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Interactive comment on "Regional influence of ocean-climate teleconnections on the timingand duration of MODIS derived snow cover in British Columbia, Canada" *by* Alexandre R. Bevington et al.

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Response to Anonymous Referee #2 (Received and published: 12 July 2019)

Dear Anonymous Referee #2,

Thank you for your kind and thorough review of our manuscript. Your comments were well received and we believe that we have addressed all of the issues that you have pointed out. Below, we highlight, point-by-point, how we have addressed your comments with reference to the section, page number and line numbers of the modifications.

Kind regards,

On behalf of the co-authors,

Alexandre Bevington

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RC2 Comment 1:

“The use of LOWESS interpolation is a novel approach but is not clear what advantages has in contrast from another cloud filled approach (e.g. Li et al, 2017; Khoramian Dariane, 2017)” Response to RC2 Comment 1:

1.1

Indeed, the novel aspects of this study are somewhat hidden due to a heavier focus on the methods and results. We have added a short section titled “7.3 Significance of results” (page 17 line 32) to summarize the novel contributions of this paper. In this section we aim to highlight that we are not the first to use a LOWESS interpolation on MODIS time series data, however, this is the first study to apply it to the MODIS snow cover product. In addition the LOWESS allows us to detect the start and end dates of snow, which is an important contribution to our understanding of snow cover in British Columbia. We suggest that to extend this work further into the past, one could use lower resolution remote sensing data, or in-situ observations, and we include the provided references of (McClung, 2013, Barton 2017). These methods could likely be implemented in other regions, however the dates of the hydrological year will likely be different, and so could the optimal NDSI threshold. Finally, we highlight that the 500 m rasters that we have produced for this study could be of interest to other fields of science, and that our results could likely improve seasonal forecasting of snow.

Here is the new section in its entirety: (7.3 Significance of results):

We are not the first to use LOWESS time series interpolation on MODIS data (Moreno et al., 2014), however, to our knowledge this is the first study to use LOWESS on the MODIS snow cover product (Fig. 1). This allowed us to not only detect SDDUR from the time series, but also SDON and SDOFF. To extend this work further back in time, one could use lower spatial resolution AVHRR data (Allchin and Déry, 2017), or investigate in situ measurements (McClung, 2013; Barton, 2017). Our methods could be used anywhere that the MODIS snow cover product is present, however the definition of the hydrological year, the LOWESS bandwidth, and the NDSI thresholds may need to be optimized. Also, our method detects the longest period of continuous snow cover and will not be as useful for areas of sporadic snow cover.

The 500 m resolution annual SDON, SDOFF and SDDUR rasters produced as intermediate data in this study fill an important gap in our understanding of the regional influence of ocean-climate teleconnections on snow cover in British Columbia. These rasters may be useful for a number of other climatological and environmental processes in the fields of hydrology, ecology, and more. Operationally, our findings can be used to constrain seasonal forecasts of snow in British Columbia. For elevation 10 bins of 500 m by hydrozone, we have LLS and rS values for the relationships between snow cover and seasonal ocean-climate teleconnections.

1.2

In addition, to better explain the LOWESS, and to highlight it's functionality with the MODIS snow cover data, we have expanded on section 4.2 (page 8 lines 8-13) and added a figure of the LOWESS interpolation of NDSI timeseries data (Fig. 1). In this section we have also briefly compared our approach to other studies by (e.g. Li et al, 2017; Khoramian Dariane, 2017).

Here is the new text in its entirety (4.2 Snow season extraction; page 8 lines 8-13):

LOWESS time series interpolation has been shown to be more resistent to gaps and outliers than other similar methods in a study of the MODIS fAPAR (fraction of ab-

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sorbed photosynthetic active radiation) product (Moreno et al., 2014). Other studies have proposed methods of removing clouds from MODIS snow cover data. Spatio-temporal filtering that uses a temporal probability of snow and a DEM (Li et al., 2017), and a spatial k-means interpolation with dynamic time warping (Khoramian and Dariane, 2017) are some of the innovative methods being developed in the rapidly evolving field. Our focus was to find a method that easily detects SDON and SDOFF, and the LOWESS does that quickly, efficiently and accurately.

