On the potential of 2D-Video Disdrometer technique to measure micro physical parameters of solid precipitation
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Answer to anonymus reviewer comment #1

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First of all, we want to thank the anonymous reviewer #1 for his revision. The comments are well considered and contribute to the improvement of this manuscript.

General issues

1. *English language. I am not a native speaker myself, so i understand very well this difficulty. I would recommend the revised manuscript to be checked by a native speaker before submission.*
   We apologize for the mistakes concerning English language. The manuscript was checked again on English spelling and grammar.

2. *Introduction. I found particularly this section a little bit confused. Many concepts are condensed in few sentences. I would recommend to expand this section and take the opportunity to provide more detailed information about the microphysical significance of the 2DVD instrument. The manuscript is short and there is space to expand and improve the introduction.*
   The introduction was rearranged slightly to make it better understandable. To concentrate more on the micro-physical significance of the 2DVD, the following paragraph was included (p3089, l23): "Micro-physical parameters which can be retrieved with a 2D-video disdrometer are for example the drop-size distribution, the size-velocity relation or shape parameters such as oblateness or surface structure of single hydrometeors. Woods et al. (2007) showed that changing the size-mass or size-velocity relation for snowflakes implemented in mesoscale model simulations, can significantly influence precipitation prediction

in mountain regions. The significance of ice crystal shapes for the interpretation of radar back scatter signals was shown for example by Hong (2007) and Hiroshi (2008)."

3. *Structure of the manuscript. The manuscript is rather short but it has a complicated nested structure of sections and subsections. I found it sometimes distracting and hard to follow.*
   To reduce the nested structure of the manuscript we unified sections 2.4.1, 2.4.2 and 2.4.3 under one section 2.4 which is called "Experimental Methods"

4. *The problem of horizontal distortion. Given the goal of the present manuscript the problem of horizontal distortion of the 2DVD images, caused by horizontal wind components, must be at least mentioned and discussed, and if possible experimentally tackled. Horizontal distortion is well described by Nespor et al. (2000), and this issue can be observed even in the most recent 2DVD designs. Distortion has a direct impact on microphysical retrievals but it can still generate self-consistent descriptors.*
   We thank the reviewer very much for this well considered comment. Unfortunately, in the framework of the present study the problem of horizontal distortion can not be tackled experimentally. This is certainly an important task which concerns all kinds of video disdrometer measurements and should be analyzed in a future study for example under defined conditions in a wind tunnel experiment. To discuss the problem of horizontal distortion in the present work, the following paragraph was included (p3091, l3): "Nevertheless, there is still the problem that horizontal wind fields can cause horizontal distortion of the spacial distribution of hydrometeors inside the measuring area and the 2DVD pictures themselves. The manufacturer supplies a software which corrects the apparent canting angle induced by horizontal velocity components for raindrops. This software was not used in the present study, because it does not apply for solid phase precipitation. Nešpor et al. (2000) showed that horizontal wind components which exist in the direct vicinity of the 2DVD housing, can influence the measurement of drop-size distributions significantly, especially for smaller hydrometeors. For this reason the measurements presented in the following were conducted under calm wind conditions."

5. *Microphysics (i). The title suggests that the microphysical interpretation of 2DVD data will be an important topic in the paper. I believe that the manuscript is instead focussed on the consistency of 2DVD measurements only. Could the authors try to link these two aspects a bit more? I see quite some potential to do so, at least when the authors are dealing with actual measurements (e.g., Sec. 2.4.3).*

   This is a very good comment which leads us to include the following paragraph (p3096, l23): "Mean values of roundness, shape factor and elongation are able to describe whether a snowfall event consists, for example, more of complex shaped aggregates of snow crystals or more of simply shaped pellets or graupel particles. Intervals with high mean elongation are expected to have low mean roundness and low mean shape factor and vice versa. Intervals with a low mean shape factor should also have a low mean roundness. Testing whether this behavior can be reproduced in 2DVD measurements gives information on the self-consistency of the instrument when real snowfall events are recorded."

   In addition the title was changed to: "On the consistency of 2D-Video Disdrometers in measuring micro physics of solid precipitation" (see also specific issues 1. and the comments by reviewer #2).

