Interactive comment on "Shallow soil moisture - ground thaw interactions and controls: Part 1: Spatiotemporal patterns and correlations over a subarctic landscape" by X.J. Guan, C.J. Westbrook and C. Spence

Guan et al. (may.x.j.guan@usask.ca)

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Response to Referee #1 Comments (in bold font)

We greatly appreciate the feedbacks provided by Referee #1, posted on 12 March 2010. We acknowledge the Referee's insights for improving this paper. The remarks will be considered in the final version of the paper.

Response to specific comments:

I enjoyed reading this paper on the spatiotemporal patterns of shallow soil moisture and ground thaw and the correlations between them. This paper will be of interest to other readers of HESS as well. It is especially interesting that the authors show the correlations between ground thaw and soil moisture for three different sites (peatland, wetland and soil filled valley) and compare the results from these sites. Very few soil moisture studies have been done in this landscape and I am already looking forward to a paper that describes the soil moisture patterns and the statistics of these patterns in more detail. This paper is well written and the figures are very clear as well. The companion paper discusses the differences in the energy and water balances of the three sites and how they affect the ground thaw depths. This paper contains enough material to be a stand alone paper but unfortunately suffers from a short discussion. Other than the discussion of the results in the T3 concepts (which is very interesting), there is very little discussion, especially on the implications of the results. The authors seem to rely on the companion paper for the discussion instead. However, there is more that can be discussed than how the differences in the water balance and energy balance of the 3 sites affect the ground thaw depths. For example, the authors raise the interesting issue that the landscape is made up of different land-types and that these land-types have different ground thaw depths and soil moisture responses. However, they do not discuss the implications of these results for catchment models or for the upscaling of their results to the catchment scale, even though this scaling issue is mentioned in the introduction (P35L13-16). I think that an expanded discussion would make the paper far more valuable. It would have been nice if the results, especially the spatial patterns were described more quantitatively (and less qualitative) as well (see for example specific comments 5 and 6 but also other locations throughout the text).

- **Good suggestions. More added to the discussion section.**
- **More information added on the implications of the found soil moisture-ground thaw patterns including how the spatial variability affects models and upscaling. Tied this with the T^3 concept since this concept's original use was for catchment scale hydrological processes.**
- **Some more quantitative values have been added to the manuscript (e.g. fraction of wetland flooded and thawed ≥1 m by the end of the study period).**

Specific comments:

#1) Expand the discussion (see general comment above)

- **Thank you. Done.**

#2) P39L1: please expand the description of the TDR probes. Were the two types of probes used interchangeably or each type of probe at one site? Were the UoS probes permanently installed? How many of those probes were there? Add a reference about the UoS probes (if available). How far apart were the repeated insertions of the TDR probes? Do you have information about the repeatability of these measurements?

- **Done, more TDR and precision information added.**

#3) P40L11-14: Move this section to 3.2? It is more a description than a result.

- **Done, moved to end of section 3.3 after SM and FT methods.**

#4) P41L1: What is the significance of listing the number of outliers? These are just extreme sites (either very wet or very dry). The discussion does not mention the differences in the number of extreme sites at all or discuss their meaning/implications.

- **Thanks for pointing out the missing discussion on outliers. Additional information about these outliers has now been added. These outliers did tell us additional information about the sites. The outliers and extreme outliers told us when and where (among the three study sites) more extreme moisture (very dry and very wet) and thaw (very shallow and very deep) values were recorded. For instance, more extreme deep frost table outliers were observed at the wetland and peatland sites than the valley site, which may be related to the wetter conditions observed at those two sites.**

#5) P41L14: Quantify these results. How much drier were they or how much faster did they dry?

- **Done.**

#6) P42L22 and P43L17: Can you quantify this relation e.g. by using a logistic regression? How many of the sites that had frost depth >1 m did not have ponding (and vice versa)?

- **At the peatland site: Thirty-two percent of the total site area was both flooded and thawed ≥1 m in the above periods. Further analysis of only the flooded grids found 83% of the flooded areas had ≥1 m of thaw by mid-July.**
- **At the wetland site: Thirty-four percent of the site was both flooded (28 May) and thawed ≥1 m (8 July). Further analysis of only the flooded grids found 91% of the flooded areas had ≥1 m of thaw.**
- **These numbers have been added now.**

#7) P45L27-P46L1: Another paper from the same group shows that during the summer areas with the deep soils remained wetter (Advances in Water Resources 2006). Therefore in order to be able to state that "...regions without frozen ground and that posses a stable active soil column that show locations of shallow soil can be the wettest (P49L3-4)" you need to add other

references that show that soil moisture in shallow soils is highest or refine this section and the statement in the conclusion.

