Interactive comment on "Shallow soil moisture - ground thaw interactions and controls - Part 2: Influences of water and energy fluxes" by X.J. Guan, C. Spence and C.J. Westbrook

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Response to Referee #3 Comments (in bold font)

We appreciate the constructive feedbacks provided by Referee #3, posted on 31 March 2010. We acknowledge the Referee's useful comments for improving this paper and these comments will be considered in the final paper.

Response to specific comments:

This paper investigates the influence of water and energy fluxes on heterogeneity in ground thaw in three different subarctic systems (peatland, soil filled valley and wetland). By contrasting these three systems, this detailed experimental study offers an examination of controls on patterns of wetness and ground thaw. The importance of this field study is further development of process-level understanding linked to spatial patterns and will contribute to better model prediction of patterns of shallow wetness and streamflow/watershed modeling in permafrost regions. Quantifying of water and energy fluxes are described in detail but, as identified by the other reviewers, there is no comment provided on uncertainties and whether or not the spatial interpolations in particular might affect the findings. This would be very useful to add. The manuscript is well written. I have provided some detailed comments below where I think clarification for the reader could help and where additional reference to the companion paper may be helpful.

- **More information on the error estimates, assumptions and limitations related to the water budget and Peclet estimates are added and stated more explicitly in the paper.**

Detailed Comments

• Figure 1. Elevation lines are too light to see.

- **Will update to make the lines/labels clearer.**

• p.80, line 20-22. Is both Qgs and Qgp calculated for ponded conditions or does Qgp replace Qgs for ponding (replace, correct?)? Can this be clarified on line 22 (replace and with or?).

- **When ponded, Q_{gp} replaces Q_{gs}. Line 22's "and" should read "or" instead. Corrected. Thank you.**

• Table 1. Brief mention of the methods/locations/depths of characterization for variables included in this table would be nice. Is this included the accompanying paper and if so, perhaps a reference to it would be useful here.

- **Hydraulic conductivity is described in paper 2 (P77L4-8). More Sy information has been added to this paper. Depth is included in the caption. A bit more methods information on the rest of the soil properties have been included.**

• P. 82, line 15. Discussion of contributions of snowmelt – could add reference to Figure 4 here (e.g. 45 mm at the valley site). This would require renumbering figures 3 and 4.

- **Done. Figures 3 and 4 re-ordered.**

• P. 83, line 15. Bedrock runoff is not specifically shown in Figure 4; rather total surface inflow, so the wording of this line is a little deceiving. Reword and remind the reader that we get to see surface runoff (of which bedrock is a component) in Figure 4. Might also be useful to remind the reader that these specific measurements of runoff rates, although at specific sites are being applied to all bedrock outcrops, independent of site. Since so much of the surface inflow occurs during the snowmelt, I am wondering if you don't want to comment on the total amounts (mm) that occurred during this time(the 7 day stretch or so around 28-Apr to 3-4-May) instead of or in addition to the daily max bedrock runoff, as you do later on for the 24-25 June precipitation event.

- **Added line to P83L18 to state more explicitly the curves are total surface inflow. Third point has been added in the section as a data assumption/limitation. Total bedrock inflow values during snowmelt have been added to this section.**

• P. 84, line 9. Text indicates a large decrease in lake discharge during June 7-14 but clearly this is not large enough to clearly see in the cumulative curves in Figure 4. Perhaps this can be reworded to indicate how it is reflected in figure 4 (i.e. during the June 7-14 period, cumulate curve levels out)?

- **The curve leveling out during that week is clearer in Figure 5 and this figure is now referenced in that section. This is not clear in the water budget graph because the inflow curve is shown as 1/100th of actual.**

• Figure 5 shows valley site gets the least amount of surface input but Figure 4 indicates the peatland gets the least. Is there a typo here: should 'valley' read 'peatland' in Figure 4 scaling or am I reading something wrong? When I worked through the scaling, I get surface inflows for peatland (a), valley (b) and wetland (c) of ~ 290 mm, ~ 1400 mm (graph reads ~ 140mm x 10) and ~30,000 mm (graph reads ~ 300mm x 100), respectively. This doesn't line up with p.84, line 10-15 order of magnitude description or Figure 5 where valley site has least surface water inflow. I would also suggest changing wording Figure 4 to read "…surface inflows and outflow values are 1/10th of actual for the valley site). Similar change to next sentence (replace 'at' with 'for').