6. *Comparison with styrofoam objects. This interesting comparison has been really underexploited. As a 2DVD user i would be interested to know other aspects than what shown in Fig. 10, 11, 12. For example, are the proposed shape descriptors accurately reproducing the shapes of the particle? And are they stable?*

   The reviewer has interesting and valuable proposals of how the data gained in the present study can be exploited further. The goal of the present study was to give minimum requirements to 2DVD users who want to measure solid phase precipitation, like the implementation of a special matching algorithm, or supplementary calibration in addition to the manufacturers calibration procedure. Another key aspect of the study was to test the output of the device for shape parameters which are commonly used for the description of snowflake surface structure. It so far has never been tested which influence the spacial quantization (which is inherent in the 2DVD measurement principle), has on the measurement of such shape parameters. For this reason we decided to present reproducible experiments with spheres from which we know the nominal shape parameters.

To be more specific: if i throw 100 times the same styrofoam object of known geometry, what is the associated distribution of (e.g.) measured shape factors? Are they varying a lot? Are they consistent among the two cameras? Are there any shape descriptors that are more stable (and therefore more reliable) than others? Can we combine the two cameras efficiently?
The styrofoam objects could also be used to understand how well the two camera views are capturing the complexity of 3D objects (non rotationally symmetrical like raindrops). My message here is that i see a lot of unexploited potential in terms of microphysical interpretation.
This is certainly an excellent idea to further develop this kind of experiments. Especially dropping one and the same object several times through the sensitive area is a good idea to further test the potential of 2DVDs in solid precipitation measurements. The purpose of the experiment with styrofoam particles presented in our study was primarily to test the newly implemented matching algorithm in an independent and reproducible way. The data set used for the present study does not admit the kind of interpretation proposed by the reviewer.

7. *Statistical significance of the comparison with the styrofoam objects. The authors perform some comparison by: (i) dropping 5 times individual styrofoam objects, and (ii) dropping all the styrofoam objects (all together) a single time. There are 14 styrofoam objects. Could the authors do anything to increase these numbers? I am especially worried about (ii), when the exercise is performed only one time.*
We apologize for the misunderstanding that was produced by an insufficient description of the experiment with the styrofoam objects. Therefore, the paragraph was rewritten the following way (p3096, l13): "In a second step an ensemble consisting of 42 styrofoam particles within the same size range was released at the same time from the same height as in the first step. The second step was repeated several times and for data evaluation, a case was chosen where most of the particles contained in the ensemble fully hit the sensitive area. "
In the result section we added the following paragraph (p3098, l18):

"An ensemble consisting of 42 styrofoam particles was released at the same time. As one example, the results of an experiment where 30 particles fully hit the sensitive area is shown (Fig.7). The velocities measured in the ensemble (ensemble measurements) were compared to those measured when every particle was dropped one after the other (single measurements). The ensemble measurements have a very low spread around the single measurements."

8. *Equations. Please, check that all the equation are followed by the definition of all the terms (with units).*
   We apologize if variables appear in equations without definition.
   (p3092, l2) Eq.(1) All the variables are defined in the sentence which introduces the equation.
   (p3092, l12, l15, l16) All the variables are defined within the paragraph an in l17.
   (p3093, l11, l15, l20) These are dimensionless factors. The word "dimensionless" was inserted into l9. All the variables are defined in the corresponding figure (Fig.6) and within the paragraph.
   (p3095, l7) Eq.(2) The following sentence was inserted into l8: "$p(x, y)$ denotes the width of a single camera pixel seen from the location (x, y). f_{corr} is the correction factor supplied by the manufacturer."
   (p3095, l17) Eq.(3) All the variables are defined in l18 to l20. Units were added.
   (p3097, l10) Eq.(4) The following sentence was added in l11: "$p(x, y)$ denotes the width of a single camera pixel seen from the location (x, y). f_{corr} is the correction factor supplied by the manufacturer. t is the intercept as it can be found in Tab.2 and n_{pix} is the number of shaded pixels."

Specific issues

1. *Title, and throughout the manuscript. The term "technique", as referred to the 2DVD instrument sounds not appropriate. In my view a "technique" is more a synonym of "algorithm", while the 2DVD is a*

measurement device.

The title has been changed to "On the consistency of 2D-Video Disdrometers in measuring micro physics of solid precipitation". Throughout the text, the term "2D-video disdrometer technique" has been replaced by "2d-video disdrometers" or "2d-video disdrometer devices".

