Snow Precipitation Measurement and Analysis During MASCRAD Winter Observations

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***Abstract*—We present our continued studies of winter precipitation within the MASCRAD (MASC + Radar) project, using multi-angle snowflake camera (MASC), 2D-video disdrometer, computational electromagnetic scattering methods, and state-of-the-art polarimetric radar. We also introduce some recent advancements to the observation and analysis process, and discuss new illustrative results.**

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

I. Introduction

This summary presents our continued studies of winter precipitation within the MASCRAD (MASC + Radar) project [1], introduces some recent advancements, and discusses new illustrative results. This project is developing a novel approach to characterization of winter precipitation and modeling of radar observables through a synergistic use of advanced optical imaging disdrometers for microphysical and geometrical measurements of ice and snow particles, image processing methodology to reconstruct complex particle 3D shapes, full-wave computational electromagnetics (CEM) to analyze realistic winter precipitation scattering, and state-of-the-art polarimetric radar to validate the modeling approach. The principal enabling methodologies and technologies are specifically (i) multi-angle snowflake camera (MASC) and two-dimensional video disdrometer (2DVD), shown in Fig. 1, (ii) visual hull method for reconstruction of 3D hydrometeor shapes [2], (iii) CEM scattering models and solutions based on a higher order method of moments (MoM) in the surface integral equation (SIE) formulation and the frequency domain [3], and (iv) fully polarimetric data from the CSU-CHILL radar. We develop physical and scattering models of natural snowflakes using the MASC, 2DVD, visual hull, and MoM-SIE, with the modeling and scattering calculations being analyzed against CSU-CHILL and SPOL radar observations.

II. MASCRAD Operations and Advancements to Observation and Analysis Process

We have observed and analyzed all significant snow events during the 2014/2015 MASCRAD winter campaign. Shown in Fig. 2 are examples of MASC snowflake images.

We added several other advanced instruments to the MASCRAD Field Site, including a precipitation occurrence sensor system (POSS), shown in Fig. 3, thanks to Dr. David Hudak, Environment Canada. The POSS measures the bistatic Doppler spectrum from which the mean Doppler velocity and reflectivity are obtained. Reflectivity comparisons between POSS and CHILL X-band data ensured accurate POSS calibration. Fig. 3(c) shows one such set of comparisons for a snow event. Excellent agreement can be seen.

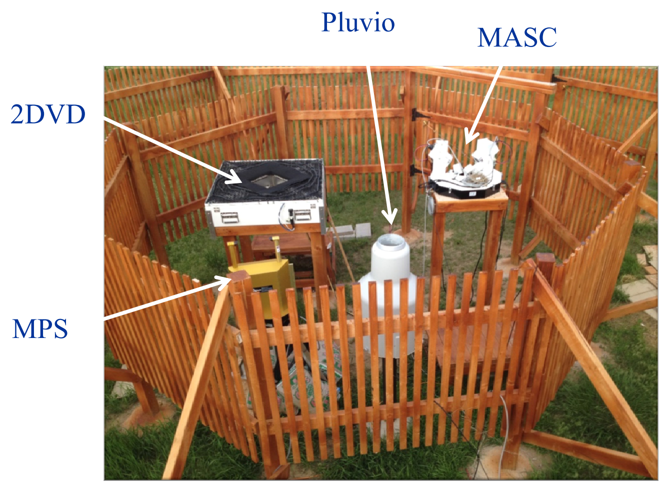

Fig.1. MASCRAD Snow Field Site, near Greeley, Colorado.

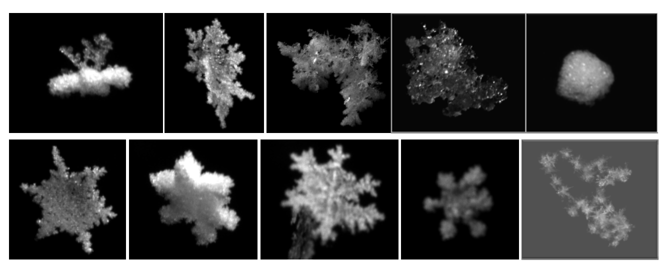

Fig. 2. Characteristic examples of images of snowflakes with contrasting forms collected by the MASC (Fig. 1) during the 2014/2015 MASCRAD winter campaign.

We use the visual hull geometrical method to reconstruct 3D shapes of snow particles and other hydrometeors based on photographs obtained by the MASC, and the corresponding 2D silhouettes of an object [2], as illustrated in Fig. 4(a). However, 3D reconstructed snowflakes from the three MASC photographs are not close enough to the real shapes of the snowflakes. In order to improve the 3D reconstruction obtained from the visual hull method, two additional cameras are added to the MASC, “externally,” to provide additional views, as shown in Fig. 4(b). All five cameras trigger simultaneously and collect images at a 2-Hz rate. We perform 5-camera software self-calibration of the MASC, to obtain a correction matrix that is then used as an input to the visual hull code to correct for a non-perfect mechanical calibration. Without this, the visual hull fails to create 3D reconstructions for many snowflakes.

