Review of the paper "Relationships between Snowfall Densities and the Main Types of Solid Hydrometeors Deduced from Measured Size and Fall Speed for snowpack modeling applications" by M. Ishizaka et al. submitted to The Cryosphere.

This paper studies the links between the density of falling snow and the main type of hydrometeors in a snowfall, which is automatically determined from the measured size and fall speed of every hydrometeor in the snowfall. The authors use a method based on the determination of the Center of Mass Flux (CMF) which has been described in a previous publication (Ishizaka et al., 2013). They restrict their analysis to periods when the snowfall is made of similar hydrometeors (with an air temperature below 0°C). Their results reveal large differences of snowfall density between aggregates and graupel. Then, from the CMF data, the authors compute the "CMF-density" which is related to the density of the main type of hydrometeors. Relationships between snowfall density and "CMF density" are then established as a function of the main type of hydrometeors (graupel or aggregate). At the end of the manuscript, the authors discuss potential impact of their research for snowpack modeling.

Ishizaka et al. addressed an interesting topic for the snowpack modeling community but also for the weather forecasting community since an accurate estimation of snowfall density is necessary to correctly estimate the depth of new snow resulting from a snowfall event. My main comments about this study concern (i) the potential application for snowpack models and (ii) the determination of the "CMF density" and its relationship with the density of accumulated snow on the ground. These questions need to be clarified prior to publication in TC. They are listed below (General comments) followed by more specific and technical comments. Finally, there are too many language and spelling issues, so I strongly suggest an accurate editing by a native speaker.

General Comments

1) In the title of the paper, the authors use the expression "for snowpack modeling application" suggesting that this paper could have direct applications for snowpack modeling. However, the authors only include a discussion regarding this point in Section 3.5. Therefore, I strongly recommend extending and improving this discussion to enhance the impact of the manuscript. So far, the expression "for snowpack modeling application" should not be used in the title since it is not accurate. Below I listed several points that could be treated or better explained:

- as mentioned by the authors, detailed snowpack model used parameterizations for the density of newly fallen snow that depends on air temperature, surface snow temperature, wind speed, … (e.g. Anderson, 1976, Pahaut, 1976, Hedstrom and Pomeroy, 1998, Lehning et al. 2002). If these data are available at their experimental site, the authors could compute the values of density of newly fallen snow given by these parameterizations and compare them with their measurements. It should reveal a large scatter between the parameterized and the measured values that could potentially ne discussed as a function of the main type of hydrometeors (graupel or aggregate)

- to really illustrate the impact for snowpack modeling, I recommend the authors to derive continuous time series of snowfall density over given time periods. In combination with other atmospheric variables, the authors could use these time series of snowfall density to drive a detailed snowpack model and discuss the impact for snowpack modeling. There is no need to do it over a whole winter but the authors could select a period with successive snowfall events and present the impact on the simulated snowpack. This would allow the authors to discuss the issues related with changes of snow types during a snowfall event. They suggest (P9 L 16-18) that short time interval (less than 5 min) could be used to derive snowfall densities. Does it work?

- as mentioned in the abstract the main types of falling snow at Nagoaka consist of rimed particles and aggregates. The author should also discuss in the main text the abilities and limitations of their method for those who want to apply in other regions where different types of crystals in snowfall prevail.
- finally the authors should mention how their method can be applied practically. Is it only restricted to experimental sites where disdrometers data are available? Can they use their method to develop parameterizations that can be applied in atmospheric models?

2) The "CMF density" (Eq 7, P8) is used by the authors to derive a quantitative value from the CMF data. The authors should clarify the definition of this "CMF density". Is it taken from the density chart (Fig. 8b) at the bin corresponding to d_{CMF} and V_{CMF} (respectively the averaged size and fall velocity of all hydrometeors weighted by their mass flux)?
Did the authors consider other formulations to derive a density computed from disdrometer data? For example, Brandes et al (2007) computed the bulk snow density from 5-min disdrometer data using the ratio between the total precipitation mass and the precipitation volume. The authors could for example compute the ratio between the total mass flux for a given period and the total volume flux for the same period. The volume flux can be obtained assuming a spherical shape for each particle of diameter *d,* as done by the authors to compute the CMF density. Such method has been employed by Milbrandt et al. (2012) to derive the density of falling snow from a cloud microphysical scheme implemented in an atmospheric model.

The "CMF-density" depends on the mass-size relationship chosen for the main types of hydrometeors as described in Ishizaka et al. (2013). Many mass-size relationships can be found in the literature for the different kinds of solid hydrometeors (e.g. Mitchell, 1996; Rasmussen et al. 1999). It would be interesting if the authors could discuss the sensitivity of the "CMF density" to the mass-size relationships used in the CMF method.

The relationship between snowfall density and CMF-density is interesting since it illustrates the influence of accumulation processes on snowfall density. I recommend the authors to extend the discussion regarding accumulation processes since they need to be taken into account to transform a "density" of falling snow in the air derived from a disdrometer into a density of fallen snow on the ground. What are the expected effects for density when aggregates are accumulating on the ground? The authors should also precise the range of usual graupel densities (P8 L23).

Specific comments

P2 Introduction: The author should better present in the introduction the need for improvements in the determination of falling snow density: (i) for snowpack modeling and (ii) for wintertime weather forecasting. Concerning this last point, they can for example refer to Roebber et al (2003), Ware et al. (2006) or Milbrandt et al (2012).
The recent study of Colle et al. (2014) presents also a detailed study of the impact of crystal habit and riming intensity on the density of snowfall (related to the snow-to-liquid ratio).

