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Discussions
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Interactive comment on "Precipitation Transition Regions over the Southern Canadian Cordillera during January–April 2010 and under a Pseudo-Global Warming Assumption" *by* Juris D. Almonte and Ronald E. Stewart

Juris D. Almonte and Ronald E. Stewart

juris.almonte@gmail.com

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We thank reviewer 2 for their critical and helpful comments. Below we address each one.

Comment: Abstract, line 13: change "reanalysis" to "reanalysis-driven" or delete the word.

Response: Good point.

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Revised Text: The term “reanalysis-driven” is now used.

Comment: Sec. 2.2, first paragraph: I recommend specifically noting here that Thompson one moment microphysics scheme was used in the WRF simulations and rain, snow, and graupel are produced from the scheme (i.e., no ice pellets). Here, the authors wrote accumulation at the lowest level was used. Could you clarify if mixing ratios of graupel, rain, and snow (that are available as 3D data) were used in your study or surface graupel, rain, and snow. If the lowest model height mixing ratios were used, please indicate how far above the ground (in general) the level is.

Response: Good point. The surface graupel, rain and snow 2D outputs were used for this study and not 3D data. These surface 2D outputs take into account several microphysical processes, such as melting, evaporating, sublimation, deposition, and autoconversion.

Revised Text: Starting from line 108, the manuscript now reads: “Two 13 year high-resolution convective-permitting simulations from 2000 to 2013 were carried out by Liu et al. (2016) using the Weather and Research Forecasting (WRF) model version 3.4.1. This model was configured using the Thompson aerosol-aware microphysics scheme (Thompson and Eidhammer, 2014) with one-moment prediction of mass mixing ratio for cloud water, snow and graupel and two-moment prediction of the number concentration for cloud ice and rain. This scheme does not include ice pellets. ”

Comment: Sec. 2.2, last paragraph: Ice pellets can exist in transition regions. Did you consider situations with ice pellets? If so how did you determine ice pellets from the model outputs? If it was explained in Sec. 2.2 that only rain, snow, and graupel categories are simulated in the mp scheme, then other readers may not wonder about how ice pellets were dealt with in this study.

Response: Thank you for your suggestion. Ice pellets were not considered in this study and this is now clarified in the manuscript. Concluding remarks have also been revised.

Revised Text: This has been adjusted and is the same as the revised text mentioned in an earlier comment: “This model was configured using the Thompson aerosol-aware microphysics scheme (Thompson and Eidhammer, 2014) with one-moment prediction of mass mixing ratio for cloud water, snow and graupel and two-moment prediction of the number concentration for cloud ice and rain. This scheme does not include ice pellets. These variables are then used as a basis for calculating the hourly surface snow, graupel and rain as discussed by Thompson and Eidhammer (2014). The determination of surface freezing rain requires a temperature criterion which is discussed in Section 2.2.”

In concluding remarks: “Ice pellets were not considered in this study, but can certainly occur within transition regions, when an inversion of warm air aloft occurs. A future study may consider using the bulk microphysics scheme developed by Cholette et al. (2019) that explicitly predicts not only ice pellets but also wet snow.

New reference: Cholette, M., H. Morrison, J.A. Milbrandt, and J.M. Thériault: Parameterization of the bulk liquid fraction on mixed-phase particles in the Predicted Particle Properties (P3) scheme: Description and idealized simulations. J. Atmos. Sci., 76, 561–582, https://doi.org/10.1175/JAS-D-18-0278.1, 2019.

Comment: Table 1: change “temperature criterion. . .” to “Wet bulb temperature criterion. . .”.

Response: Thank you, this has been done.

Revised Text: “A wet bulb temperature criterion $\leq 0^\circ$ C was used to exclude rain, whereas a criterion $> 0^\circ$ C was used to exclude freezing rain.”

Comment: Sec. 3.1, line 156: Change “precipitation availability” to “precipitation observation availability”.

Response: Good point.

Revised Text: The phrase “precipitation observation availability” is now used.

Comment: Figure 3: Panel (a) is said to be showing the simulation result mapped over a coarser 10km x 10km grid, but it looks like it is on a 4 km x 4 km grid space. Could you verify if a correct figure was used? The blue color scale makes it difficult to see where values are high/low. I would suggest using a different color scheme.

Response: Thank you for your comment. We have verified that Panel (a) is on a 10 x 10 km grid and was regridded using a conservative interpolation using National Center for Atmospheric Research Command Line. We have also considered a different colour scheme but we feel the current one showing the gradient of precipitation accumulation is fine.

