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Interactive comment on "Fallspeed measurement and high-resolution multi-angle photography of hydrometeors in freefall" *by* T. J. Garrett et al.

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We thank the reviewer for the thoughtful comments. Outlined below are specific responses.

...it is worth to mention some previous scientific communications describing successful implementation of digital cameras for hydrometeors fall velocity or diameter measurements, see e.g. Licznar et al. 2007 (Microprocessor Field Impactometer Calibration: DoWe Measure Drops' Momentum or Their Kinetic Energy? J. Atmos. Oceanic Technol.,vol 25) and references herein.

This paper is very interesting, and we appreciate it being brought to our notice since

it has relevance to some current work we are doing aimed at directly measuring snowflake mass. However, with regards to the article we've submitted, it is not clear that the paper has strong relevance. The photography described in this paper was lab-based, and incidental to the operational instrument discussed. The photography was aimed at helping calibrate a piezo-electric impactometer, but was not part of the impactometer itself. By contrast, the photography we are employing is part of the MASC, and is immensely higher resolution. Further, photography is not used to measure fallspeed, rather a motion sensor technique.

Presenting the current state of art of hydrometeors recording by automated ground-based disdrometers it is also necessary to mention about 2D-VIDEO-DISTROMETER (see http://www.distrometer.at/). MASC and 2D-VIDEO-DISTROMETER operational basics seem to be at least partly similar. Similarities and differences of both devices should be discussed and explained.

This instrument is already discussed in the introduction, although we decided not to reference it specifically by name because it falls into a class of instruments. Current the text reads:

Constraining the problem with empirical data has proved challenging. Traditionally this has been done through the painstaking manual examination of individual hydrometeors (Locatelli and Hobbs, 1974; Bruintjes et al., 1987; Mitchell et al., 1990; Theriault et al., 2012). Automated groundbased disdrometers have recently helped eliminate human subjectivity and allowed for greater statistical power (e.g. Kruger and Krajewski, 2002; Barthazy et al., 2004; Yuter et al., 2006; Newman et al., 2009; Zawadzki et al., 2010). Nonetheless, these newer instruments require imaging small, complex, fast-moving particles on a laser diode optical array, and this can lead to significant sizing errors (Yuter et al., 2006). Further, the images are normally silhouettes with a very coarse resolution of about 200 m, which makes it very difficult to confidently discriminate particle habit (Barthazy and Schefold, 2006). It is impossible to assess the extent of riming from 40 m diameter droplets within silhouetted images at 200 m resolution, or to easily *discriminate them from tight clumps of aggregates.*

Is it possible to estimate some ratio of rejected hydrometeors versus recorded by MASC hydrometeors (that passed a focus threshold)?

The text has been amended to read

With this setup, a 10 mm camera depth of field corresponds to just 2.5 % of the trigger depth of field, implying that just one in forty photographed images is in sharp focus. As shown in Fig. 1, one option for increasing the in-focus fraction is to physically block part of the lower emitter array. For example, if the two outermost emitters are blocked, then the trigger depth of field is reduced from 3100 mm to 1400 mm. This does not change the number of in-focus images collected, but it does reduce the number of images that must ultimately be processed as rejects.

Is it possible to record the whole hydrometeor size distribution of natural precipitation by MASC and compare it with DSD spectrum recorded by some disdrometers?

Size distributions are currently shown in Fig. 3. Comparisons with disdrometers are beyond the scope of our current study since we did not measure falling raindrops at our high altitude winter measurement site. We have plans to do a full comparison with other instruments in the future.

Finally is it possible to compare at least roughly mass of hydrometeors recorded by MASC with precipitation mass measured by some weighing gauge?

There is currently no commercially available instrument that measures the mass of individual hydrometeors, at least that we know of. In fact this would be extremely difficult in ambient conditions given how little snowflakes weigh. That said, we are currently designing a hot plate device that will do precisely what the reviewer suggests. The goal is to place it directly underneath the MASC aperture so that a correspondence can be drawn between the snowflake images and individual snowflake mass.

The title of paper suggests that MASC is suitable for measurement of hydrometeors in general, whereas the measurements of frozen hydrometeors only are discusses in manuscript. Is MASC designed also for liquid hydrometeors measurements?

The MASC is designed to photograph whatever triggers the cameras, whether it is snowflakes, raindrops or insects. All that is required is that the object partially block the near-infrared sensor-emitter pairs. We have not yet obtained images of rain at our high altitude location at Alta, but we currently have our instrument ready to photograph raindrops in the valley (unfortunately we are in a severe drought). In the lab, the instrument photographs titrated droplets from a syringe. The text has been modified to read.

