Anonymous Referee #3

J. Kumar et al. presented a pilot study using PFLOTRAN model to investigate the role of micro-topography in soil thermal dynamics of different types of ice-wedged tundra, which is important for further studying the responses of large-amount of frozen soil carbon to warming. Field measurements were provided for parameterization and validation. Therefore, I think the topic is important and the method is appropriate .

The 3-D modeling is computing-intensive, it is hard, if not impossible, to be coupled in large-scale climate or terrestrial ecosystem models to investigate the effects of fine scale heterogeneity. Meanwhile, it is well-known that micro-topography of ice-wedged tundra ecosystem plays an important role in redistribution of surface water and vegetation growth. Therefore, the manuscript should focus on quantitatively assessing the role of micro-topography in soil thermal dynamics by comparing sensitivity tests with and without 3-D heat transfer.

We agree with reviewer comments. While the role of micro-topography in tundra ecosystem, effort to develop high resolution process based models for these processes have been limited in the literature. In the presented study we have developed a framework for numerical rigorous high resolution modeling of hydrologic processes. We have demonstrated the ability of the models to capture the effect of micro-topography. We have presented qualitative and quantitative results for a set of simple case studies. Our study provides the base framework to make possible the further detailed analysis suggested by the reviewer. We are actively working on these issues and will report the results in future publications. And we also have made our best effort to archive and publicly release all source codes, workflows, and input/output data sets from the study to allow others interested in conducting such studies.

Unfortunately, the manuscript reached two main conclusions: 1) the 3-D modeling can properly simulate the soil thermal dynamics under the complex micro-topography, which is good; and 2) microtopography is important, which is already known without the 3-D modeling.

The role of microtopography in tundra ecosystems has been studied primarily through field-based investigation. Modeling studies using traditional 1D approaches have been focused around particular sites and thus may or may not be extensible and/or applicable to new or larger regions of interest. The 3-D modeling approach developed in our study enables the modeling of these processes from first principles using a microtopography-resolving model. Patterns due to polygonal microtopography emerge in the model organically, without explicit spatio-temporal flow patterns defined in the model. This enables such studies in any region of interest where high resolution DEM are available to capture the topography in the model. We believe this is key and a new contribution of the presented work beyond published literature.

I believe the authors can do better work with this 3-D model and provide readers more informative results than the current one. I do not recommend publication of the manuscript in the current form.

I would suggest the authors to split the manuscript into two since there were already too much content in the current manuscript. The first deals with model description, model validation and detailed sensitivity tests on only one of the four sites. The second manuscript then deals with differences among different types of ice-wedged tundra ecosystems and upscaling to larger regions.

We thank the reviewer for suggesting a set of analysis where the presented 3-D modeling framework can applied to gain important insights. Under the NGEE-Arctic project we have been working on addressing these questions. However, it's a multi-faceted and complex problem that requires a series of designed steps.
The presented study is the first key step towards that goal and is focused on developing an end-to-end modeling framework to simulate the thermal flow processes in this micro-topographic environments. We applied the methodology at four different study sites of interest and developed methods to synthesize and use the best available data for a field scale study. We have identified a number of key processes and analysis that are needed but were not included but are subject of ongoing work and will be reported in the future.

In close coordination with observation team we currently are working on addressing the data gaps identified in our study which would allow us to conduct a watershed to regional scale application of our framework at Barrow, Alaska.

While we agree with and are working on majority of analysis suggested by the reviewer, we believe we have designed our steps slightly different. The presented approach is our first step that provides us with the numerical framework to conduct the other investigations.

More specifically, I would suggest to do the following model runs on one site in the first manuscript: 1) shut down the lateral heat flow in the 3-D model and compare the results with those using fully 3-D heat transfer. This work is to demonstrate the importance of lateral heat exchange; 2) in one simulation, use the same soil texture for all microtopography positions, e.g. rim and center. Compare results with different soil textures; 3) prepare future climate data using GCM outputs under different scenarios. You might also need to convert atmospheric driving to near surface soil temperatures for different micro-topographic components. The long-term simulating might reveal some modeling issues, e.g. lateral boundary conditions; 4) implement different amount of

excess ice in soil column to test whether excess ice causes disagreement between simulated or measured soil temperatures.

We would also like to highlight a number of recent studies conducted by our NGEE-Arctic colleagues that complement ours and address some of the suggestions identified by the reviewer. Atchley et al. 2015 conducted a comprehensive 1-D model based calibration study at Site C and identified limitations due to lack of lateral flows that can be addressed by a 3-D model. Harp et. al 2016 extended the work of Atchley et al. 2015 to conduct a Null-Space Monte Carlo method based systematic uncertainty analysis to quantify the effect of soil property uncertainties on permafrost thaw under CESM projected RCP 8.5 scenario from year 2006 to 2100. Findings from their study would help guide the parameterization in our model.