Authors' responses to the Reviewer #1

We would like to express our appreciation to the Reviewer #1 for your constructive reviews and helpful advice.
We have revised our manuscript and corrected mistakes according to your general and specific comments.

The revised manuscript file is "manuscript_Ishizaka_snowfall_density_R2.pdf".

Fist of all, the title has been slightly changed by following the editing process of a native speaker.
The new title is "Relationships between Snowfall Density and Solid Hydrometeors Based on Measured Size and Fall Speed, for Snowpack Modeling Applications"

Our responses to the comments are described as follows:

Responses to the general comments 1)
Comparison of estimation of snowfall density by our method with by a method used in current snowpack model

On the reviewer's instruction, we added the new section 3.4.1 to discuss applicability of our method. In the section, we presented comparison of estimated snowfall density using our method with that used in the snowpack model developed by Lehning et al. (2002) and showed time series of observed and estimated densities.
As mentioned in the section, it was hard to satisfy preconditions for the comparison, but the results suggested that information about hydrometeors should be necessary for accurate estimation of snowfall density.

Practical use
In the added section 3.4.1, we also described how practically obtained snowfall density of a event from a short time CMF (5-min CMF) during the event, which can be obtained from the measurement of size and fall speed of hydrometeors. (P10 L25-28; in the revised manuscript: same in below)
We also described additional equipment, which are necessary for practical operation of our method in the summary. (P13 L8-12)

Applicability to other snowy region

We mentioned our idea in the summary. (P13 L18-22)

Applicability in an atmospheric model

We believe it will be capable to apply our method to the atmospheric model if the model could output accurate microphysical properties that enable to calculate CMF. We briefly comment this idea in the summary. (P13 L12-14)

Responses to the general comments 2)

Definition of CMF-density

We presented the detailed definition of the CMF-density in the section 3.3.1 using Eq. (5) and Eq. (6).

Bulk density

The bulk density can be deduced from the disdrometer data. We calculated bulk density using the disdrometer data and compared them with the observed density in section 3.4.1. The ratios between bulk and observed density strongly depend on the main type of a snowfall event (P11 L12-24). These results indicate the importance of type of hydrometeors in the snowfall density problem.

Dependence of CMF-density on the mass-size relationship

As the reviewer points out, CMF-density and CMF itself depend on the choice of the mass-size or size-fall speed relationships and so on. We have already discussed these situations in the previous study (Ishizaka et al., 2013). We think it is difficult to determine the best choice of them and it should be practically resolved in case by case, namely, considering the predominant types of hydrometeors in the targeted snowy region where they are used. The problem also relates to application possibilities of the method to other regions, especially to the region where small particles are predominant. Thus we mentioned this problem in the last part of the section 3.3.2 (P10 L4-7), and added the following sentence in the last part of summary.; “It might be necessary to establish…..including a review of the mass-size relationships which affect CMF-density（P13 L21−22）” to describes the application possibilities of our method in colder snow regions, where snowfall may be consisted with small particles and no appropriate mass-size and size-fall speed relationships have not been established,

We think further discussion about this problem is outside of the scope of this manuscript.

Relationship between snowfall density and CMF-density

We think that CMF-density should reflect density of snow in the air because it was derived from data of hydrometeors in the air while snowfall density is measured on the ground. Thus relationship between CMF-density and snowfall density should indicate the relationship between density of snow in the air and that on the ground. We added more detailed discussion on this problem in the section 3.3.2 using the quantitative relationships expressed by Eq. (8) and Eq. (9). (p9 11-21) Moreover the ratio of bulk density for aggregate type snowfall is considered to relate this problem, which we briefly mentioned in the section 3.4.1. (p11 20-21)

Figure 10 in the previous manuscript was eliminated because it could not accurately express the argument given in the revised manuscript.

Responses to specific comments

Improvement of introduction

On the reviewer's instruction, we added description on the need for improvements in the determination of falling snow density for both snowpack modeling and winter weather forecasting. We are very grateful to the reviewer for suggesting useful references.

