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]

RC2: 'A useful contribution', Anonymous Referee #2

General remark. The framework of the paper is Earth System modeling. The authors implement small-scale snow redistribution and 3D soil physics (2D in the setup used here). The results show that a simple snow redistribution parameterization based on microtopography has a very beneficial effect on a range of simulated variables. This is very nice. However, I think that the paper almost entirely misses a thorough discussion of an implementation strategy for these development in the ultimate context of Earth System modeling. This will happen on much larger spatial scales.

How will you move from an explicit fine-scale representation to a sub grid implementation? Will the choice be only to include snow redistribution (i.e. aren't there already enough results to decide that a 3D soil physics will be an overkill in the Earth System modeling context)? Will the model have two tiles (polygon centers and rims), with snow being shuffled from one tile to the other? Or is the whole thing probably going to be more complex, with an explicit modeling of 3D soil physics supposing an idealized polygon of some finite size? What will be done if the model domain does include areas that are not polygonal tundra (it's supposed to be a global model if I understand correctly)?

Response:

This study is a necessary first step of documenting the role of fine scale processes associated with microtopography and lateral redistribution of water and energy in the subsurface. We acknowledge that a development of a sub grid structure to parsimoniously capture impacts of microtopography and lateral subsurface processes on coarser grid scale is a worthy scientific research, but such a new development is beyond the scope of the current work.

However, here are some thoughts on possible approaches to parsimoniously include fine scale processes. As suggested by the reviewer, investigate how accurate is a two-tile

approach as compared to explicitly modeling the transect when snow redistribution is accounted for within the model. Additional simulations will be needed to investigate how well the two-tile approach performs when biogeochemical cycling is included. Exclusion of lateral subsurface processes has a greater impact on predicted subgrid variability than on spatially averaged states. Thus, one possible extension of the current model would be to explicitly include an equation for the temporal evolution of sub grid variability of using the approach of Montaldo and Albertson (2003). The use of reduced-order models as described by Pau et al. (2014) is an alternate approach to estimate fine scale hydrologic and thermal states from coarse resolution simulation. We have added discussion of these topics to the Discussion section (page 20, Lines 468-4477)

If there are issues with computing time already in a 2d setting, is it realistic to go to 3d?

Response:

Moving beyond a 1D land model to a 2D/3D model will certainly increase the computational cost of the simulation. However, the land component is typically the least expensive component of an Earth System Model. ALM is less than 5% of the total computational cost of a fully coupled ACME simulation (ACME Performance team, personal communication, May 25, 2017). Even though there is some leeway in increasing the computational cost of the land model, the need to include higher spatial dimensional processes in land surface models has been made by many studies (Chen et al. (2006); Kim and Mohanty (2016); Maxwell and Condon (2016)). Lateral subsurface processes can be included in the land surface model via a range of numerical discretization approaches of varying complexity such as adding lateral flux of water and energy as source/sink term in the existing 1D model, implementing an operator split approach to solve vertical and lateral processes in a non-iterative model, or solving a fully coupled 3D model. Increased computational cost is not the only factor limiting application of ALM-3D to a global simulation. The subgrid hierarchy structure of the land model, which presently does not have any topological information, needs to be updated to include lateral connectivity. We have added some Discussion on theses topics to the revised version (Page 20, Lines 477-483).

Some words on validation/tests on larger scales?

Response:

Model validation is an integral part of model development. Ongoing projects of the U.S Department of Energy such as the NGEE-Arctic (https://ngee-arctic.ornl.gov) and the NGEE-Tropics (http://ngee-tropics.lbl.gov/) are expected to provide a wide range datasets related to land surface model at regional scales. Additionally, the Distributed Model Intercomparison Project Phase 2 (DMIP 2) provides a comprehensive datasets and modeling protocol for benchmarking distributed hydrologic models (Smith et al., 2012) and estimates of water table depth at global scales are available from Fan et al. (2013). Our future work will focus on application and validation of ALM-3D at regional scales. We have added some discussion of these issues to the Discussion section (page 20, Lines 483-486)

Answers to some of these questions might be pretty obvious, but I nevertheless think that a proper discussion of these and other related questions is required.

