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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Recent climatic, cryospheric, and hydrological changes over the interior of western Canada: a synthesis and review" *by* C. M. DeBeer et al.

C. M. DeBeer et al.

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Response to Reviewer 1

Reviewer comment (RC): This paper sets out to provide a synthesis and review of climatic, cryospheric and hydrological changes over the interior of western Canada. The review aspect is handled reasonably competently (with some updating needed in some sections), but the paper does not really provide much synthesis and new insight from the research carried out in CCRN. My recommendation to the authors is develop a more concise version of this paper and place most of the material in the current paper

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in “Supplementary Material”. The observed changes can be summarized in a single Table and key graphics, with the discussion organized along thematic lines e.g. drivers of change, response and interactions of the regional hydroclimate, important feedbacks and linkages, key knowledge gaps for providing relevant information for decision makers. As it stands, the paper is largely an update of the IPY paper of Derksen et al. (2012) and does not make a significant contribution to the scientific literature.

Author response (AR): We thank the reviewer for the suggestions. To summarize, the review aspect is handled well but the synthesis is lacking. In the revised manuscript, we will improve the synthesis section and take on board the suggestions provided by Reviewer 1 and 2. The suggestion to place most of the current material in a supplementary material section and focus on a few graphics we believe will diminish the value of the review, which is the core of the paper. However, we will explore methods to tighten the manuscript and reduce its length. In the revised manuscript, we will expand the synthesis and integrate the suggestion of thematic linkages. While we do acknowledge that there are similarities with the Derksen et al. (2012) review paper, there is considerable new material and the scope is broader and more focused on hydrology.

RC: Detailed comments: - The Abstract lacks quantitative information coming out of the review. The claim that the paper provides an integrated review of observed changes is somewhat presumptuous. The phrase “further diagnosis is required. . .” is vague. Diagnosis of what? What are the key issues undermining confidence? Suggest you also change “predictions” to “projections”.

AR: Noted. We will reign in some of the abstract language and improve it to more accurately reflect the manuscript.

RC: - P. 8617 lines 12-13: This statement needs nuancing a bit. It is true of recent satellite- based datasets but not of reanalyses and in situ climate data. Perhaps a more general statement along the lines of “Observational datasets are of varying length with most of the satellite-derived information covering a relatively short period of record.

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Evaluating change across datasets is challenging as data may not be homogeneous, may reflect different spatial and temporal scales (e.g. in situ observation versus a satellite-derived spatial average), and may be responding to different processes (e.g. snow depth ob- servations made in open areas at climate stations will not capture the influence of changing vegetation on snow cover)."

AR: Noted. We will restate.

RC: - P. 8618 line 25-30: What about the CNRCWP network?

AR: Noted. We will include the other two relevant NSERC Climate Change and Atmospheric Research (CCAR) Programme networks (Canadian Network for Regional Climate and Weather Processes (CNRCWP) and Canadian Sea Ice and Snow Evolution (CanSISE) Network) in the description of current initiatives.

RC: - P. 8620 lines 10-11: This reads like you interpolated the data to generate CANGRD! I think you need a bit more documentation for CANGRD. Unfortunately the available online documentation for CANGRD is rather poor. However, here is how it was described in Rapaic et al. (2015): "The reference dataset chosen was CANGRD because it includes the latest version of the Adjusted and Homogenized Canadian Climate Data (AHCCD) from Mekis and Vincent (2011) and Vincent et al. (2012). The CANGRD dataset uses optimal interpolation of station anomalies combined with high-resolution thin-plate spline estimates of the monthly mean field to obtain gridded monthly values at a nominal 50 km resolution (Milewska & Hogg, 2001; Milewska et al., 2005; Zhang et al., 2000)." You can get the refs from Rapaic et al. Rapaic ÌĄ, M., Brown, R., Markovic, M., & Chaumont, D. (2015). An Evaluation of Temperature and Precipitation Surface-Based and Reanalysis Datasets for the Canadian Arctic, 1950–2010. Atmosphere-Ocean, 53(3), 283-303.

