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Interactive comment on "Detecting the permafrost carbon feedback: Talik formation and increased cold-season respiration as precursors to sink-to-source transitions" *by* Nicholas C. Parazoo et al.

Anonymous Referee #1

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Review of "Detecting the permafrost carbon feedback: Talik formation and increased cold-season respiration as precursors to sink-to-source transitions"

The authors ran the Community Land Model (CLM) version 4.5 up to 2300, using RCP 8.5 forcing. They then perform an in depth analysis of permafrost-region dynamics in this simulation, including identifying key events: Talik formation (related the degradation of permafrost) and sink-to-source transition, i.e. the point at which the land surface changes from a net sink of carbon from the atmosphere, to a net source. It is interesting to note that this behaviour (starting as a sink and transitioning to a source) is identified

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across a large fraction of the current permafrost zone. However, the total carbon source is apparently only 11.6 GtC by 2300, which is low compared with previous estimates.

The authors extensively analyse different variables such as thawed volume (a newly defined metric), active layer depth, primary production, respiration and fires, and how these influence talik formation and sink-to-source transition. They find three main drivers of sink-to-source transition: 1. Active layer thickening in cold, carbon-rich high Arctic permafrost 2. Talik formation leading to winter respiration in low Arctic, warmer soils 3. Fire driven carbon source in more productive regions which dry out, and a lot of vegetation is burned. They also showed some indicators of talik formation such as a rapid increase in thawed volume immediately preceding talik formation.

This is a very thorough analysis and a well written paper that will make a great publication in The Cryosphere, after some small revisions. In general I would like to see a bit more analysis about the size of the carbon sources, not just the timing of transition. This could comprise a bit of discussion of the cumulative carbon source (11.6 Gt), and the significance of this - compared to previous estimates, and the time trajectory of the cumulative source (i.e. when does the Arctic as a whole become a net source?). And then if they could break that down to say which of the different types of source (driven by AL, talik or fires) has the bigger contribution to the total source or if these are all comparable magnitude, that would be add some value to the paper. It's fine saying that we should monitor the high Arctic systems as they will become a source soonest, but if this source is likely to be very small, there would not be so much point?

I also suggest considering the soil types at the boreholes. It would hopefully be possible to get an idea of this from a site description or by asking the PI. For example if these are peaty soils that might explain the very slow progression of freeze-thaw compared with CLM (also relatedly, the water content).

Finally the paper is rather long and I would suggest reducing in length where possible. I have indicated a couple of points below.

Line-by-line comments

Introduction: L62: ‘Shifts in vegetation community’ is mentioned in the introduction as being an important factor, but is this considered here? Are you running with dynamic vegetation? If you are, this should mentioned and if not, this omission should be discussed later on. L70: Same for soil organic matter export by rivers.

L86-87: Include more recent references for total permafrost carbon quantity, such as Hugelius et al 2014, Biogeosciences (https://www.biogeosciences.net/11/6573/2014/bg-11-6573-2014.pdf), and there is also a new paper by Jackson et al coming out in November with revised estimates, this will be in Annual review of Ecology, Evolution and Systematics (http://www.annualreviews.org/doi/abs/10.1146/annurev-ecolsys-112414-054234).

Methods: L138-142 The standard RCP 8.5 only goes until 2100 so presumably some extension is used here? Could you mention what this looks like - for example, does it stabilise at some point or does the global temperature and CO2 just keep increasing? I also think it would be useful for comparing with the permafrost thaw results, to see a plot of the global temperature across the three centuries of future simulation. I suggest adding this at least as a supplementary figure (as there are already a lot of figures in the main manuscript).

L152-154 “The C source transition represents a shift of ecosystem C balance from a neutral or weak C sink to a long-term source driven by onset of permafrost thaw and respiration of deep SOM” - here you suggest that the deep SOM alone is driving the transition, whereas your analysis suggests that it is driven by different things depending on region. Maybe you can qualify this sentence a bit?

