Response to Referee #2's comments

Authors responses are shown in bold font.

Authors: We would like to thank both referees for their helpful and constructive comments and thorough reviews. We have improved the flow of the paper and added more information about the VIIRS snow maps and quantitative comparisons between the new MODIS and VIIRS cloud-gap filled snow maps. We have emphasized the novelty of the work as requested by both referees. We have also re-stated our objectives as requested by both referees, and changed the title to better reflect the content of the paper.

Referee #2

Referee: The manuscript provides an overview of MODIS snow products development, including the newest snow gap-filled (CGF) maps, efforts related to their validation and clouds removal, describes the methodology of daily snow-gap-filled maps preparation, presents several examples from the western and eastern USA and concludes that the Aqua MODIS snow gap-filled maps should not be used as the basis of Environmental Science Data Record (ESDR).

Referee: I recommend major revision and have the following comments:
1. Objectives, novelty -Manuscript authors are among the leading scientists in MODIS snow products development, evaluation and utilization. However, the objectives of this manuscript are not clear to me. The manuscript feels more like a collection of ideas and examples than a systematic exploration/summary of the MODIS CGF snow cover products advantages and uncertainties (manuscript title).

Authors: We agree and have restated the objectives and clarified the novelty of the work in the revised manuscript. Below you will find the new statement of the objectives (that now appears in the Abstract and in the Introduction) and a discussion of novelty of the work. Since Referee #1 made the same comment, we are using a response that is very similar to the one we used to respond to Referee #1 regarding these points.

Authors: We have improved both our 1) statement of the objectives of the work, and 2) our identification of its scientific novelty as follows:

1) **The following was added to the Abstract and to the Introduction:**

"The objective of this paper is to introduce the new MODIS and VIIRS standard CGF daily SCE products and to provide preliminary evaluation of uncertainties in the gap-filling methodology so the products can be used as the basis for a moderate-resolution Earth Science Data Record (ESDR) of SCE."

2) **We now describe clearly the novelty of this work as compared to earlier work (e.g., Hall et al., 2010):**

We introduce the CGF products derived from the MODIS and S-NPP VIIRS. These products have not been introduced previously in the peer-reviewed literature. In the present paper, we describe new cloud-gap filled (CGF) MODIS and VIIRS algorithms and products (targeting hydrologists, climate scientists and modelers) that will become available to the scientific community in the fall of 2019. These products include quality-assurance (QA) information that can be manipulated by a user to develop a unique product that can be tuned to a user's particular study area. This new and unique capability has not been possible using earlier MODIS snow products. Uncertainties of the products are addressed in terms of their use in the hydrological community.

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Also new is the finding that the Terra MODIS CGF snow product is superior to the Aqua MODIS CGF snow product, and the reason for this is discussed. Following on from this, we make the case that an Earth Science Data Record (ESDR) can be developed to begin in 2000 using Terra MODIS data, and continue through the present and beyond using VIIRS and JPSS data. New comparisons between the Terra MODIS and S-NPP VIIRS CGF snow products have been added: the comparisons are performed for a time series consisting of three months in the winter/spring of 2012. We have not previously published Terra MODIS vs. S-NPP CGF snow-map comparisons in the peer-reviewed literature. Furthermore, we are not aware of anyone else doing such comparisons.

Additionally, new comparisons between the Terra MODIS and S-NPP VIIRS CGF snow products have been added: the comparisons are performed for a time series consisting of three months in the winter/spring of 2012. We have not previously published Terra MODIS vs. S-NPP CGF snow-map comparisons in the peer-reviewed literature. Furthermore, we are not aware of anyone else doing such comparisons. A new Figure 9 has been added as shown below:

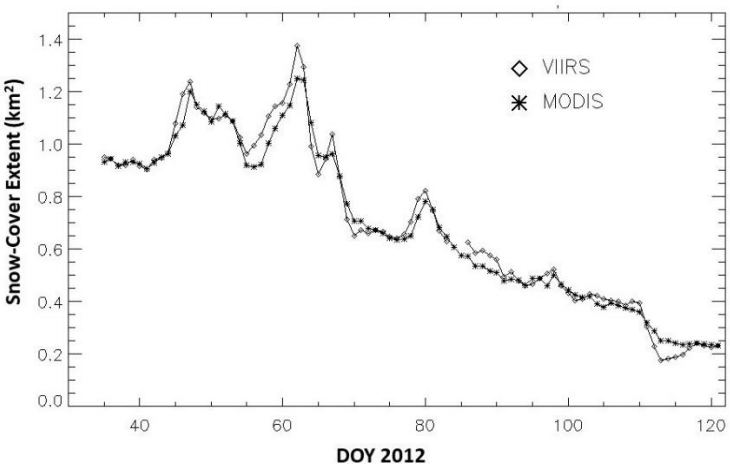

Figure 9: Time series showing differences in snow-cover extent (SCE) derived from Terra MODIS and S-NPP VIIRS cloud-gap filled (CGF) snow maps for a nearly 3-month period extending from 4 February – 30 April 2012. Though the time series began on 1 February, snow-cover extent from 1 – 3 February snow cover is not shown because, in this example, the gap-filling algorithm was started on 1 February had not filled most of the gaps from clouds until 4 February.