AR: We thank the reviewer for this information and will clear up any confusion in the revised manuscript.

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Reviewer comment: - P. 8622 Section 2.3: The material referenced in this section seems rather dated. I suggest you contact Xuebin Zhang at Env Canada to see if there have been any more recent analyses of extremes carried out for Canada. The recent paper by Casati and de Elia (2015) would be relevant. Casati, B., & de ElìĄa, R. (2014). Temperature Ex- tremes from Canadian Regional Climate Model (CRCM) Climate Change Projections. Atmosphere-Ocean, 52(3), 191-210.

Author response: Xuebin Zhang is a member of the CCRN network that funded this work. We will update this section and contact Dr. Zhang about potential updates.

RC: - P. 8622: It would be useful to point out the linkages between an increasing frequency of winter warms spells and hydrology in this section. Winter warm spells also impact snowpack properties (e.g. formation of ice layers) with important ecological consequences. I think this is discussed in the other Callaghan et al (2011) paper. Callaghan, T. V., Johansson, M., Brown, R. D., Groisman, P. Y., Labba, N., Radionov, V., ... & Wood, E. F. (2011). Multiple effects of changes in Arctic snow cover. Ambio, 40(1), 32-45.

AR: Noted - will will adapt and integrate.

RC: - P. 8624 Change Heading 3.1 to “Adjusted precipitation datasets for Canada”. The pre- cipitation data were adjusted for systematic changes in procedures and in- strumentation but they were NOT homogenized (i.e. consistency evaluated through comparisons with surrounding stations).

AR: Noted

RCt: - P. 8624 lines 15-17. Clarify the text to avoid giving the impression that this project carried out the interpolation of station values in CANGRD.

AR: As above, we will clarify.

RC: - P. 8624 Section 3.2: The recent paper by Rapaic et al. (2015) is relevant to this section. They found that CANGRD gave increasing precipitation trends that were two

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times higher than other datasets.

AR: Thank you for this information - we will incorporate into the review.

RC: - P. 8625 lines 20-21: Vincent et al. (2015) updated the climate trends presented in Zhang et al (2000). You should be citing the results from the recent paper.

AR: Noted. We will incorporate in the revised manuscript.

RC: - P. 8631 line 16. Replace “They found. . .” with “He found. . .” to be consistent with the reference. The Derksen et al (2004) paper is probably more relevant than Brown (2000) as their study region over central NA approximates your region of interest. Their March SWE series suggests the region went through an extended period of above average SWE from about 1945 to 1980. Derksen, C., Brown, R., & Walker, A. (2004). Merging conventional (1915-92) and passive microwave (1978-2002) estimates of snow extent and water equivalent over central North America. Journal of Hydrometeorology, 5(5), 850-861.

AR: Again, thank you for this information.

RC: - Section 4.2: This section is well written but the linkages need to be highlighted be- tween changing snow (e.g. earlier melt onset, changing melt dynamics, winter melt events, changing snowpack properties) and hydrology, permafrost etc. What is happening to the vertical gradient in SWE over the mountains? How are changes in the solid/liquid fraction of precip affecting runoff amount and timing? What does a shorter snow season mean for soil moisture and ET?

AR: We will enhance linkages in the revised manuscript as we strengthen the synthesis portion of the work.

RC: - no comments on following sections. - Section 9.2: I was expecting more synthesis here and less restating of findings from the various sections. What significant insights have been obtained on climate-cryosphere-hydrology linkages and understanding from CCRN research? What are the key gaps in the science that need to be addressed to

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meet user needs? What are the user needs?

AR: We will take this comment on when revising the manuscript. We thank the reviewer for providing considerable information that will strengthen the review aspect of this paper, and as other reviewers also note, the synthesis will be improved upon in the revised manuscript.

