Dear editor, reviewers

We would like to thank you and the reviewers for the constructive and insightful comments and suggestions to improve our manuscript. We have carefully revised the manuscript according to the suggestions and comments, and provide point-by-point response following each comment and suggestion.

In the following, reviewer comments are given in black and responses are given in blue (the revised sentence was set in italics). The corresponding changes have been made in the revised paper with track changes.

We think the revised manuscript has addressed all the reviewers' comments and hopefully it is now suitable for publication in The Cryosphere

Sincerely,

Xiongxin Xiao

*********************Reply to comments from anonymous reviewer 1#*********************

REVIEWER 1

This manuscript describes the development and validation of a technique to estimate fractional snow cover (FSC) from passive microwave brightness temperatures. Optical FSC estimates for algorithm training and validation were derived from MODIS Collection 6. Surface snow depth measurements and an independent passive microwave snow extent classifier were also used for evaluation. Overall, the study is comprehensive and detailed. I commend the authors for the thorough nature of the study – multiple combinations of passive microwave measurements are considered, sensitivity to various configurations of the retrieval are compared, and multiple datasets are used for evaluation. Because of this comprehensive approach, description of the analysis is sometimes unclear in some places, and the logic is not always clear on the back and forth conversion between FSC information derived via the retrieval and comparison with MODIS, and binary snow extent information used for evaluation. This can get confusing in places. But overall, the technique shows good promise, and this initial overview makes for a new contribution worthy of publication The Cryosphere.

Please note that the paper requires a thorough edit for grammar, English usage, and word choice. Edits of this nature were too numerous to identify individually in my review.

Response: Thanks for your valuable comments and suggestions to improve our manuscript. We have replied to each comment below. The manuscript has been edited by a native English speaker. Additionally, to make the description of the conversion from fractional snow cover to binary snow cover clear, we changed "random forest FSC" to "random forest SCA" in binary snow cover area information evaluation in the revised manuscript.

General comments

Please double check all the data citations in Section 2.1 and Section 2.2. Some citations are missing from the reference list. While it's fine to provide the URL to the NSIDC webpage which hosts the data, the proper data citations (which are provided under the "Citing These Data" tab on the NSIDC webpages) must also be used.

Response: Thanks for your suggestion. We updated and added the corresponding data citations for the dataset used in Section 2.

Section 2.3.2: why is the IGBP land cover data product described here in addition to the MCD12Q1 product? This dataset does not seem to be used in the analysis: :

Response: MODIS land cover data have several classification scheme, including the IGBP classification schemes. The MODIS land cover data with IGBP classification scheme was used as the basis data of fractional snow cover retrieval model

Page 6 lines 14-23: Previous work has shown the potential for passive microwave SWE datasets, despite high uncertainty in the SWE retrievals, to provide useful snow extent information. This provides additional justification for the approach developed in this study. A brief mention of this could be added to this paragraph, including a citation to: Brown, R., C. Derksen, and L. Wang. 2010. A multi-dataset analysis of variability and change in Arctic spring snow cover extent, 1967-2008. Journal of Geophysical Research. 115: D16111, doi:10.1029/2010JD013975.

Response: Thanks for your suggestion. We cited the related literature and added the description about snow parameters (snow cover extent, snow depth and water equivalent) retrieval in page 7 lines 16-19 as follows:

"A number of published work have demonstrated the potential to derive snow depth and SWE using passive microwave radiation data (Kim et al., 2019; Wang et al., 2019). Despite the high uncertainties associated with snow depth and SWE estimations, using passive microwave data can provide useful snow cover extent information (Brown et al., 2010; Foster et al., 2011)."

Section 3.1: I was disappointed e that the analysis period was limited to January and February. This is a real limitation because the spring period is the most important with respect to the snow-albedo feedback and the contribution of snow melt to streamflow. Additionally, the snow melt period may pose significant challenges to the use of passive microwave data because of a loss of sensitivity to snow when it is wet. This limitation to the study is acknowledged in Section 5.1, but I suggest the conclusions and discussion clearly emphasize that these results are applicable to dry snow conditions, and that performance is likely to be weaker during snow melt.

Response: Thanks for your comment. We do agree that the estimation and analysis of fractional snow cover should cover the whole snow cover season (autumn, winter and spring). Noted that the fractional snow cover estimation work we're doing will cover all the year round. Additionally, we clarified the description information of applicable condition for this study in Section 6 (page 26 lines 1-3) based on your suggestion:
"These models established using several data sources in January and February had better applicability in dry snow conditions, while estimation results could be less accurate in wet snow conditions."

Section 3.2: the short-term cloud filter for single days of cloud cover is clearly described (page 8 line 21) but it's not clear how longer cloudy periods are dealt with. If cloud is present for two or more consecutive days, is that pixel masked as cloud as described on page 9 line 3? Please state this clearly.

Response: Thanks. If cloud is present for two or more consecutive days, the pixel would be masked as cloud according to short term cloud filter. Additionally, we revised and clarified the description about the short term cloud filter (page 9 lines 21-24)
"*2) Short-term temporal filter: if the status of a pixel in the input image (MCD10A1) in a given day (t) was cloud and both the preceding (t - 1) and succeeding (t + 1) days were snow-covered (or snow-free), the pixel in the output image (MCTD10A1) in the given day (t) was assigned as snow-covered (or snow-free) (summarized by Eq. 2)*..."
and revised the confused term "filter" in original sentence to
"*We adopted the most rigorous pixel filtering rule, by which one clouded pixel cannot be allowed within a 15*15 pixel window*" in page 10 lines 4-5.

Section 4.1.1: there is virtually no difference in performance between scenarios 1, 4, and 5, as summarized in Table 4, with the main difference in performance between scenarios due to the inclusion of ancillary fields (lat/lon; topography). While I agree that "location information and topographic factors play a crucial role in snowpack distribution" can a more physically-based explanation be provided for these results?

Response: Thanks for your comment. The results of Scenarios-1, 4, and 5 show that there indeed were no significant differences among these three scenarios. Generally speaking, inputting more information could make great contribution to improving the performance of snow cover parameters estimation. However, we found that inputting more information did not provide too much contribution for the performance improvement of fractional snow cover by analyzing the results of Scenarios-1, 4, and 5. Thus, we conclude that the input variables in Scenarios-1 have redundant information and it makes model establishment more time consuming. These statements have been similarly described in our manuscript "*The comparison among Scenarios -1, 4, 5 indirectly indicates that the variables used in Scenario -1 may have some information* *redundancy and slightly weaken the efficiency of the random forest retrieval model*" in page 17 lines 17-19

Additionally, we added the explanation for the "location information and topographic factors" in page 17 lines 6-9

"*In this study, the retrieval method required these five basic input variables as auxiliary information in order to learn the characteristics of snow cover under different surface conditions to assist in accurately estimating snow cover properties. In contrast, in the absence of these basic input variables, the established model has no advantage in accurately predicting the characteristics of fractional snow cover under complex surface conditions*"

Section 4.3/Figures 6 and 7: the scatterplots seem to illustrate that the retrieval is capable of identifying low snow fraction and high snow fraction, but with less skill across the intermediate values. This may be in large part due to issues with the reference snow fraction from MODIS, which seems to be clustered around low and high snow fraction values as shown in Figure 7 (with the exception of forested areas as shown in Figure 7a). Please consider adding some text to the first paragraph of Section 4.3, or strengthening the text on page 20 lines 10-20 to make clear how the performance of the retrieval can be influenced by the behaviour of the reference dataset.

Response: Thanks for your comment. In order to clarify the influence of reference dataset to fractional snow cover retrieval, we added the following statement in page 20 lines 28-29.

"*This is mainly because a smaller number of samples with intermediate values from the reference dataset used in the training model may not properly capture the characteristics of the surface condition with intermediate fractional snow covers*"

Figure 8: the paper would be strengthened with more emphasis on the presentation of spatial results. Figure 8 is really important, but I found it unclear, especially panel D (the sub-panels within panel D are hard to read). Why is there so much white space in panel B? Zero snow fraction needs to have a separate colour than the range of 0 to 0.3, in order to clearly show where the retrieval estimates no snow versus very low fractions of snow (e.g. 0.1 to 0.3). I suggest a clear set of maps be presented, with emphasis on a comparison between MODIS and passive microwave estimates at the continental scale (as in panels B and C) for some key events which extended the snowline.