Figure 2, below, has been revised to demonstrate differences/similarities between the MODIS and VIIRS snow-cover products.

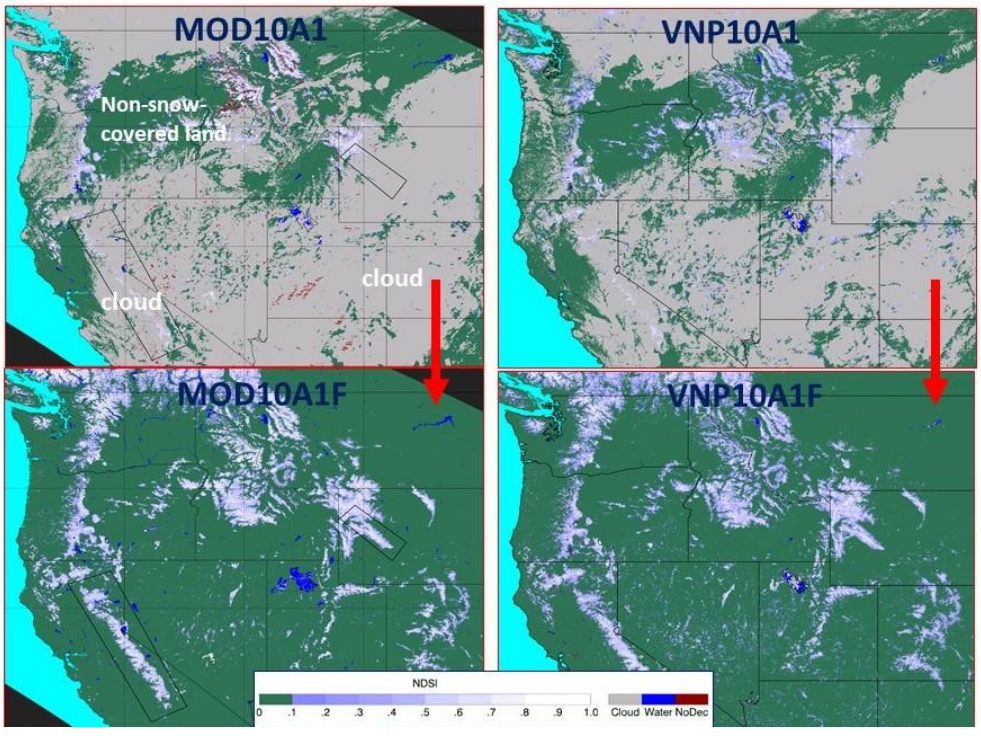

Figure 2: Examples of MODIS and VIIRS standard and cloud-gap filled (CGF) snow maps on 14 April 2012 for a study area in the western United States/southwestern Canada (see **Fig. 1**). **Top left**: MODIS MOD10A1 C6.1 snow map showing extensive

cloud cover on 14 April 2012. **Top right**: VIIRS VNP10A1 C1 snow map also showing extensive cloud cover on 14 April 2012. **Bottom left**: MOD10A1F C6.1 CGF map corresponding to the MOD10A1 snow map in the top row, also for 14 April 2012. **Bottom right**: VNP10A1F CGF map corresponding to the VNP10A1 snow map in the top row, also for 14 April 2012. In all of the snow maps, non-snow-covered land is green. Regions of interest containing the Sierra Nevada Mountains in California and Nevada (109,575 km^2), and the Wind River Range in Wyoming (22,171 km^2), are outlined in red on the MODIS snow maps. The following MODIS tiles were used to develop the MODIS composites: h08v04, h09v04, h10v04, h08v05, h09v05, h10v05. Each VIIRS swath that included coverage of this study area was composited to create a daily map, then the daily maps were used to create the VNP10A1F snow map for 14 April 2012.