- **Thanks for pointing this out so we can clarify this. Figure 5 is the volumetric total whereas the Figure 4 values are depth units. The peatland site is larger than the valley site (1.4 ha versus 0.04 ha), although there was less surface input to each of the peatland unit area, when the total site area was used, more water was accumulated in the peatland site than the valley site, volumetrically.**
- **The technical change suggested is corrected.**

• In figure 4, are surface outflow and lake inflow exactly the same or are these cumulative curves slightly different (might be useful to point out to the reader considering they lie on top of each other).

- **Total wetland outflow is 196 mm higher than Lake 690 inflow. This has been added to caption. Same thing done for valley inflow and outflow.**

• P. 86, line 15. This line needs clarification. How was the total ground heat flux calculated for these 'lumped flooded regions'? Does this mean that at low flow Qgw ~ 0 and Q gp was calculated from temperature gradients? But the text indicates Qgw was not necessarily zero. Some confusion here because the text implies uniform treatment of these flooded areas but a range of heat flux values are estimated. Can this be clarified? Also, was this only an issue for the wetland site (paragraph seems to indicate so)?

- **Both Qgw and Qgp were calculated for the flooded area. Instead of an absolute flux, a range was provided instead. If the water was stagnant, then the energy contribution was expected to be lower (i.e. Qgp), and with more moving water, the energy contribution was expected to increase (i.e. P86L17-18 "…the energy from the flooded areas ranged from the Qgp value to the Qgw"). Given the fraction of flooded area was not distinguished between stagnant versus flowing, a range of values was given in section 4.2.1 instead.**
- **This is now clarified in the paper.**
- **Only the wetland site had this issue since the peatland and valley sites had no surface flow after snowmelt (with very small temperature gradient in early spring, Qgw was low during that period).**

• In discussion of the Peclet number (methods, p. 81; and results , p87), it would be useful to explain its application for - rational for applying over uniform site area (soil covered area of each site?). This seems to get lost in the discussion immediately preceding section 4.4.2. where the advective Qgw is described as spatially variable.

- **The Qgs and Qgp equations calculate these flux over one unit area (Equation 13). Whereas, the dF/dt term in the Qgw equation accounts for total energy the inflow water carries. To conceptualize an one to one comparison for conductive against advective forcings and comparing these values among sites, it was simplest to visualize how much conductive energy versus the amount of advective energy may be available to one single grid. This is one of the key motivations to apply the Qgw over the whole area. This was not a big issue for the peatland and valley sites since these sites only had surface flow during snowmelt period and Qgw in this period was very low due to a small temperature gradient. This was not the case for Lake 690 flow over the wetland site, it is now stated more explicitly that surface runoff was never 100% over this site and the given mPe of 1.1 is more accurately >1.1. This has been added to the discussion section for clarification.**

• P.88, line 11-15. I would suggest the authors refer again to the companion paper here on the aspects of the spatial patterns of frost table depth. This would also be useful when discussing the heterogeneity of thaw observed in the peatland (p.89, line 7).

- **Reference to companion paper added. P89L3-7 also briefly recaps the peatland frost table patterns.**

• p.90, line 10-12. When the authors refer to the 'energy-based paradigm', do they mean that in order to fully understand runoff generation in permafrost regions, we need to incorporate the energy-balance as it controls frost table depth, thaw, release of water, spatial variation in storage, etc…? The authors refer to Quinton and Carey (2008) on p71, line 13-20; it might be useful to use the terminology 'energy-based paradigm' here as well.

- **That is correct. Energy forcings including aerodynamic energy and radiant energy are important controls on runoff contribution areas in cold regions. With this close coupling of the energy and hydrological fluxes, a new paradigm is needed to better account for the energy terms. More information added to P71L13-20.**