Response Reviewer #2

The authors investigate the occurrence of rain on snow events with a single model ensemble. Overall this is a very interesting paper with a good application of the bottomup approach that has recently been endorsed for studying compound events.

Using the compound exceedance of a precipitation and temperature threshold seems relatively naive, given that large increases in temperature in the future will lead to very different snow cover patterns, a key determinant of ROS events. A more appropriate variable than temperature seems to me the difference in surface snow amount between consecutive days, which could be used as a proxy for snowmelt. This is available from the model output. With this it should be possible to build a better compound index that should also be more reliable in future projections.

The main goal of this study was to understand how the frequency of winter weather extreme events (temperature and precipitation), simulated by CRCM5-LE, is modulated by large scale atmospheric circulation. Studying such events are mostly relevant if they have societal implications. A strong shift in high flows occurrence from spring to winter was observed recently in southern Ontario and is expected to continue in the future. Therefore, we decided to define temperature and precipitation thresholds that may explain the generation of high flows in several watersheds in Ontario. Defining an index based also on snow would have been interesting but is not in the scope of this study. A major originality of the study was the calculation of future weather regimes for each member of CanESM2-LE to investigate how the variability of atmospheric circulation will impact the winter weather extremes. The weather regime of a given day impacts directly local temperature and precipitation conditions and investigating also snowmelt adds a level of complexity. Indeed, snowmelt of a given day depends also on the atmospheric conditions occurring weeks before the extreme events (major snowfalls following by cold conditions keeping the snow on the ground). Therefore, weather regimes of these days would also need to be investigated. The need of studying the sequence of weather regimes occurring prior to a high flow event in future studies was discussed at the end of section 4.4.

Moreover, when using snowmelt in the index (With Rain on snow index (ROS) for example) some questions are arising. ROS index does not take into consideration the rain only events while it can have a significant impact on high flows. The occurrence of ROS events is decreasing in the Great Lakes region because of an increase in days without snow on the ground (Jeong and Sushama, 2018)**, but this doesn't lead to a decrease in high flows. Our index takes into consideration rain events even with the absence of snow on the ground, conditions that are expecting to become more frequent in the future. The proposed index is not meant to be better than ROS but is adapted to the study of weather extreme events simulated by CRCM5-LE and how they are impacted by large scale atmospheric circulation. As stated in the discussion, ROS and our index can be studied together to understand the future evolution of different hydrometeorological extreme events (Rain only, rain on snow, snowmelt).**

PRMS hydrological model was previously set up in this region (Champagne et al., 2019) which gave us the opportunity to discuss the shortcoming of this index to explain high flows events.. We used PRMS to investigate how the future evolution of high flows is corelated to the future evolution of weather extreme events. But the objective was not to create an index using snow data from PRMS output. Nevertheless, to strengthen the discussion around snowmelt, we propose to add a figure showing the evolution of snowmelt between 1961-1990 and 2026-2055 corresponding to each weather pattern. This will feed the discussion on the need to study the impact of the sequences of weather regimes on snowmelt and high flows.

I suspect streamflow is very non-gaussian distributed. In particular, it's asymmetric and bounded from below. Taking the mean +3 standard deviations as an indicator for extremes is thus very unintuitive and not really appropriate for such a distribution. I would suggest to use a high percentile (e.g. above the 99th percentile, or something similar, could also be more extreme). This can then also be translated easily into a return period.

The mean +3 standard deviations will be changed to 99th percentile in the identification of high flows for each watershed.

Would it be an option to us only the weather patterns based on the observations and classify the models according to those? This might reduce differences between models and observations with respect to the occurrence rate of heavy precip and warm events (the authors discuss this point in sec 4.1).

The models were classified according to the weather patterns calculated with the observations (20thCR reanalyses). The daily Z500 anomalies from the observations were first transformed by principal component analysis (PCA) keeping 80% of the spatial variance. The principal components identified were then classified into recurrent weather patterns using a k-means algorithm. The eigenvectors of the PCA as well as the k-means centroids of the patterns identified using the observations, are used to identify the weather regimes for each member of CanESM2-LE. The explanations of the method used to calculate the CanESM2 weather regimes will be improved in the new manuscript

Please mention somewhere explicitly how the compound index is defined. Is it just the occurrence of events where both temperature and precipitation exceed a certain threshold? Or the number of such occurrences?

The compound index is simply defined by the number of days with a temperature exceeding 5 degrees and precipitation exceeding 10mm. The information will be explicitly added to the method section.

Minor comments: I would recommend the authors to do a thorough spell check and grammar check. There are a number of minor grammatical errors and typos in the text.

A spell and grammar check will be done for the entire manuscript.

L 49: start new paragraph

L59: "preconized" ?

L67: “contributes to”: maybe better: “explains the variability of”

L69: “occurrence of the index”: an index does not occur, it has a certain value. Better “relationship between the index and recent large-scale atmospheric circulation” (“past” sounds a bit like historical)

These modifications will be done as suggested

L84: Univariate bias correction might induce artefacts when studying compound events (Zscheischler et al., 2019), this might be highly relevant here. Consider applying a multivariate bias correction approach.

The bias correction approach used in this study was used in a previous study in the area (Champagne et al., 2019). For consistency with this previous study, the same bias correction technique was applied. We also identified the number of extreme events using the raw data (Figure R1) and found a higher difference between simulations and observation compared to the bias corrected data (Figure 4 in the main manuscript). These results are showing that this bias correction method is satisfactory. A reference to a multivariate bias correction approach will be added to the discussion.

Figure 2: “blue lines correspond to high flows” is unclear. There is one blue line in the precipitation figure and a red line in the temperature figure. It looks as if they would just correspond to the mean of the boxplots. It would be surprised if the highflows would align so well with the precipitation amounts. Please clarify.

These blue and red lines correspond to the mean of the boxplots. These lines are not giving valuable information and will be removed for clarity.

Section 3.2: I assume this is after bias correction?

Yes the results are given using bias correction data. This information will be added to the manuscript

Figure 4 and following: are these comparisons on the same spatial grid?

These comparisons are on the same spatial grid because the bias correction was performed at each observed grid point. The modelled grid-point the closest from each observed grid point was identified and the corresponding temperature and precipitation were bias corrected. These bias corrected data are represented at each observed grid point in the figures.

Figure 8: why do so few events result in high streamflow?

Few events result in high flows because even though the index is a condition to produce a high flow event the generation of high flows also needs other conditions (other rain events in the previous days, snowmelt amount). This will be more discussed in the manuscript.

Consider reporting the events as relative numbers (e.g. sections 3.2, 3.3). This might be more intuitive as it is easier for the reader to put the occurrence probability into context.

The relative numbers will be added to the manuscript.

Some method description appear in the results, e.g. L 215 and following.

These elements of methods will be added to the method section.

L220: I assume TOT are the events as simulated with the hydrological model? This should be mentioned somewhere explicitly.

The mention ''simulated by PRMS'' will be added to the manuscript

References:

Champagne, O., Arain, M. A. and Coulibaly, P.: Atmospheric circulation amplifies shift of winter streamflow in Southern Ontario, Journal of Hydrology, 124051, doi:10.1016/j.jhydrol.2019.124051, 2019.

Jeong, D. and Sushama, L.: Rain-on-snow events over North America based on two Canadian regional climate models, Climate Dynamics, 50(1–2), 303–316, doi:10.1007/s00382-017-3609-x, 2018.

Zscheischler, J., Fischer, E. M. and Lange, S.: The effect of univariate bias adjustment on multivariate hazard estimates, Earth System Dynamics, 10(1), 31–43, doi:10.5194/esd-10-31-2019, 2019.