The following findings are new:

- **Differences in cloud masking between MODIS and VIIRS affect the snow map results of both the standard product and the new CGF snow maps;**
- **Differences in cloud masking between the Terra MODIS and the Aqua MODIS affect the snow map results of both the standard product and the new CGF snow maps;**
- **The Terra MODIS snow maps are superior to the Aqua MODIS snow maps in C6 and C6.1;**
- **Development of an Earth Science Data Record that uses Terra MODIS and S-NPP VIIRS CGF snow maps is introduced.**

In earlier work (e.g., Hall et al., 2010), we described a methodology that would provide daily, cloud-free snow maps globally using a gap-filling method with the daily climate modeling grid (CMG) composited products at 5-km resolution. Subsequent work (e.g., Hall et al. 2015) demonstrated the utility of this method applied to the daily tiled products for a study area in the Wind River Range of Wyoming. This basic gap-filling method, described in Hall et al. (2010), has been adopted as the basic algorithm of the standard product, M*D10A1F, using the daily gridded products of individual observations at 500 m resolution and including *many* enhancements to the basic algorithm that was described in Hall et al. (2010).

In short, this paper is very timely because MODIS C6.1 and VIIRS C2 products are due to become available during the fall of 2019 and there is a great deal of information in this paper, especially in its revised form, that will be useful to users of the products.

Referee: At the end of the introduction it is mentioned "...In this paper, we describe the MODIS Terra and AQUA CGF algorithm, data products and uncertainties...." and "we also discuss the development of a moderate-resolution ESDR of SCE and using MODIS and VIIRS standard snow-cover maps". The latter is in my opinion not true, because the ESDR is just mentioned in the manuscript (its development is not discussed) and the same holds for VIIRS (it is not discussed, just mentioned that it exists and should extend the data through the 2030s). The CGF algorithm was already described in Hall et al. (2010). While the manuscript is informative, better indication of its novelty would be helpful.

Authors: We agree that we should have explicitly stated the novelty of this new work and we have now done that. Also please see discussion of novelty above.

We also now have images, snow maps and a graph showing VIIRS data as discussed in response to Referee #1's comments (new or revised Figures 2, 3 & 9).

In regard to the ESDR, we show an example of the Terra MODIS – VIIRS data continuity in the revised manuscript which is an important step towards development of an ESDR. We agree that an ESDR is not developed and have changed wording to suggest that the CGF products could be used as the basis of an ESDR. In this work we discuss some of the issues relevant to development of an ESDR such as continuity between products from different sensors and discuss differences such as that the VIIRS maps show slightly more snow than do the Terra MODIS maps because there are generally fewer clouds mapped by the VIIRS cloud mask.

Referee: 2. Study area and period - I would welcome an explanation of study area and period selection. Why were particular study area and regions of interest selected? Fig. 1 presents western United states and part of southern Canada as the study area, but in the abstract and elsewhere, the northeastern United States are mentioned as well.

Authors: In the revised manuscript in Section 4, we have included the following: "To enable some early evaluation of the products we produced CGF Terra and Aqua MODIS time series of areas in the western U.S. and in the northeastern U.S. and southeastern Canada. Here we provide evaluation and some validation for study areas in the western U.S. and a study area in the northeastern U.S./southeastern Canada. We also look at regions of interest (ROI) within our primary western U.S./southwestern Canada study area shown in Fig. 1. We selected the year 2012 for the time series because both MODIS and VIIRS data were available in that year. Comprehensive global validation studies will not be possible to perform until the data sets are released through NSIDC and the entire MODIS and VIIRS records have been processed. This will take several months following initial release of the data; the full data records should be available in 2020."

Referee: Do the selected areas allow evaluation of uncertainties related to some issues mentioned in the text, e.g. rapid snow disappearance during the snowmelt or melting of the newly fallen snow during the cloudy periods?

Authors: This large area in the western U.S. was selected because we are familiar with the area. The time series includes rapid snow disappearance during snowmelt and melting of newly-fallen snow. However we did not focus on those issues during our analysis.

Referee: Figs 2,4,5,6 present data from spring 2012 (why namely that year?) while Fig. 7 shows the comparison of MODIS and Sentinel images for December 2016 (because the Sentinel data did not yet exist in 2012?).

Authors: There was nothing special about the year 2012, or even 2016. These figures are examples. A random selection of dates during the snow season was selected. Sentinel data is available starting from about July 2015, so a 2016 winter image was used.

Referee: 3. Methodology and results - Because the objectives are not stated clearly, the methodology is in my opinion confusing as well. Lines 235-247 describe how are daily CGF maps created (methodology), but then the result on how quickly was a nearly cloudfree map obtained (in other areas and on other dates it can probably be achieved later or even earlier, a more systematic exploration would be interesting) is given.