Response:

We added text in the discussion section that answers all of the questions raised by the reviewer.

Specific comments.

- L.24 : "Three ten-years long simulations" : Is that good English?

Response:

The text has been modified to “Multiple 10-years long simulations”

- L.55 : "Xu, 2016#154"

Response:

The incorrect citation has now been removed in the updated version of the manuscript.

- L61: The reference to Friedlingstein et al., 2006 is good but there has been quite some work on this more recently. In general, there are very many pre-2007 references and much less after that period. Maybe the bibliography could be a bit updated. For example, in line 78, the review by Schuur et al. in Nature 2015 might be worth citing.

Response:

- L.166. "The flow water" -> "The water flow" or "The flow of water"

Response:

The text has been updated to ‘The flow of water’.

- L. 198. I suggest to clarify the writing here. What about this: ". . .. zeta is the diagonal entry of the banded matrix (eq. 11-17)", then provide eq. 11-17. Then: "small phi is a column vector given by:", then put eq. 18. I think that would be clearer.

Response:

As per reviewer suggestions, description of equations 11-18 has been separated into a description of equations 11-17 followed by a description of equation 18.

- The same applies to eqs. 25-32. Separate eq. 32 from 25-31. I think that eq. 28 should read "eta=..." (not "mu=...") and eq. 29 should read "mu=..." (not "xi=...")

Response:

As per reviewer suggestion, description of equations 25-32 has been separated into two. Additionally, equations 28 and 29 have been correctly updated.

- Line 232: Please say clearly that this means that there is no geothermal heat flux represented in the model.

Response:

The text updated to explicitly state that geothermal heat flux was not accounted for in this work.

- L. 261: "to simulate SR", not "to simulated SR"

Response:

The text has been updated.

- L. 273: "its", not "it’s"

Response:

The text has been updated.

- L.277: A broken link to some internal reference. same at line 328, 342, 343

Response:

All broken references have been updated.

- L. 285: with do you put the dimension meters in square brackets?

Response:

Square brackets have been removed.

- L. 289: "SP mode": that’s an internal nickname. Its meaning becomes clear at the end of the paper ("satellite phenology") but this is not required here. Either explain the acronym of leave it out.

Response:

Text has been updated to explain the acronym.

References

Chen, Y., Hall, A., and Liou, K. N.: Application of three-dimensional solar radiative transfer to mountains, Journal of Geophysical Research: Atmospheres, 111, n/a-n/a, 2006.

Fan, Y., Li, H., and Miguez-Macho, G.: Global Patterns of Groundwater Table Depth, Science, 339, 940-943, 2013.

Kim, J. and Mohanty, B. P.: Influence of lateral subsurface flow and connectivity on soil water storage in land surface modeling, Journal of Geophysical Research: Atmospheres, 121, 704-721, 2016.

Maxwell, R. M. and Condon, L. E.: Connections between groundwater flow and transpiration partitioning, Science, 353, 377-380, 2016.

Montaldo, N. and Albertson, J. D.: Temporal dynamics of soil moisture variability: 2. Implications for land surface models, Water Resources Research, 39, n/a-n/a, 2003.

Pau, G. S. H., Bisht, G., and Riley, W. J.: A reduced-order modeling approach to represent subgrid-scale hydrological dynamics for land-surface simulations: application in a polygonal tundra landscape, Geosci. Model Dev., 7, 2091-2105, 2014.

Smith, M. B., Koren, V., Reed, S., Zhang, Z., Zhang, Y., Moreda, F., Cui, Z., Mizukami, N., Anderson, E. A., and Cosgrove, B. A.: The distributed model intercomparison project – Phase 2: Motivation and design of the Oklahoma experiments, Journal of Hydrology, 418, 3-16, 2012.