The last two paragraphs of the introduction in the previous manuscript

We deleted them and revised the final part of the introduction.

Categories "small groups 1 and 2"

As the reviewer's suggestion, we also think it is better to rename these categories, but we could not conceive more appropriate abbreviation for them. We only renamed them with a minor change, namely, "small group" to "small particle group", with more detailed description for them in the section 2.4. (P5 L21-23)

Wind effects to snowfall itself

We added the description about wind effects relating hydrometeors to the text. (P12 L4-6)

Feasibility of using our relationships to an initial density for numerical snowpack model

As mentioned in the response to general comment 1), we added more concrete discussion for the applicability of our method to a numerical snowpack model in the section 3.4.1.

Responses to technical comments

Text

"the horizontal size distribution"

→ “the horizontal particle size distribution” (P2 L15)

which aspects of the study by Kajikawa et al. (2006) are important・・・

The aspects were added as follows:

“for example the contributions of kinetic energy flux and hydrometeor size to density” (P2 L20)

Location of FSO

The longitude of FSO was added.

Units of variables in Equations

We gave units to all variables in Equations.

A reference for Eq.(3)

Eq.(3) in the previous manuscript was moved to Appendix Eq.(A1) in the revised one and a reference was given.

Errors in Eq.(4) and Eq. (5)

Eq.(4) and Eq. (5) in the previous manuscript was moved to Appendix Eq.(A1) and Eq. (A2) in the revised one and erroneous expressions in both the equations were corrected.

refer to Vionnet et al, 2012 instead of Vionnet et al, 2002

→corrected.

SSA(snow specific surface area)

We described SSA as one of shape or geometrical factors. (P11 L26) We also have an interest in SSA for one of important factors to describe snow microstructures.

References for an avalanche danger relating to the crystal type of snowfall

One reference was added. (P11 L28 and in references)

Figures

Fig.6 and Fig.7

A black contours were added around the mark of CMF points.

The correlation coefficient for the regressions in Fig.9 and others

The coefficient of determination R2, which is square of the correlation coefficient is described

to each regression.

Fig 10: the differences between the two accumulation processes are not visually clear.
We eliminated Fig.10 in the previous manuscript as mentioned above.

Language and spelling (text and figures)
The submitted revised version (manuscript_Ishizaka_snowfall_density_R2.pdf) was checked and corrected by a native speaker.

Text
Plural form of nouns
We reexamined this problem and revised the manuscript.

Abstract L29 use "snowpack" instead of "snow pack"
→corrected.

Abstract L29 "practical use"
→corrected. (P1 L32)

P2 L21-22: the use of paragraph made of a single sentence….
We reexamined paragraphs in the previous manuscript and revised to avoid one-sentence paragraphs.

P3 L 8 use "snowfalls" instead of "snow falls"
→corrected.

P3 L 16 "through which snow falls and accumulates"
→corrected. (P4 L3)

P 3 L27 double use of "falling"
→corrected. (P4 L14)

P 5 L 8: the formulation "rather complicated situation" should be rephrased.
→revised. (P6 L7-9)

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

→revised to different expression in the section 2.4. (P5 L16)

P7 L 21-22: the sentence “It is found …. for a event has” is complicated….
→revised (P7 L26-27)

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

Figures

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

References (not included in the previous manuscript)
We again appreciate your introduction of the references. They are very useful to improve our manuscript.

Authors' responses to the Reviewer 2

We would like to express our appreciation to the Reviewer #2 for your constructive reviews and helpful advice.
We have revised our manuscript and corrected mistakes according to your general and specific comments.

The revised manuscript file is "manuscript_Ishizaka_snowfall_density_R2.pdf".

