THE 2021-2024 WINTER PRECIPITATION GROUND VALIDATION FIELD CAMPAIGN AT THE UNIVERSITY OF CONNECTICUT

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ABSTRACT

During three consecutive winter seasons, between December 2021 and April 2024, several ground-based wintry precipitation measurement instruments were deployed at the University of Connecticut's main campus. The instruments included an assortment of K-band and W-band profiling radars and Ka-Ku band scanning radars, weighing, and tipping bucket pluviometers, laser disdrometers, high-speed and high-resolution cameras for quantitative precipitation measurement, weather stations, and an unmanned aircraft system for environmental variables. The goal of this field campaign is to provide a dataset for validating NASA Global Precipitation Measurement (GPM) products, and to examine the error characteristics of co-located ground-based instruments. In this manuscript, we present the instrument suite and discuss possible uses of this unique set of measurements for remote sensing applications.

Index Terms— Precipitation, Snow, Ground Validation, Field Campaign, GPM

1. INTRODUCTION

A trivial task for a human observer such as determining the phase of falling precipitation still poses significant challenges to state-of-the-art, automated instruments. Accurate quantitative measurements of wintry precipitation accumulations present even more challenges, especially when observations are taken under strong wind conditions, or in the presence of obstacles. For some instruments, these challenges are exacerbated by the need to retrieve particle size distribution or estimate fall speed, a process which introduces further uncertainties.

While surface observations from ground-based instruments are often considered the "ground truth" when compared to satellite-based remote sensing observations, co-locating several identical instruments, or several different instruments for measuring the same quantity, may provide evidence that each of these instruments estimates their own "ground truth", and differences between these estimates may be significant under particular weather conditions.

Originally ideated in 2020 for developing a dataset suitable for ground validation of satellite-based observations of wintry precipitation, the NASA campaign at the University of Connecticut [1] was progressively expanded over the years to include multiple instruments from various institutions to specifically address the characterization of uncertainty of different ground-based wintry precipitation measurement instruments. The unique location of this campaign, in the middle of the U.S. Atlantic Coast Storm Track, in an area prone to nor'easters in winter months, allowed collection of an unprecedented dataset characterized by a large number of events with multiple precipitation phase transitions.

After introducing the sites and the ground validation instruments in Section 2, we will highlight, in Section 3, possible uses of this dataset for validating satellite remote sensing observations and for characterizing the errors of the different instruments.

2. THE 2021-2024 FIELD CAMPAIGN

For this NASA Global Precipitation Measurement (GPM) Ground Validation (GV) field campaign two sites were chosen at the University of Connecticut's main campus,loc in Storrs, CT, USA. The "GAIL" site, located at an elevation of 149 m.a.s.l., and the "D3R" site, located at 213 m.a.s.l.. The two sites are distant approximately 3.2 km from each other. The D3R site was used only during winter 2022-23, while the GAIL site was used during the three winter seasons (Figure 1). Further information about the sites can be found in [1].

Figure 1: The GAIL site deployments during winter 2021-22, winter 2022-23 and winter 2023-24.

In order to develop a dataset of comparable and consistent observations, a core set of instruments was deployed every year at all sites. This set consisted of: (i) a METEK 24 GHz K-band Micro Rain Radar (MRR-2 in 2021-22 and MRR-Pro in 2022-23 and 2023-24), (ii) an OTT Hydromet Pluvio^2 weighing bucket Gauge (Pluvio), (iii) two MetOne 380 12" orifice tipping bucket rain gauges on a Platform for In situ Estimation of Rainfall Systems (PIERS), (iv) a MetOne All-in-one-2 sonic weather sensor (AIO-2), (v) an OTT Hydromet PARSIVEL^2 laser disdrometers (Parsivel), and (vi) a Precipitation Imaging Package (PIP) video disdrometer.
During winter 2022-23, to enhance the set of data collected in conjunction with the NASA's Investigation of Microphysics and Precipitation for Atlantic Coast Threatening Snowstorms (IMPACTS) field campaign [2], the Ka-Ku band Dual-frequency Dual-polarized Doppler Radar (D3R), the 94 GHz W-band radar mounted on the Aerosol, Cloud, Humidity Interactions Exploring and Validation Enterprise (ACHIEVE) lab, and the R.M. Young mechanical anemometer (RMYoung) were also deployed at the D3R site, while the Snowflake Measurement and Analysis System (SMAS), and the CSU-Modified Multi-Angle Snowflake Camera (MASC) were deployed at the GAIL site.
During winter 2023-24, to investigate the error characteristics of the different core instruments, an additional set of core instruments (MRR-Pro, Pluvio, PIERS, AIO-2, Parsivel, PIP) was deployed, at the GAIL site, together with the SMAS, MASC, the RMYoung and a Vaisala CL51 ceilometer. Finally, flights of a low-altitude Weather Unmanned Aerial System (WxUAS) providing measurements of pressure, temperature, humidity, particle size distribution, and radar reflectivity were performed above the GAIL site during some late-season winter storms. Specific descriptions of the instruments listed in Table 1, such as measurement characteristics, and measured and derived quantities can be found in reference [1], while a subset of observations collected during the 25 February 2023 event by the AIO-2, Parsivel and PIP at the D3R site is shown in Figure 2.

