Comments on "Projecting circum-Arctic excess ground ice melt with a sub-grid representation in the Community Land Model" by Lei Cai et al submitted to The Cryosphere.

General

Permafrost soils usually contain large amount of ground ice. Its melting has significant impacts on infrastructure, landscape and hydrology. Ground ice also affects the timing and speed of permafrost thaw. This paper modelled the effects of ground ice on permafrost thaw using a sub-grid representation in the Community Land Model. They first test the implementation in Lena River delta. It shows that using three land units of different ground ice provides more realistic results than using one average ice land unit. The modelled thawing depths also very different among the three land units and from using the average ice content. Then they implemented the representation across the circum- arctic region using four land units (no ice, low, mid and high ice) and compared with the results using average ice content. The results shows more realistic pathways of permafrost degradation and a different total area with permafrost comparing to using average ice. The circum-arctic excess ice data are rough, the CAPS dataset is a very broad generalization of the complex ground ice conditions and how to use the dataset is not straightforward. However, this study does show some progress to include ground ice in a more realist way than previous studies (no excess ice, or using average for an entire grid) and it provides a general range of the large-scale impacts of such sub-grid differences. The paper is well prepared in language and figures.

Authors' reply: Thank you very much for your valuable comments. We agree that the rough excess ice dataset is the main challenge when we conducted this study. Unfortunately, the CAPS data is still the best excess ice data available on the global scale although it was released more than 20 years ago. In this way, we have to design a tiling scheme to fit the CAPS data into the sub-grid framework we developed, which is not straightforward and contains fairly empirical estimates on excess ice contents and located depths. Although with the challenges on the initial condition of excess ice, we manage to convey through this manuscript that a sub-grid scale modeling of excess ice in the global land models is necessary for retrieving the permafrost dynamics in the circum-arctic regions, and we have had the modeling tool prepared before the new generation of excess ice dataset becomes available.

Major points

The test study shows very different active-layer thicknesses among the three land units and from the one-unit with average-ice (Figure 4). The paper did not provide much about the results of active-layer thickness for the circum-arctic modelling. It would be important to add this part in the results and analysis. Observations on ground subsidence is sparse and highly depend on the local conditions. An improved modelling of active-layer thickness would provide some support evidence about the usefulness of including excess ice in sub-grids.

Authors' reply: The reason we did not mention the difference of active layer depth brought by the excess ice in the global case is that it is somewhat complicated because of a technical rather

than scientific reason. Theoretically, the presence of excess ice makes the permafrost thermal regime more stable and a shallower active layer. However, it does not always show in the modeling case, because the model initializes soil into discrete layers that are with different thickness. For most land models, the thickness of each soil layer is not the same from top to bottom. Usually, deeper soil layers are also thicker. In the original soil set-up of the CLM5, the typical soil layer thickness for the depth between 0.5 to 1 meters is 0.15 meters, while that for the depth between 3 to 4 meters is more than 0.5 meters. In this way, for the regions with a thicker active layer (e.g. > 2 meters), the presence of excess ice is not associated with a shallower active layer simply because the above soil layer is too thick (which also means the chunk of soil is bigger) to make the stable thermal regime distinguishable. We have now added some discussion in the main text to give readers some more insights.

"Compared to the grid average ice case, even more permafrost areas are sustained in the subgrid ice case" (Line 313-314). However, Figure 9 shows the permafrost area difference between sub-grid case and no ice case is similar to the difference between the average ice case and no ice case before the 2050, after that the latter reached about 1 million km2. That means the permafrost areas under average ice case and sub-grid ice case are similar before the 2050s. After that, the modelled permafrost area under average ice case is larger than under sub-grid ice case. In the last two panels in Figure 7, the shaded area in the second panel seems larger than the second panel. That is not consistent with the results in Figure 9. Not sure whether my understanding is correct. Any way, it would be useful and interesting to provide more explanation and analysis about the differences among these three cases (no ice, average ice and sub grid ice).

Authors' reply: In figure 9, we compared the actual area of permafrost in the sub-grid scale. For example, for a certain grid point with a total area of 0.2 million km2, only a landunit with 20% area weight has permafrost remaining (ALT <6.49 m). Then the area of permafrost for this grid point is 0.02 million km2. But in figure 7 and 8, we compare the permafrost degradation on the grid scale. In figure 7, the complete degradation of permafrost refers to the condition that all the sub-grid landunits in one grid cell are without permafrost. In figure 8, a grid cell is considered "discontinuous permafrost" if some landunit has permafrost while some others not. We have added more content in the figure caption to prevent misunderstandings.