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RC2 Comment 2:

“The result shows latitudinal changes of magnitude of SDON, SDOFF, and SDDUR. Hammond et al (2018) showed a change of snow persistence in BC associated to elevation change with similar latitude and probably SD could have elevation relationship as well. I suggest running an elevation analysis to looking for elevation dependent factor in your 65 thousand locations. The elevation-latitude SD changing could be a great complement to current results.”

Response to RC2 Comment 2:

2.1

Indeed, elevation (z), latitude (y) and longitude (x) are important controls on snow cover in British Columbia. The focus of our study is on the regional influence of ocean-climate teleconnections on the timing and duration of MODIS derived snow cover in British Columbia, Canada. And as such, the analysis of xyz variables as controls on snow is somewhat outside of the scope of this paper, however, we understand that completely excluding them is a lost opportunity and may cause confusion. As such, we have added a paragraph to section 5.3 (page 12, lines 9-13) and a new figure (Fig 2) where we briefly analyze how the mean snow cover changes for SDON, SDOFF, and SDDUR by XYZ.

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Here is the new text in its entirety (5.3 Snow season results; page 12 lines 9-13):

In addition to summarizing the snow cover by hydrozone, we investigate the influence of latitude, longitude and elevation on the values of SDON, SDOFF and SDDUR (Fig. 2). Overall, they are all important controls on snow cover in British Columbia. Elevation is the most important terrain variable and influences SDON, SDOFF and SDDUR by -30.1, 66.9 and 97.0 days per vertical kilometer, respectively, while the influence of latitude is -3.2, 3.9 and 7.2 days per degree of latitude, respectively, and where longitude has the least important influence of 1.9, -2.4 and -4.3 days per degree of longitude, respectively (Fig. 2).

Additionally, we provide some analysis of the elevation dependency of the ONI/PDO relationship in section 5.5 (page 14, lines 7-15) and in Fig. 3.

Here is the new text in its entirety (5.5 Elevation dependency; page 14 lines 9-13):

Using rS and LLS (Fig. 3) we find that for SDON, all significant results ($p < 0.05$) have positive median rS and LLS (Fig. 3). Indicating that when the ONI and/or PDO are in their warm phase, SDON increases (becomes later) to a similar degree at all elevations. The range of values per elevation bin is smaller for the ONI than the PDO at low elevations. However, the number of significant relationships diminishes above 2000 m asl. Nearly all SDOFF rS and LLS values are negative for all elevations and trend towards zero at 2500 m asl. Below 2500 m asl, values decrease until 500 m asl, and increases again at 0. This suggests that lower elevations are more sensitive to changes in ONI and PDO. SDDUR has a very similar distribution by elevation as SDOFF. These results provide evidence that there are significant interactions between elevation and the ONI and PDO influence on SDOFF and SDDUR regionally over BC, with the largest magnitude and most highly correlated relationships occuring at lower elevations. The influence of elevation on the response of snow cover to the ocean-climate teleconnections is consistent with McClung (2013) who found that the influence of El Niño on avalanche frequency and moisture content was less important at higher elevations.

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RC2 Comment 3:

The MODIS snow cover Collection 6 has been significantly revised and data content has been increased compared with the previous collection. For the MYD10A1 integrated a Quantitative Image Restoration (QIR) algorithm (Gladkova et al., 2012) to restore the Aqua MODIS band 6 to allow use exactly the same product for MYD10A1 and MOD10A1. I suggest including the advantages of the new collection of Aqua MODIS to highlight your novel cloud filled approach.

Response to RC2 Comment 3:

3.1

Thank you for highlighting this important research that allows for the generation of Aqua MODIS band 6 data, on which the NDSI is dependent. We have incorporated a brief explanation of the QIR in section 3.2 (page 6, lines 6-8).

