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Interactive comment on "Observation-based modelling of permafrost carbon fluxes with accounting for deep carbon deposits and thermokarst activity" *by* T. Schneider von Deimling et al.

T. Schneider von Deimling et al.

thomas.schneider@awi.de

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We thank the referees for their constructive comments which were very helpful for improving our manuscript. By having performed additional model simulations and by showing additional model output (as suggested by both reviewers) we now provide additional information for the interpretation of our model results. This information allows to illustrate the role of individual carbon pool contributions and of model dynamics from hydrologic and depth changes.

In the following we reply to all referee comments (in italics) point by point.

1) I agree with Referee 1, who called for a better explanation of the differences between organic and mineral soils in main manuscript text.

We now discuss the segregation of organic and mineral pools in section 2.2 in the revised manuscript (see also reply to referee 1).

2) I have some questions about the treatment of "wetlands" in this study, particularly the application of thaw depth changes under saturated conditions. Permafrost thaw in permafrost plateaus typically results in ground subsidence, impoundment, and collapse-scar bog /fen formation, followed by rapid wholesale loss of near-surface permafrost. This is an abrupt thaw process that could have been considered in this study. The prescribed thermal parameters don't appear to account for non-conductive heat transfer that occurs following these ecosystem state changes, and likely underestimates thaw rates.

In our model description of permafrost degradation we account for abrupt thaw by separately considering carbon pools which are subject to strongly enhanced thaw following ground subsidence and thermokarst formation. This does not only concern mineral soils but also our considered organic-rich pools. This point is illustrated now in the additional new figure S3 in the supplement of our revised manuscript. This figure shows the contribution of thermokarst affected soil carbon in mineral, organic, Yedoma, and refrozen thermokarst deposits. Yet we do not consider the case of a transformation of a thermokarst-affected ground into a wetland including fen/bog formation, (neither do we consider the potential reversion of a wetland into a lake). These are aspects of future model improvement. To account for the reviewer's comment, we now discuss the transformation of aerobic into anaerobic compartments in more detail in section 2.1 of the revised manuscript and in section 2.3 of the supplement.

Accelerated thaw of peatland permafrost carbon has been reported e.g. by Payette et al. (GRL, 2004), but the concurrent fast terrestrialization proofed to stabilize the carbon balance of the investigated region. Therefore, from the viewpoint of permafrost carbon fluxes it is questionable to what extent accelerated thawing of specific permafrost features (such as peat plateaus) will have a strong impact on the large-scale Arctic carbon balance. On smaller scales, lateral thaw may also be important to consider (McClymont, JGR 2013, Baltzer et al., GCB 2014) and is likely to result in enhanced thawing at the edge of peat plateaus in sporadic and discontinuous permafrost regions.

With a focus on large-scale permafrost dynamics, Wisser et al. (ESD, 2011) have simulated soil temperatures in peatlands responding more slowly to increasing air temperatures due to the insulating properties of peat. Further, the occurrence of permafrost in warmer regions (sporadic and isolated permafrost) is mostly linked to frozen peat, which indicates that peat can be more resilient to thaw than mineral soils. In the revised manuscript we now acknowledge that organic rich soils can reveal enhanced thaw rates due to non-conductive heat flow which we do not account for in our model setting - and we stress that we therefore consider our carbon fluxes from thawing of wetland permafrost being conservative (see section 3.2, page 16).

3) The authors should describe if and how the depth distributions of soil carbon (e.g. Harden et al. 2012) were prescribed in this model. This seems like an important component, given the approach of tracking recently thawed C released in response to active layer thickness increases.

We now describe the vertical carbon profile in section 2.1 of the revised manuscript.

4) This paper would be greatly strengthened by some additional modeling simulations or sensitivity analyses designed to quantify how the inclusion of yedoma and thaw lake dynamics impacted total C loss and climate warming.

We have performed additional model simulations to illustrate how thaw lake dynamics and the inclusion of deep carbon deposits affect total circumpolar carbon release (see new supplementary figure S4). We have also prepared two additional figures which show the contribution of carbon fluxes separated into soil types, aerobic/anaerobic

fractions and deep deposits (see new supplementary figures S2 and S3). We have extended the discussion of individual pool contributions in the revised manuscript in section 3.3.

