

Interactive comment on “Effects of midwinter snowmelt on runoff generation and groundwater recharge in the Canadian prairies” by Igor Pavlovskii et al.

Anonymous Referee #2

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Review of Effects of midwinter snowmelt on runoff generation and groundwater recharge in the Canadian prairies by Igor Pavlovskii, Masaki Hayashi and Daniel Itenfisu

This paper explores the occurrence and drivers of mid-winter snow melt in southern Alberta, Canada and the implications that this has upon runoff generation groundwater recharge. It highlights the importance of this often-overlooked phenomena and how it can have temporally lagged consequences upon the main snowmelt event. Significant field data has been collected and described in detail which makes it a unique and valuable dataset to address the objectives. Despite this I find that the article will need

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some major revisions before I recommend its acceptance. Major comments are first articulated, followed by minor/specific comments.

Major comments: Level of analysis:

There is a lot of information in this paper that is still fairly raw. Details and context are critical but overall if the level of presented could be at a more synthesis level that would clarify the arguments. For example, a main point of this paper was identifying the different energy sources over the melt season. This was done in a qualitative manner with respect to time series of hourly energy fluxes. It would be much more compelling (and the data seems available to do this) if the authors could calculate the energy balances of the melt periods to quantitatively say how much energy for melt came from turbulent versus radiation exchange. Discuss in terms of the total energy (J) for periods of interest rather than instantaneous maximum rates ($W m^{-2}$)

Citations:

There is a lot of information already on prairie snowmelt processes that seems to not be fully referenced. It would strengthen this paper to put it into a firmer context of what has already been published. Significant snowmelt research on the prairies goes back to the 1970's at the Division for Hydrology at the U of S— some of these papers are cited but many that are relevant are not.

What do energy balance terms represent?

Turbulent fluxes measured with eddy covariance and radiation from net radiometers are used to quantify the energy balance terms. There is no discussion of what these observations represent as a snow cover depletes. The EC footprint will vary with wind speed and direction and will have variable contributions from both snow -covered and snow-free ground. Are these bulk averages therefore truly indicative of the energy contributions to snowmelt? As non-snow features increase contribution to the radiometer footprint a similar influence also occurs (but no subject to wind direction or speed like

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the turbulent fluxes). These interpretation challenges for the energy balance observations need to be at least addressed.

Focus of paper?

The title of paper specifies that is “Effects of midwinter snowmelt on runoff generation and groundwater recharge in the Canadian prairies”. Much of the paper considers the quantification of the energy sources driving mid-winter melts while runoff generation and groundwater recharge questions seem to be more ancillary. I feel that the title and paper content are somewhat disconnected.

Advection over patchy snow

Both large-scale and small-scale advection is mentioned in this paper. This is only introduced in the discussion section and the differences are not clearly defined. This should be incorporated into the introduction more formally. There has been a lot of recent work that has tried to disentangle this phenomena that could benefit this discussion.

Mott, R., M. Lehning, and Megan Daniels. 2015. “Atmospheric Flow Development and Associated Changes in Turbulent Sensible Heat Flux over a Patchy Mountain Snow Cover.” *Journal of Hydrometeorology* 16: 1315–1340. doi:10.1175/JHM-D-14-0036.1.

Mott, R., S. Schlögl, L. Dirks, and M. Lehning. 2017. “Impact of Extreme Land Surface Heterogeneity on Micrometeorology over Spring Snow Cover.” *Journal of Hydrometeorology* 18 (10): 2705–2722. doi:10.1175/JHM-D-17-0074.1.

Schlögl, Sebastian, Michael Lehning, and Rebecca Mott. “How are turbulent sensible heat fluxes and snow melt rates affected by a changing snow cover fraction?.” *Frontiers in Earth Science* 6 (2018): 154.

Marsh, P., J.W. Pomeroy, and N Neumann. 1997. “Sensible Heat Flux and Local Advection over a Heterogeneous Landscape at an Arctic Tundra Site during Snowmelt.” *Annals of Glaciology* 25: 132–136.

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Essery, R., R.J. Granger, and J.W. Pomeroy. 2006. “Boundary-Layer Growth and Advection of Heat over Snow and Soil Patches: Modelling and Parameterization.” *Hydrological Processes* 20 (4): 953–967.

Liston, Glen E. 1995. “Local Advection of Momentum, Heat and Moisture during the Melt of Patchy Snow Covers.” *Journal of Applied Meteorology* 34: 1705–1715.

Granger, R.J., J.W. Pomeroy, and J. Parviainen. 2002. “Boundary-Layer Integration Approach to Advection of Sensible Heat to a Patchy Snow Cover.” *Hydrological Processes* 16 (18): 3559–3569.

Blowing snow

Blowing snow is a critical component of the winter time mass balance. This phenomenon needs to be addressed. Can it be discounted from time-lapse camera observations? If not the sublimation of blowing snow will challenge the comparison of runoff to antecedent precipitation.