P2-3 L30 L 6: the end of the introduction is not clear and it is hard for the reader to identify the main objective of the study and the structure of the paper. Please consider rewriting the two last paragraphs of the introduction.

P6 L 6: The authors should consider renaming the two categories identified as "small groups 1 and 2". It would help the reader to identify more easily which kind of falling snow particles belong to these groups.
P9 L32: the authors should also precise if there is an expected effect of wind during the snowfall itself; for example the fragmentation of aggregates.

P 10 L 28: as mentioned earlier, with the current version of the manuscript, the authors cannot say that they have shown "the feasibility of using the relationships to an initial density for numerical snowpack model".

Technical comments

Text

P2 L 15: what the authors mean by "the horizontal size distribution"?

P2 L19-20: which aspects of the study by Kajikawa et al. (2006) are important according to the authors?

P3 L10: please provide the detailed location of FSO in terms of latitude and longitude. A map showing the location of the experimental site would help the reader.

P3 Eq (1) please precise the units of the variables used in this equation. This remark is general and concerns the other equations in the paper.

P5 L 10: please add a reference when mentioning Eq. (3).

P5 Eq (4) and Eq (5): the formulations of Eq (4) and (5) are erroneous. Indeed, η is missing in Eq (4) and (5).

P 9 L 8: please refer to Vionnet et al, 2012 instead of Vionnet et al, 2002

P 9 L21: snowpack models use also the snow specific surface area (SSA) (e.g. Carmagnola et al., 2014) to describe snow microstructure.

P9 L23: please add a reference concerning the influence of the crystal type of snowfall on the avalanche danger.

Figures

Fig. 6: the location of A3 is hard to identify on this figure since the color of the point is almost white. Maybe the authors could add a black contour around the point so that it can be more easily identified. This remark should be also considered for Fig. 7.

Fig. 9: precise the correlation coefficient for each regression.

Fig 10: the differences between the two accumulation processes are not visually clear.

Language and spelling

There are too many language and spelling issues. I listed some of them below but I strongly recommend an accurate editing by a native speaker.

Text

Abstract and rest of the text: the authors often use the plural form of nouns (“snows”, “snowfalls”, “densities”, …). I have the feeling that it is not really necessary. Please check the relevance of using it with a native speaker.

Abstract L29 use “snowpack” instead of “snow pack”

Abstract L29 “practical use”

P2 L21-22: the use of paragraph made of a single sentence is sometimes surprising. Maybe the authors can gather this single sentence with the previous or the next paragraph.

P3 L 8 use “snowfalls” instead of “snow falls”

P3 L 16 “through which snow falls and accumulates”

P 3 L27 double use of “falling”

P 5 L 8: the formulation “rather complicated situation” should be rephrased. Snow compaction is not a “situation” that occurs from time to time but a process that occurs as soon as snow accumulates on the ground.

P 6 L 10-11: use “the size component” instead of “a size component”

P7 L 21-22: the sentence “It is found …. for a event has” is complicated and hard to understand. The authors should rephrase it;

P 9 L 6-7: use “snowpack” instead of “snow pack” (same for P9 L 21)

Figures

Caption of Fig. 9: add a space between kg and m^{-3}

References (not included in the submitted manuscript)

Brandes, E. A., Ikeda, K., Zhang, G., Schönhuber, M., & Rasmussen, R. M. (2007). A statistical and physical description of hydrometeor distributions in Colorado snowstorms using a video disdrometer. *Journal of applied meteorology and climatology*, *46*(5), 634-650.

Carmagnola, C. M., Morin, S., Lafaysse, M., Domine, F., Lesaffre, B., Lejeune, Y., ... & Arnaud, L. (2014). Implementation and evaluation of prognostic representations of the optical diameter of snow in the SURFEX/ISBA-Crocus detailed snowpack model. *The Cryosphere*, *8*(2), 417-437.

Colle, B. A., Stark, D., & Yuter, S. E. (2014). Surface Microphysical Observations within East Coast Winter Storms on Long Island, New York. *Monthly Weather Review*, *142*(9), 3126-3146.

Milbrandt, J. A., Glazer, A., & Jacob, D. (2012). Predicting the snow-to-liquid ratio of surface precipitation using a bulk microphysics scheme. *Monthly Weather Review*, *140*(8), 2461-2476.

Mitchell, D. L. (1996). Use of mass-and area-dimensional power laws for determining precipitation particle terminal velocities. *Journal of the atmospheric sciences*, *53*(12), 1710-1723.

Rasmussen, R. M., Vivekanandan, J., Cole, J., Myers, B., & Masters, C. (1999). The estimation of snowfall rate using visibility. *Journal of Applied Meteorology*, *38*(10), 1542-1563.

Roebber, P. J., Bruening, S. L., Schultz, D. M., & Cortinas Jr, J. V. (2003). Improving snowfall forecasting by diagnosing snow density. *Weather and Forecasting*, *18*(2), 264-287.

Ware, E. C., Schultz, D. M., Brooks, H. E., Roebber, P. J., & Bruening, S. L. (2006). Improving snowfall forecasting by accounting for the climatological variability of snow density. *Weather and forecasting*, *21*(1), 94-103.