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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 #1 (Received and published: 8 July 2019)

Dear Anonymous Referee #1,

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 modifica-

tions.

Kind regards,

On behalf of the co-authors,

Alexandre Bevington

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RC1 Comment 1:

"[. . .] my main concern is somewhat unclear/confusing formulation of the significance and novel scientific contribution of the results. As the authors clearly state the results are consistent with many previous studies evaluating the impact of teleconnections on snow characteristics in the study region. I wonder to what extent are the emerged regional patterns significant in terms of novel scientific contribution and how can these result be generalized to other regions or time periods. The novel method used for cloud filtering (by using LOWESS interpolation) is somewhat hidden in terms of formulation of the novelty. I would suggest to extend the discussion section and compare the results with some relevant previous studies (e.g. McClung, 2013, Barton 2017) to indicate more clearly how do the new results fit to previous studies and how the interpolated (cloud reduced) MODIS datasets can improve (are improving) the prediction of the impact of ONI and PDO. Are the mean absolute errors of prediction comparable/small/large compared to results of previous investigations [. . .]"

Response to RC1 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 its 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).

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 absorbed 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.

1.3

As for how our errors compare to other studies, we have highlighted specific error bars from other studies in the introduction (page 2 line 23) and, stated our errors in section 5.1 and Fig 2, then again in 7.1 (page 16 line 14).

Here is the new text in its entirety (1 Introduction; page 2 line 23):

Lindsay et al. (2015) were able to demonstrate using MODIS that nearly half of Alaska and surrounding areas experienced intermittent snow–covered periods with field validated accuracies between -12.2 and +33.9 days.

Here is the new text in its entirety (5.1 Workflow validation):

Comparisons of the M*D10A1 derived SDDUR and SDDUR-ASWS were made over the study period (Fig. 2). The spatially corresponding M*D10A1 pixel was compared for each ASWS station and for each hydrologic year and we calibrated our workflow using 75% of the ASWS data. The parameter values that minimized the combined MAE were a LOWESS bandwidth of 0.2, and a NDSI threshold of 30 for SDON and SDOFF. The error distributions for SDON, SDOFF and SDDUR are summarized in Fig. 2. The bias corrected MAE of 8.7, 8.9 and 13.1 days was observed for SDON, SDOFF and SDDUR, respectively. We acknowledge that other bandwidth and NDSI threshold combinations may improve results in other geographic regions or within sub-regions of BC, and is dependent on the training data used in this study. However, we caution over optimization of 10 parameters due to the inherent difference is scale between the MODIS pixels and the ASWS snow pillows. Using the remaining 25% of the ASWS stations, which we use as a validation dataset, we find bias corrected MAE of 12.7, 12.6 and 16.6 days for SDON, SDOFF and SDDUR, respectively (Fig. 2).

Here is the new text in its entirety (7.1 Snow season extraction):

Calibrating our workflow to a subset of the ASWS resulted in MAE values slightly lower than those reported in other studies (e.g., Lindsay et al., 2015).

1.4

We also add on page 14, lines 15-18 that the influence of elevation on the response of snow duration to the teleconnections in this region is generally consistent with McClung, 2013, who found that the influence of El Nino on Type 2 avalanche frequency and moisture content was less important at higher elevations.

Here is the new text in its entirety (5.5 Elevation dependency; page 14, lines 15-18):

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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RC1 Comment 2:

“Section 4.1. (MODIS processing). Why not to use also MOD10A1 data from 2001 and 2002? Will it have some impact on the results? MODIS mapping accuracy. It will be interesting to see the overall accuracy of the cloud reducing (interpolation) method (based on comparison of MODIS and ASWS). This will allow to put in more context the results of error assessment of the start, end and duration of snow cover.”