Overall structure:

Paper needs more focus – less details. The science story is there: the turbulent flux energy source for mid-winter melts lead to more effective infiltration and the high radiation driven melt rates of the spring main event will have less effective infiltration and more runoff/depression focused recharge. The information presented should be limited to that which that support this main conclusion (if I interpreted correctly). In addition, the end of the discussion ends abruptly. It would be appropriate to add an additional section that discusses the implications of the mid-winter melt phenomena under climate change if there are any limitations to this type of speculation.

Specific comments

Abstract: ends abruptly with three separate conclusions. Is there a way to synthesize the conclusions better?

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Page 1 Line 21-22: “hydrologic partitioning between streamflow and evaporative losses”. What about infiltration or other sub-surface storage terms?

Page 1 Line 23: this is a prairie focused paper – is there a more appropriate citation for this?

Page 1 Line 29-30: unclear sentence

Page 2 Lines 1: snowmelt as main component of surface runoff is referenced in many other sources.

Page 2 Line 16-18: Many authors have looked at snowmelt energy dynamics/physics on the prairies – here is a small sample. While not specific to mid-winter melts these do provide a lot of physical understanding to describe snowmelt processes in the prairies.

MacDonald, Matthew K., J.W. Pomeroy, and Richard L.H. Essery. 2018. “Water and Energy Fluxes over Northern Prairies as Affected by Chinook Winds and Winter Precipitation.” *Agricultural and Forest Meteorology* 248: 372–385. doi:10.1016/j.agrformet.2017.10.025.

Granger, R.J., and D.M. Gray. 1990. “Net Radiation Model for Calculating Daily Snowmelt in Open Environments.” *Nordic Hydrology* 21: 217–234.

Norum, D. I., D.M. Gray, and D.H. Male. 1976. “Melt of Shallow Prairie Snowpacks: Basis For a Physical Model.” *Canadian Agricultural Engineering* 18 (1): 2–6.

Harder, P., W.D. Helgason, and J.W. Pomeroy. 2018. “Modelling the Snow-Surface Energy Balance during Melt under Exposed Crop Stubble.” *Journal of Hydrometeorology* 19 (7): 1191–1214. doi:10.1175/JHM-D-18-0039.1.

O'Neill, A.D.J, and D.M. Gray. 1973. “Spatial and Temporal Variations of the Albedo of Prairie Snowpack.” *Unesco-WMO-IASH Symposia* 1: 176–186.

Gray, D.M., and P.G. Landine. 1988. “An Energy-Budget Snowmelt Model for the Canadian Prairies.” *Canadian Journal of Earth Sciences* 25 (8): 1292–1303.

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Granger, R. J., and D. H. Male. "Melting of a prairie snowpack." *Journal of Applied Meteorology* 17.12 (1978): 1833-1842.

Page 2 Line 19-21: Objectives do not reference runoff generation or groundwater recharge explicitly even though title does.

Page 3 Line 29-30: Any relationship between snow depth and density? See: Shook, K., and D.M. Gray. 1994. “Determining the Snow Water Equivalent of Shallow Prairie Snowcovers.” In *Eastern Snow Conference*.

Page 4 Line 7: What are snow gauges?

Page 4 Line 15-17: How accurate how accurate is the delineation of the pond watersheds- assuming that this was used to multiply the precipitation to get total water volume.

Page 4 Line 28-30: Without a reference it is speculation to say that it is impossible for snowcover formation to be delayed to January.

Page 6 Line 9: Is this not indicative that there is blowing snow processes occurring (specifically sublimation) and this process should be addressed?

Page 6 Lines 11-21: How valid for snowmelt are your eddy covariance observations when SCA is < 1?

Page 7 Lines 2-5: Can one assume that high latent heat fluxes are related to snow surface exchange or could this also be from a separate source like ponded meltwater in non-snow areas?

Page 8 Lines 9-12: This sentence is confusing- please clarify.

Page 10 Lines 13-15: “studies” is plural but only cite one reference?

Page 10 Line 17-20: small scale advection may be limited by the duration of a positive net radiation but the advection flux can still be large, and depending on state of

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snowpack and its SCA, and may lead to significant melt and SCA change. The authors should predicate this point with acknowledgment of this nuance.

Page 10 Line 28-31: difficult sentence

Page 11 Line 3-6: To put this into context of previous research perhaps stick with nomenclature of Granger et al. 1984 who termed this “limited” infiltration.

Page 11 Line 13: Wasn’t this observed. Then why is this speculative with “may”?

Page 11-12 Conclusions: Portions seem to be rather repetitive from the end of the discussion?

Figure 3, 6 ,7: I find it difficult to get meaningful information with these hourly time series plotted for the four stations identified by colour. Hard to differentiate. Would it be possible to plot the total energy balance terms for the specific melt events? Overall figures have a lot of information and superimposed text which make them quite information dense.

Figure 11: this figure highlights that there are significant differences in mid-winter melts across the Canadian Prairies -likely due to the area of influence of chinooks. Perhaps this could be elaborated in the discussion to place these findings in the context of the broader Canadian Prairies and how the influence of mid-winter melts on runoff generation will vary across the region.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., <https://doi.org/10.5194/hess-2018-423>, 2018.