Response to Reviewer #2

We would like to thank all reviewers for their insightful comments, which helped us to improve the manuscript. Our revisions reflect all reviewers' suggestions and comments. For detail, please refer to the responses as follows: reviewer comments in black fonts, responses are in blue fonts.

**Reviewer #2**

p. 3138, l. 13: Better than what? Need to be more precise here about what you are treating as your reference case.

We rewrote that part of the abstract. Now it reads: These improvements allowed us achieve better agreement with the estimated carbon stocks in permafrost-affected soils using historical climate forcing.

p. 3138, l. 19: Hugelius et al., 2014 state the range of C is 1100-1500 Pg, with a best estimate of 1300Pg. That paper is an update of the Tarnocai database, so the newer estimate should be used.

We correct our estimates accordingly.

p. 3139, l. 7-12. Not sure the phrae "typically assumed a spatially uniform permafrost carbon density" is an accurate characterization of all of those papers. And also not sure if it si necessary for your argument; the point is that frozen volume matters, irrespective of what the soil carbon content is or how it is calculated.

We corrected the sentence as follows: Consequently, any biases in the simulated ALT could influence the initial amount of frozen carbon, even if different models initialize the frozen carbon in the same way. (L.42)

p. 3139, l. 18. More accurate to say "the same thermal biases that lead to deeper modeled active layers also lead to warmer soil temperatures."

We implemented suggested changes. (L.44)

p. 3141, l. 11. This isn't the correct reference for the CRUNCEP dataset. Better to put a link to the Viovy website as is typically done.

We have added the recommended reference. We included the original reference as well because we used the CRUNCEP dataset as corrected by the Multi-scale Synthesis and Terrestrial Model Intercomparison project (MsTMIP, nacp.ornl.gov).

p. 3141, l. 20. Is this relevant? Can't the model read inputs from restart files anyway?

That is right, the model reads its inputs from the restart file. The sentence explains why we choose 900yr for the spinup in opposed to, for example, a 1000yr due to computing constraints. We shortened the sentence accordingly.

p. 3141, l. 22. The citation should be moved to the end of the sentence and the name of the RCN is either the Permafrost Carbon Research Coordination Network, or the Permafrost Carbon Network.

We implement suggested improvements.

p. 3142, l. 19. I think you are missing a sentence here to transition from how you set the total C stocks to how you set the partitioning among pools. Also what are nominal turnover times of these pools at some reference temperature?

We included the following transition sentence: 'The carbon in each layer is divided into three pools as follows:...' The nominal turnover times for theses pools are 5 years for the slow pool, 76 days for the structural pool, and 20 days for the metabolic pool. We defined the different pools in the text. (L.136)

p. 3143, l. 10. I think the right reference for this is Koven et al., (2009); also note that that model does not include sedimentation processes.

We corrected the corresponding citation. (L.173)

p. 3143, l. 21-23. How do these assumed C densities compare with observations, such as the vertical profiles shown in Harden et al., 2012? It would seem well, given that observed C densities top out at about 60-80 Kg C / m3 for all three permafrost soil types, so maybe useful to mention that as a check on the parameters used here.

We inserted a paragraph and a Figure 5 (see below) showing the simulated vertical carbon distribution. We included the following paragraph into the results section: To illustrate soil carbon distribution with depth we selected three representative areas: a continuous permafrost area corresponding to tundra type biome above the Arctic circle, an area in the boundary of continuous and discontinuous permafrost corresponding to the boreal forest biome, and an area near the south border of the discontinuous permafrost corresponding to poorly vegetated-rocky areas. We calculated mean and standard deviation of the carbon density distribution with depth for 200 grid points around each of the three selected locations. Simulated typical carbon densities from selected locations are shown on Figure 5. All profiles shown on Figure 5 show a similar pattern: a 20-30 cm SOL with reduced carbon content at the bottom of the active layer. In contrast, the observed vertical carbon profiles show fairly uniform carbon density with depth throughout the active layer and into the permafrost Harden et al., (2012). SiBCASA lacks the cryotubation processes such as cryotic mixing that would redistribute carbon within the active layer. As a result, the carbon at the bottom of the active layer decayed and respired away during spinup. (L.318)