Here is the new text in its entirety (3.2 MODIS snow cover product, page 6, line 6-8)

[. . .] The magnitude of this difference is exploited by the NDSI and normalized between -1 and 1, where pixels with NDSI > 0 have snow present, and those <= 0 are snow free Riggs and Hall (2015). The Aqua MODIS band 6 suffered failures shortly after launch, and as such MYD10A1 uses a reconstructed band 6 by applying a Quantitative Image Restoration (QIR) algorithm (Gladkova et al., 2012). Additionally, a series of data screens are applied to allow quality control of the NDSI results, these include data flags stored in the product as a quality assurance band (Riggs and Hall, 2015). [. . .]

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RC2 Comment 4:

"The NDSI threshold was 30. The previous Collection 5 had a threshold of 40 to define a pixel as snow but this fixed threshold doesn't work well in different vegetation cover condition. I suggest states the vegetation condition (as NDVI) range in your locations in order to define the limits of your NDSI threshold."

Response to RC2 Comment 4:

4.1

This is a very interesting comment. Indeed, it is difficult to use a fixed NDSI threshold with variable land cover over our study area (∼1 million km2). We took an approach of having the data speak for itself. Klein et al. 1998 suggest that a single NDSI threshold (0.4) is not optimal, as it excludes snow covered regions with slightly lower NDSI values but relatively high NDVI values. Although we do not adapt the threshold based on NDVI, we optimized our workflow to ASWS stations and selected the NDSI threshold that minimized our errors; this threshold was NDSI of 30. It is important to note that this threshold is not applied to the raw data, but is dependent on the smoothing factor of the LOWESS, thus direct comparison of NDSI thresholds based on the raw data is difficult. There are many sources of potential error here, of which the most important is perhaps the bias of the ASWS locations, typically being near treeline (section 3.4, page 6 lines 21-24). Given we do not have enough data in all land cover types, we assume that this works best. We expand our description of our threshold selection in section 5.1 and have added Figure 1 (see above) to demonstrate that a threshold of 30 is reasonable.

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References

Allchin, M. I. and Déry, S. J.: A spatio-temporal analysis of trends in Northern Hemisphere snow-dominated area and duration, 1971–2014, Ann. Glaciol., 58, 21–35, https://doi.org/10.1017/aog.2017.47, 2017.

Barton, M.: Twenty-Seven years of manual fresh snowfall density measurements on Whistler Mountain, British Columbia, Atmosphere-Ocean, 55, 144–154, 2017.

Dariane, A. B., Khoramian, A., and Santi, E.: Investigating spatiotemporal snow cover variability via cloud-free MODIS snow cover product in Central Alborz Region, Remote Sens. Environ., 202, 152–165, 2017.

Gladkova, I., Grossberg, M., Bonev, G., Romanov, P., and Shahriar, F.: Increasing the accuracy of MODIS/Aqua snow product using quantitative image restoration technique, IEEE Geoscience and Remote Sensing Letters, 9, 740–743, 2012.

Hammond, J. C., Saavedra, F. A., and Kampf, S. K.: Global snow zone maps and trends in snow persistence 2001-2016, Int. J. Climatol., 38, 4369–4383, https://doi.org/10.1002/joc.5674, 2018.

Khoramian, A. and Dariane, A. B.: Developing a Cloud-Reduced MODIS surface reflectance product for snow cover mapping in mountainous regions, Geosci. J., 7, 29, 2017.

Monitoring snow cover variability (2000–2014) in the Hengduan Mountains based on cloud-removed MODIS products with an adaptive spatio-temporal weighted method, J. Hydrol., 551, 314–327, 2017.

Lindsay, C., Zhu, J., Miller, A. E., Kirchner, P., and Wilson, T. L.: Deriving snow cover metrics for Alaska from MODIS, Remote Sensing, 7, 12 961–12 985, https://doi.org/10.3390/rs71012961, 2015.