Specific Comments 1. Page 16602, Lines 15-18: I'm not sure that I agree with this statement, although it's difficult to say without a better definition of mineral vs. organic soils. Clearly peatlands are highly vulnerable to permafrost thaw. Ground ice volumes are variable, and differences between organic and mineral will depending on the thickness of the deposit, no? Please clarify and add citations to justify statement.

We have updated the corresponding section in the revised manuscript and now emphasize the vulnerability of peatlands if conditions are favourable for enhanced thaw (see also our comments above, point 2).

2. Page 16602, Line 18: While this statement about anaerobic environments is generally true, some recent studies have shown the potential for large C loss from deep thawed peat deposits

We now mention the work of Camill et al. (Climatic Change, 2005) and Johnson et al. (ERL 2013) at page 3 (line 29) to underline that peat deposits can be highly vulnerable to thaw.

3. Page 16602, Line 21 – Hydrologic and redox conditions

Modified accordingly.

4. Page 16603, Line 12 – remove hyphen from "bio-geochemical"

Modified accordingly.

5. Page 16603, Line 24 – replace "underline" with "note" or "observe". Also I think it would be good to mention why thermokarst has not been included to date in these models.

Modified accordingly.

6. Page 16604, Line 15, Change this to "pools governed by different environmental controls"

Modified accordingly.

7. Page 16606, Line 3 – Change composition to texture, unless you mean "chemical composition"

Modified accordingly.

8. Page 1606, Lines 25 – 27 –Would be good to cite Gao et al. (2013) and justify here wetland increase in the text here. How do those scenarios reconcile with findings of Avis et al. (2011)? Also add Gao et al. (2013) to reference list.

We now refer to the work of Gao et al. (2013) and Avis et al. (2011) to stress that future changes in wetland extent are subject to large uncertainty.

9. Page 16613 , Line 1 – Use different word here than "exemplarily"

Modified accordingly.

10. Page 16616, Line 8 – Correct grammar here: should be "after the middle of the century"

Modified accordingly.

11. Page 16619, Line 2 – Grammar – omit "of" here

Modified accordingly.

12. Page 16622, Line 13 – Correct grammar here "despite of the organic matter"

Modified accordingly.

13. Page 16622, Line 19 – Omit "of" from "Despite of"

Modified accordingly.

14. Table 1, footnote e – I have some issue with the assumptions regarding thaw rates in wetland soils. In many cases, saturated conditions in high-latitude peatlands function to accelerate thaw rates, due to non-conductive heat transfer processes. This approach for wetlands needs better justification in the text.

See our comments made in the general discussion above (point 2).

15. Table 1, Footnote d – Not entirely sure what you mean by "thaw rates are exemplary". Could you elaborate? Did you conduct a validation experiment in comparing observed vs. modeled thaw rates for some sites?

Our simulated thaw rates depend on four key factors: thermal ground properties, mean annual ground temperatures, active layer depth, and magnitude of the regional warming anomaly which drives permafrost degradation. We calculate thaw rates for each pool in each latitude band for each time step depending on those factors. In table 1 we show the range of our simulated thaw rates which is spanned by cold and warm mineral soil permafrost under the conditions specified under footnote d.

16. Figure 5 - Add decimals to RCP scenarios?

Modified accordingly.

17. Supplemental, Page 2, Lines 15-18 – The authors should provide more detail here about soil temperature dynamics. This "lag" or "phase shift" in ground temperature has been well quantified in prior numerical evaluations. Please detail the assumptions made here.

We now have detailed our assumptions in section 2.1 of the supplement.

18. Supplemental, Page 3, Line 13 – This section primarily describes variation in thermal properties across soil types, but what about variation in thermal properties with frozen and unfrozen ground?

We do not explicitly account for differences in thermal diffusivities between frozen and unfrozen ground. As the ratio of unfrozen to frozen ground generally increases from northern to southern permafrost (because of a deepening of the active layer) we expect that an increasing contribution of unfrozen soil layers to the thermal ground state should show a general north-south dependency. In our thaw rate parametrization we introduce a latitudinal scaling of the calculated thaw rates (see section 2.2 in the supplement) and thus indirectly account for the above mentioned effect.

Interactive comment on Biogeosciences Discuss., 11, 16599, 2014.