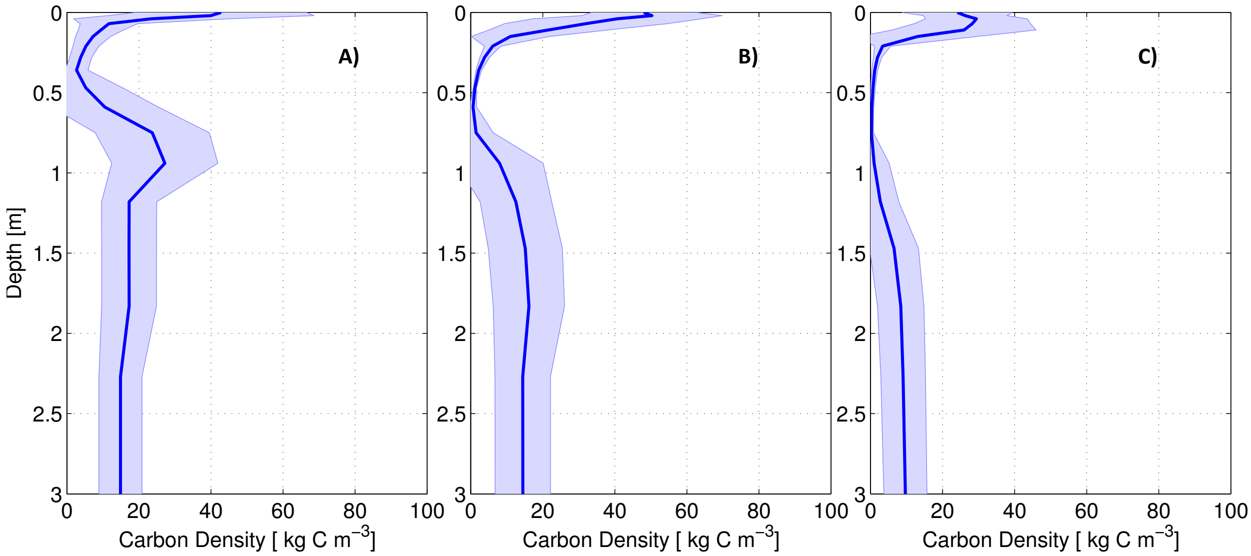


**Figure 5.** An averaged soil carbon distribution from 200 grid cells A) for the tundra region in continuous permafrost zone, B) for the boreal forest on the boundary between continuous and discontinuous zones, and C) for the low carbon soil at the south border of the discontinuous permafrost zone. The solid blue curve indicates the mean the white blue shading indicate the spread in the soil carbon density.

p. 3144, l. 5. I'm not sure I understand the purpose of OLTmax. In the peatland case, OLT can be several meters.

We used OLTmax early in the development phase as a diagnostic tool to analyze our results. However, we now see that it does not provide much additional insight and decided to remove it from the paper.

p. 3144, l. 10-19. Useful to discuss that functional roles the prognostic roots play in the model behavior. Do they control productivity directly, or are they jsut used to track C stocks into the ground? Also, what is the basis for linking leaf growth to root growth, as in line 22?

Fine roots supply nutrients and water for photosynthesis, so essentially the leaves and roots together define the photosynthetic capacity of the plant. Plants have optimized carbon allocation to grow only enough fine roots to properly supply the leaves with water and nutrients. So, as plants grow new leaves, they also grow new fine roots to supply them with nutrients and water. Linking root growth to leaf growth is a convenient and simple way to represent this coupling in SiBCASA.

Here we take this coupling one step further and recognize that frozen soil reduces the plant photosynthetic capacity and regulates root and leaf growth. Plants cannot photosynthesize in frozen soil. Frozen soil in the root zone reduces the photosynthetic capacity of the plant by limiting the water available for photosynthesis. Roots cannot grow in frozen soil and if roots can't grow, leaves can't grow. The changes we made link soil thermodynamics to root growth, leaf growth, and plant photosynthesis.

p. 3145, l. 3. Need to explain how Fice works. Is this just a step function of one below freezing and zero above, or is it more complex?

We added text explaining that Fice is calculated from the liquid water and ice content of each soil layer, both of which are prognostic variables, accounting for latent heat effects. Fice varies from zero for a completely thawed soil layer to one for a completely frozen soil layer. (L.233)

p. 3145, l. 6-10. This looks self-contradictory. Either you limit roots to unfrozen layers, or you use an exponential profile, which necessarily continues to have roots (perhaps small, but nonzero) in the frozen layers. Need to explain this better.

We included a better explanation. See earlier comments.

p. 3145, l. 10. If Fice is not a step function, then there will still be some root growth in partially-frozen soils?

Yes, there will be root growth in a partially frozen soil layer. We added text stating this in the manuscript.

p. 3146, l. 18. Some discussion of how thermal dynamics were calculated in the old version is needed, since that is being used as a reference case. Was soil organic matter included in the thermal calcualtions at all, or if so, how did it differ from the current version? More generally, is the comparison against the old model the right comparison? Maybe it would be more informative to use just the new version, but turn off various processes to understand their relevance?