Response to Reviewer 2

RC: The review component of this work is well researched and well presented, although some gaps are apparent and some literature has been missed (see details below). Nevertheless, this manuscript falls short with respect to the synthesis component. Although the authors do a good job of painting an overall meta-picture of cryospheric change, they fail to synthesis an overall system response, particularly as to why unambiguous cryospheric changes have not manifested into detectable hydrologic (i.e. streamflow) changes. Going into greater depth on this last issue would be of far greater relevance to a hydrology audience. Right now all the authors have to offer is the rather flaccid statement "How watersheds respond to this change is being actively pursued within CCRN by improving our process-based knowledge of these systems combined with diagnostic testing and prediction using numerical models". There is enough re- search between MAGS, BOREAS, DRI, WC2N, IPY and IP3 that the authors should be able to at least offer a rudimentary outline of potential or proposed linkages between cryospheric and hydrologic change.

AR: As with Reviewer 1, we will take this constructive criticism on board in the revised manuscript. We will work to integrate this information to provide a more detailed synthesis while providing information on emerging questions and uncertainties in understanding.

RC: As it currently stands, this manuscript is predominantly a review article, the content of which overlap substantially with the recent review of cryospheric changes presented in Derksen et al. (2012). Although one could argue that by using alternative data

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sources, this work serves to present additional evidence of, and therefore, increases the robustness of any overall conclusion of “unambiguous changes in temperature, snow and ice”, that alone isn’t enough to merit this as a standalone piece of publishable work, particularly in a hydrology-focused journal. In its current form this manuscript is a failed opportunity to both point out knowledge gaps in process understanding linking cryospheric and hydrologic change, and provide guidance regarding priority research questions for an important region of Canada.

AR: As stated above, we will refocus the revised manuscript to provide more synthesis. We thank the reviewer for the constructive criticism.

RC: Detailed Comments Page 8618, Line 26: Use Stewart et al. (2011) as a reference for the DRI network.

AR: Noted.

RC: Page 8618, Line 29: I also could not find a reference for the IP3 network, but a link to the website would be collegial.

AR: Noted.

RC: Page 8620, Lines 5-9: Showing a map of station density here would be quite compelling (see example figure 1 which shows the locations of AHCCD precipitation stations. The figure was extracted from presentation given by EÌĄva Mekis at the DRI Precipitation and Drought Indices Workshop, Toronto, April 30, 2009, http://www.drinetwork.ca/09precip/mekis.pdf).

AR: Noted. We will seek to incorporate in a revised manuscript.

RC: Page 8620, Line 11: Clarify that the CANGRD data set is a product of Environment Canada. The readers should also be referred to http://open.canada.ca/data/en/dataset/3d4b68a5-13bc-48bb-ad10-801128aa6604 for the data source and description. Nevertheless, CANGRD is no longer a readily available product, so some additional text should be devoted to the methodology behind it

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(i.e. what interpolation technique).

AR: We will clarify in the revised manuscript.

RC: Page 8631, Line 8: Is the assertion ". . . and our own analysis . . ." backed-up be submitted or published research. If not, then either include the relevant work in the manuscript or remove this statement.

AR: Noted.

RC: Page 8638, Line 8: The acronym CALM is not defined.

AR: We will define in the revised manuscript.

RC: Page 8646, Lines 21-22: Include a reference to Adam et al. (2006). Also, Luce et al. (2013) give an example of how misrepresenting high-elevation precipitation trends results in an apparent paradox between observed annual streamflow and precipitation trends in the Pacific Northwest.

AR: We thank the reviewer for these references and suggestions.

RC: Page 8646, Section 9.1: The very recent climate data comparison work of Rapaic ÌĄ et al. (2015) for the Canadian Arctic is highly relevant to any discussion of climate data uncertainty and should be cited.

AR: Noted.