Instrument (owner)	2021-22	2022-23	2023-24
MRR-2 (NASA)	✓	✗	✗
Pluvio (NASA)	✓	✓	✓
All-in-one-2 (NASA)	✓	✓	✓
Parsivel (NASA) [3]-[5]	✓	✓	✓
PIP (NASA) [6]-[9]	✓	✓	✓
D3R (NASA) [10], [11]	✗	✓	✗
ACHIEVE (NASA) [12]	✗	✓	✗
MRR-Pro (NASA)	✗	✓	✓
PIERS (NASA)	✗	✓	✓
SMAS (CSU) [13]-[15]	✗	✓	✓
MASC (CSU) [13], [16]	✗	✓	✓
RMYoung (NASA)	✗	✓	✓
Additional Pluvio (NASA)	✗	✗	✓
Additional MRR-Pro (NASA)	✗	✗	✓
Additional All-in-one-2 (NASA)	✗	✗	✓
Additional Parsivel (NASA)	✗	✗	✓
Additional PIP (NASA)	✗	✗	✓
Additional PIERS (NASA)	✗	✗	✓
Ceilometer (NASA)	✗	✗	✓
WxUAS (OSU)	✗	✗	✓

Table 1: List of instruments deployed during the three winters of the NASA field campaign at UConn.