Response: Thanks you very much for your valuable suggestion.

1) The MODIS binary snow cover image (Fig. 8A) was translated to the reference MODIS fractional snow cover (Fig. 8B) by applying the pixel filtering rule at a 15*15 pixels window that do not allow an cloudy pixel when calculating the fractional snow cover. Then it resulted in that many pixels to be masked as "fill value" (white in Figure 8).

2) We modified and clarified why the separate color map was used in here.

"*Fig. 8 shows the comparison between our estimated fractional snow cover and the reference MODIS fractional snow cover, and more importantly, provides another perspective for snow cover identification in Section 4.4. Thus, Fig. 8B and 8C used 0.3 as the threshold of fractional snow cover to define snow-covered and snow-free area, and this was adopted through the experiments in Section 4.4*" in page 20 lines 11-14.

3) Moreover, according to your suggestions, we strengthened the description of spatial results in order to improve the legibility of each image (Fig. 8), and revised the statements as follows:

"*Apart from the scatter plots and statistical analysis, Fig. 8 shows the distribution pattern of snow cover from a spatial perspective, including MODIS composite binary snow cover (Fig. 8A), MODIS fractional snow cover (Fig. 8B), and the estimated fractional snow cover by the proposed algorithm (Fig. 8C). When the most rigorous pixel filtering rule at the 15*15 pixel window was applied (see Section 3.2), the large number of cloud covered pixels (yellow) in Fig. 8A resulted in most areas of the MODIS fractional snow cover image (Fig. 8B) being represented by a "fill value". Additionally, the number of intermediate values for MODIS fractional snow cover in winter would be much lower than the number of values near the two extreme values (0 and 1). In contrast, the estimated fractional snow cover from passive microwave brightness temperature data can provide almost complete coverage and continuous spatial information on snow cover (Fig. 8C; Fig. S-7 in the Appendix). Fig. 8 shows the comparison between our estimated fractional snow cover and the reference MODIS fractional snow cover, and more importantly, provides another perspective for snow cover identification in Section 4.4. Thus, Fig. 8B* *and 8C used 0.3 as the threshold of fractional snow cover to define snow-covered and snow-free area, and this was adopted through the experiments in Section 4.4. This means that the pixel was identified as snow cover when fractional snow cover value was less than 0.3. From Fig. 8A – C, the spatial pattern of estimated fractional snow cover from the proposed method seems to accurately capture the distribution of snow cover from MODIS under clear-sky conditions, such as the snow-free area in most areas of North America, and snow-covered areas in northern Canada. Fig. 8D presents a specific example comparing these two fractional snow cover datasets and MODIS composite binary snow cover products in central Canada on February 27th, 2017. Based on this example, we find that our estimated fractional snow cover was capable of obtaining snow cover distribution when most of the area was covered by cloud, which was not the case for MODIS. This example also show that the extent of snowline observed in the MODIS binary snow cover image (500 m), which was the boundary between snow-covered and snow-free, was well described and exhibited by the estimated fractional snow cover (6.25 km)*" in page 20 lines 3-23.

Moreover, the estimation results comparison of fractional snow cover for MODIS and our proposed algorithm in continuous value has been shown in the supplement file:

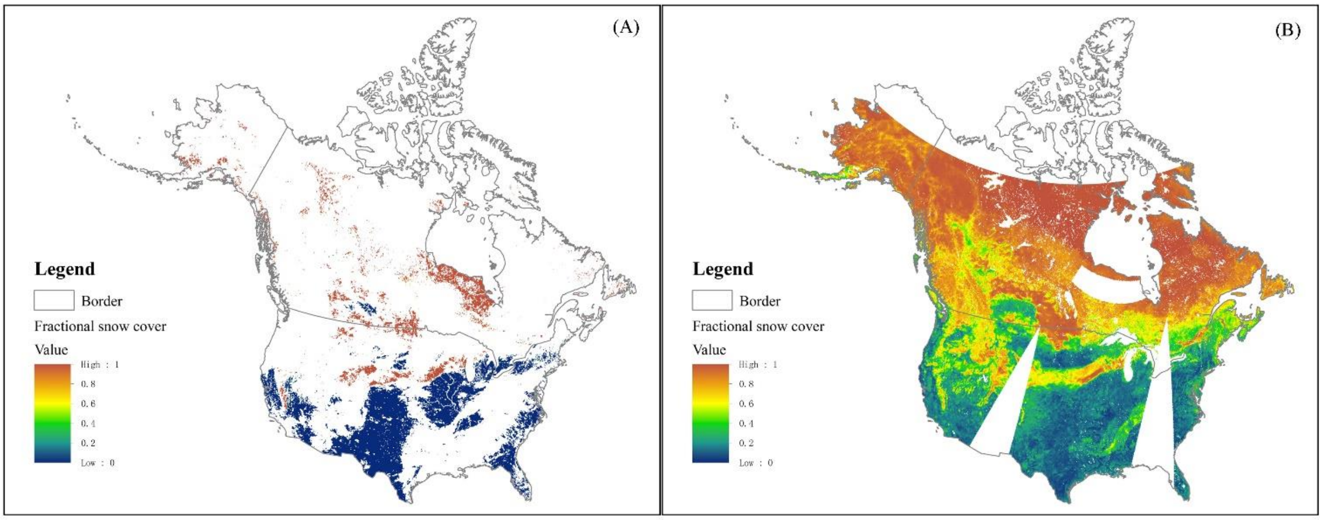


Figure S-7. Comparison of the reference MODIS fractional snow cover (A) with our estimated fractional snow cover (B) in continuous value (6.25-km) on February 27th, 2017 (2017058)

Page 18 lines 3-6/Page 19 lines 27-28/Page 22 lines 1-3: the explanation for the potential over-identification of snow in the microwave retrievals (compared to the Grody product) is not convincing. The misclassification of snow extent due to non-snow scatterers (like cold deserts/frozen ground) is not a prevalent issue in North America. To better understand the statement that "the non-snow scatterer is the major source of snow cover misclassification for random forest FSC results" it would be clearer to show a map of locations where the RF classifier identifies snow and the Grody algorithm does not. This aspect needs to be explored in more detail in the final manuscript.

Response: Thanks for your comment. Although the commission error of the proposed algorithm in snow cover identification only have 0.17, we provided additional information to explain this kinds of error. As you say, the non-snow scatters (like cold deserts, frozen ground) is not a prevalent issue in North America. According to our study, we can also conclude that the snow cover misclassification effected by cold deserts and frozen ground is not prevalent issue in North America. We then specified the different source error for commission error and revised the statement as follows:

"*The records, which were misclassified as snow cover by random forest SCA, although they are non-snow scatter components (precipitation, cold desert, and frozen ground), account for 70.1% of total misclassification records (CE = 0.17), of which 63.0% comes from precipitation, 6.4% from cold desert, and 0.7% from frozen ground*" in page 23 lines 5-8.

Following your suggestion, we first analyzed the confidence of the comparison results between Random forest SCA and

Grody's algorithm SCA, when the in-situ station observation is absent. We provided the following statistical metrics (Table A) using the data in 2017. We can see that the percentage of "True observation" for Grody's algorithm only is 24.9% when RF classifier identifies snow-covered and the Grody's algorithm does not (Condition B); inversely, it should be classified as snow-covered. If we do not use the in-situ observation as the "true" observation, we do not have high confidence to say that the detection results by our proposed algorithm in Condition B are not right. Moreover, we show an example that provides a map for different condition combinations of Random forest SCA and Grody's algorithm SCA (Fig. S-9). The inconsistencies between Random forest SCA and Grody's algorithm SCA usually occurred in the mid-latitude region, in which it has the low fractional snow cover (Figure S-7). And also we revised the statement to

"*For different results for these two snow cover mapping algorithms, we have used an example to show the inconsistencies and consistencies in mapping between the random forest SCA and Grody's algorithm SCA (Fig. S-9)*" in page 23 lines 10-11.

Table A. The effect of precipitation, cold desert and frozen ground in snow cover misclassification. FP is false positive that means it is the number of pixels that are misclassified as snow cover by Random forest FSC. $SD_{obs} = 0$ denotes snow-free measured in station, otherwise, it is snow-covered; $SC_{Grody} = 0$ denotes snow-free (precipitation, cold desert and frozen ground) determined by Grody's algorithm, otherwise it is snow-covered; $FSC \leq 0.3$ denotes snow-free cover detected by our method, otherwise, it is snow-covered.