Revised Text: There is no revised text.

Comment: Sec. 3.2.1, line 202: It is good that the authors indicate issues with the gridded data product. However, should “>5mm” be “<5mm” according to Lespinas et al. (2015)? It may also be good to state that the density of observations used in generating CaPA drops significantly across US-Canada border as you go northward.

Response: Thank you for this comment. Precipitation events > 5mm are underestimated according to Lespinas et al. (2015). It is true that the density of observations decreases substantially, moving northward. Your suggestion has been added to the text.

Revised Text: One change was made as follows: “The density of stations used in generating CaPA drops significantly across the US-Canada border as one moves northward.”

Comment: Sec. 3.2.2, line 220: Could you briefly explain how the data were adjusted by Mekis and Vincent (2011)?

Response: Environment and Climate Change Canada have deployed different types of precipitation measurement equipment and have conducted field experiments with the various precipitation gauges. They found greater accuracy with newer precipitation

gauges, therefore they employed different quality control techniques, dependent on the precipitation gauge variety including loss from evaporation, wetting loss and retention correction.

Revised Text: “Adjusted data by Mekis and Vincent (2011) were used where available and these include Glacier NP Rogers Pass, Golden and Fernie. Mekis and Vincent (2011) adjusted for errors in both rainfall and snowfall measurements. For rainfall measurements, rain-gauge specific corrections for three of the major gauge types were used within ECCC and each was adjusted for undercatch from wind, wetting at both the funnel and the receiver or container, and evaporation. Snowfall when measured by a ruler was converted to water equivalent by applying a snow water equivalent adjustment factor. This factor was determined by comparing gauge and snow ruler measurements following the techniques described by Metcalfe et al. (1994).”

New reference: Metcalfe, J. R., Ishida, S., and Goodison, B. E.: A corrected precipitation archive for the Northwest Territories of Canada. In Mackenzie Basin Impact Study, Interim Report# 2–Proceedings of the sixth biennial AES-DIAND meeting of Northern Climate and Mid Study Workshop of the Mackenzie Basin Impact Study, Yellowknife, Northwest Territories (Canada), 1994.

Comment: Figure 4: correct “WRF CCTRL” to “WRF CTRL” in the legend.

Response: Thank you for catching this. It has been fixed in the legend.

Revised Text: Please see attached figure.

Comment: Sec. 4, line 260: Sentence starting with “Of these, 93% (94%). . .” does not indicate which value is associated with the CTRL simulation. Correct the sentence accordingly.

Response: Thanks for pointing that out.

Revised Text: “Of these, 93% (94%) had a transition region occurrence under the CTRL (PGW) simulations.”

Comment: Sec. 4-5: I may have missed it but there is no mention of how much relative humidity changed from CTRL to PGW simulations over the study area. This study does not mention about how change in cloud mixing ratio and vapor mixing ratio (in PGW) would impact evolution various hydrometeors. A short discussion on change in moisture (not only temperature) would be good.

Response: Good suggestion. We have included a discussion of change in relative humidity. Cloud mixing ratio and water vapor mixing ratio were not specifically examined in this study. However, it would be expected that under PGW there would be more water vapour and this could lead to more accretion and graupel.

Revised Text: "The CTRL relative humidities were lower (5–27%) when compared to the ECCC stations. The largest discrepancy was at Revelstoke particularly at the beginning of the study period from January to mid-March. For transition regions, these subsaturated surface conditions could mean that the model may be underestimating precipitation at the surface due to sublimational or evaporative losses and it could have an effect on the type of transition precipitation since the melting process is slowed."

"Although not considered here, it is expected that the higher water vapour content and would lead to more accretion and graupel."

Comment: Figure 10: The two panels are identical (western sub-region?). Please check.

Response: Sorry for our mistake.

Revised Text: The correct panels are now used and are attached.

Comment: Sec. 6.1, line 496: Correct "the order of precipitation occurrence be related to .." to " occurrence can(is?) related to. . ."

Response: Thank you for noticing that.

Revised Text: "The order of precipitation occurrence can be related to atmospheric

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rivers."

Comment: Sec. 6.1, line 508: Change "This idealized . . . at Whistler Mid Station . . ." to ". . . at Whistler Mid Station CTRL . . . "

Response: Good suggestion.

Revised Text: "This idealized situation is evident at Whistler Mid Station CTRL. . ."

Comment: Sec. 6.2, Figure 14: It is unclear from this section and Fig. 14 that the future climate will increase avalanche risk. Figure 14 shows that less transition regions at ski resorts in PGW which contradicts Lines 471-477 and analysis given prior to this section where clearly states an increase in transition region in PGW. Please clarify.