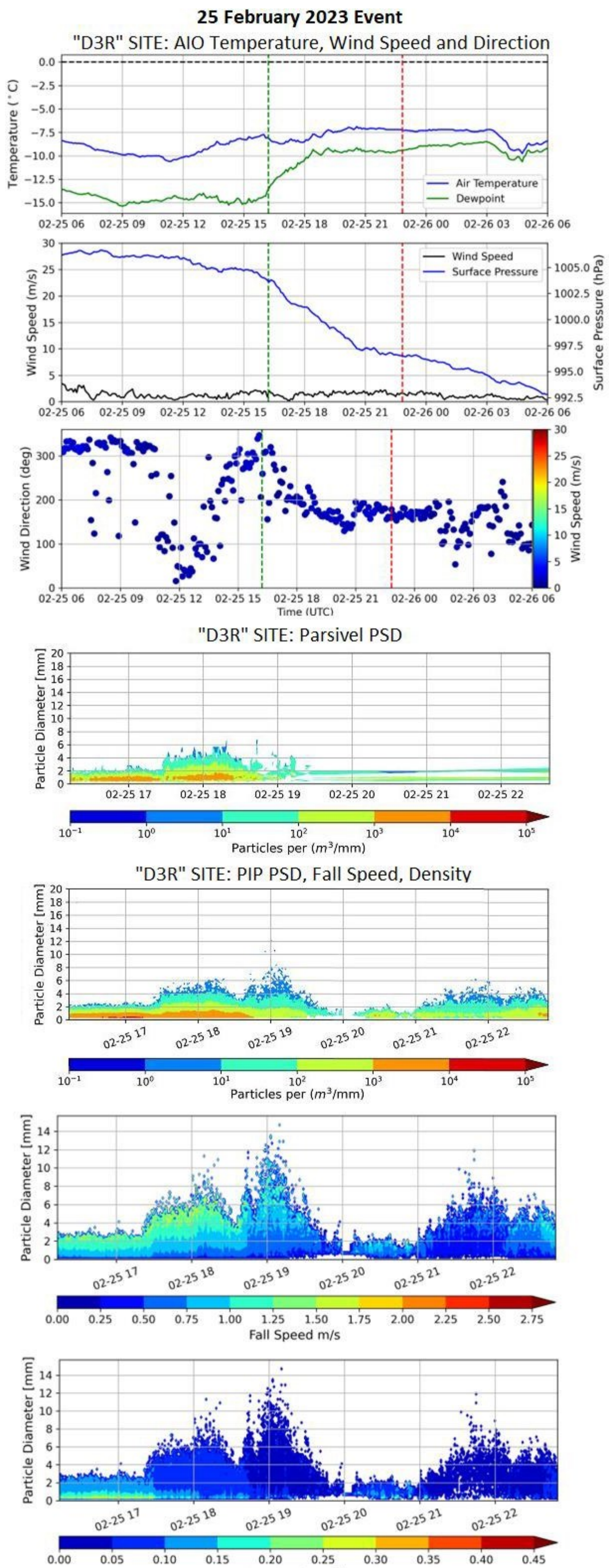

Figure 2: Observations from the AIO-2, Parsivel, and PIP collected at the D3R site during the 25 February 2023 event.

3. DISCUSSION

The NASA GPM GV field campaign at UConn provides an unprecedented set of wintry precipitation observations from multiple traditional and novel precipitation measurement instruments that can be used for validating ground-based and satellite remote sensing observations. Specifically, AIO-2 collects observations of weather state variables, providing a necessary context for precipitation observations or model validation. The Pluvio and the PIERS rain gauges are traditional instruments for measuring precipitation amount and rate and are commonly used as reference to calibrate and validate GPM satellites or other ground-based instruments. The MRR-2, MRR-Pro, and ACHIEVE, operating respectively in the K-band and W-band, were primarily used to retrieve vertical profiles of precipitation and clouds, and can be used to validate satellite instruments like the Cloudsat's Cloud Profiling Radar (CPR) [17], operating in the same frequency as the ACHIEVE. The D3R exactly matches the Ka and Ku bands of the GPM's Dual-Frequency Precipitation Radar (DPR) [17], and together with the ACHIEVE, was also used to match observations from the NASA ER-2 high-altitude aircraft flying above UConn during a storm as part of the NASA IMPACTS campaign, with its suite of instruments which include W-band, X-band and Ka-Ku band radars. The NASA P3, which carried in-situ instruments to measure temperature, moisture, pressure, and wind as well as the cloud and precipitation particles at flight level, also overflew the UConn site during one storm as part of NASA IMPACTS; the P3 measurements augment the interpretation of the satellite, ER-2, and ground-based remote sensing measurements. The Parsivel and PIP disdrometers, beyond estimating precipitation rate and amount, can also observe microphysical precipitation properties such as particle size distribution (PSD), which can be used to validate microphysical modeling schemes. Also, the SMAS and MASC look into the microphysical properties of snowflakes, by reconstructing their 3-D structure, or by classifying snow crystals. The WxUAS vertical profiles provide in-situ validation for ground and space-based sensors making inferences about the atmosphere's thermodynamic structure on the ground and at low altitude. This is particularly important for hydrometeor classification with height due to possible phase changes between the precipitation generation and surface layers and the potential reflectivity overlap between different precipitation types and intensities [18]. When placed all together, these observations from multiple and diverse instruments allow for a holistic representation of the temporal evolution of the state of the atmosphere, from the macroscopic to the microscopic scale, at the deployment site. They represent an unprecedented set of co-located observations for remote sensing validation and applications and will be made available, after completion of quality control, as a dataset that will be published together with reference [1].

4. REFERENCES

[1] Filipiak, B., and Coauthors, “Winter Precipitation Measurements in New England: Results from the Global Precipitation Measurement Ground Validation Campaign in Connecticut,” *Earth System Science Data*, In preparation.

[2] McMurdie, L. A., and Coauthors, 2022, “Chasing snowstorms: The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) campaign,” *Bulletin of the American Meteorological Society*, 103, E1243–E1269, 2022.

[3] Löffler-Mang, M. and Joss, J., 2000. An optical disdrometer for measuring size and velocity of hydrometeors. *Journal of Atmospheric and Oceanic Technology*, *17*(2), pp.130-139.

[4] Löffler-Mang, M. and Blahak, U., 2001. Estimation of the equivalent radar reflectivity factor from measured snow size spectra. *Journal of Applied Meteorology and Climatology*, *40*(4), pp.843-849.