No.	Conditions	Observation		Percentage of "True observation"	
		$SD_{obs} = 1$	$SD_{obs} = 0$	Random Forest	Grody's algorithm
A	$SC_{Grody} = 0$ & $FSC \leq 0.3$	17435 (13%)	116069 (87%)	87%	87%
B	$SC_{Grody} = 0$ & $FSC > 0.3$	60601 (75.1%)	20063 (24.9%)	75.1%	24.9%
C	$SC_{Grody} = 1$ & $FSC \leq 0.3$	4379 (51.5%)	4120 (48.5%)	48.5%	51.5%
D	$SC_{Grody} = 1$ & $FSC > 0.3$	80167 (90.3%)	8575 (9.7%)	90.3%	90.3%

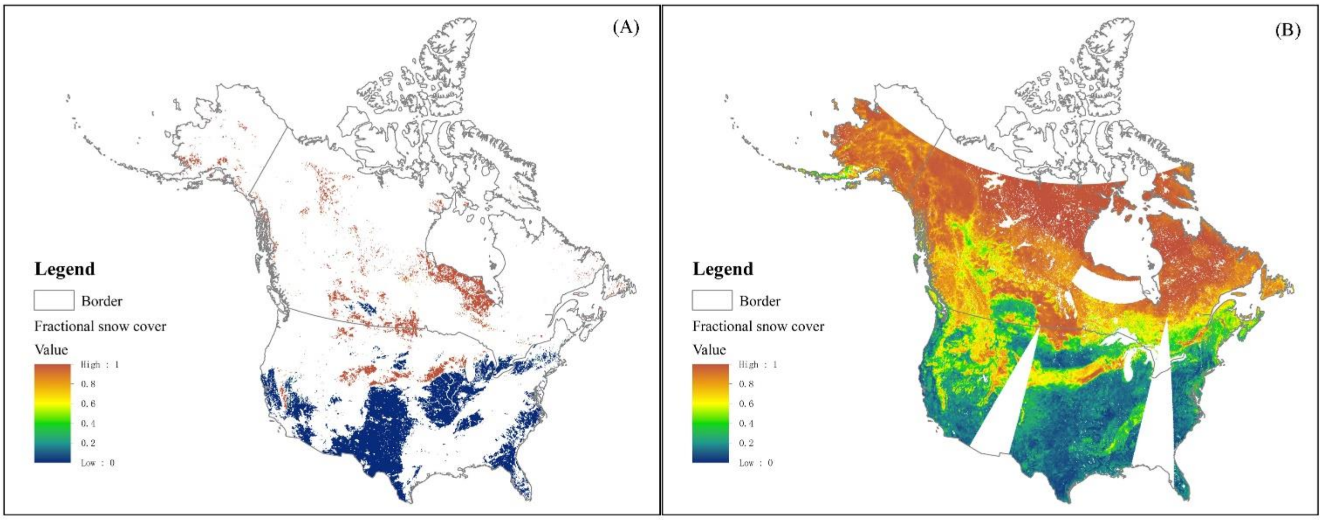


Figure S-7. Comparison of the reference MODIS fractional snow cover (A) with our estimated fractional snow cover (B) in continuous value (6.25-km) on February 27th, 2017 (2017058)

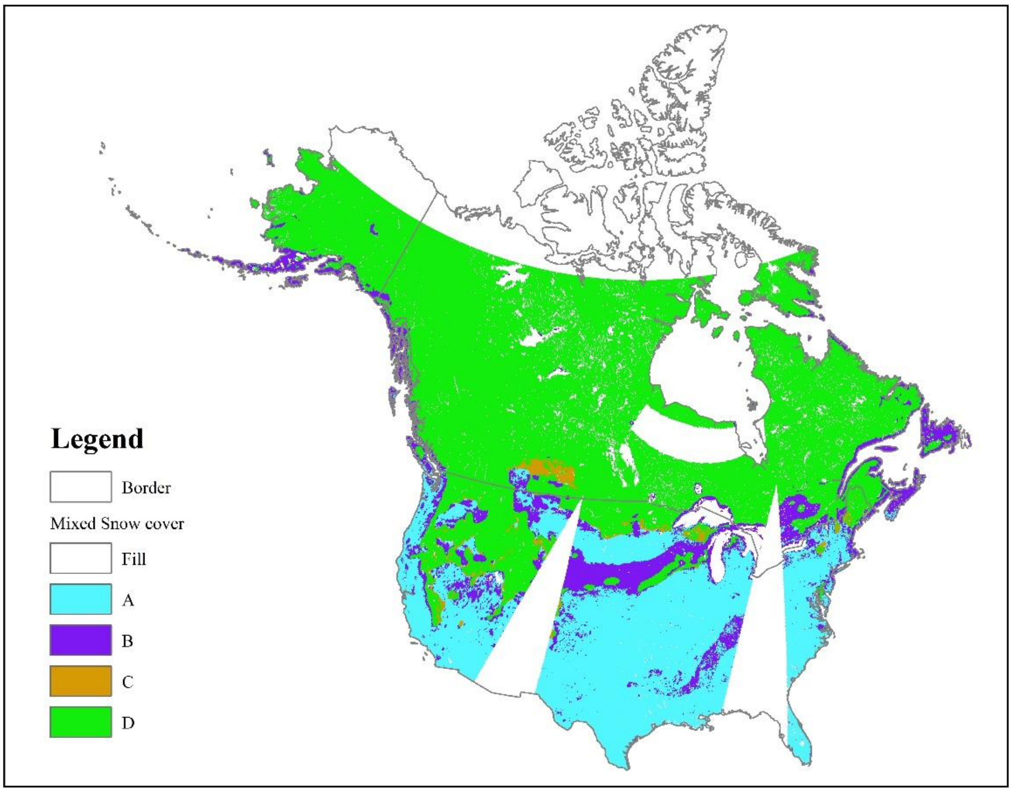


Figure S-9. The mixed snow cover detection map for different condition combinations of Random forest SCA and Grody's algorithm SCA on February 27th, 2017 (2017058) (the meaning of A-B can refer to Table A).

Editorial comments:

Abstract line 23: change '0.31 million' to '310 000'

Response: Thanks. "0.31 million" was changed to "*310 000*" in page 1 line 30.

Abstract line 26: I suggest not referring to the passive microwave dataset used for comparison as 'Grody's snow mapping algorithm' in the abstract.

Response: Thanks. We changed the statement to "*There was significant improvement in the accuracy of snow cover identification using our algorithm; the overall accuracy had increased by 18% (from 0.71 to 0.84), and the omission error had reduced by 71% (from 0.48 to 0.14), when the threshold of fractional snow cover was 0.3*" in abstract.

Page 2 line 2: change 'cycles' to 'cycle'

Response: we changed "cycles" to "*cycle*" in page 2, line 11.

Page 2 line 5: 'vast number of water resources' awkward wording

Response: we rephrased the sentence to "*Snowpack also stores a huge amount of water…*" in page 2, lines 13-14.

Page 3 lines 20-25: when possible, try to use product names instead of the author names. For example, the Kelly (2009) reference refers to the NASA standard AMSR-E snow water equivalent product. The citations should be retained, just the product names changed.

Response: Thanks you for your comment. We inquired each algorithm and tried to find their products. If the corresponding products were not found, author's name was used as the name of the algorithm. We revised the statement to "*Specifically, they involved the application of common passive microwave snow cover mapping algorithms, such as Grody's algorithm (Grody and Basist, 1996), National Aeronautics and Space Administration (NASA) Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) SWE algorithm (Kelly, 2009), Singh's algorithm (Singh and Gan, 2000), Neal's algorithm (Neale et al., 1990), the FY3 algorithm (Li et al., 2007), and the South China algorithm (Pan et al., 2012) …*" in page 4 lines 4-8.

Page 3 line 28 and page 20 line 17: change 'patch' to 'patchy'

Response: the word "patch" was revised to "*patchy*" in page 4, line14 and page 24 line 6.

Page 4 line 7: change 'predict' to 'retrieve'

Response: we changed "predict" to "*retrieve*" in page 4 line 25.

Page 5 line 7: change 'America' to 'United States'

Response: We changed "America" to "*United States*" in page 5 line 26.

Page 8 line 4: not clear what is meant by 'fill'

Response: We changed to "*fill value*" in page 9 line 4.