The data about ground ice is rough and how to use the current data is based on some assumptions or artificial choices. It would important to indicate that uncertainties more clearly in the text (the paper already indicated that at different places).

Authors' reply: We have added more discussion on the uncertainty because of the excess ice initialization.

Minor points

Line 28-29: delete “enhance” or “improve”.

Authors’ reply: We have made the change as you recommended.

Lines 42-44, “The existence of excess ice and its distribution in permafrost can significantly affect the rate of permafrost thawing”. It would be useful to add some references here.

Authors’ reply: We have added more references.

Line 58: “over generations”. It seems strange to say model versions as “generations”. It would be clearer to say “in recent years” or so.

Authors’ reply: We have made the change as you recommended.

Line 67: “Separate from this”, revised to “In addition”

Authors’ reply: We have made the change as you recommended.

Line 71-74. Check the grammar for this long sentence.

Authors’ reply: We have checked the grammar.

Line 74-95: “the depth distribution of ground ice can vary substantially on the order to 10-50 meters horizontally 75 and 10 meters vertically”. Is the depth to the top of ground ice or also including the thickness of ground ice? Probably you want to say both. Check and consider revising the sentence.

Authors’ reply: Actually here we just mean the depth of ground ice rather than both the depth and thickness since it is what the cited studies brought.

Line 165: “Satellite Phenology (SP) mode”, I do not know what is that. Some explanation would be helpful.

Authors’ reply: We have had an explanation for that. SP mode means it does not involve slowly evolving biogeochemical processes such as soil carbon accumulation (Line 180).

Line 220: “Have the same area fraction of low ice landunit”, You may add “(20%)” to make it clearer. What is the reason behind this assumption?

Authors’ reply: We make this assumption based on the fact that segregated excess ice is distributed widely throughout the permafrost region. So we assume that all the grid points in the CAPS data have some extent of low content ice. Since we define the volumetric content of excess ice in the low ice landunit as 25%, and the lowest category of excess ice in the CAPS

data has 5% in volumetric excess ice content, we just assume that this 5% excess ice is contributed by 20% area weight of low content excess ice that is 25% in volumetric excess ice content.

You must have a percentage of land as no excess ice as the total percentage is less than 100% in Table 2 (e.g., for 5% CAPS, the no excess ice area would be 80%). If that is the case, it would be clearer to indicate the no excess ice areal percentage in Table 2, and the scheme actually uses four landunits (as shown in Figure 1) rather than three. For the grid-average ice case, you used the average of the three land units (Line 242) or the four land units?

Authors' reply: We have made the change in Table 2 as you recommended.

Figure 3. The legend is in km2. You may provide the area of a grid or using % of the area of a grid.

Authors' reply: Because the grid cell with a lower latitude has a larger area. We think using km2 can provide more information here.

Line 259-260: "A small amount of excess ice (24kg/m2) melts during the spinup period", which case?

Authors' reply: It is the average ice single-landunit case. We have added such information to the sentence to make it clear.

Lines 302-303: "We define the permafrost degradation in this study as when all the landunits in one grid cell has an active layer thickness greater than 6.5 meters". That is different from the sentence in line 238. Probably the sentence in lines 302-303 is for how you treat the grid in figure 7. If so you can indicate its applications.

Authors' reply: It is a matter of scales. In this study, only global simulation has permafrost degradation condition analyzed. For figure 7 and 8, we addressed analysis on the grid scale, and we regard full permafrost degradation when the permafrost in all landunit in one grid point has disappeared (ALT > 6.5m). For figure 9, we addressed analysis on the landunit scale to compare the actual permafrost area. In this way, we calculate the area of each landunit with permafrost degraded (ALT > 6.5 m). We have reworded these sentences to make this point clear.

Line 350: "as projected until 2100", probably revise to "as we modelled". No observations beyond present.

Authors' reply: We have made the change as you recommended.

Line425, 438: "modelling", "modelled", be consistent with "Modeling" and "Modeled"

Authors’ reply: We have made the change as you recommended.