L201-204: “For comparison to projected trends in CLM4.5, we recalculate observed trends using the inter-site average from all 9 sites at 3 unique locations: northern Siberia (67°N, 144°E), southwest Siberia (61°N, 115°E), and southeast Siberia (59°N, 131°E).” This is not entirely clear. You were talking about using 6 sites and now it says

9, but then you end up with 3? Can you make it more clear? Did you combine sites into groups based on approximate locations. . .?

Results: L228 Do you mean 2300?

L266 “Our simulations show a similar drying pattern in shallow layers (∼0-1 m depth) in the 4 decades prior to talik onset (Fig. 2D).” The shallow drying does not appear to be shown on Figure 2D, only the total column soil moisture?

L281-2 “we find more pronounced tilting of the thawed layer with time and depth” This is not obvious to me from the plot. I might just suggest deleting this.

L290-2 “the rate of thawing and drainage in response to permafrost thaw may be underestimated in deeper CLM4.5 layers near bedrock due to reduced heat capacity.” Sorry if I am missing something here but it doesn’t seem to me like reduced heat capacity would reduce the rate of thawing, but rather than it would thaw more quickly because less heat is needed to thaw? Can you check this? Thanks.

L313-315 “however, our comparison to observations suggests that simulated thaw rates in this region and for similar permafrost temperatures are underestimated”. This is not totally clear. Which comparison with obs? Are you referring to the comparison against thaw rates in Siberia which comes in the following section? Or are you inferring this from your comparison against borehole temperatures?

L335-336 “5 Siberian borehole sites which recorded at least 5 years of data spanning multiple decades:” Earlier you were talking about having 6 sites (or 9, or 3) and here it is 5. Please just clarify this a bit!

L337 “Records at these locations show a decrease in thaw volume” Do you mean an increase? On the next line it also refers to ‘negative trends’, which doesn’t seem to fit with the plots/results (or the expectations!). Maybe these things should read ‘increase in thaw volume’ and ‘positive trends’?

L345-346 “(layer thickness increases exponentially with depth along the Siberian tran-

sect)" This is not totally clear. Do you mean that active layer thickness increases exponentially with latitude…? Is that data shown somewhere? (It doesn't necessarily need to be, maybe just write 'data not shown' if it isn't)

L348-355. I'm not sure how much this is adding overall. It gets a bit confusing. Where you say "(vertical dashed line)", I would change to '(vertical dashed lines on Figure 5)', assuming this is what you're referring to? Anyway, it gets confusing when talking about groups of sites and it being hard to identify those groups. I would maybe condense these lines to something along the lines of "There is considerably spatial variability in thaw trends, for example site X is this far from site Y [relatively close] but with Z difference in trends [relatively large]. Talik formation occurs at several sites, at different times between 1957 and 1990 (shown by vertical dashed lines on Figure 5). We acknowledge the difficulty…"

L364-366 "The simulated trend in thaw volume shows a change in sign at northern locations (blue), acceleration of thaw at southwest sites (orange), and reduction of thaw at the southeast sites (brown)". This sentence suggests that the thaw volume reduces at the southeast sites, I guess because the thaw volume in CLM is less than the observations, but I would be inclined to interpret this instead as: the CLM simulation always had a too-small thaw volume, and there was never any 'decrease in thaw volume' in the simulation. But it is not possible to tell from the plot - Why did you not include the historical CLM simulation on the plot so it would overlap with the observed period? I also wouldn't say there is a "change of sign" at the northern locations. I guess you refer to the fact that the thaw volume is slightly decreasing at the northern sites historically, and increasing in the future? But as you say this is a very small trend so I would probably instead interpret this as a relatively stable site that shifts to degradation towards the end of the century? I also find figure 6 a bit confusing with the symbols and what they represent. So apparently the circle represents 'thaw onset in January' but this happens considerably sooner in the simulation than 'thaw onset in March', which doesn't make sense to me? Thaw onset should get earlier each year? In the main text it implies this

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is actually referring to deep thaw lasting throughout the winter (but this is not implied in the figure caption!). Maybe it would just be best not to include the symbols at all. This would make the plot simpler to interpret. Lines 369 “Our simulations show a shift to accelerated soil thaw beginning in the early 2080s”. This sounds like you are referring to the whole simulation and not just this one particular point - can you make this more clear?