Page 18 lines 10-14: this text is unclear and seems very anecdotal. I think it can be removed.

Response: Thank you. We removed these unclear statements.

Figure 1: Add units to the legend. Why is there negative elevation?

Response: Thanks. We updated Figure 1. The negative value is located in the lake region which is under the land surface.

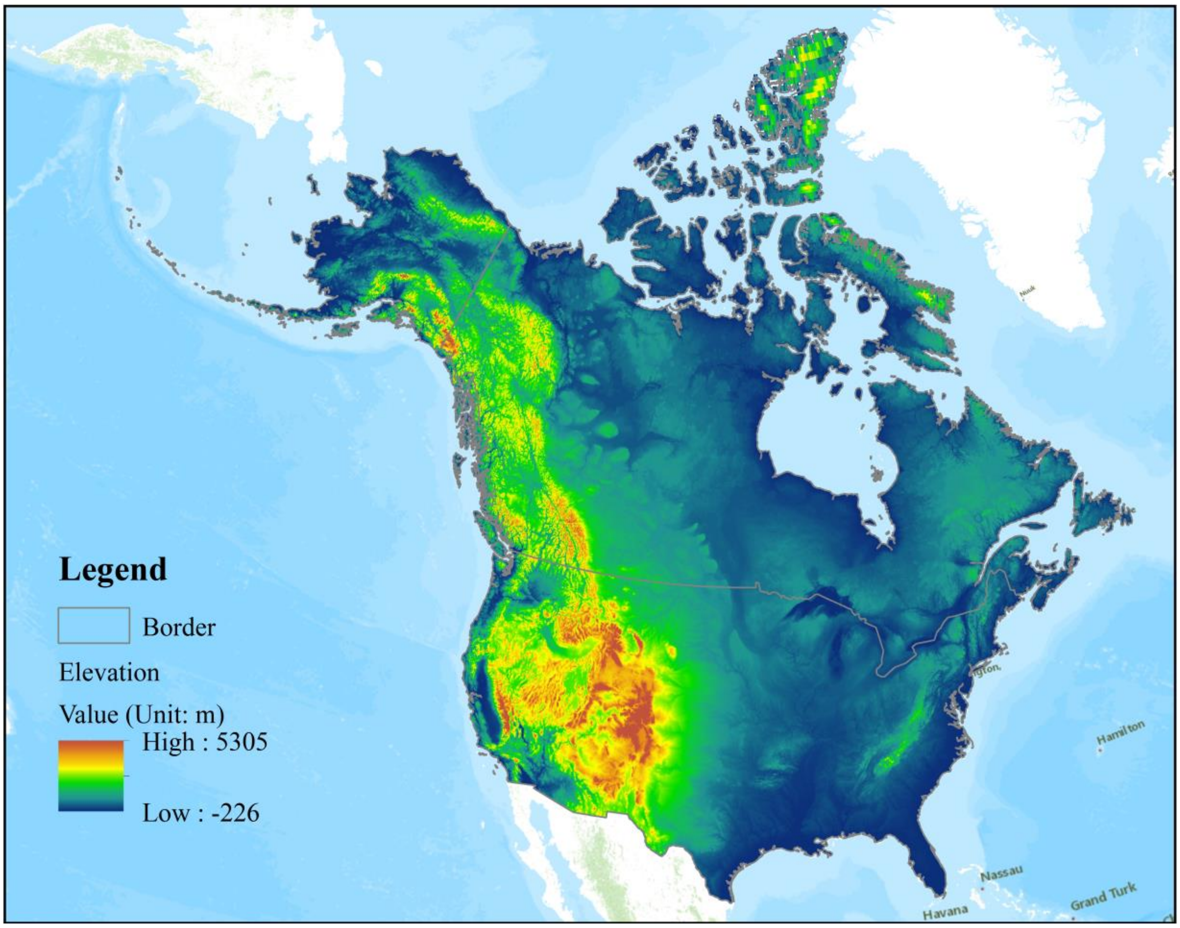


Fig. 1 Topographic map of North America.

Figure 4: caption is not clear

Response: The caption of Fig. 4 changed to "*The performance of random forest models with increasing the size of training sample for shrub type*"

Figure 9: add x-axis label to indicate snow depth

Response: Thanks. We added x-axis label to Fig. 9

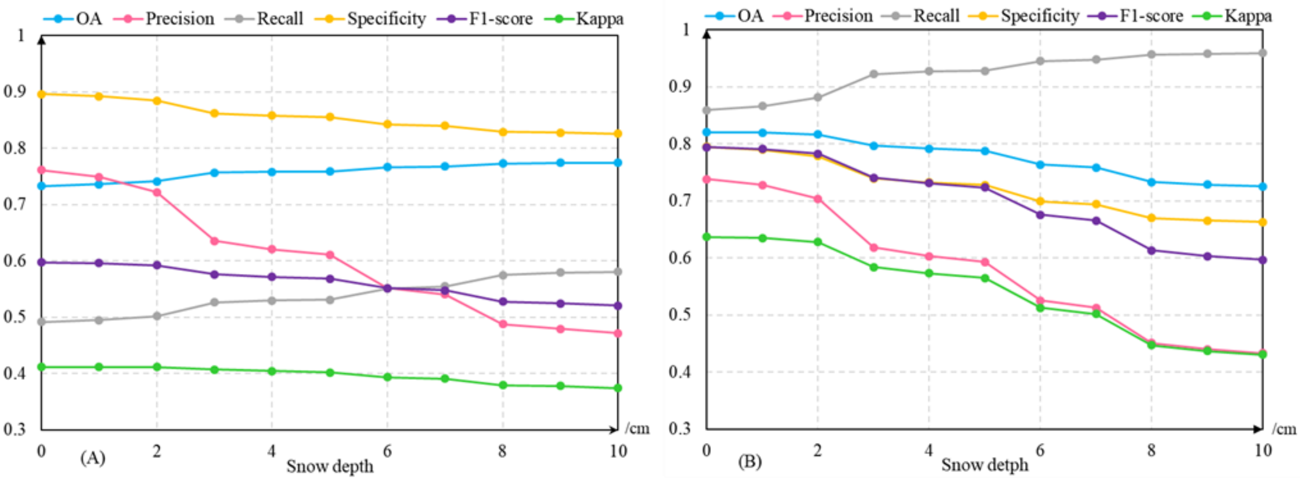
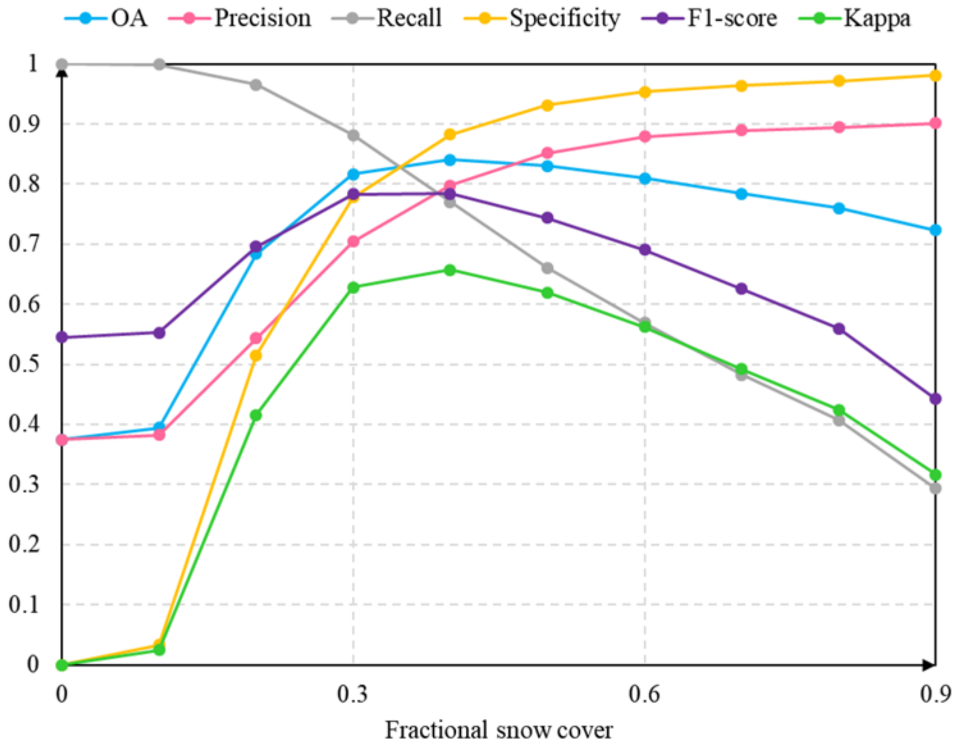


Figure 10: add axis labels

Response: Thanks. We updated the Fig. 10.



