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Interactive comment on "Modeling the spatio-temporal variability in subsurface thermal regimes across a low-relief polygonal tundra landscape" *by* J. Kumar et al.

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Comment by Adam L. Atchley, Dylan R. Harp, Ethan T. Coon, Cathy J. Wilson

The authors present an impressive modeling effort investigating 3D water and energy simulations of polygonal tundra. Their research is of interest to the community as it undoubtedly yields insight into the thermal hydrology of polygonal tundra. Furthermore, a modeling effort informed by extensive field measurements provides a unique opportunity to validate and properly shape the process rich models currently being developed for terrestrial Arctic applications. It is for this particular reason, that we are first interested in this manuscript and second concerned with the message in section 5.1. In particular, we refer to line 2-3 on page 25, "At our study sites, while calibration may

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Discussion paper

compensate for lack of data, it does not improve our understanding of the system."

In section 5.1 the authors provide reasons for not calibrating the model to the observed data available at the study site, specifically that process rich models have high degrees of freedom and therefore are plagued with non-uniqueness (equifinality). In other words, there are multiple combinations of parameters, or more generally model structures (Beven, 2006) that can produce optimized results which fit observed data equally well. While the authors do not quantitatively demonstrate the existence of equifinality here, non-unique parameter combinations certainty exist in this situation, as has been systematically identified for thermal hydrological models at the same site by Atchley et al. (2015) using multi-try calibration and rigorously quantified by Harp et al., (2016) using Null-Space Monte Carlo. However, it is our understanding that the literature addressing equifinalty does not argue for giving up calibration as a lost cause, but rather strongly suggests that additional efforts are required to account for a set or distribution of parameter combinations consistent with observations (e.g. Vrugt et al., 2009, Vrugt and Ter Braak, 2011; Bárdossy, 2007; Tonkin, 2009) and model structural error (Beven, 2005; Clark et al., 2008; Fenicia et al., 2011; Larson et al., 2014). The research behind calibration and model optimization has long since evolved from simple parameter fits to more strategic calibration methods (Hill, 1998). Therefore, we believe that equifinality does not provide a justification to avoid calibration, especially if the objective of the modeling exercise is to improve understanding of system and model behavior. On the contrary, it has been our experience that, while difficult, time-consuming, and computationally expensive, extensive, systematic multi-try calibration can yield important system understanding and identify model capabilities and limitations. The work presented in Atchley et al., (2015) at the same site at the Barrow Environmental Observatory, shows that systematic multi-try calibration can be used as a tool to reduce model structural error and achieve system understanding. For example, calibration efforts led to the recognition of the importance of the representation of snow distribution and depth hoar formation in our models. These insights are not simply better model parameters, but are physical representations of system components;

this effort led to better system understanding. Furthermore, quantifying the equifinality of the combined model and represented system then allows for quantification of model uncertainty, where for example the projected ALT uncertainty attributed to parameter uncertainty can be measured and compared to meteorological and/or climate model uncertainty (Harp et al., 2016). Moreover, the parameter sensitivity quantified by such exercises has, in our opinion, provided valuable information for reducing model uncertainty. Porosity and material thermal conductivity measurements are shown to have the greatest potential to reduce projected ALT uncertainty (Harp et al., 2016), thereby directing which additional field data and process understanding are necessary to reduce uncertainty.

In the context of the model presented in this manuscript, we realize that exhaustive model calibration may be computationally infeasible, and we also do not over look the valuable contribution presented here as the 3D representation of energy and water fluxes in freeze-thaw polygonal tundra indeed pushes the boundaries of process-rich mechanistic modeling. Therefore, it is not our wish to force model calibration and parameter sensitivity analysis on the current manuscript. However, we strongly encourage the authors to reconsider the stated view of model calibration and to discuss how calibration and parameter sensitivity may provide insight into model performance as well as system understanding in polygonal tundra.

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