# Measurement and Analysis of Rain Precipitation at MASCRAD Instrumentation Site in Colorado

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***Abstract*—We present our ongoing studies of rain precipitation synergistically using a 2D-video disdrometer, particle spectrometer, precipitation occurrence sensor system, Pluvio precipitation gauge, state-of-the-art polarimetric CSU-CHILL radar, and a higher order electromagnetic scattering method. We present and discuss measurements and analyses for several rain events in 2015 at MASCRAD Instrumentation Site in Colorado.**

***Keywords—rain observations; polarimetric radar; scattering; remote sensing.***

## I. Introduction

This summary presents our ongoing studies of rain precipitation at a surface instrumentation site near Greeley, Colorado, using a 2D-video disdrometer (2DVD), meteorological particle spectrometer (MPS), precipitation occurrence sensor system (POSS), Pluvio precipitation gauge, fully polarimetric data from a state-of-the-art polarimetric radar, and a higher order computational electromagnetic scattering method. The surface instrumentation was installed within the 2/3$^{rd}$ scaled DFIR double wind-fence (the same one used for the MASCRAD snow observation project [1]), as shown in Fig. 1 [2]. Our long-term goal is to combine advanced comprehensive observations and numerical models to greatly enhance understanding of rain drop oscillations (in particular, those forced by drop collisions) and terminal fall speed distributions, and their implications for the interpretation of polarimetric radar measurements in moderate-to-intense convective rain events.

## II. Rain Observations Using Surface Instrumentation at MASCRAD Site

The first event of the Greeley campaign, namely, the long duration event of 17 April 2015, was analyzed in terms of the drop size distribution (DSD) characteristics. While the MPS enabled drop concentration measurements down to 0.1 mm, the 2DVD had recorded drops as large as 5 mm associated with the (non-hail producing) thunderstorm for the event. Fig. 2 shows the 1-minute rainfall rates (with running average over 3 minutes) from the 2DVD and Pluvio measurements, as well as the combined 2DVD and MPS drop size distribution based rain rates [2]. An excellent agreement of the data measured by the three different instruments can be observed.

Fig. 3 shows the 4-hour DSDs from the 2DVD and POSS for a rain event on 19 August 2015, and we see the discrepancy for equivalent diameters $D_{eq} < 0.7$ mm, with 2DVD showing considerably lower drop concentrations. Similar discrepancy was also noted between the 2DVD and MPS, and it can be largely attributed to the underestimation of the concentration of small drops by the 2DVD (as a result of the matching procedure's inability to perform accurate matching of tiny drops from the two cameras). For larger drops ($D_{eq} > 0.7$ mm), there is excellent agreement between 2DVD and POSS data.

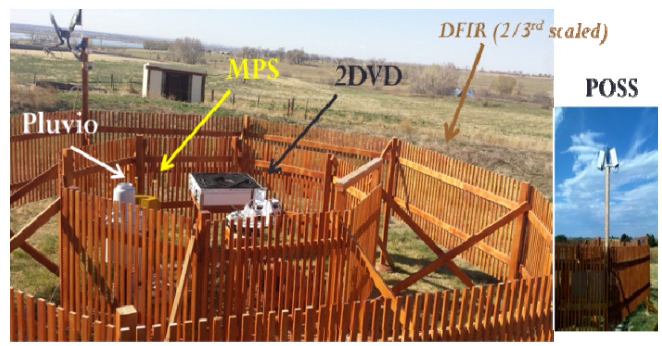


Fig. 1. Rain precipitation observations at MASCRAD Instrumentation Site, near Greeley, Colorado.

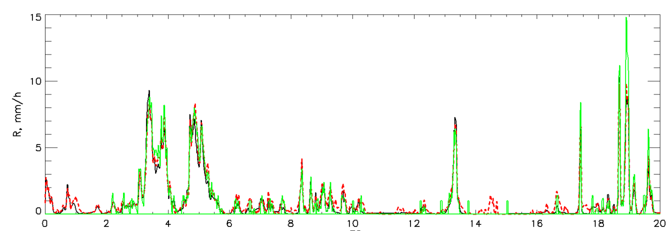


Fig. 2. 1-minute rain-rate ($R$), averaged over 3-min, from 2DVD (black), Pluvio (green) and 2DVD-MPS combined DSD based $R$ estimated (red), for a rain event on 17 April 2015.

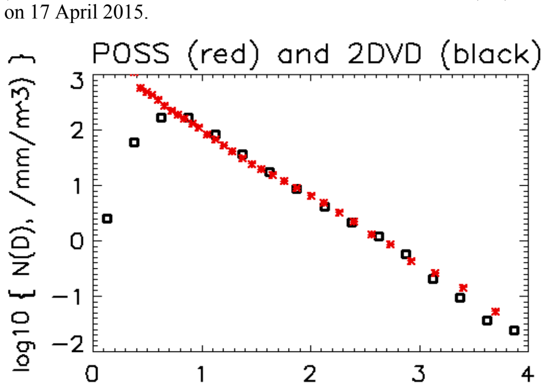


Fig. 3. 4-hour DSDs from the 2DVD and POSS for a rain event on 19 August 2015.

