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Ann. Geophys. Discuss., author comment AC1
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Reply on RC1

Nirasindhu Desinayak et al.

Author comment on "Snow cover variability and trend over the Hindu Kush Himalayan region using MODIS and SRTM data" by Nirasindhu Desinayak et al., Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2021-29-AC1, 2021

Authors: Authors are thankful to the reviewer for the thoughtful comments. The suggestions to include some of the relevant and recent work in this area has been incorporated in the revised manuscript. The pointwise response related to data/plots, limitations of snow cover algorithm, and cloud cover issues, shadows are given below. We are hopeful that the Reviewer and Editor would find the updated content responsive to the valuable comments/suggestions by the reviewer.

Review status: this preprint is currently under review for the journal ANGEO.

Snow cover variability and trend over Hindu Kush Himalayan region using MODIS and SRTM data

Nirasindhu Desinayak et al.

Status: open (until 31 Jul 2021)

Comment types: **AC** – author | **RC** – referee | **CC** – community | **EC** – editor | **CEC** – chief editor | : Report abuse

- **RC1**: 'Comment on angeo-2021-29', Anonymous Referee #1, 28 Jun 2021

This work requires more rigor. The authors are requested to modify the manuscript as per the following comments.

Page 1:

- i) Do the authors think the period 2000-2017 can be considered long enough to be termed "long term"? Since the focus is on snow cover the authors are requested to be clear wherever they mention glaciers.

Response: The use of space-based Earth observation data records in this study can be considered as "relatively long-term". The manuscript, including the abstract section, has been modified accordingly. In terms of climate change, we agree that 30-year or even 100-year datasets may be more illuminating, but the fact that even this decadal record

suggests accelerated change is valuable and makes a case for continuity of these observations. Because the remote sensing coverage for global snow cover monitoring is relatively shorter than this, the present study is an effort to provide analysis over this highly sensitive region to make a case for greater attention to the impact of climate on snow cover globally. We envision that this analysis can be repeated in the future to assess the validity of our findings and conclusions with considerably longer-term datasets.

- ii) Why did the authors choose to use coarser resolution MODIS in presence of higher resolution Landsat data?

Response: We used this unique and only available dataset over such a large and remote region (Himalayan and Tibet region) of the world to understand the regional and altitude-wise changes in the snow cover. This is the best and available dataset in the grid format, as mentioned in the manuscript and known as the Climate Modeling Grid (CMG) dataset, that captures changes over the study area. With this regional perspective, one may now choose to focus on the areas showing significant changes (hotspots/anomalies) to delineate and better understand these changes in greater detail using higher resolution snow cover data, including mass balance studies. We have now suggested such a need/prospect for future research to the revised manuscript.

iii) The authors are requested to consider rewriting the Abstract for better readability.

Response: We agree with the reviewer, and we have made some changes to improve the readability of the abstract.

- iv) The authors present some important figures with large variation (like 74-7900 years). This is quite a large deviation to be considered good for a scientific prediction. Please define clearly what are the "other parameters" which are assumed to be unchanged. How is it justified to consider a "no-change" situation?

Response: The extrapolation and projections of relatively long-term trend from the satellite data show that the changes occurring over the Himalayas are varying to a large extent (spatially and altitude-wise). The linear trend is dependent on historical data, the contributing factors, processes, and feedback mechanisms, assuming they stay the same moving into the future. In reality, the current and past contributing factors may or may not be the same in future, thus our projection/extrapolation should be viewed with caution; however, they do provide some insight and what to watch for going forward. In the relevant sections of the manuscript, the details of linear trend and its extrapolation (in such no-change situations originating from linear trend based on historical data and conditions only) are clarified. The authors agree with the reviewer that projecting future changes in snow cover is considerably more difficult and complex than using a linear-trend analysis but it is a starting point for illustrating a greater need for observations and understanding of this highly sensitive region of the world with so many people depending on this source of freshwater resources. As suggested by the reviewer, we have modified the sentence for better readability.

Page 2:

- i) The authors are requested to cite the following article where they mention the "anthropogenic emissions of soot..."

-Gautam et al., "Satellite observations of desert dustâ□□induced Himalayan snow darkening", Geophysical Research Letters, 2013.

Response: We are thankful to the reviewer for this suggestion. The suggested article has been included in the manuscript.

- ii) In the section discussing the “Regional warming and decrease in snow cover”, the authors are requested to separate the discussion between the changing state of snow cover and glaciers over the HImalayan region. Furthermore, it is difficult to summarize the information presented in this section and the idea still appears quite vague.