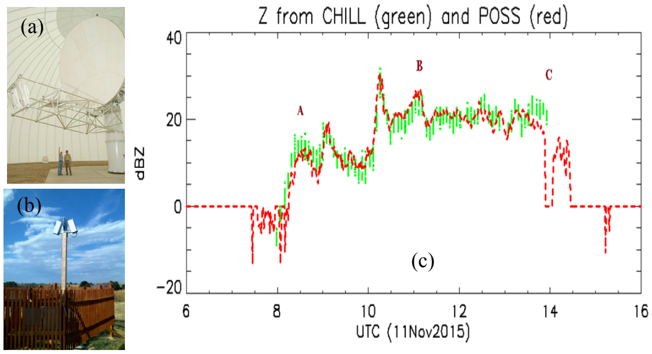

Fig. 3. (a) CSU-CHILL radar; (b) POSS; (c) dBZ comparison between POSS and CHILL X-band data over MASCRAD Site (Fig. 1) during a snow event.

(a) (b)

Fig. 4. (a) Illustration of visual hull reconstruction of 3D shapes based on three MASC photographs. (b) Two “external” downward looking cameras added to the CSU MASC, to improve 3D reconstruction of snowflakes.

III. Additional Illustrative Results from 2014/2015 MASCRAD Winter Campaign

Fig. 5 shows an example of snowflake shape reconstruction using the upgraded MASC, in Fig. 4(b), and new processing methodology. We observe very good results, which are much better than any snowflake 3D realistic-shape reconstruction data in the literature. Fig. 6 shows illustrative results of higher order MoM-SIE scattering calculations based on the MASC and 2DVD images captured at the MASCRAD Field Site (Fig. 1), during an unusual winter graupel shower event on February 16, 2015, in comparison with CSU-CHILL radar data. As can be seen, the computed differential reflectivity, Z_{dr}, and linear depolarization ratio, LDR, single-particle values (given just for illustration; the full analysis based on all collected particles for the event is ongoing) agree well with those measured simultaneously by the radar.

Acknowledgement

This work was supported by the National Science Foundation under grant AGS-1344862.

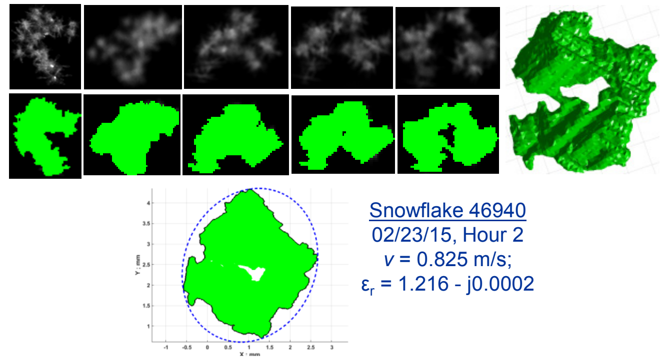

Fig. 5. Example of the MASC-visual hull measurement-reconstruction of a snow aggregate at the MASCRAD Field Site (Fig. 1): (upper panel) MASC photographs and corresponding projections of the resulting reconstruction, and generated 3D mesh; (lower panel) bottom view (normal to the flow) obtained from the reconstructed 3D shape, needed for the estimation of the density and dielectric constant (permittivity) of the particle using the theory of Böhm, and measured velocity and computed dielectric constant of the snowflake.

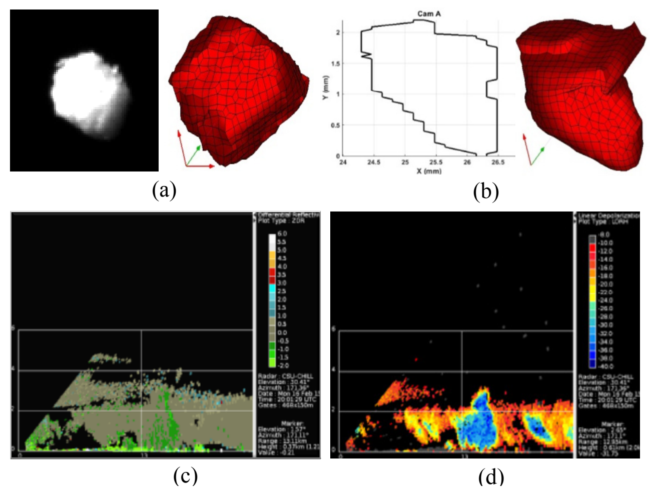

Fig. 6. Illustrative results of higher order MoM-SIE scattering calculations based on both (a) MASC and (b) 2DVD images captured at the same time at the MASCRAD site (Fig. 1) during the unusual winter graupel shower event on Feb. 16, 2015 and the resulting 3D shape reconstructions, in comparison with the corresponding CSU-CHILL radar RHI plots of (c) Z_{dr} and (d) LDR. Results: 2DVD: $\varepsilon_r = 1.407 - j0.0002$, $Z_{dr} = 0.138$ dB, LDR = −35.43 dB; MASC: $\varepsilon_r = 1.3638 - j0.0005$, $Z_{dr} = 0.186$ dB, LDR = −37.34 dB; CHILL Radar: $Z_{dr} = -1$ to 0.5 dB, LDR = −38 to −28 dB – at the 12.92-km range).

References

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