Response: Thank you for pointing this out. Lines 471-477 refer to Figure 13 and refers to the entire duration of the study, whereas Figure 14 illustrates the order of precipitation type at each ski resort only over a few days (14-16 January), and is not representative of the 4 month period. Text for Figures 13 and 14 has been revised to clarify this.

New Text: Text in relation to Figure 13 now reads "Under CTRL the average 4 month transition region occurred within the elevation range of 12 ski resorts but, under PGW, this average occurred within the elevation range of 16 ski resorts (Fig. 13). Six additional ski resorts were added under PGW but two were lost because the average 4 month transition region height moved above them (Grouse Mountain and Mt. Seymour). These six additional ski resorts could experience more human-triggered avalanches if no avalanche mitigation efforts are made."

Text in relation to Figure 14 now reads "This precipitation evolution at ski resorts is shown for 14–16 January, as an illustrative example in Fig. 14. This figure is not an accurate representation of the entire study period (January–April 2010)."

Comment: Also, Figure 14 may be modified with horizontal lines separating each ski resort so that CTRL vs PGW comparison at a site can be done easily. Also indicate

which ski resorts are on the eastern / western sub-regions or use separate panel plot for each sub-region.

Response: We considered following this suggestion of examining each ski resort but did not feel that it is necessary. We are just trying to show the general pattern. We have also improved the figure somewhat to more clearly indicate ones on the eastern and western sides.

Revised Text: The new figure is attached and revised caption is below.

Figure 14: Timeline of precipitation type under CTRL and PGW at ski resort base from 14 January 0000 UTC, 2010 to 16 January 1200 UTC, 2010. Precipitation occurrence is shown as rain (blue), green (snow), red (transition region) and grey (no precipitation). Ski resorts are separated into western sub-area (top) and eastern sub-area (bottom) and within each sub-area are organized from west (top) to east (bottom).

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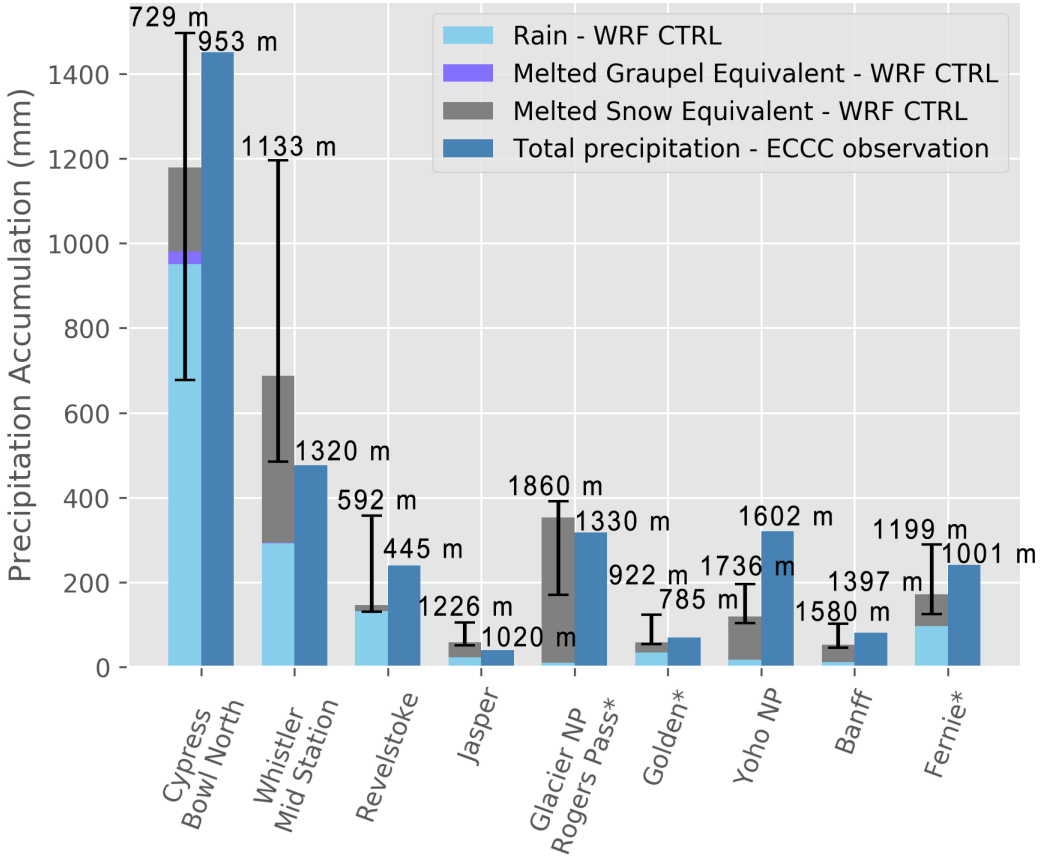

Fig. 1. Figure 4. Total precipitation accumulation from January to April, 2010. The left-hand bars represent the closest CTRL grid point, separated into three components, including rain ...