McClung, D. M.: The effects of El Niño and La Niña on snow and avalanche patterns in British Columbia, Canada, and central Chile, J. Glaciol., 59, 783–792, 2013.

Moreno, Á., García-Haro, F. J., Martínez, B., and Gilabert, M. A.: Noise reduction and gap filling of fAPAR time series using an adapted local regression filter, Remote Sensing, 6, 8238–8260, 2014.

Pan, C. G., Kirchner, P. B., Kimball, J. S., Kim, Y., and Du, J.: ABoVE: Rain-on-Snow frequency and distribution during cold seasons, Alaska, 2003-2016, 2018.

Saavedra, F. A., Kampf, S. K., Fassnacht, S. R., and Sibold, J. S.: Changes in Andes snow cover from MODIS data, 2000–2016, The Cryosphere, 12, 1027–1046, https://doi.org/10.5194/tc-12-1027-2018, 2018.

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2019-61, 2019.

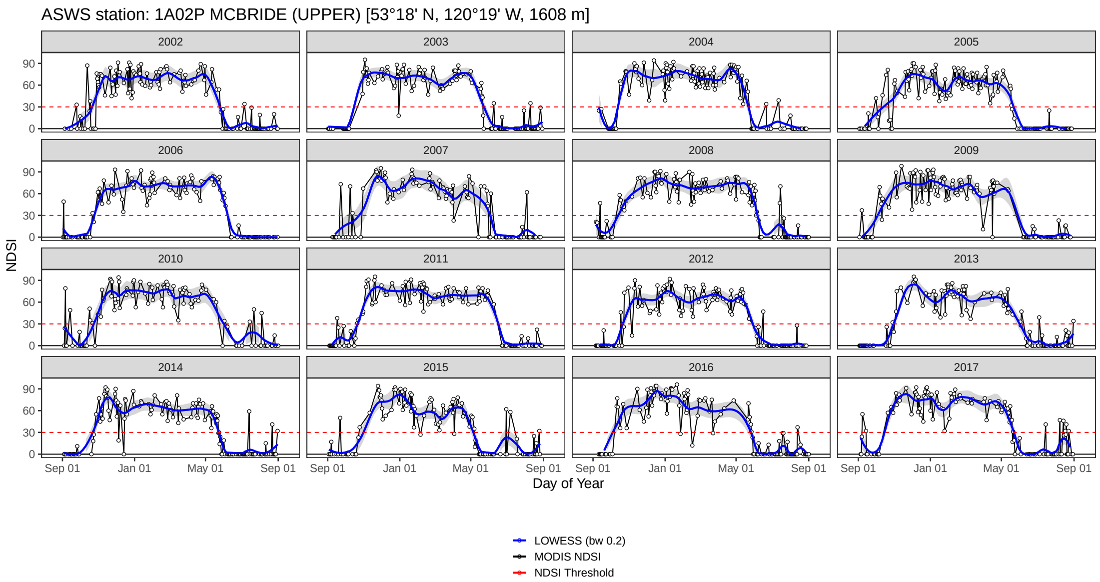

Fig. 1. Example of the LOWESS temporal interpolation at the ASWS station 1A02P for the hydrological years 2002-2017.

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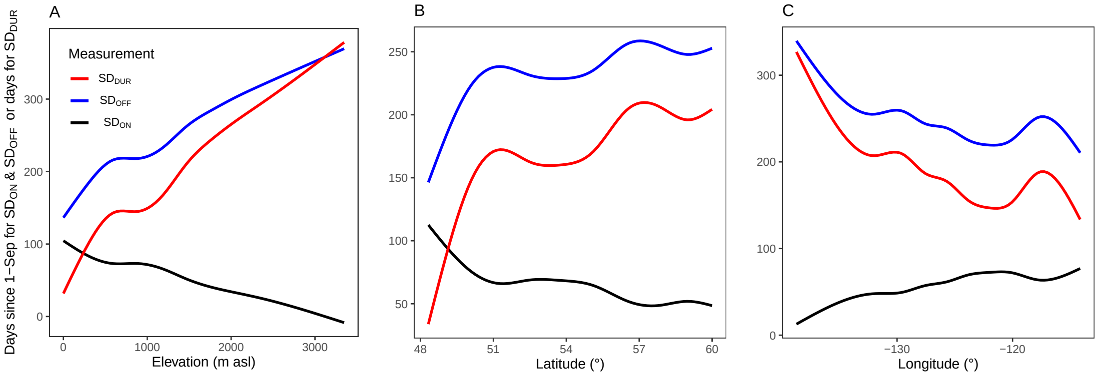