- **We did make use of the 2006 Adv Water Resources paper by Tromp-van Meervald and McDonnell during the preparation/review phase of this study and it provided a lot of useful information to help think through this particular study relating soil moisture to a number of hillslope characteristics. We did try to avoid making an absolute statement saying in areas without frozen ground, the wettest locations were at spots with shallow soil due to lower storage capacity (i.e. we used "can be", P49L4 rather than "is"). Since the following feedback of wetter soil→ more latent heat transfer to frozen ground→increase ground thaw→increase storage capacity→more water storage→wetter soil→(repeat) is not found in regions without frozen ground, our finding of wetter soil is often found at deeper thaw locations is still correct. Whereas, in regions such as temperate areas, more locations with shallow soil-wetter soil patterns are expected. Lines on P45 and P49 have been edited to better reflect these points.**

#8) P47L26: How is connectivity defined? This connectivity could be described in more detail in the results section. The results sections could describe the spatial differences and spatial patterns in a bit more detail as well (or quantify them more – see also comments 5 and 6).

- **Added a short definition. We did not chase the connectivity question in this paper so we will avoid discussing connectivity too much further since we do not have the geostatistical values.**

#9) Table 1: what caused the number of sites to be different for each survey? Was this due to late snow cover at some sites? Due to soil frost in the top 10 cm? Due to other reasons? Explain in the methods section.

- **Yes, snow and/or <0.10 m of ground thaw at the beginning of the season did not fully bury the full length of the TDR probe in soil and thus no values were recorded. This information has now been added in the methods section.**

#10) Figure 2 and text: Compared to other soil moisture studies, the variability (e.g. the difference between the 25th and 75th percentile) in soil moisture is huge. It would have been nice if this variability would have been mentioned explicitly in the text and described in more detail.

- **P42L9-11 hint at the cause of this large variability observed both at the peatland and wetland sites due to a large difference in soil moisture measured on hummocks and hollows. In combination with the added outlier discussion from above, details about dry hummocks and wet hollows leading to large soil moisture ranges have been added to manuscript.**

It would also be good if these soil moisture values and this variability would have been compared with the results of other peat/wetland moisture studies.

- **A study of a peat plateau in the Northwest Territories, Canada with comparable moisture-thaw processes by Wright et al. (2009) was referenced a few times (e.g. P45L10). The patterns observed at our study sites are more comparable to**

patterned grounds than peat/wetlands lacking the hummocky landscape. Quinton and Marsh have done some extensive studies in hummocky landscapes. One pattern they noted was preferential hillslope runoff through inter-hummock (i.e. hollow) channels (Quinton and Marsh, 1998). These papers are referenced a number of times in the companion paper. But upon reading your comment, it seems appropriate to make mention of this information in Paper 1 too.

It would especially have been useful if it was discussed how this huge variability influenced the results. Would you have found the same relationship between soil moisture and ground thaw for the peatland and wetland if you had split the dataset for these sites in a separate dataset for hummocks and hollows? Do both show the same relation between soil moisture and frost depth? I assume that if you had split the dataset in a separate dataset for hummocks and hollows the variability (of more than 50% for the 25th -75th percentile) would have been significantly reduced. Is that right?

- **The variability can be linked to the correlations described in section 4.3. Even though we found an obvious correlation between water presence and deeper thaw depth, the highest r_s calculated was 0.66 at the peatland site (Section 4.3, Fig. 10a). One explanation for the r_s not being any higher would be the "noise" from the large range of values measured.**
- **If the dataset was split for hummocks and hollows, the range of variability would decrease and give different correlation between moisture and thaw. Both papers do give quick points indicating hummocks behave differently from hollows. To place more focus on intra-site comparison, the hummock and hollows at the peatland and wetland sites were not separated.**

#11) Figure 2: Are sample sites with frost depth >1 m also excluded from the soil moisture figures?

- **All soil moisture values were kept. This information is now more clearly stated in the caption.**

#12) Figures 3-8: It would be nice if there was a scale on these figures (and a north arrow) as well

- **The caption for each of those figures indicate the size of the cells and there is already one north arrow for each figure (bottom left corner).**

#13) Figure 9: Explain in the caption that points with a frost table >1 m were excluded from the calculation of the medians and that the medians are thus biased to the points with shallow frost tables

- **Caption has been updated to note all frost table ≥1 m were excluded from the median calculations to focus on shallower thaw locations.**

#14) Figure 10b: How is this result influenced by the decision to take out the points with deep soil thaw and thus calculating the correlation between a different number of points and progressively biasing it to drier sites/shallow soil thaw sites? Or is there very little bias because as the season progressed and the thaw depth increased, the correlation between soil moisture and thaw depth became poorer for the peatland and

wetland sites with deep thaw? It would have helped if there was a very short discussion about this bias in the text so that the reader is not left wondering how much bias there is in the results.

- **One of the primary reasons frost table depths ≥1 m were removed was the decoupling between shallow moisture and deep thaw. Removing those points did add some bias to sites thawed less than 1 m (and at some locations, were drier), but it was necessary to omit the deep locations for our study purpose. Deep locations would be more controlled by other processes (e.g. groundwater flow, briefly discussed in Paper 2, P91L1). A brief discussion has been included now.**

#15) Figure 12: How were the locations of the three sites on this figure calculated? Are they estimated based on the results and thus represent a rough ranking rather than a clear measure of the 'actual roles'? If so, it would be good to mention this in the caption.

- **The locations were based on approximate ranking from our results. This information has been added to the caption.**

Editorial suggestions:

- **Thank you. All accounted for now.**