*********************Reply to comments from anonymous reviewer 2#*********************

REVIEWER 2#

Overview and General Comments

This manuscript describes a new approach of estimating fractional snow fraction from satellite-based passive microwave (PM) sensors and higher resolution MODIS snow cover estimates. The authors present different regression and machine learning type algorithms, including multi-regression, artificial neural networks (ANN), and a random forest regression technique, for estimating the PM-based snow cover fraction using the MODIS snow cover as a reference input to the algorithms along with accounting for different PM retrieval and ancillary datasets, like vegetation types. The methods are demonstrated and validated against independent in situ measurements across the region of interest (Canada and the US).

Overall, the paper includes comprehensive descriptions of the data and methods used, and detailed background and justification for the work presented. It also is within the scope and appropriate for the journal, The Cryosphere. The supplementary material does help support the overall findings in the paper. However, some of the methods and conclusions may require some revision and may not be conclusive enough as there is a limitation on the years evaluated and the wintertime period focused on. A few major and minor comments are noted in this review that hopefully help to strengthen the paper and the organization of the methods and results presented. There are a few sections that were difficult to follow and some of the English grammar and syntax was unclear.

Response: Thanks for your suggestions and positive comments. According to you suggestion and comments, we have carefully revised the manuscript and provided point-by-point response following each comment.

One downside to this study is that the authors only focused on seven years of available passive microwave and optically based snow cover observations and then just the peak snow months of January and February. Though it seems to make sense to focus only on when the snowpack is at the peak months and more spatially continuous, however, it is also worthwhile to capture the temporal and spatial heterogeneity in the accumulation and ablation seasons and more fully test the algorithms described and applied in this study. Otherwise, the algorithms are only somewhat effective for peak wintertime in US and Canada and not applicable for studies, like prescribing observational snow cover conditions in climate projection or snow-land-atmosphere climate interaction studies, which are pointed out as one primary reason to perform this present study.

Response: Thanks you very much. We do agree with your comment on extending the study period to the snow cover accumulation and ablation stages/seasons for the fractional snow cover retrieval models. For this issue, we have discussed in Section 5.1 and provided the detailed discussions

"*...In this study's datasets, a greater number of records were located near the extreme values of the fractional snow cover (0 and 1). Thus, it is reasonable to use stratified random sampling (Dobreva and Klein, 2011), however, not the proportional distribution of target values suggested by previous studies (Nguyen et al., 2018; Millard and Richardson, 2015). Even in this cases, the overestimation and underestimation often occur near 0.0 and 1.0 in the training datasets (Fig. 7 A – D) and evaluation datasets (Fig. 7 a – d), respectively. This is mainly because a smaller number of samples with intermediate values from the reference dataset used in the training model may not properly capture the characteristics of the surface condition with intermediate fractional snow covers. Therefore, it is necessary for future studies to increase the amount of samples by extending the study period to the snow accumulation and snow ablation stages (Xiao et al., 2018), where there is much more shallow snow and "patchy" snow cover. Another option is using data from multi-source sensors to generate reference snow cover data (e.g., Sentinel -1 Synthetic Aperture Radar data). By doing this, the proportion of fractional snow cover values in* *the training sample may be distributed as evenly as possible (Colditz, 2015; Jin et al., 2014; Lyons et al., 2018)*" from page 23 line 28 to page 24 line 9.

In fact, the same idea on "It is also worthwhile to capture the temporal and spatial heterogeneity in the accumulation and ablation seasons and more fully test the algorithms described and applied in this study" has been one major task of our ongoing work. Specifically, it is to establish different fractional snow cover retrieval models on different snow cover stages (snow cover accumulation stage, snow cover stabilization stage and snow cover ablation stage), and to analyze the spatiotemporal variation characteristics of the estimated fractional snow cover.

Also, in relation to the timeframe of the training and validation data years, only having one year to perform the validation seems quite limiting, as a given year can be hard to note overall performance given snow cover can vary greatly from year to year (e.g., snow drought conditions). This is somewhat reflected in Figure 7 (right column panels), which show how highly variable and not as predictable in the validation year (2017). Please explain why a longer period of record is not used, e.g., 2002-2019 (Terra+Aqua MODIS combined) and the passive microwave combined product by Brodzik et al. (2018), to perform the training and validation period. Perhaps, use Water Years (WY) 2002-2013 for training and WY 2014-2018 for validation?

Using only one year for testing and a second year for validation is very limiting for this study, and it is highly recommended for additional years to be included. Also, for the four different approaches of estimating the fractional snow cover from passive microwave should have longer evaluations performed in this context as the summary of the results would be inconclusive for one year of validation.

Response: Thanks for your comments and suggestions. In the absence of available published materials on fractional snow cover estimation from passive microwave data, the first emphasis of this study should explore the possibility of estimating fractional snow cover estimation from passive microwave brightness temperature data. Therefore, we conducted a series of experiments with 8 years data (January and February only) to demonstrate the feasibility of estimating fractional snow cover from passive microwave data, as described in Section 6 (page 26 lines 4-11)
"*Numerous studies have investigated the relationship between common snowpack physical properties (e.g., snow depth and water equivalent) and passive microwave brightness temperature at different frequencies and polarizations (Chang et al., 1987; Dietz et al., 2011; Kim et al., 2019; Xiao et al., 2018). Unlike many previous studies, this study innovatively used passive microwave data to directly estimate fractional snow cover. The results showed that it is possible to directly obtain an estimated fractional snow cover with high accuracy from high-spatial-resolution passive microwave data (6.25 km) under all weather conditions. Further detailed study on the use of high spatial resolution passive microwave data for fractional snow cover estimation presents itself as an interesting research direction for the development of the studies on fractional snow cover estimation*". Overall, this study has basically achieved its preset goals.

Moreover, at the beginning of our experiment, we also tested and validated the performance of fractional snow cover retrieval model with the remaining data of 2011-2016 (besides the dataset used for training samples); its conclusion is consist with that of the current experiment (using a single year of data), and the accuracy indexes (MAE and RMSE) are not significantly different. To make sure that each experiment is completely independent, we then gave up the above experimental design and adopted that the data of different years were used in different phases. As a basis of estimating fractional snow cover from passive microwave data, there will be a lot of researches to carry out in future studies, such as to apply this algorithm to other study region and other study period, to improve the fractional snow cover retrieval algorithm, to generate a high accuracy product for change characteristics analysis of snow cover area.

Furthermore, one issue that has to be explained in detail is the use of the data in this study. As to Fig. 7, the major reason for the relatively even distribution of the data used in the left column panels with capital letters (A-D) is that these training data are obtained by applying a stratified random sampling strategy in the 6 years total available data (2011-2016; January and February). Distinct from the training datasets, the testing dataset and evaluation dataset cover 2010 (Fig 6; Fig S-4, 5, 6 in the Appendix) and 2017 (Fig. 7), respectively. Through analyzing the distribution of the fractional snow cover datasets in 2010 and 2017, we found that more than 70% of the value are near 0 and 1. This feature also can be noted in all the fractional snow cover data available during 2011-2016.