Fig. 2. Three panel plot of the influence of elevation (A), latitude (B) and longitude (C) on the mean MODIS derived value at each random sample point.

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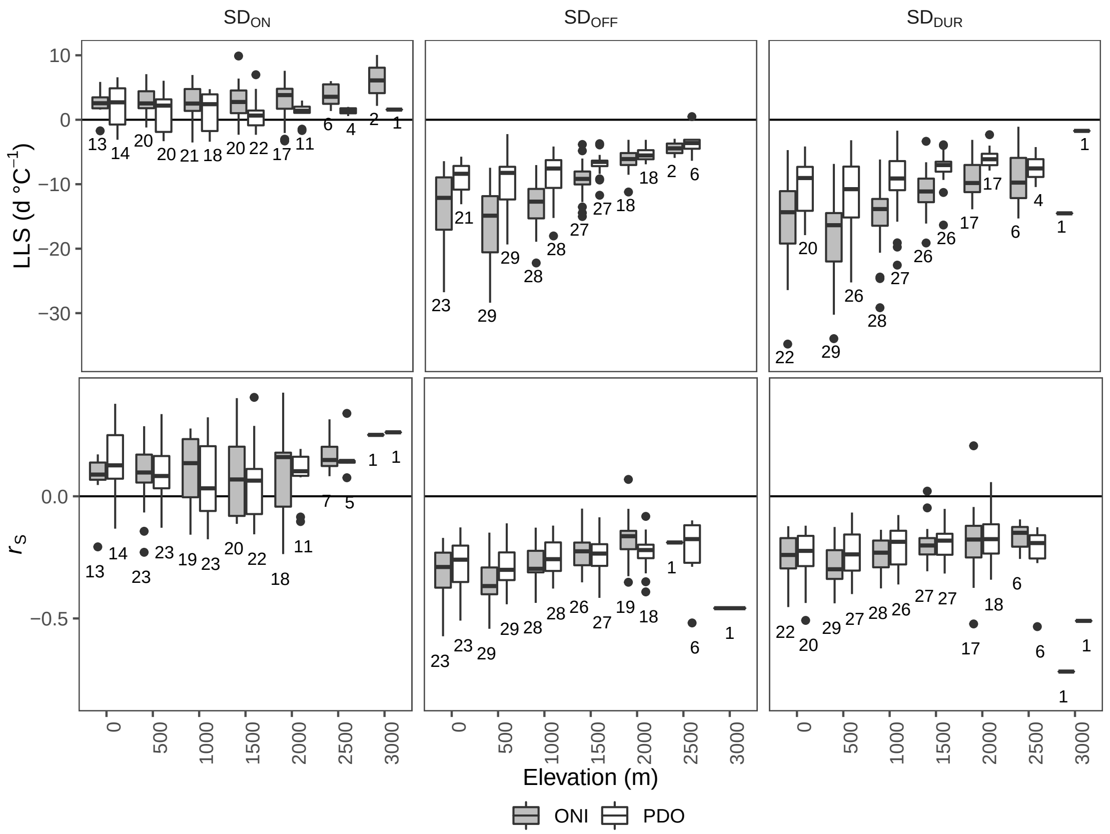

Fig. 3. Linear least squares (LLS; top panel) and Spearman correlation coefficients (rS; bottom panel) per hydrozone for SDON, sdoff and SDDUR with ONI and PDO in 500 m elevation bins.