Fist of all, the title has been slightly changed by following the editing process of a native speaker.
The new title is "Relationships between Snowfall Density and Solid Hydrometeors Based on Measured Size and Fall Speed, for Snowpack Modeling Applications"

Our responses to the comments are described as follows:

Response to general comments 1

Uncertainty of the approximated relationships

We recognize our observed data are not enough for statistical analysis. Our aim of this study is to establish a critical relationship between hydrometeor types and snowfall density, so we strictly selected the observation data at the event with almost the same type of hydrometeors. Although we carried out observations in three winter seasons and obtained 53 events, only 34 events could be used (other 19 event were not suitable for this study because they occurred under the complex precipitation condition). It was hard to increase sampling events. Therefore we could not obtain enough data to statistically analyze. For these reasons, to clear uncertainty of the relationships, we described the correlation efficient and standard errors for them in the revised manuscript. Furthermore, we estimated the density for snowfall events using the obtained relationships to examine applicability of our method in the section 3.4.1. The density estimated with the relationships approximately corresponds with observed density. This might be a sort of validation for the relationships.

Response to general comment 2

Comparison of our method to currently employed methods in numeric snowpack models

On the reviewer's instructions, we added the new section 3.4.1 in the revised manuscript to discuss applicability of our method. In the section, we presented comparison of estimated snowfall density using our method with that used the snowpack model developed by Lehning et al. (2002) and showed time series of observed and estimated densities.

Responses on specific comments

Uncertainty of scale

The scale used here have an uncertainty of about 0.2mm, with which error originates is fairly small and negligible. We described this information in the revised manuscript. (P5 L28; in the revised manuscript: same in below)

Paragraphs on densification error

On the reviewer's recommendation, we moved the paragraph that deviated the densification error to the Appendix in the revised manuscript.

Errors in Eq. (4) and Eq. (5)

Eq.(4) and Eq. (5) in the previous manuscript were moved to the Appendix Eq.(A1) and Eq. (A2) in the revised one and erroneous expressions in both the equations were corrected.

Section 3.1 "Classification of snowfall events" in the previous manuscript

On the reviewer's recommendation, the section was moved to the method section giving section no. 2.4 in the revised manuscript.

Applicability of our method to different snow types and long lasting events

Although we carried out short time observations to select almost the same type snowfall, we did not select typical aggregate case and graupel case arbitrarily. In our method, all type events are classified into the aggregate or graupel or two small particle groups, even though if it does not have typical characteristics of the classified type.

For long lasting event, we can estimate the density from each short interval density as mentioned in the section 3.4.1 combining measured mass flux. However for more accurate long term estimation, we should consider the effect of densification and metamorphosis to the accumulated snow at each interval. Moreover, we also should consider the effect of other meteorological effects to the accumulated snow. These effects should strongly depend on hydrometeors types. For these reasons, we think they are the remained issues for the future studies.

Figure Captions

On reviewer's instruction, we reexamined all Figure Captions and revised them. We again appreciate the reviewer's advice accompanying the specific example.

Specification of section in referring previous section

We described the section number in referring the previous section.

Responses on technical corrections

• P1 L31: plactical -> practical

→ corrected. (P1 L32)

• P2 L21-22: Try to eliminate one-sentence paragraphs.

We reexamined paragraphs in the previous manuscript and revised to avoid one-sentence paragraphs.

• P3 L12: "The winter temperature, around 0C..." Is this the mean winter temperature?

→revised as following:

"A temperature of around 0 °C during many snowfall events" (P3 L28-29)

• P3 L28: "CCD" Please define this abbreviation.

→"CCD (Charge-Coupled Device)" (P4 L14)

• P8 L25: "SI" -> S1

→ corrected. (P9 L22)

• P10 Summary: The summary should be autonomous and abbreviations should be defined.

Abbreviations were defined in the summary.

• I recommend to rephrase the following sentences to make them more precise:

– P4 L19: "If different snow types, ..."

→revised (P5 L1-3)

- P7 L21: "It is found that the densities..."

→revised (P7 L26-27)

• Missing/spare spaces:

→ All of them were corrected. Not listed individually.

Language

There are numerous lingual issues.

The submitted revised version (manuscript_Ishizaka_snowfall_density_R2.pdf) was checked and corrected by a native speaker.