L382 “A total of 6.8 million km2 of land is projected to transition”. This is not clear in the abstract which reads like it’s only around 3 million km2.

L388 “followed by gradual decline to 0.5 Pg C by 2300”. Does this suggest the temperature has stabilised and things are moving back towards equilibrium or is it more complicated than that? Could you comment? Including the supplementary plots of temperature trajectories that I suggested earlier might clear this one up.

L405-412. Here you are talking about NBP as positive, increasing, but in the plot (and according to your stated sign convention), a source is represented by negative NBP, decreasing. Please make this paragraph consistent.

L437 - Again wrong sign convention for NBP?

L437-438 “In general, C sources in these regions are more sensitive to C emissions from deep soil thaw” Have you actually quantified how much of the C is coming from deep soil. . .?

Figure 10: I think this could also be a supplementary figure or removed altogether, maybe giving slightly more detail on the numbers where it’s mentioned in the text.

Figure 11 / Lines 453-461. I am struggling to interpret the upper plot on this Figure, and I am wondering whether this part adds much to the analysis. Since the analysis is already long I might suggest removing this paragraph and figure.

I suggest doing a bit more quantification of the contribution to total carbon sources. If there is a total of 11PgC emitted by 2300, what fraction of that comes from the three

different ‘categories’ of points in the trimodal distribution? I think it would be really useful to know which are the important carbon sources - or whether they are all similar. (I have made this comment again above)

L472 “GPP and total respiration show nearly linear increases (∼15% per decade)” Minor point but an increase of 15% per decade would be exponential, not linear.

L485-487 “The trend in soil vs litter respiration explains almost the entire trend in net ecosystem C balance from neutral to net source (Fig. 12 G – H).” I’m not sure what you mean by this. I would have thought the trend in NBP is determined by the difference between GPP and total respiration, rather the difference between soil and litter respiration? And how do you draw these conclusions from the plots? Please could you make this clearer! Thanks.

L494 NF was only defined at the beginning of the paper and never used again until this point, which means that I had forgotten what it meant by now. You don’t use this abbreviation much so I suggest you don’t need it.

Discussion: L526-529 “Experiments demonstrating the sensitivity of talik to soil drying within the active layer across soil hydrology schemes in previous (CLM4), current (CLM4.5), and newly available (CLM5) versions of CLM could provide key insight on soil thermal dynamics in frozen or partially frozen conditions.” This comes out of the blue a bit, and I am also not clear about why this would be useful? Comparing different hydrology schemes could be useful if one is more realistic than the others or includes different processes? But it is not clear that this would be the case in different CLM versions? It might be better to look at a purpose-built permafrost model, for example, or a model that resolves discontinuous permafrost.

L538-540 “thus appears to be driven by combination of warming and increased nitrogen availability resulting from permafrost thaw”. I would suggest changing “appears to be” to “may be”. . . you haven’t looked at nitrogen here, and it is not totally clear/agreed that permafrost thaw will increase nitrogen availability.

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L605 “Our main results emphasize an emergence of cold season processes” Not sure what you mean by ‘an emergence of cold season processes’. . .? Rephrase?

L629-630 “Active-layer deepening leads to C sink-to-source transitions in some regions, talik-driven permafrost loss in others,. . .” This should be rephrased, “C sink-to-source transitions are caused by active layer deepening in some regions, talik-driven permafrost loss in others,. . .” Otherwise the sentence doesn’t quite make sense, it sounds like active-layer deepening is causing all of the other things!

Hope you find these comments helpful. Best wishes!

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