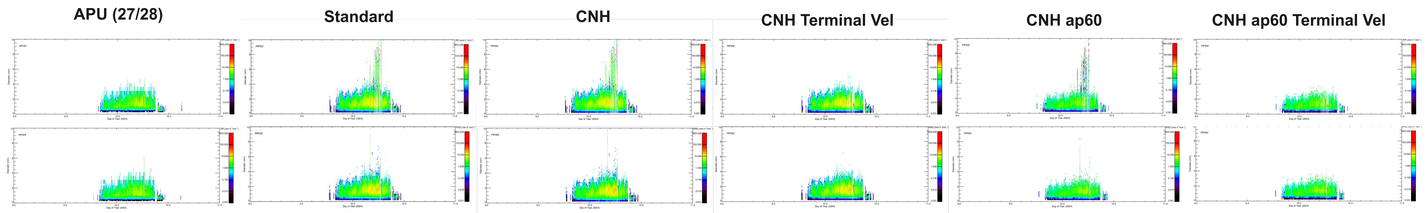
4 Rainfall Analysis (UCONN 2024 January 9−10)

Particle Size Distributions



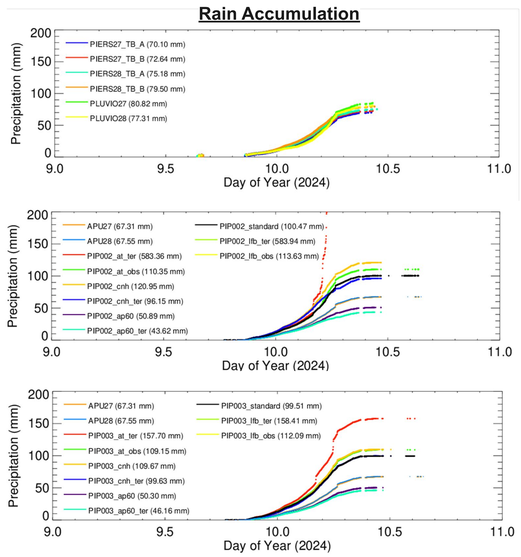
Time series of Particle size distributions for the January 9−10, 2024 rain event. Each row displays distributions from different PIPs: the top row for PIP002 and the bottom row for PIP003, except first column for PARSIVEL (APU27 and APU28). From left to right, the PIP methods include Standard, CNH, CNH terminal velocity, CNH ap60, and CNH ap60 terminal velocity. The x-axis represents observation period given as day of year, and the y-axis represents particle diameter. The color bar indicates particle concentration. Notably, PIP 002 shows spurious large particles early on January 10, coinciding with camera lens anomalies, contributing to erroneous high rain totals. Processing methods applying terminal velocity screening tend to remove majority of these larger particles. The underestimation of small drops (D_{eq} < 0.5 mm) by PARSIVEL is evident. This is the size regime where PIP performs better resulting in more accurate particle distribution parameters (e.g. mean mass diameter, normalized intercept parameter), which are critical for spaceborne precipitation retrievals and weather and climate models.

Rain Rate Distributions



Time series of rain rate distributions for the January 9−10, 2024 rain event. The legend is the same as particle size distribution except that the color bar indicates the normalized rain rate. The rain rate is proportional to third-to-fourth moment of raindrop size and receives majority of its mass from mid-size raindrops (1 < D_{eq} < 3 mm). There is a shift in size regime regarding the major contribution to the rainfall in very light and very heavy rain. The contribution of small drops and very large drops (D_{eq} > 5 mm) to the total mass are relatively low and are well marked in time series. The spurious large drops results in anonymously high rain rates and can be eliminated through terminal velocity screening. Unfortunately, the velocity screening is not applicable for the standard processing since size and velocity are independently processed.

Rain Accumulation



Rain accumulation over time from January 9−10, 2024. The top panel show rain accumulations from four different tipping bucket and two Pluvio weighing bucket gauges. As a consensus, the total rainfall is 75 mm, which is considered as a reference. The tipping bucket gauges are superior to weighing bucket gauges in rain. The bottom panels display the corresponding accumulations from nine PIP processing methods two PARSIVEL disdrometers. PARSIVEL underestimates rainfall by 10%. Among the PIP processing, the CNH terminal velocity is the most consistent with the reference, but still overestimates by 32%.

5 Summary

The PIP's CNH tracking algorithm surpasses the standard algorithm by identifying particles with fall velocities 2.5 times higher. This improvement allows spurious particles to be screened using a terminal speed threshold, a method used by PARSIVEL and other disdrometers. However, PIP tends to overestimate total rainfall during events compared to reference gauges. This is likely due to spurious particles accumulating on the heat map, which can be addressed through statistical analysis in future research.

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