Response: We agree with the reviewer that the region's warming and related studies are important. We have attempted to summarise this issue with some recent papers in this sub-section (1.1 Regional warming and decrease in snow cover). We've added two more references (Duan and Wu 2006; You et al. 2017) that provide greater detail about the warming and cloud cover issues and their impact. The updated summary, as well as the pertinent material contained in the cited references, will provide an overview of the research conducted on the region's warming. Because the current study focuses on the fluctuation of snow cover, the authors expect that the summary supplied with more references will suffice given the manuscript's emphasis on snow cover.

Page 3:

- i) The authors are requested to separate the increasing temperature and precipitation since it is counterintuitive to visualize that both together cause decrease in persistent SCA.

Response: Based on published research in this area, some observed variations in the snow cover and associated changes over the Tibetan plateau between 2003 and 2010 have been cited. As suggested by the reviewer, we have modified the sentence for better readability in the revised manuscript.

- ii) The authors are requested to cite the following article, which discusses the seasonal variation in snow cover and its altitudinal trend, in the section discussing the “Seasonal changes in snow cover”.

-Muhuri et al., “Snow cover mapping using polarization fraction variation with temporal RADARSAT-2 C-band full-polarimetric SAR data over the Indian Himalayas”, IEEE JSTARS, 2018.

Response: We are thankful to the reviewer for this recent article based on SAR data. The suggested article has been included in the suggested section of the manuscript.

Page 4:

- i) Line 105-111: The authors are requested to cite a recent work discussing the performance of the snow cover mapping algorithms in mountainous areas affected by forests and topographic shading.

-Muhuri et al., “Performance Assessment of Optical Satellite Based Operational Snow Cover Monitoring Algorithms in Forested Landscapes”, IEEE JSTARS, 2021.

Response: We are thankful to the reviewer for suggesting this latest article. The suggested article has been included in the manuscript.

Page 5:

- i) The authors are requested to introduce terrain shadow masks in their analyses.

Terrain shadow changes as a function of the time of the year due to solar elevation angle variation. These are the regions of ambiguity. Shadow masks will provide a more robust touch to this work.

Response: The data, its quality, robustness, and broad limits are summarised in the sub-section (1.5 Reported analysis of MODIS snow cover data). As mentioned in the manuscript, the cloud cover and topographic shading in the mountainous regions are known to be major factors affecting the accuracy of snow cover products. The inclusion of such dynamic shadow masks may further improve the snow cover algorithms and the corresponding datasets, especially in higher resolution datasets (<500 m). This may be considered as beyond the scope of the present analysis (based on MODIS data). In this study, the fill values (such as for cloud) have been taken care of during data processing.

Page 8:

- i) Fig 5 a): The authors are requested to plot the elevation range wise snow cover extent histogram as plotted in the following article,

Response: We agree with the reviewer that information regarding "elevation range wise snow cover extent" would be useful to readers. Please note that the desired data regarding "elevation range wise snow cover extent" is already provided in Table 1 and 2. Table 1 also provides a month-by-month breakdown of this data, and Table 2 shows the variability of such data by zone.

-Muhuri et al., "Snow cover mapping using polarization fraction variation with temporal RADARSAT-2 C-band full-polarimetric SAR data over the Indian Himalayas", IEEE JSTARS, 2018.

Response: We are thankful to the reviewer for suggesting this article. It has been included in the revised manuscript.

- ii) In the trend analysis how did the authors take into account the errors in the snow detection algorithm? How did the authors deal with partially or completely cloud covered conditions? How did the authors handle the snow cover in forested areas? There is little discussion regarding these issues in the manuscript.

Response: We agree with the reviewer that these are all important contributing factors that affect remotely sensed observations of such a large and remote area. The process of converting top of atmosphere radiance measurements to Earth surface-based geophysical parameters, such as snow cover, takes into account as much as possible the impact of these contributing factors. Quite often, field campaigns are conducted to better characterize and account for such contributing factors, and the remaining effects are included/reported as errors associated with such products. The MODIS 5km snow cover dataset is a widely used/referenced product that captures very well elevation-wise spatial variability and temporal trend in the snow cover as a function of time (i.e., several months to years). The data, its quality, robustness, and broad limits are summarised in the sub-section (1.5 Reported analysis of MODIS snow cover data). As mentioned in the manuscript, the cloud cover, forest cover, and topographic shading in the mountainous regions are known to be major factors affecting the accuracy of snow cover products. Despite these limitations, the MODIS snow cover data has been demonstrated to be reliable in various studies. The cited references (including the suggested references by the reviewer) discusses the potential contributions of factors identified by the reviewer.

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Authors: Authors are thankful to the reviewer for the comments. We have revised the manuscript as per the suggestions. We are hopeful that the Reviewer and Editor would find the updated content satisfactory.