RC: Page 8648, Lines 11-16: For a hydrology journal, this rather superficial explanation is insufficient. There is enough research to delve deeper into this issue (see following comment).

AR: We will seek to improve in the revised manuscript.

RC: Pages 8647 – 8649, Section 9.2. Use results from WECC sites (and additional research from other regions) to delve a bit deeper into how hydrologic system responds (or is expected to respond) to climatically-driven cryospheric trends. For example, what

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is the importance of 1) permafrost and groundwater interactions and feedbacks (e.g. Ge et al. 2011; Walvoord et al. 2012); 2) Soil moisture, evaporation and changes in growing season length; 3) lakes & wetlands and the effects of intermittent connectivity, dynamic drainage area and closed drainages (e.g. Shaw et al. 2012; Brannen et al. 2015); 4) the presence (or absence) of glaciers and streamflow response to climate change/variability (e.g. Fleming and Clarke 2003); and 5) the spatial heterogeneity (lateral and vertical) on hydrologic response to climate change/variability in mountainous terrain (e.g. Fleming et al. 2007). In other words, what do we currently know about processes linking the cryosphere and hydrology, how complete is this picture, and what are the knowledge gaps?

AR: We thank the reviewer for these clear suggestions that we will help guide the revised manuscript.

RC: Figure 2 through 4: Are the dots representing statistically significant trends missing? Or are their simply no statistically significant trends in any of these figures?

AR: There does indeed seem to be a problem with the figures. The dots are missing in the online version. This will be corrected for the revised manuscript, and the correct figures are included in this response.

RC: Figure 6: It is difficult to read the text in this figure.

AR: We will improve the figure in the revised manuscript.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 8615, 2015.

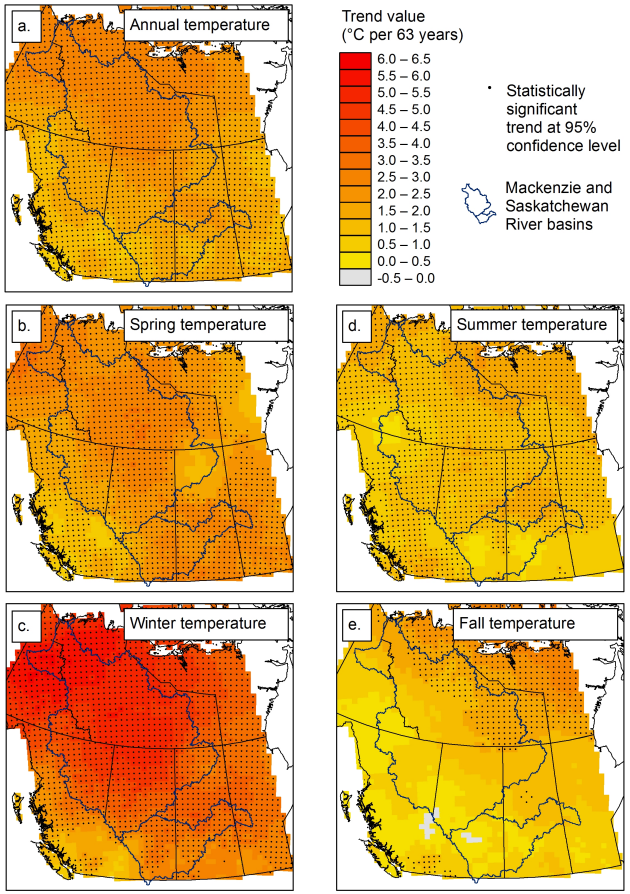

Fig. 1. Spatial patterns of trends (°C per 63 years) in annual and seasonal average air temperatures over the period 1950–2012 across western Canada, based on analysis of CANGRD temperature data.