Response to RC1 Comment 2:

2.1

This is a very simple, yet very important question. We have highlighted that there is some variability in the start date of the time series of studies that use MODIS time series, and have added a line (Section 3.2 page 5, lines 6-8) that highlights previous studies that use 2000, 2001, 2002, and 2003 as the beginning of their timeseries. We use the 2002 hydrological year because it is the beginning of the period of overlap between MODIS Aqua and Terra, thus we have 2 views of British Columbia per day (Section 3.2 page 5, lines 5-6). This has many advantages of having more data on our time series, and also we have only one error assessment to do. Incorporating the 1999-2001 period would require a separate error assessment as we have about half the satellite images.

Here is the new text in its entirety (3.2 MODIS snow cover product; page 5, lines 5-8):

We only use imagery acquired after 1 Sep 2002 as this is the first hydrological year where both platforms are fully operational. Other studies begin their analysis of the MODIS snow cover product in 2000 (Saavedra et al., 2018), 2001 (Hammond et al., 2018), 2002 (Dariane et al., 2017) and 2003 (Pan et al., 2018).

2.1

As for the comparison of MODIS and ASWS data, we have Figure 2 that highlights the errors between the MODIS methods and the ASWS data for our calibration (75% of the ASWS stations) and the validation data (25% of the ASWS stations). This figure is discussed in section 5.1, where we assess our errors.

See response 3.2 above

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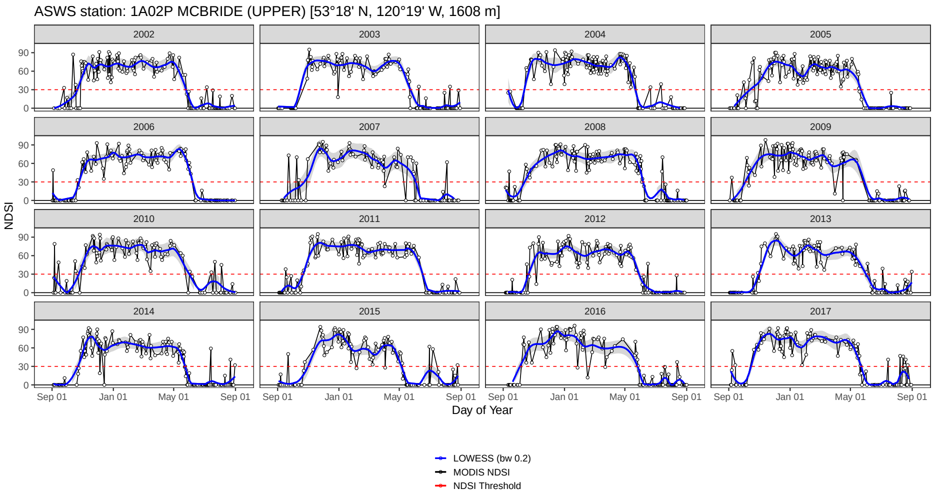

Fig. 1. An example of the LOWESS time series interpolation of MODIS NDSI data at the ASWS station 1A02P McBride (Upper) for the hydrological years 2002-2017.

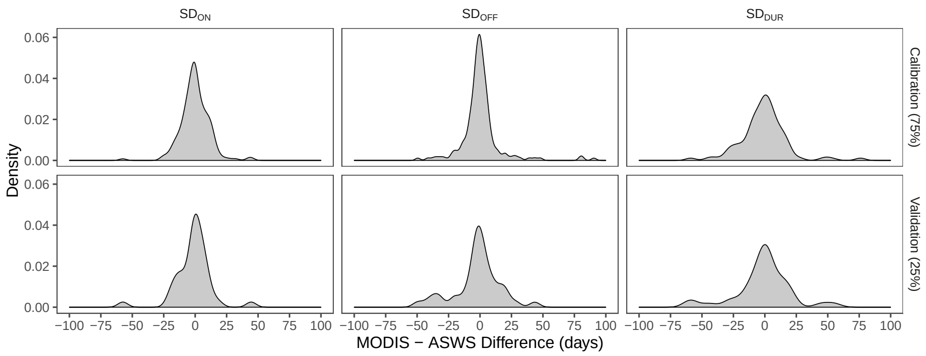

Fig. 2. Distribution of errors calculated from the difference between MODIS and ASWS values for each snow measurement.