Impacts of microtopographic snow-redistribution and lateral subsurface processes on hydrologic and thermal states in an Arctic polygonal ground ecosystem [MS no. gmd-2017-71]

RC1: 'Review of the manuscript by Bisht et al.', Anonymous Referee #1

General comments:

Manuscript by Bisht et al. presents simulation results in an Arctic polygonal ground ecosystem using an improved ALM model including lateral processes and snow redistribution. The conclusions are partly supported by modeling results, e.g., 1) snow depth variation was affected by snow redistribution, but not by lateral processes of thermal flow, 2) active layer depths was affected by lateral energy fluxes. Like many others, this work again stresses that advances in the land surface modeling is needed. In fact, the simple snow redistribution approach in the paper can be readily incorporated into land models.

My main reservations are the selection of the 2D transect and model validation. Why the transect is not selected where the sensors (as shown In Figure 1) are located? It makes the comparison between the model and observation meaningless.

Response:

We acknowledge that the 2D transect used for simulations in this study does not align with the sensor location. The objective of this work was not to validate the model for the few grid cells that exactly align with the observations recorded in the rim and center of a polygon, but to quantify relative differences between simulations for rim and center of a polygon. As noted in Figure 2, all grid cells above the dashed line were classified as rim, while all grid cells below the dashed line were classified as center. The model accurately captures the snow depth differences between rim and center when SR is turned on (Table 1). Additionally, errors in simulated temperature for all soil depths are lower for rim and center when SR is included (Table 2). Thus, our comparison of model results against observations is reasonable and the comparison we present indicates the model accurately represents system characteristics important for the conclusions of our paper.

Specific comments:

1) Lengthy texts in the Introduction that are not directly related to the study.

Response:

We have removed text in introduction describing changes in NEP within Arctic ecosystems as simulation in this work did not have an active biogeochemistry cycle.

2) Line 100-101: define "active layer thickness" for general readers.

Response:

We have added a definition for active layer thickness.

3) Line 126: define ALM.

Response:

We have updated the text to define ALM.

4) Line 158-160: redundant as already described in lines 126-128.

Response:

We have updated the text to remove redundancy.

5) Line 169: check unit of Q.

Response:

The units of Q have been corrected to [m^{-3} of water m^{-3} of soil s^{-1}]

6) Define z in Eq. 2 and other variables in Eq. 4.

Response:

All terms in Equation 2 and 4 are now defined.

7) Eqs. 17 and 18, check the third term on the RHS.

Response:

Third term in equation 17 and 18 is updated.

8) Eq. 23: write cn as ci,j,k

Response:

In equation 23, c_n is now defined as $c_{n_{i,j,k}}$. Additionally, equations 25-32 have been updated.

9) Define ω' in Eqs. 25-31

Response:

In equation 25-31, ω' is now replaced by $1 - \omega$, where ω is defined as the weight in the Crank-Nicholson method.

10) Line 312: from Fig. 2, I see less dependence of average snow depth on topography with SR.

Response:

We have fixed the typographical error and the text now reads "*With SR, a much <u>smaller</u> dependence of winter-average snow depth on topography is predicted*"

11) How well is the 3D model developed in the paper compared to analytical solutions or other well established numerical models?

Response:

In this work, we extended the existing 1D physics formulations for subsurface hydrologic and thermal processes to included lateral processes. Thus, we did not compare existing physics formulations against analytical solutions or other numerical models, but we did ensure that lateral coupling was implemented correctly. Sanity checks were preformed to ensure the 3D model solution is the same as in the 1D vertical model when the problem setup is horizontally homogeneous (Results not shown).

The thermal model is independent of gravity. Thus, additional tests were performed to ensure the numerical solution of the thermal model for propagation of heat is identical in a 1D column that is oriented horizontally and vertically. A test was performed to study the propagation of a heat perturbation that was applied on the left and top boundary of a spatially homogeneous 2D domain (Figure 1, below). The difference of simulated temperature between the two cases was of the order of the tolerance of the numerical solver (Figure 1c). An additional test was performed in which a sinusodially varying temperature perturbation was applied on the left and top boundary; and the difference in results was again within tolerance of numerical solver (Figure 2). These tests ensured that lateral coupling was correctly implemented within the model. To address the reviewer's concerns regarding testing, we have added description of these analyses to the Supplementary Material (Page 2, lines 18-40, and a reference to these tests has been added to the main text (Page 12, lines 241-244).