We modified the methods and discussion section to reflect the fact that the original version of SiBCASA included the effects of organic matter on soil thermodynamic properties (Schaefer et al., 2009), but not a dynamic SOL and rooting depth. We always strive to build a model flexible enough to turn different processes on and off. We are not software engineers, however, and in this case we found that our code to switch the dynamic SOL and rooting depth processes on and off did not work properly and produced odd results at isolated pixels. We did learn that the dynamic SOL and rooting depth were coupled such that you had to run them both together to get good results. So rather than spend several weeks debugging code that would not affect our results, we decided simply to compare the new and old versions.

I don't see any information about vertical C profiles in the results, which would seem like a crucial analysis to assess the approach presented here. What does a typical profile look like? How do overall C profiles compare against datasets such as Harden et al., 2012?

We inserted the paragraph with the corresponding figure on the vertical distribution of soil carbon (see Figure 5).

FIgure 4: This should compare predicted GPP to a reference dataset such as that of Beer

et al. to assess whether the GPP changes imporve the model relative to observations?

The major goal was not compare the simulated GPP with measured GPP but rather to indicate the effect of soil thermal conditions on photosynthesis and its feedback to the overall GPP. Our goal was to illustrate the reduction in GPP when the soil thermal physics is coupled with plant photosynthesis. Preliminary comparisons of indicate the SiBCASA simulated GPP may be too high globally, but the cause of this bias is the remotely sensed phenology used as input and not the soil biogeochemistry and thermodynamics. Including such a comparison here would 'open a can of worms' and introduce ideas that are completely unrelated to SOL dynamics. This would greatly dilute the emphasis of the paper of SOL dynamics, so we decided not to include it here. We are planning a rigorous comparison under the MsTMIP project.

Figure 5: Also show the final version, as in fig. 6 here, to note the effect of using variable C density.

The old Figure 6 is now Figure 7 includes the result of the initialization with the constant density.

Figure 6, and also discussion points in the text about comparison of low C bias relative to observations in SE Canada and SW Siberia (p. 3148, l. 28, p. 3149, l. 12-27). The reason why these soils have such high C is that they are vast peatland complexes. I think you should clarify the ways in which the model does and does not include peat-like behavior. I.e. the accumulation of organic rich surface layers does seem like peat-like behavior. But only if there are feedbacks between soil saturation, C accumulation, and soil physical properties, as in peats. So the question to pose is: should the model capture the vast peatland complexes in SW Siberia and SE Canada, or not? Getting this right would require both having the right processes in the model, as well as having the right distribuition of saturated soils.

We appreciate this comment and include a better explanation of the frozen carbon input and reasoning of why we are not getting permafrost in those regions. We agree that we do not explicitly represent peat-lands in those areas, which might cause the non-existence of permafrost in those locations.

Figure 6. Given that you start with the NCSCD data in the permafrost layers, this isn't strictly a valid comparison, as there is a clear circularity in comparing input data against reference data. So it would be more appropriate to restrict the comparison to only the active layer C stocks to avoid this. You could sample the NCSCD only to the thaw depth predicted by SiBCASA, and then compare to only the active layer C stocks in SibCASA, to make such a comparison.

We agree up to a point. The current version of the manuscript includes a better explanation of the frozen carbon input. In our case, it is not fully circular simply because we inserted only frozen carbon instead of whole soil carbon profiles from NCSCD. Moreover, during model equilibration soil carbon within the active layer equilibrates according to the input from the vegetation. The frozen carbon also equilibrates itself based on fluctuations on the thaw depth. Therefore equilibrated carbon differs from

NCSCD map. Initially, we did not expect any match between these datasets. The main goal of this comparison was to show that now we can better preserve frozen carbon and therefore better match NCSCD.

p. 3150, l. 29 - p. 3151, l. 6. This is speculation. There are many reasons why a model may overestimate or underestimate permafrost area, e.g soil processes, snow processes, albedo, etc. So it is not correct to infer that actual permafrost area is being lost just because a model does not simulate permafrost in a given area.

We agree. We change the paragraph with following:

Simulated permafrost vulnerability is tightly coupled with the accurate modeling of the present permafrost distribution, which depends on soil thermal properties. We calculate soil thermal properties based on prognostic soil carbon and soil texture from the Harmonized World Soil Database (HWSD) (FAO et al., 2009). Observations indicate that soils in the southeast Canada have high soil carbon as a result of a large number of peat lands (Hugelius et al., 2014). Peat has low thermal conductivity and could preserve permafrost even at NSATs about zero degrees centigrade (Jafarov et al., 2012) even if the surrounding areas do not have permafrost. However, the HWSD input data does not have enough soil carbon in the southeast Canada and southwest Russia, as a result, we could not simulate permafrost in those regions. (L.419)

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