2. *The present manuscript does not present any specific microphysical application of 2DVD data but it is focussed on its potentials. In this context it is crucial that the authors show a complete knowledge of the state-of-the-art of the literature on the subject. I believe that some valid additional references should be considered. As an example:*

   - *Nespor et al. (2000). This is an important piece of literature about the potential limitations of the instrument.*
   - *Cao et al. (2008)*
   - *Schöhuber et al. (2008)*

   Micro-physical importance of the 2DVD was highlighted introducing the paragraph: "Micro-physical parameters which can be retrieved with a 2D-video disdrometer are for example the drop-size distribution, the size-velocity relation or shape parameters such as oblateness or surface structure of single hydrometeors. For example, Cao et al. (2008) used a comparison between 2D-video disdrometer data and data retrieved with an S-band polarimetric radar to improve drop-size distribution models. Woods et al. (2007) showed that changing the size-mass or size-velocity relation for snowflakes implemented in mesoscale model simulations, can significantly influence precipitation prediction in mountain regions. The significance of ice crystal shapes for the interpretation of radar back scatter signals was shown for example by Hong (2007) and Hiroshi (2008)." All mentioned publications were cited in the text (p3089, l21) and (p3091, l3).

3. *Page 3089, line 20. "hydrometeor classification" instead of "snow event classification"?*

   "snow event classification" was replaced by "hydrometeor classification".

4. *Page 3090, line 10. Add a sentence describing the structure of the paper in the end of the Introduction. "Section 2 is about XXX, Section*

3 describes YYY. . . "

The sentences "Section 2 describes the 2DVD and the experimental methods, section 3 focuses on the results which are discussed in section 4. Conclusions for 2DVD-users are drawn in section 5." were introduced at the end of the introduction.

5. *Page 3091, line 22. You might also underline that the velocity of "winter" hydrometeors is lower, and explain why it is so.*
   (p3091, l22) was rewritten the following way: "In case of solid phase precipitation the fall velocity is lower than for liquid phase hydrometeors. Complex surface structures increase drag forces and the vertical fall velocity for solid phase hydrometeors depends not only on size but also on shape and degree of riming (Locatelli and Hobbs, 1974; Barthazy and Schefold, 2006)."

6. *Page 3093, list of items. Here the authors list some hydrometeor descriptors. Why these descriptors have been chosen among the ones of Grazioli et al. (2014)? Are these the best possible ones to describe geometrical properties or is there any other reason?*
   Obviously more descriptors for size and shape of solid phase hydrometeors exist. The present work is part of a larger project dealing with below-cloud scavenging of atmospheric aerosol by solid phase precipitation. The listed parameters elongation, roundness and shape factor were expected to have major influence on the mechanism of scavenging by different types of solid phase hydrometeors. This is the reason why we focused on the mentioned ones.

7. *Page 3093, points (a) and (b). It can be misleading to say that rain or graupel have elongation and roundness of approximately one. I suggest to clarify that rain and graupel have higher roundness (with respect to other hydrometeors) but raindrops are more and more oblate as their size increase, and graupel can exhibit quite peculiar conical shapes. About dendrites: they have high roundness if they are "seen" along their major planar dimension. If we see a dendrite "from the side" it will look very elongated.*
   (p3093, l11) changed to: "Rain or graupel particles have lower elongations than other types of hydrometeors."
   (p3093, l15) changed to: "Rain or graupel particles are expected to

have a larger roundness than other types of hydrometeors."
(p3093, l20) changed to: "The shape factor of rain and graupel particles is expected to be larger than the one for other types of hydrometeors."

8. *Page 3094, point (f). Please clarify the definition of D_{eqd}. Is it the same as Huang et al. (2010); Grazioli et al. (2014)? If i look at your definition of the volume (point e) it seems not the case.*
The definition of the volume and therefore, the definition of D_{eqd} is the same as in Schönhuber (1998). The reference is included in p3094, l9.

9. *Page 3095, line 4. Any additional information about this correction factor f_{corr} (if possible for copyright-related reasons) would be greatly appreciated by the scientific community that works with 2DVD data.*
The correction factor f_{corr} is supplied by the manufacturer. Every instrument has its own table of correction factors which is found with a calibration procedure performed by the manufacturer.

10. *Page 3099, line 20. Could you be more specific? Could you provide any quantitative value to support this statement? As an example, how much can the calibration values change over time? Or, how often should the instrument be calibrated?*
The following sentence was included to p3099, l20: "Following the recommendations of the manufacturer to calibrate the plane distance every six month, every 2DVD user should include a check for the validity of the size measurement to this procedure."