However, although the stratified random sampling strategy is applied to the 6 years of data to select the training data, these training datasets over four types of land cover are not evenly distributed in each sub-interval between 0 and 1 (Fig 7A-7D). Especially, the number of intermediate fractional snow covers in winter would be much lower than the number of fractional snow covers near the two extreme values (0 and 1). This indicates that if the study period only increases the number of years without extending the study period to the other two seasons (autumn and spring), the study period cannot provide a satisfactory data set for training samples (and testing and evaluation samples), of which the distribution of each sub-interval should be very even. That is because there are many shallow snow and "patchy" snow cover in autumn and spring season and it can provide more diverse values of fractional snow cover. Thus, the best and the most effective solution is to extend the study period to the other two seasons and not only to increase several years of data in winter. Actually, we have realized the importance of expanding the study period to the other two seasons and discussed it in Section 5.1 as follows:
"*… In this study's datasets, a greater number of records were located near the extreme values of the fractional snow cover (0 and 1). Thus, it is reasonable to use stratified random sampling (Dobreva and Klein, 2011), however, not the proportional distribution of target values suggested by previous studies (Nguyen et al., 2018; Millard and Richardson, 2015). Even in this cases, the overestimation and underestimation often occur near 0.0 and 1.0 in the training datasets (Fig. 7 A – D) and evaluation datasets (Fig. 7 a – d), respectively. This is mainly because a smaller number of samples with intermediate values from the reference dataset used in the training model may not properly capture the characteristics of the surface condition with intermediate fractional snow covers. Therefore, it is necessary for future studies to increase the amount of samples by extending the study period to the snow accumulation and snow ablation stages (Xiao et al., 2018), where there is much more shallow snow and "patchy" snow cover. Another option is using data from multi-source sensors to generate reference snow cover data (e.g., Sentinel -1 Synthetic Aperture Radar data). By doing this, the proportion of fractional snow cover values in the training sample may be distributed as evenly as possible (Colditz, 2015; Jin et al., 2014; Lyons et al., 2018)*" from page 23 line 28 to page 24 line 9.

Some of the methods sections are hard to follow, though the authors provide many details there and in the Supplemental material. For example, Section 3.3.1 of "Selecting input variables" was at times hard to follow and why each scenario was selected. Improving the organization of the sections to flow better in terms of their logic and why different experiments were performed would be helpful for the overall background and discussions of this study.

The English grammar and syntax used require additional review and editing by editorial services to help correct these issues before resubmitting. A few suggested corrections are offered below in the technical corrections section.

Response: Thanks for your positive comment to improve our manuscript. The revised manuscript has been proof read by a native English speaker. Additionally, we clarified the background of the variables selection and setting for each scenarios, and revised the statement about why different experiments were performed in Section 3.1 (from page 10 lines 19 to page 11 line 14).
"*A decision tree was established using all variables shown in Scenario -1 (Table 1), and was utilized to compare with five scenarios in terms of prediction performance and efficiency. Note that these 19 input variables were determined by using the Correlation Attribute Evaluation method in the Waikato Environment for Knowledge Analysis 3.8.3 (WEKA) data mining software. This method evaluates the worth of the attribute by measuring the correlation between the attribute and the target (Frank et al., 2004; Eibe Frank, 2016). The brightness temperature and its linear combination can also directly be used to detect snow cover based on Xu et al. (2016) study; thereby, Scenario -2 only contained brightness temperature and its linear combination without consideration to the effects of location and topographic factors. Wiesmann and Mätzler (1999) reported that V and H polarizations were dominated by scattering and snow stratigraphy, respectively. Thus, Kim et al. (2019) only assimilated V polarization with an ensemble snowpack model to estimate snow depth. Therefore, in Scenario -3, we attempted to evaluate the performance of the established retrieval model by only using the brightness temperature in 19, 37 and 91 GHz*

(V polarization) based on Wiesmann and Mätzler (1999) and Kim et al. (2019). In Scenario -4, we used similar input variables to those used for snow depth estimation in Xiao et al. (2018), and examined whether these same parameters can or cannot estimate the fractional snow cover. In Scenario -5, unlike the variables used in Scenario -4, we attempted to use the basic input variables coupled with the brightness temperature linear combination for fractional snow cover retrieval.

There are other variable selection strategies based on the importance rank when using random forest method. For example, Mutanga et al. (2012) implemented a backward feature elimination method to progressively eliminate less important variables, whilst Nguyen et al. (2018) summarized the grade of the variable and selected the top eight important variables as the input variables in the training model. Similarly, this study assessed the importance of input variables on four land cover types using the same size of the training sample (15 000) (Xiao et al., 2018). We then counted the number of times of each variable that was ranked in the top nine important variables (summarized in Table S2, Appendix), which were then used as the input variables for Scenario -6 (listed in Table 1). By assessing the performance of models established by these six scenarios, an optimal combination of input variables for the fractional snow cover retrieval model may be selected (see Section 4.1.1). All input variables were normalized to [0, 1]."

Specific Comments

Abstract: The authors introduce "Grody's snow cover mapping algorithm" towards the end of the abstract without any other background. Perhaps they could provide one introductory phrase on this algorithm within the abstract to give more context.

Response: Thanks for your comment. We revised the original sentence to "*There was significant improvement in the accuracy of snow cover identification using our algorithm; the overall accuracy had increased by 18% (from 0.71 to 0.84), and the omission error had reduced by 71% (from 0.48 to 0.14), when the threshold of fractional snow cover was 0.3*" in Abstract

Page 2, Lines 9-10: The authors mention that snow cover data from station measurements are "time-consuming, [and] cumbersome,". What do the authors mean by these adjectives? Please clarify here. Any dataset, including satellite, requires time and careful derivation of the final product. However, in situ snow cover data are spatially discontinuous and require more time to maintain.

Response: Thank you. According to your suggestion, we clarified the sentence to "*Snow cover data is typically obtained from meteorological stations or in-situ manual measurements, which is spatially discontinuous and labor intensive*" in page 2 lines 17-18.

Page 6, lines 11-12: Would like to point out here that North America includes Mexico as well. The authors should specify that their study domain spans the continental U.S. and Canada only.

Response: Thank you. We specified the study domain definition and revised the original sentence to "*Fig. 1 shows the elevation pattern for North America, limited to Canada and United States in this study.*" in page 7 lines 3-4.

Page 7, lines 10-11: Authors state here that "to the best of our knowledge, there are no researchers have developed fractional snow cover : : : using passive microwave data." Please take a look at the following references and cite appropriately:

Foster, J.L., D. K. Hall, J. B. Eylander, G. A. Riggs, S. V. Nghiem, M. Tedesco, E. Kim, P.M. Montesano, R. E. J. Kelly, K. A. Casey and B. Choudhury (2011): A blended global snow product using visible, passive microwave and scatterometer satellite data, International Journal of Remote Sensing, 32:5, 1371-1395, DOI: 10.1080/01431160903548013

Response: Thanks for your comment. The study carried out in Foster et al. (2011) was to yield a blended snow cover product with a 25-km resolution by combining MODIS snow cover product, AMSR-E snow water equivalent product, and QSCAT data, which have several parameters including snow cover extent, snow water equivalent, fractional snow cover, onset of snowmelt and areas of snow cover that are actively melting. We find that there is essential difference between Foster's study and our work in fractional snow cover estimation. In contrast, current study devoted to retrieving fractional snow cover from passive microwave brightness temperature at 6.25-km resolution, which means that the estimated results are based on passive microwave data. We changed it to "*Second, to the best of our knowledge, there are few attempts to directly develop fractional snow cover from passive microwave data*" in page 8 lines5-6

Page 8, lines 24-27: It would be helpful here to provide a lead in sentence to introduce your first two equations.

Response: Thanks your valuable suggestion. We revised and clarified the description about these two equations as follows (in page 9 line 16-26):

"*1) Combining snow cover images from two sensors on a given day: the first simple filter was applied under the assumption that snowmelt and snowfall did not occur within the two sensor observations. Whether a pixel in Terra (S_t^{Aqua}) or Aqua (S_t^{Terra}) snow cover image in a given day (t) was observed as snow cover or snow-free, the pixel in the output image (MCD10A1) was assigned the same ground status (shown in Eq. 1). The results showed about 3% of cloud cover was removed compared to MOD10A1 (Gafurov and Bárdossy, 2009).*

2) Short-term temporal filter: if the status of a pixel in the input image (MCD10A1) in a given day (t) was cloud and both the preceding (t - 1) and succeeding (t + 1) days were snow-covered (or snow-free), the pixel in the output image (MCTD10A1) in the given day (t) was assigned as snow-covered (or snow-free) (summarized by Eq. 2). Compared to the first filter, this short-term temporal filter may markedly reduce the number of days (10% ~ 40%) for cloud coverage and increase the overall accuracy of snow cover detection (Gafurov and Bárdossy, 2009; Tran et al., 2019)..." in page 8 lines 22-30.

Page 8, last line: "Calculation areas should be in a larger feet : : :" What is meant here by "feet"? It does not seem to make sense to use this word here, but perhaps "footprint area" makes more sense? Please correct.

Response: Thanks for your suggestion. We corrected the sentence to
"*Calculated areas should be a larger footprint area than the pixel resolution to avoid MODIS geolocation uncertainties...*" in page 10 lines 1-2.