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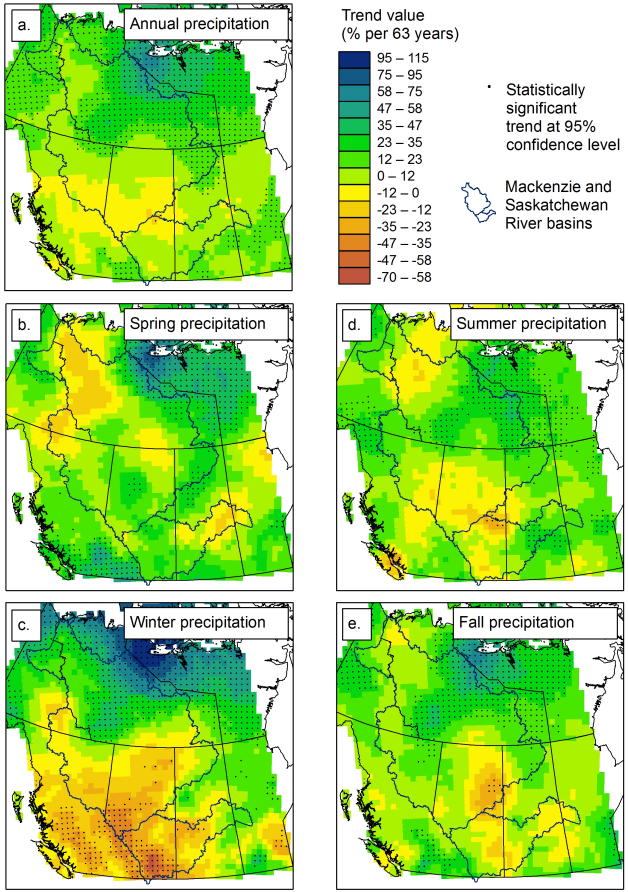

Fig. 2. Spatial patterns of trends (percent per 63 years) in annual and seasonal totals of precipitation over the period 1950–2012 across western Canada, based on analysis of CANGRD precipitation data.

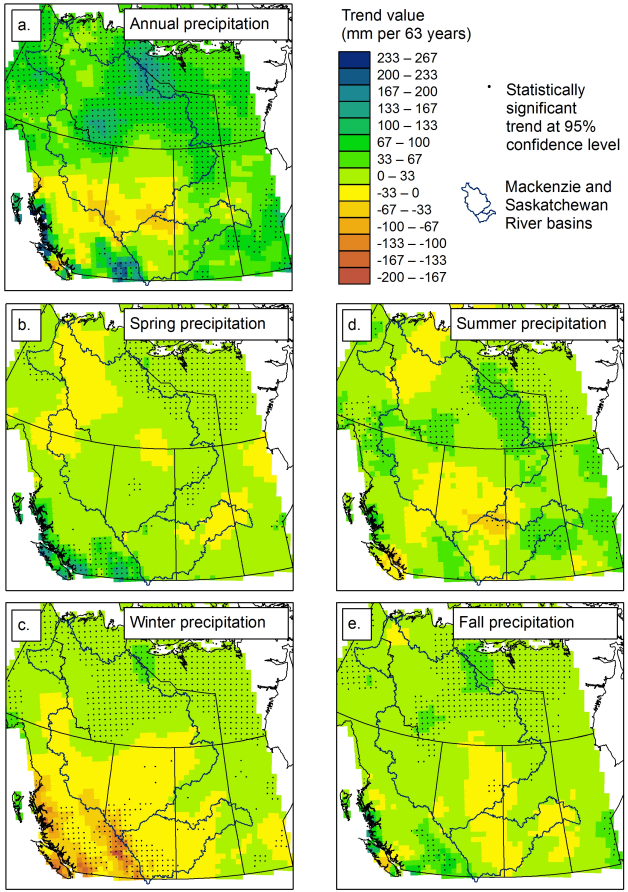

Fig. 3. Spatial patterns of trends (mm per 63 years) in annual and seasonal totals of precipitation over the period 1950–2012 across western Canada, based on analysis of CANGRD precipitation data.

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