[5] Tokay, A., Wolff, D.B. and Petersen, W.A., 2014. Evaluation of the new version of the laser-optical disdrometer, OTT Parsivel 2. *Journal of Atmospheric and Oceanic Technology*, *31*(6), pp.1276-1288.

[6] Newman, A.J., Kucera, P.A. and Bliven, L.F., 2009. Presenting the snowflake video imager (SVI). *Journal of Atmospheric and Oceanic technology*, *26*(2), pp.167-179.

[7] Pettersen, C., Bliven, L.F., von Lerber, A., Wood, N.B., Kulie, M.S., Mateling, M.E., Moisseev, D.N., Munchak, S.J., Petersen, W.A. and Wolff, D.B., 2020. The precipitation imaging package: Assessment of microphysical and bulk characteristics of snow. *Atmosphere*, *11*(8), p.785.

[8] Helms, Charles Nelson, Stephen Joseph Munchak, Ali Tokay, and Claire Pettersen. "A comparative evaluation of snowflake particle shape estimation techniques used by the Precipitation Imaging Package (PIP), Multi-Angle Snowflake Camera (MASC), and Two-Dimensional Video Disdrometer (2DVD)." *Atmospheric Measurement Techniques* 15, no. 22 (2022): 6545-6561.

[9] Tokay, A., Helms, C.N., Kim, K., Gatlin, P.N. and Wolff, D.B., 2023. Evaluation of SWER (Ze) Relationships by Precipitation Imaging Package (PIP) during ICE-POP 2018. *Journal of Hydrometeorology*, *24*(4), pp.691-708.

[10] Chandrasekar, V., Mathew Schwaller, Manuel Vega, James Carswell, Kumar Vijay Mishra, Alex Steinberg, Cuong Nguyen et al. "Dual-frequency dual-polarized Doppler radar (D3R) system for GPM ground validation: Update and recent field observations." In *2012 IEEE International Geoscience and Remote Sensing Symposium*, pp. 346-349. IEEE, 2012.

[11] Vega, M.A., Chandrasekar, V., Carswell, J., Beauchamp, R.M., Schwaller, M.R. and Nguyen, C., 2014. Salient features of the dual-frequency, dual-polarized, Doppler radar for remote sensing of precipitation. *Radio Science*, *49*(11), pp.1087-1105.

[12] Loftus, A.M., Tsay, S.C., Pantina, P., Nguyen, C., Gabriel, P.M., Nguyen, X.A., Sayer, A.M., Tao, W.K. and Matsui, T., 2016. Coupled aerosol-cloud systems over Northern Vietnam during 7-SEAS/BASELInE: A radar and modeling perspective. *Aerosol and Air Quality Research*, *16*(11), pp.2768-2785.

[13] Kleinkort, C., Huang, G.J., Bringi, V.N. and Notaroš, B.M., 2017. Visual hull method for realistic 3D particle shape reconstruction based on high-resolution photographs of snowflakes in free fall from multiple views. *Journal of Atmospheric and Oceanic Technology*, *34*(3), pp.679-702.

[14] Notaros, B., 2021. Meteorological electromagnetics: optical and radar measurements, modeling, and characterization of snowflakes and snow. IEEE Antennas and Propagation Magazine, 63(2), pp.14-27.

[15] Thant, H., Huang, G.J., Bringi, V.N. and Notaros, B.M., 2022, July. Snowflake Measurement and Analysis System (SMAS). In 2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI) (pp. 523-524). IEEE.

[16] Garrett, T.J., Fallgatter, C., Shkurko, K. and Howlett, D., 2012. Fallspeed measurement and high-resolution multi-angle photography of hydrometeors in freefall. Atmospheric Measurement Techniques Discussions, 5(4), pp.4827-4850.

[17] Skofronick-Jackson, G., M. Kulie, L. Milani, S.J. Munchak, N.B. Wood, and V. Levizzani, “Satellite estimation of falling snow: A global precipitation measurement (GPM) core observatory perspective,” *Journal of applied meteorology and climatology*, 58(7), pp.1429-1448, 2019.

[18] Reeves, H.D., N. Lis, G. Zhang, A.A. Rosenow, “Development and testing of an advanced hydrometeor-phase algorithm to meet emerging needs in the aviation sector,” *Journal of Applied Meteorology and Climatology*, 61(5), pp.521-536, 2022.