Page 11, lines 2-3: MODIS Collection 5 products are considered older and not "current", as they have been replaced by Collection 6. Recommend removing "current" here.

Response: Thank you. We removed "current" and revised the sentence to "*This type of regression method has been applied in generating the standard MODIS fractional snow cover product Collection 5...*" in page 12 lines 12-13.

Subsection 3.4.1: The authors discuss both the linear and multi-linear regression methods here, which makes the discussion confusing to follow. They then have the reader refer to the Supplementary material for more information. It is recommended that the authors better describe in this subsection how the "linear regression" is applied. Was it based on the equations in Salomonson and Appel (2004) or new linear equations and parameters derived for the four different vegetation categories? Please try to better organize and explain this linear method in this subsection.

Response: Thanks for your comment and suggestion. We revised the statement about linear regression method as follows:
"*For optical remote sensing studies, there is a classical and general linear regression method used to estimate the sub-pixel*

snow cover area in medium- to high-spatial-resolution image. This only involve the relationship between NDSI and fractional snow cover derived from high-resolution snow cover maps (Salomonson and Appel, 2004; Salomonson and Appel, 2006). This type of regression method has been applied in generating the standard MODIS fractional snow cover product Collection 5. Similarly, the multiple linear regression method was used as a reference method in this study to estimate fractional snow cover based on passive microwave data. The inputs were the same as the other three methods in this study…" in page 12 lines 8-15.

Page 14, lines 10-11: Please provide citations and references where possible for the metrics, especially Cohen's kappa coefficient and the F1 score.

Response: Thanks. We add the citation for the metrics and correspondingly the sentence was revised to "*Six accuracy assessment indices were used for the analysis of snow cover detection capability (Liu et al., 2018; Gascoin et al., 2019); overall accuracy (OA), precision (that is, a positive prediction value), recall, specificity (that is, the true negative rate), F1 score (Zhong et al., 2019), and Cohen's kappa coefficient (Foody, 2020).*" in page 16 lines 4-7.

Page 15, Lines 11-12: Authors indicate here that their "Scenario-6" variable sensitivity case "generated the worse performance, with the low R, the great MAE and RMSE". When looking at Table 4 results, Scenario-6 appears to perform rather well overall. Perhaps it would help if the authors specify here that of the Scenarios of 1, 4-5 and 6, Scenario-6 performs the "worst". It is also recommended to change the last part of that sentence to: " this scenario's setting had the third worst performance with lower R values and higher MAE and RSME values."

Response: Thank you very much for your suggestion. We revised the statement to "*Moreover, when compared to Scenarios-1, 4, 5, the setting in Scenario-6, where input variables were selected by importance, had the third poorest performance, with a low R, and a high MAE and RMSE*" in page 17 lines 13-16.

Page 15, line 31 to top of Page 16: Make "Figure" plural and change the last part of this sentence to something like: "show that this finding was not coincidental." This sentence is a bit hard to understand in what is meant by "not coincidental". Please elaborate or better explain the meaning here.

Response: Thanks. We clarified the statement and revised to "*Interestingly, the 0.3% training sample size had the shortest modeling time of the three sample size (Fig. 4); Figs. S-1, 2, 3 also exhibit similar findings on modeling time.*" in page 18 lines 5-7.

Page 16, line 29: Please clarify here what is meant by "neglected to assess the rationality of estimated value : : :". Are you referring to the out-of-bounds events that occur in the other methods, other than the random forest approach and that that "rational" was not well checked?

Response: Thanks for your suggestion and comment. We revised the sentence to "*Previous studies have generally neglected the analysis and evaluation of whether the estimated value is out-of-range*" in page 19 lines 8-9.

Page 21, line 1: Authors state that only a few studies validate the accuracy of MODIS snow cover products in forested areas. Actually, there are several in addition, including:

Arsenault, K.R., P.R. Houser and G. J.M. De Lannoy, 2014: Evaluation of the MODIS snow cover fraction product, Hydro. Proc., 30, 3, pps. 980-998. https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.9636

Kostadinov, T. S., and T. R. Lookingbill, 2015: Snow cover variability in a forest ecotone of the Oregon Cascades via MODIS

Terra products, Rem. Sens. Env., 164, pps. 155-169. https://www.sciencedirect.com/science/article/pii/S0034425715001303

Response: Thank you very much for your suggestion. We added the suggested literatures and revised the statement to "*Several studies have validated and evaluated the accuracy of MODIS snow cover products, particularly in forested areas (Parajka et al., 2012; Zhang et al., 2019; Arsenault et al., 2014; Kostadinov and Lookingbill, 2015)*" in page 24 lines 20-22.

Page 22, lines 14-16: The first statement here about the "strong limitations in the understanding of physical mechanism" is a bit hard to understand. Are the authors referring to the underlying physics and characteristics that relate the fractional snow to the signature of the passive microwave bright temperature responses? Perhaps, it might be better to frame these concluding statements more in that way vs. "mechanisms".

Response: Thanks for your constructive suggestion. We clarified and revised the sentence to "*However, it also contains significant limitations in understanding the physics that relates fractional snow cover to the signature of passive microwave brightness temperature (Cohen et al., 2015; Che et al., 2016). Future studies need to use physical snowpack models and radiation transfer theory to explore the physical mechanistic relationships between microwave brightness temperature and fractional snow cover (Pan et al., 2014)*" in page 26 lines 16-20.

Table 1: In the row of references, does the Xiao et al. (2018) paper cover both Scenario-4 and -5 columns in the table? If so, it might be helpful to specify this in the body of the paper.

Response: Thanks. The Xiao et al. (2018) study only cover the variables used in Scenario-4, not in Scenario-5. Thus, we did not provide the related reference for Scenario-5.

Figure 8: In panel A, more binary MODIS snow cover present (e.g., large green pixeled areas in Canada), but that does not seem to get translated over to panel B for the fractional MODIS snow cover (mostly filled in with no fractional values). Please explain why most of the derived MODIS snow cover fraction is removed here, especially over Canada? Also, for the MODIS snow fractional product, there is no fractional snow representation between 0.3 and 0.8, the other two categories shown in panel B. What is happening here in that regard – no fractional snow within 0.3 and 0.8 at any noticeable gridcells? Please provide an explanation in the text as well.

Response: Thanks for your suggestions to improve our manuscript.

1) The MODIS binary snow cover image was translated to the reference MODIS fractional snow cover by applying the pixel filtering rule at a 15*15 pixels window that do not allow an cloudy pixel when calculating the fractional snow cover. Therefore, many pixels (6.25-km) were masked as "fill value" (white in Figure 8).

2) Each category (0-0.3; 0.3-0.5; 0.5-0.8; 0.8-1) was exhibited in MODIS fractional snow cover image (Fig. 8B), just the difference in the amount of pixels. The intermediate values of fractional snow cover usually can be found at the edge of the two extreme values (0 and 1).

Based on your suggestion, we revised the description about Fig. 8 as follows:

"*Apart from the scatter plots and statistical analysis, Fig. 8 shows the distribution pattern of snow cover from a spatial perspective, including MODIS composite binary snow cover (Fig. 8A), MODIS fractional snow cover (Fig. 8B), and the estimated fractional snow cover by the proposed algorithm (Fig. 8C). When the most rigorous pixel filtering rule at the 15*15 pixel window was applied (see Section 3.2), the large number of cloud covered pixels (yellow) in Fig. 8A resulted in most areas of the MODIS fractional snow cover image (Fig. 8B) being represented by a "fill value". Additionally, the number of intermediate values for MODIS fractional snow cover in winter would be much lower than the number of values near the two extreme values (0 and 1). In contrast, the estimated fractional snow cover from passive microwave brightness temperature data can provide almost complete coverage and continuous spatial information on snow cover (Fig. 8C; Fig. S-7 in the Appendix). Fig. 8 shows the comparison between our estimated fractional snow cover and the reference MODIS fractional snow cover, and more importantly, provides another perspective for snow cover identification in Section 4.4. Thus, Fig. 8B* *and 8C used 0.3 as the threshold of fractional snow cover to define snow-covered and snow-free area, and this was adopted through the experiments in Section 4.4. This means that the pixel was identified as snow cover when fractional snow cover value was less than 0.3. From Fig. 8A – C, the spatial pattern of estimated fractional snow cover from the proposed method seems to accurately capture the distribution of snow cover from MODIS under clear-sky conditions, such as the snow-free area in most areas of North America, and snow-covered areas in northern Canada. Fig. 8D presents a specific example comparing these two fractional snow cover datasets and MODIS composite binary snow cover products in central Canada on February 27th, 2017. Based on this example, we find that our estimated fractional snow cover was capable of obtaining snow cover distribution when most of the area was covered by cloud, which was not the case for MODIS. This example also show that the extent of snowline observed in the MODIS binary snow cover image (500 m), which was the boundary between snow-covered and snow-free, was well described and exhibited by the estimated fractional snow cover (6.25 km).*" in page 20 lines 3-23..

