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Interactive Comment

Interactive comment on "An improved representation of physical permafrost dynamics in the JULES land surface model" *by* S. Chadburn et al.

S. Chadburn et al.

S.E.Chadburn@exeter.ac.uk

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We thank the referee very much for her/his comments. Please find below our response and updated text.

Response to general remarks

1. In order to see how the model behaves across different climate conditions and soil types we have performed large-scale model simulations. We have then compared these simulations with available observations, to see whether the model captures the overall patterns of soil temperature and thaw depth. We see that it is able to do this a lot better with the model improvements. The results from these simulations can be found

in the following discussion paper: http://www.the-cryosphere-discuss.net/9/1965/2015 The observations with which we compare are pan-Arctic and cover wide areas.

2. I agree that Section 2.2.5 was a bit confusing. When the soil column depth is extended, there is an extension both of the ordinary soil column to 10m and the addition of the bedrock column as well. I have therefore moved this section to come immediately before the description of bedrock (Section 2.2.3) and added the following paragraph: "In this last case, soil column depth is increased even further by adding an extra column to the base of the hydrologically active column, to represent bedrock. This bedrock column adds another 50 m, bringing the total soil column to 60 m. See Section \refsec:bedrock for details."

This then leads on to the next Section describing the bedrock code.

3. In the abstract I have added a short sentence, following the sentence "The thermal and hydraulic properties of the soil were modified to account for the presence of organic matter, and the insulating effects of a surface layer of moss were added, allowing for fractional moss cover." I have added: "These processes are particularly relevant in permafrost zones." More significantly, I have re-written the conclusion to make this point clearer. Here is the new text:

"Improvements have been made to the physical representation of permafrost in the JULES land-surface model. Additional processes represented include an insulating moss layer, the physical properties of organic soil, and a bedrock column. In addition, the representation of snow and discretization of the soil have been modified.

These developments are extremely relevant for the Arctic in general, since soils in the continuous permafrost zone are often organic-rich and covered by moss, which is certainly the case at Samoylov Island, where we run the model simulations. It is therefore important to include these processes in global land-surface models.

In the simulations, soil temperatures and active layer thickness (ALT) are significantly improved by the model developments. Firstly, increasing the model depth and resolution is necessary to correctly simulate the physical processes. It has been shown that a shallow soil column cannot give realistic permafrost dynamics, see eg. \citelawrenceetal2008, and a high enough resolution is required to correctly solve the physical equations. Once this basic function of the model has been improved, including the new, permafrost-relevant processes of organic soils and moss leads to a great improvement in summer soil temperatures. The RMSE in summer soil temperatures decreases from 4.0°C to 0.7°C, and the ALT reduces by 0.7 m to fall within within 0.1 m of the observations. This suggests that the most important processes for the summer have been included.

In the shoulder seasons, the zero-curtain duration is strongly related to soil moisture. This requires further work in JULES, as the model does not obtain the saturated conditions observed in the field. The relevance of this is seen by fixing the soil moisture in the '*saturated*' simulation, which alters the timing of freeze-up from 30 days to only 13 days too early.

Snow is the most important process for winter soil temperatures, which can be seen here by the high correlation (0.85) between soil temperature error and snow depth error in the winter months. Soil temperatures are particularly sensitive to shallow snow, hence our improvement to the snow model is essential for simulating soil temperatures in the shoulder seasons. The snow on Samoylov Island is shallow and highly wind-blown, which is typical of these low-lying tundra regions. We find that the fresh snow density required to obtain the correct mid-winter snow density in JULES is too high, indicating a need for further work, potentially to include more snow compaction processes.

Another area for future development is the vegetation, since there are currently no specific high-latitude PFT's in JULES. The moss cover represented here is a first step towards simulating tundra vegetation, however this represents only the physical effects of a constant layer of moss, leaving more work to be done, for example on growth, carbon cycling, and on other types of vegetation.

We believe that we have significantly improved the representation of permafrost processes in JULES, providing generic model improvements that could be adopted in other GCM land-surface schemes. However, this is still a work in progress for the whole community. Even if a model simulates the right processes in a 1D column, scaling these up to represent sub-grid heterogeneity in a large grid-box is still an open problem \citepmusteretal2012,langeretal2013. In most global land-surface models, only vertical processes are simulated, meaning the lateral flow of heat and water, and blowing snow are all omitted. Techniques to include these processes are currently under development \citep[e.g.,][]tianetal2012,esserypomeroy2004,yietal2014. Of course on the large scale, models are still heavily constrained by the availability and uncertainty of observational data."

Specific remarks

Page 727, line 5: The formulation "based in ERA40" is at least misleading. ERA40 data is only available from 1958, so no data for the period 1901-1957 can be based on ERA40. Please reformulate. The period prior to 1958 does also use ERA40 data: random years of ERA40 data are used to construct a timeseries, and monthly bias-corrections are then applied based on observed data from 1901-1957. I have clarified this in the text.

Page 728, line 12: remove brackets. Done.

Page 729, line 2: Replace "futher" with "further". Done.

Page 729, line 23: Labelling the standard mineral soil case with "std" is not a good idea, as most readers will connect this abbreviation with some kind of standard deviation. I agree - I have changed the label to 'min4l' (meaning mineral, 4 layer) throughout the paper.

Page 732, line 17: What is the rational for using a depth of 32 cm? This number is *presented somewhat unexpectedly to the reader.* 32cm is the depth for which observations are available that is closest to the depth of one of the JULES model layers, thus it can be compared without interpolation and the extra uncertainty that this would bring.

Page 732, line 22: Replace "shows" with "show". This was the case in my uploaded version and changed during typesetting but I will make sure it is correct in the final version!

Page 733, lie 10: "as large as". Good point. Done.

Page 734, line 1: "which is about. . .". Done.

Page 742, line 25: Is this the correct reference? Shouldn't ECMWF (2009)in the main text refer to ERAInterim? You are right, this is the wrong citation. I have put the correct one into the bibtex file.

Interactive comment on Geosci. Model Dev. Discuss., 8, 715, 2015.