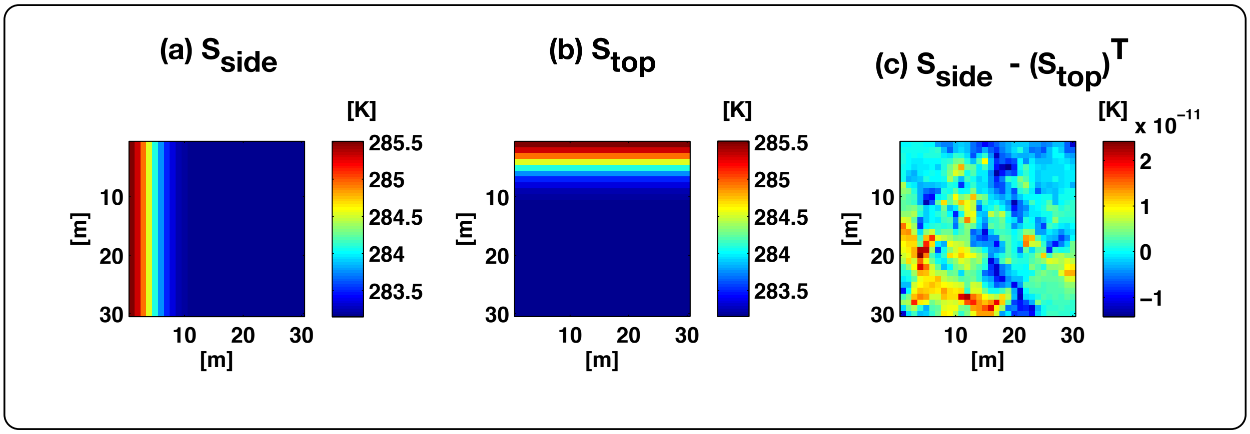

Figure 1. Propagation of a spatially homogeneous temperature perturbation applied on the (a) left and (b) top boundary of a spatially homogeneous 2D transect at the end of 1-day. (c) The difference in evolved temperature between two cases is many orders of magnitude smaller than the predicted states.

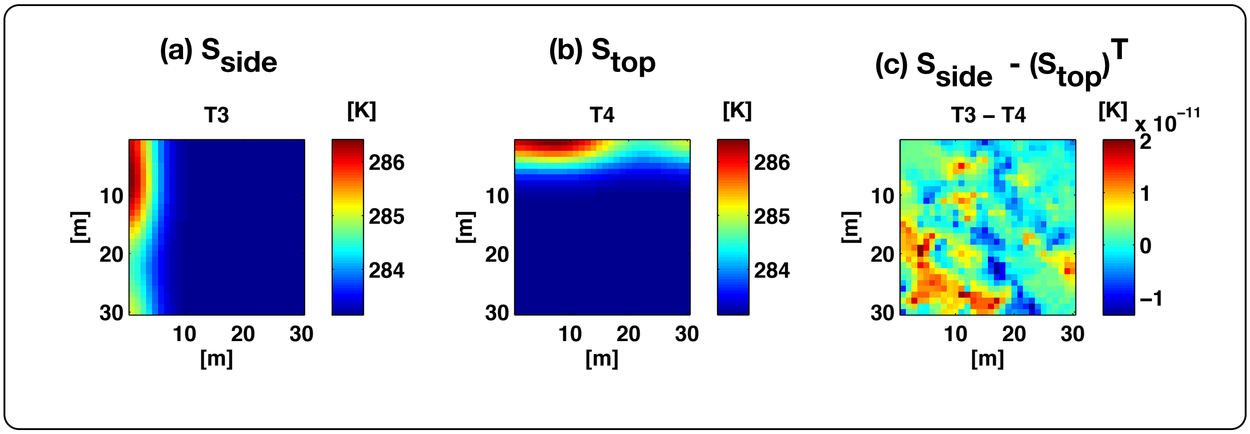

Figure 2 Same as Figure 1 except a sinusoidally varying spatial temperature perturbation is applied.

12) Where are the locations of center and rim in the model simulations? Fig. 1 shows two snow sensors and five temperature sensors. At what locations are the simulation compared to the corresponding observations?

Response:

The dashed line in Figure 2 classifies the 2D transect into rim and center. All grid cells that have surface elevation above the dash line are classified as rim, while all grid cells below the dashed line are marked as center.

13) As the authors noted on line 246 that PETSc is a scalable solver, so what is constraining the 3D simulation (statement on line 447)?

Response:

ALM is embarrassing parallel and has no cross processor communication because it is a 1D, vertical-only model. Even though PETSc is a scalable solver, the current implementation of the 3D model is serial. Thus, our model is capable of solving a 3D problem on each processor independently but unable to solve a parallel, 3D problem. We have updated the text in Section 3.5 (Page 19, lines 443-447) to clarify this point.

14) Because of the computational constraint, I don't agree with the last statement on line 510-512.

Response:

We have updated the text to reflect that the current model is serial (Page 19, Lines 444-445). Even though the current version of the ALM-3D model is sequential, we believe it would be very useful for applications in the Earth System Model context. One potential future application would be to solve 3D subsurface hydrologic and thermal processes within a watershed. To this end, the domain decomposition of ALM in future versions could be modified such that all grid cells within a watershed are assigned to a single processor. In such an application, ALM-3D v1 would be an appropriate candidate.

15) Figure 1: what's the legend? DEM?

Response:

The legend indicates the height in meters (now added to Figure 1).