## III. Scattering Analyses Based on Observations

Scattering analysis of rain particles and calculation of "particle-by-particle" scattering matrices and polarimetric radar observables based on the reconstructed 3D particle shapes obtained from surface hydrometeor observations are performed using the higher order method of moments (MoM) in the surface integral equation (SIE) formulation [3]. One component of our investigations is utilization of the measured 2DVD-based asymmetric drop shapes as well as the corresponding theoretically derived shapes as input to the MoM-SIE scattering code. Namely, in some cases, a significant fraction of moderate-to-large drops are undergoing mixed-mode oscillations arising due to sustained drop collisions which result in asymmetric drop shapes [4].

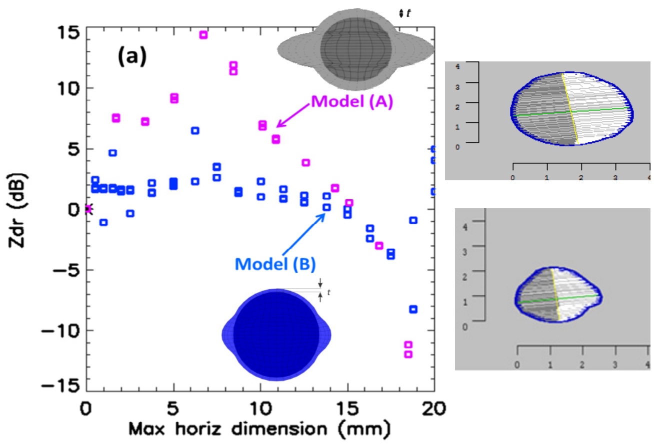


Fig. 4. (a) Single particle MoM-SIE $Z_{dr}$ calculations for two models of melting hail. 2DVD-based contours of (b) a large rain drop and (c) a melting hail, for event on 5 June 2015.

Another component is comparison of scattering amplitudes from rain drops with melting hail modeled as shown in Fig. 4(a), where model (A) is based on aircraft probe measurement [5] and model (B) is reconstructed from the 2DVD image taken during the 2015 Greeley campaign. Calculations at S and X band data were compared against CHILL dual-band frequency measurements during several rain/hail mix events at MASCRAD site. For example, given in Fig. 4 are the S-band simulation results for the two melting hail models, and Fig. 5 shows the $Z_h$ [5] and $Z_{dr}$ [5] sector scans performed at 02:39 UTC on 5 June 2015. The white-circled regions show moderate $Z_h$ and low $Z_{dr}$ which is expected for rain, whereas the yellow circled regions show moderate $Z_h$ but relatively high $Z_{dr}$. Examples of hydrometeors detected by the 2DVD are shown in Fig. 4(b). The calculated $Z_{dr}$ values are much larger than those for rain for the smaller particle sizes whereas for larger particle sizes, the reverse appears to be the case. From Fig. 4(a), for the 2DVD image of the melting hail in Fig. 4(c), one would expect its $Z_{dr}$ to lie between 1.9 dB and 7.5 dB depending on the 'shape' of the ice-sphere – water torus scatterer. This range of values is larger than those expected for equi-volume rain drops which is around 1 dB. Our results suggest that the CHILL S-band scans, in Fig. 5, which showed higher than expected (for rain) $Z_{dr}$ over the ground instrument site were indeed due to such small melting hydrometeors, at the time when such particles were detected by the 2DVD.

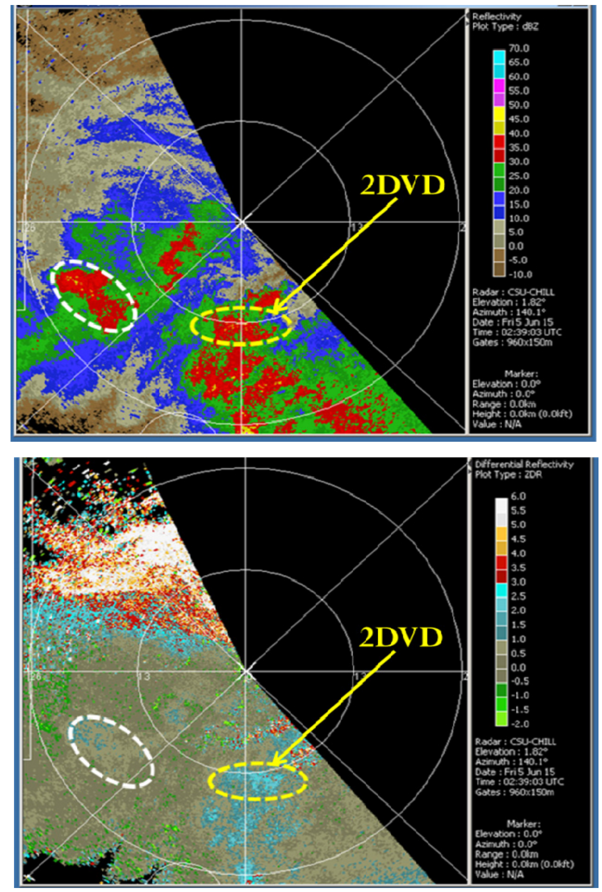


Fig. 5. CHILL S-band $Z_h$ (upper panel) and $Z_{dr}$ (lower panel) sector scans, for rain/hail mix event on 5 June 2015.

## Acknowledgement


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