11. *Page 3100, line 23. Could you add a reference for the blurring edge filter?*
The reference OpenCV (2015) was included in l23.

Figures and tables

The caption of tables and figures need to be much more descriptive and precise. Please, provide the units of measurement, either in the table/figure itself or in the caption, of any quantity appearing in the table/figure. Secondly, a caption should include the explanation of what is shown, while the *interpretation of the authors should be included in the main body of the paper.*

1. *Table 1. The definition of the terms appearing in the table should be included in the caption.*
2. *Table 2 and 3: ditto.*
   The definitions of the terms appearing in tables 1, 2 and 3 are included to the captions.
3. *Figure 1. I suggest to avoid the "interpretative" sentences (you can mention in the main body of the text that this design is less prone to wind effects)*
   The caption of Fig.1 has been changed to: "The Compact 2DVD at the measuring site."
4. *Figure 1. The first time that i went fast through the manuscript and i saw this set-up (2DVD ending up into a precipitation gauge), i was expecting some interesting comparisons (i.e., calculation of the density of specific types of snow flakes), while it seems that the gauge is never used in this work. If this is the case, it should not even be mentioned nor shown.*
   The setup with the gauge is used for another publication for bulk density calculations (Bernauer et al., 2015). The caption of Fig.1 has been changed to: "The Compact 2DVD at the measuring site."
5. *Figure 1. Is it the instrument installed on the edge of a wall or a balcony? Please note that it should be avoided to install disdrometers and gauges on "edge" locations.*
   The authors are aware of the fact that disdrometers and gauges should not be placed on edge locations. Nevertheless, the circumstances at the measuring site did not admit any other location.
6. *Figure 2. Is this an adaptation of Fig.3 of Kruger and Krajewski (2002)? If this is the case, please mention it.*
   Fig.2 was fully made by the authors themselves, with the inspiration of Kruger and Krajewski (2002). To honor this, the reference was included.
7. *Figure 4. The fact that the rain falls much faster makes you choose a wide range on the y-axis, and the difference among ice-phase hydrom-*

eteors is not evident any more. Could you split this figure in two (rain vs other) or use a logarithmic y-axis to allow better readability?
y-axis from Fig.4 was changed to log-scale.

8. *Figure 9. Could you define in the text how the relative standard deviation is calculated? Could these high values be only due to a normalization with respect to small quantities? To answer to this questions it would be helpful to show also the absolute standard deviation.*
The relative standard deviation was calculated by dividing the standard deviation (calculated for 30 to 70 measurements for every single size) by the nominal value of the analyzed parameter. For size-related parameters the reviewers comment is certainly true. For the shape parameters, elongation, roundness and shape factor, the nominal values are one, independent from the size of the sphere. The following sentences were included in the text (p3100, l6): "The relative standard deviation was calculated by dividing the absolute standard deviation by the mean value of the analyzed parameter. For the size-related quantities, this can also be one reason for increasing relative standard deviation with decreasing size."

9. *Figure 10 and 11. The caption of these two figures is an interpretation and not an explanation of what is actually shown in the different panels. Please, leave the interpretation in the main body of the manuscript.*
Fig.10: Caption was changed to: "Comparison between measured and expected values for the shape parameters. Elongation (a and b), roundness (c and d), shape factor with (g and h) and without (e and f) treatment with a blurring edge filter."
Fig.11: Caption was changed to: "Comparison between measured and expected values for equivalent diameter (a), volume (b) and vertical velocity (c)."

10. *Figure 12: ditto. Also, has the "whole ensemble" experiment been performed only once? Why not repeating this experiment multiple times as well?*
Fig.12: Caption was changed to: "Comparison of velocity measurements of single styrofoam objects (dropped one after the other) and of the whole ensemble (all particles dropped at the same time from the

same height)."

See general issues 7 for detailed description of the experiment with styrofoam particles.

11. *Figure 13: ditto. As mentioned before, could you maybe try to provide something more about the microphysics? Here we only observe self-consistency of 2DVD measurements.*

    Fig.13: Caption was changed to: "Comparison between mean shape parameters measured for real snowflakes. Higher elongation means lower roundness (a) and lower shape factor (b), lower roundness means lower shape factor (c) (and vice versa)."

    The linkage between micro-physics and shape parameters measured by the 2DVD was handled with the comment in general issues 4.

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