Authors: The objectives are now stated clearly. Please see author comments above. We've included in this revision, a new graph (revised Fig. 3) that compares the MODIS and VIIRS CGF snow maps in terms of how long each time series takes to remove clouds. The new Figure 3 is shown below.

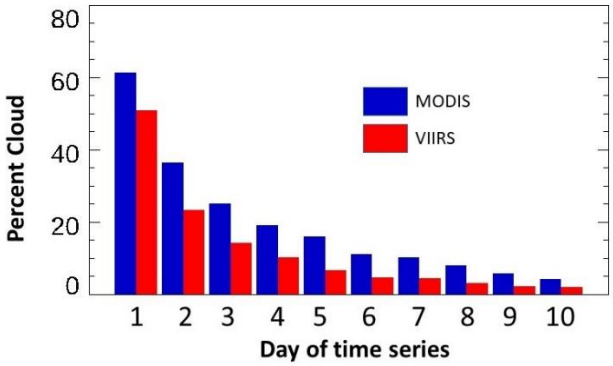

Figure 3: Percent cloud cover in a Terra MODIS (MOD10A1F) and an S-NPP VIIRS (VNP10A1F) time series of snow-cover maps for the western United States study area (see location in Fig. 1). Note that the percentage of cloud cover decreases dramatically in the first few days following the 4 February 2012 initiation of the CGF time series, denoted here as Day 1.

Referee: This result is followed by continuation of methodology (uncertainty based on the cloud persistence count and how the CPC is recorded). I recommend division of Methodology and Results.

Authors: We agree and have separated the Methodology and Results sections and it now reads more clearly in the revised paper.

Referee: I agree that validation of the satellite data is only possible by comparison with measurements. The manuscript presents validation against the NOAA snow depth data provided by the dense network of meteorological stations. Such networks are not available in other countries. Can we trust that the CGF maps are valid also in those parts of the world where the network density does not allow detailed validation?

Authors: Evaluation of the CGF maps in other countries will have to wait until the products are released and available to download through NSIDC (in the fall of 2019). In

areas of the world where the network of meteorological stations is not dense enough to allow validation, there are other methods to evaluate the uncertainties. These methods, discussed in the paper, include comparison with other snow maps, comparison with higher-resolution satellite data (such as with Landsat or Sentinel data), and comparison with surface reflectance maps such as from MODIS and VIIRS.

The MODIS SCE products have been validated and evaluated in many regions of the world; there are numerous peer reviewed articles published on this topic. However, the VIIRS SCE daily tiled product has not yet been released; only the swath product is available, so evaluation research has not yet appeared in the literature because users tend to be more comfortable using a tiled product than a swath product. In our comparisons between MODIS and VIIRS CGF products we have found very good agreement between MODIS and VIIRS SCE and CGF products thus there is the expectation that the VIIRS products will have similar accuracy to that reported for MODIS. We acknowledge, however, that the comparisons are necessarily limited because product production has not yet begun.

Referee: I would welcome a comment on this. Is it possible to conclude that Aqua snow maps tend to have have more clouds than the Terra snow maps globally? Can it not be only the case in some areas while in others it would be vice versa?

Authors: It is not possible to conclude that there is more cloud cover in Aqua snow maps than in the Terra maps based on our research. Cloud cover amount and location can change a little or a lot between Terra and Aqua overpasses. For example, over the Rocky Mountains in the western USA a Terra overpass at about 10:30 am local time may have a clear view of the peaks but daily convective cloud formation over the peaks may occur, and when Aqua passes over about 1:30 pm local time there could then be clouds over the peaks. Daily cloud dynamics, as your questions suggests, can vary greatly depending on location. What we are concerned about is consistent accuracy in the detection of clouds in the Terra and Aqua cloud products that are used as inputs to the swath level snow cover algorithm. Accuracy of cloud detection has an effect on the extent of snow or cloud mapped in the snow cover products.

Referee: 4. Discussion and conclusions - I appreciate the note that CGF snow products have all uncertainties of the original products as well as additional uncertainties that are related to the age of the snow measurement (l. 445-447).

Authors: We have clarified that statement a bit by indicating that there are additional uncertainties that are related to cloud-gap filling.

Referee: Minor comment - text in lines 52-56 could be omitted.

Authors: We want to put the medium-resolution Earth Science Data Record (ESDR) into context by referring to the coarse-resolution product and therefore we've decided to retain some of that paragraph. We have shortened the paragraph and focused it more into the context of the medium-resolution ESDR.