The near-infrared motion sensor device that is used for triggering the cameras and measuring fallspeed has been designed to detect the smallest hydrometeors, whether liquid or ice.

Page 4835(16): “In all regards, the range of possible characteristics is broad. The atmosphere seems to allow for most possibilities.” These statements are insufficient as the discussion of a wide results dataset (approximately ten thousand images). The range of measured parameters values should be clearly reported.

We have modified the text to read

From this dataset, Fig. 3 shows probability distributions for maximum dimension Dmax, equivalent radius req , aspect ratio a, orientation j, complexity q and fallspeed V . Median values with lower and upper quartiles for these quantities are: D_{max} = 1.7 [1.2 2.4] mm; r_{eq} = 0.65 [0.47 0.90] mm; α= 0.71 [0.57 0.83]; θ= 36 [18 56]°; χ= 1.2 [1.4 1.6]; V = 0.53 [0.18 1.03] ms^{-1}. In general, the size and fall- speed measurements are broadly consistent with past measurements of snow that indicate typical linear dimensions of order 1 mm and fallspeeds of order 1 ms^{-1} (Barthazy and Schefold, 2006; Brandes et al., 2007, 2008; Gunn, 1967; Heymsfield and Westbrook, 2010; Magono and Nakamura, 1965; Mitchell et al., 1990; Yuter et al., 2006; Zawadzki et al., *2010). The hydrometeors that were observed tended to have low complexity, with a clear preference for a near unity aspect ratio, suggesting a dominance of riming. The maximum dimension tended to lie nearer the horizontal than the vertical, although a wide variety of orientations was observed (cf., Xie et al., 2012).*

It is also possible to check for the existence of some relations between measured parameters (e.g. fall velocity versus maximum hydrometeor dimension, reported for instance at the book of Pruppacher and Klett "Microphysics of Clouds and Precipitation").

The text currently reads

However, 280 in general, the size and fallspeed measurements are broadly consistent with past measurements indicating typical linear dimensions of about 1 mm and fallspeeds of about 1 m/s (Barthazy and Schefold, 2006; Brandes et al., 2007, 2008; Gunn, 1967; Heymsfield and Westbrook, 2010; Magono and Nakamura, 1965; Mitchell et al., 1990; Yuter et al., 2006; Zawadzki et al., 2010).

We do not go into further detail in this paper for the reasons outlined below.

Fig. 3 suggests appearance of some rare hydrometeors with high fall velocity of about 8-10 m/s. These are values exceeding rainfall terminal fall velocities. In addition, as claimed by author: "what was measured was not necessarily the hydrometeor terminal velocity, but rather a hydrometeor settling speed representing a convolution of the terminal velocity within a turbulent wind field"

Yes. In fact one of the very surprising results to come out of our experiment is that the typical mass-fallspeed relationships discussed in, e.g., Prupaccher and Klett only become evident under less turbulent conditions. Otherwise, fallspeed distributions seem to be roughly independent of size and shape. It turns out that there are basic physical reasons to suggest why turbulence might produce this result, that are not widely appreciated in the atmospheric sciences literature. Our intention is to explore this issue

further through a more thorough analysis and submit these results in a follow-on paper.

We have amended the text to read

However, there is no coincident transition in fallspeed. The reasons for this are unknown but may be related to the absence of a windscreen around the instrument: the settling speed is being modified by turbulence in the air.

Were also negative fall velocities recorded during field campaign caused by snowflakes updraft? Is MASC suitable to record hydrometeors with negative fall velocities?

The ability to measure negative fallspeeds came up in discussion of the instrument design. It would be a good feature to have, but it turns out to be difficult to implement within the context of the instrument logic and physical construction. The way the instrument is designed, a hydrometeor must first trigger the upper motion sensor bank, and then the lower motion sensor bank. If they are triggered sequentially, then the cameras are triggered. The cameras are placed within the box in alignment with the lower sensor bank. It is difficult to see how negative velocities could be measured using this setup. That said, it is clear from Figure 3 that negative velocities are likely to be rare.

"However, this might easily require over 50GB of shared computer memory." Please explain how was this necessary DDSCAT calculations computer memory estimated?

Our text now reads:

However, this might easily require over 50 GB of shared computer memory given that each grid point requires 1KB of memory (Draine and Flatau, 2008).

Technical corrections Page 4829(13): "where |n| is the refractive index" precisely: "where |n| is the complex refractive index"

Changed to

“where n is the complex refractive index”

Fig. 3. Description and scale for vertical axes should be added.

These are probability distribution functions, which is now made more clear in the caption.

Interactive comment on Atmos. Meas. Tech. Discuss., 5, 4827, 2012.