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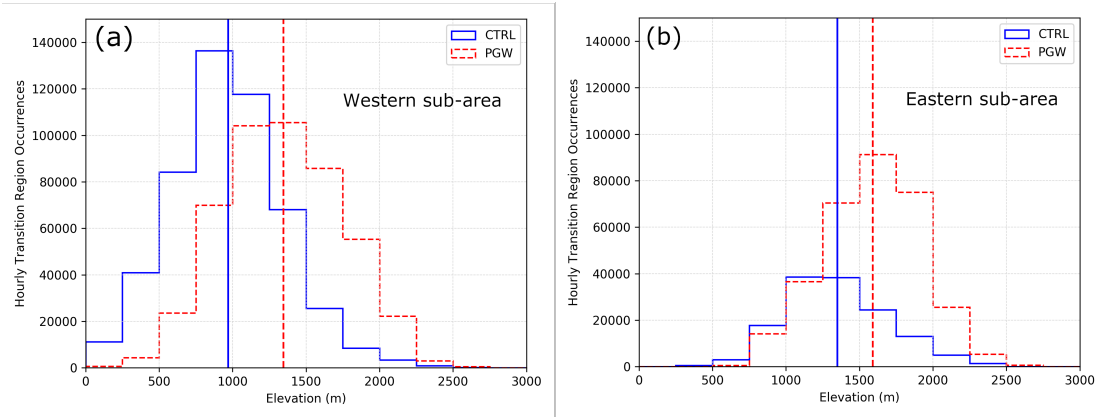

Fig. 2. Figure 10. Transition region occurrences for the (a) western and (b) eastern sub-areas binned according to elevation. Vertical solid blue lines and dashed red lines represent the average elevation ...

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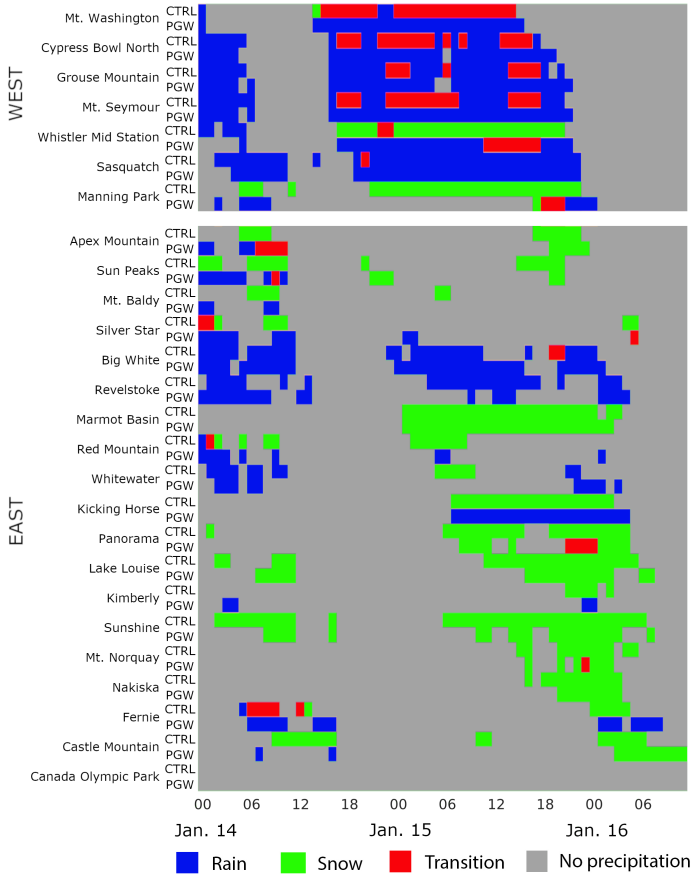

Fig. 3. Figure 14: Timeline of precipitation type under CTRL and PGW at ski resort base from 14 January 0000 UTC, 2010 to 16 January 1200 UTC, 2010. Precipitation occurrence is shown as rain (blue), green ...