Finally for Figure 8, it would be helpful to assign a different color and category for the non-snow pixels (at fractional value of 0.) in panels B and C to better discriminate the non-snow areas from the snow-based areas. Currently, snow-free pixels are lumped in with the low snow fraction category of 0 to 0.3.

Response: Thanks for your comment. In this study, we clarified why 0.3 is adopted as the threshold of fractional snow cover. "*Fig. 8 shows the comparison between our estimated fractional snow cover and the reference MODIS fractional snow cover, and more importantly, provides another perspective for snow cover identification in Section 4.4. Thus, Fig. 8B and 8C used 0.3 as the threshold of fractional snow cover to define snow-covered and snow-free area, and this was adopted through the experiments in Section 4.4*" in page 20 lines 11-14.

In addition, a comparison example of the reference MODIS fractional snow cover with our estimated fractional snow cover in continuous value (Figures S-7 vs Fig 8.) in the supplement have been provided to show the continuous change characteristics of fractional snow cover in the Norther America on February 27th, 2017 (2017058).

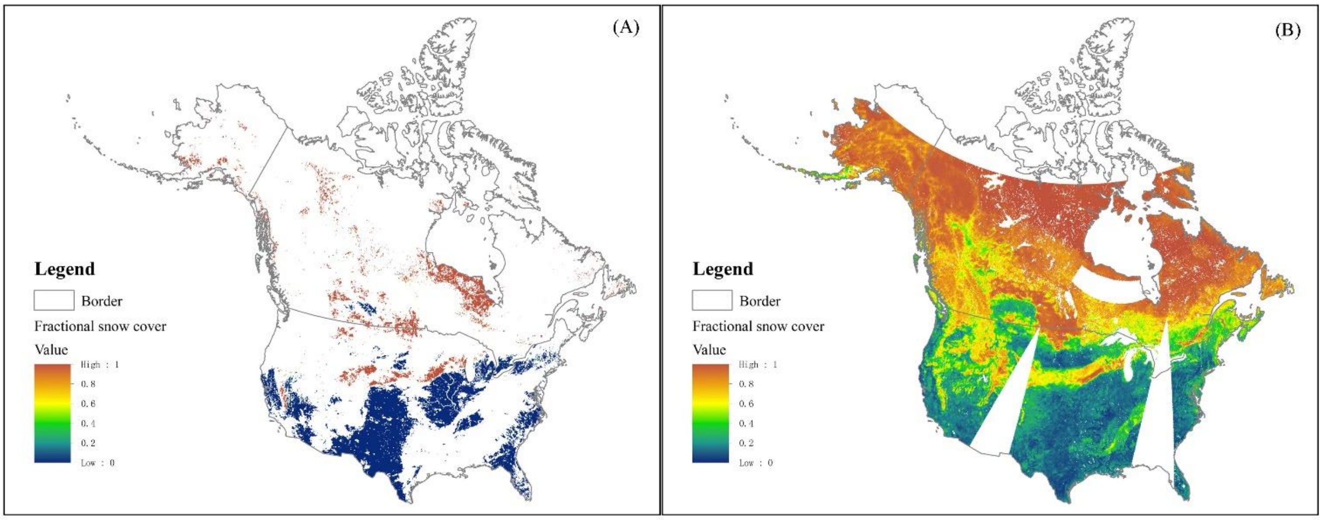


Figure S-7. Comparison of the reference MODIS fractional snow cover (A) with our estimated fractional snow cover (B) in continuous value (6.25-km) on February 27th, 2017 (2017058)

Fig. 11: This is a nice figure that summarize and present these results well.

Response: Thanks for your positive comments.

Technical corrections

Page 2, line 25: Please specify what "FY" stands for in "FY series sensors".

Response: We revised the sentence to "*...Fengyun (FY) series sensors....*" in page 3 line 7.

Page 3, line 25: Awkward phrasing here: "To unite resolution, : : :" Perhaps try: " To be at a common resolution, : : :"

Response: Thanks for your suggestion. We revised the sentence to "*To achieve a common resolution, bilinear interpolation was used to aggregate the 3.125 km spatial resolution data to 6.25 km*" in page 5 lines 15-16.

Page 5, line 7: Recommend here to separate the two phrases here with either a semi-colon (between "collected" and "all available") or place the conjunction "and" after the comma.

Response: Thanks. We revised the sentence to "*... Canada and United States were collected, and all available records from these sites were included in this study.*" in page 5 lines 26.

Page 6, line 6: Please specify what "ETOPO1" stands for.

Response: Thanks. The elevation dataset's name is called ETOPO1 refer to the website (https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.ngdc.mgg.dem:316), and do not have more full name for these characters.

Page 6, line 11: Add citation and reference for "ArcGIS 10.5" software.

Response: We cited the related reference and revised the sentence to "*The slope and aspect data were obtained from ETOPO1 data by ArcGIS 10.5 (Buckley, 2019)*" in page 7 lines 2-3.

Page 6, line 17: Replace "heterogeneous" with the noun, "heterogeneity".

Response: Thanks. We replace "heterogeneous" with "*heterogeneity*" in page 7 line 9.

Page 7, line 7: MODIS misspelled here as "MODSI".

Response: Thanks. We changed "MODSI" to "*MODIS*" in page 8 line2.

Page 7, line 31: Remove "with" before "accurate".

Response: Thank you. We removed "with" before "*less accurate*" in page 8 line 30.

Page 9, line 21: Either replace the semicolon with a period, or make the word, "Thereby", lower-case.

Response: Thanks. We changed "Thereby" to "*thereby*" in page 10 line 25.

Page 9, line 27: Change the "not" in this line to "cannot". Also on that same line, the word use of "Correspondingly" here does not seem to make sense.

Response: Thanks. We revised the sentence to "... *can or cannot estimate the fractional snow cover. In Secenatio-5* ...." in page 11 line 1.

Page 10, line 5: Make "variable" plural here in "an optimal combination of input variables".

Response: Thanks. We changed "variable" to "*variables*" in page 11 line 13.

Page 13, line 6: "researches" should be changed to "researchers".

Response: Thanks you. We changed "researches" to "*researchers*" in page 14 line 23.

Page 18, line 5: Remove "be" before "misclassified" and change "into" to "as". Also, please remove the phrase, "As we all know", and change the start of the second sentence there to: "Permafrost is known to be widely distributed in the northern part of…"

Response: Thank you. We removed "be" before misclassified and changed "into" to "as", accordingly, the sentence changed to "*... these scatters were easily misclassified as snow cover in less snow cover conditions*..." in page 21 lines 7-9. And we have removed the description "Permafrost is known to be widely distributed in the northern part of…" based on the revised needs

Page 20, line 4: Change "researches" to "studies".

Response: We changed "researches" to "*studies*" in page 23 line 20.

Page 21, lines 23-24: Change "were" to "was" in relation to "The accuracy of the proposed algorithm was further : : :".

Response: Thank you. The sentence was changed to "*The results of the evaluation using the reference fractional snow cover data in 2017 showed that* ...." in page 25 lines 19-20.

Table 2 caption: "unite" should be "unit", and "clod desert" should be "cold desert".

Response: Thank you very much. We changed "unite" to "*unit*" and modified "clod desert" to "*cold desert*" in Table 2

Figure 7: The use of the capitalized and lower-case plot labels is fine but not conventional. Would it make more sense to simply use, "A, B" then "C, D", etc., for the paired columns?

Response: Thanks for your comment. Horizontally, the capital letters indicate the results in the training stage, while the lowercase letters represent the results in evaluation stage; from the vertical perspective, the results in two stages in each row are the same type of land cover which was represented by the same level of letters that are easily distinguished. The caption of Fig. 7 was modified to "... *Left column with capital letters is the results in the training stage (A-D); right column with lowercase letters is the results in the evaluation stage (a-d).*"