Author Response to Interactive Comment by Anonymous Referee #1 on "ORCHIDEE MICT-LEAK(r5459), a global model for the production, transport and transformation of dissolved organic carbon from Arctic permafrost regions, Part 1: Rationale, model description and simulation protocol" by Simon P. K. Bowring et al.

Dear Anonymous Referee #1,

Thank you for taking the time to read and review our manuscript, and in doing so providing such diligent and constructive commentary for its improvement, which we hope we have been able to assimilate into its content to the greatest degree possible in our responses, which follow below.

Specific Comments

Line 46: the "migration of permafrost line" really only makes sense on a map. Perhaps rephrase.

Thank you for spotting this conceptually misleading description in our text. The phrase has now been modified to
"... as the boundary between discontinuous and continuous permafrost migrates poleward and toward the continental interior over time."

line 50: the authors pulled out some very high number, I don't know where this came from. McGuire 2009 estimates a lateral flux of 80 Tg C and a net "arctic" land sink of 600-800 Tg C. That makes the DOC component ~10% of NEP.

Again, thank you for spotting this, which indeed looks misleading, and comes from taking a mix of upper and lower bounds for lateral flux and NEP, respectively. However, we can't find the 600-800TgC /yr sink you refer to in the reference cited. Referring to McGuire et al (2009) Table 2, the inversion-based terrestrial sink from Rödenbeck et al (2003) is 400 TgC/yr, that from Baker et al (2006) is 190 TgC/yr, and that from Gurney et al. (2003) is 230 TgC/yr. Because these estimates exclude the European Arctic, McGuire estimates that the 'true amount is 'less than' 0.5 PgC/yr which, given the uncertainty range from the inversion studies, means that he accepts the range of the net CO2 sink as being 0-800TgC yr. In Table 6 of McGuire et al., indeed the lateral carbon flux is 39 TgC/yr excluding DIC and 83 TgC/yr with it.

In our manuscript text body, we write that " the yearly lateral flux of carbon from soils to running waters may amount to ~40% of net ecosystem carbon exchange". This implies the total lateral carbon flux, and not the DOC. Thus, from a mid-point of 400 TgC/yr from the above-mentioned 0-800TgC/yr, we re-write the sentence as follows:

"*[...] the yearly lateral flux of carbon from soils to running waters may amount to about a fifth of net ecosystem carbon exchange (~400 TgC yr^{-1}), about ~40% of which may be contributed by DOC (McGuire et al., 2009). Excluding the dissolved inorganic carbon component of this flux, as well as dissolved CO_2 input from soils, the vast majority (85%) of riverine organic carbon discharge to the Arctic Ocean occurs as dissolved organic carbon (DOC), as described in (e.g.) Suzuki et al. (2006).* "

155-156: I think these numbers need to be double checked. The point of this paragraph could be clearer.

The numbers have been double-checked and are as reported in McGuire et al. (2009), but now distinguish between total evasion and the water bodies from which these occur as follows:

" *CO_2 evasion rates from Arctic inland waters (Fig. 1j,e,m), which include both lakes and rivers, are estimated to be 40-84 TgC yr^{-1} (McGuire et al., 2009), of which 15-30 TgC yr^{-1} or one-third of the total inland evasion flux, is thought to come from rivers. However, a recent geo-statistically determined estimate of boreal lake annual emissions alone now stands at 74-347 TgC yr^{-1} (Hastie et al., 2018), potentially lowering the riverine fraction of total CO_2 evasion. These numbers should be compared with estimates of Pan Arctic DOC discharge from rivers of 25-36 TgC yr^{-1}(Holmes et al., 2012; Raymond et al., 2007).*"

AO: This is my preference, but it wouldn't add much space to write out Arctic Ocean and it would be more intuitive to follow.

This is an understandable preference, given the already large number of acronyms contained in the document. The text has been modified accordingly.

249-254: This paragraph is confusing. The points could be expanded and clarified

Indeed, we find the same. The paragraph has been shortened and merged with the preceding paragraph. The processes that are novel are described then later in the text.

"*However* numerous improvements in code performance *and process additions post-dating these publications have been included in this code. Furthermore, novel processes included in neither of these two core models are added to MICT-L, such as the diffusion of DOC through the soil column to represent its turbation and preferential stabilisation at depth in the soil, as described in Section 2.11*."

265-274: This is quite confusing and makes what is new here unclear.

We have now removed the first half of this paragraph and merged the remainder with the preceding, so as to avoid unnecessary complexity and confusion. The section removed is:

" Where these differences were so large as to prove a burden in excess of the scope of this first model version, such as the inclusion of the soil carbon spinup module, they were omitted from this first revision of MICT-L. The direction of the merge –which model was the base which incorporated code from the other –was from ORCHILEAK into MICT, given that the latter contains the bulk of the fundamental (high latitude) processes necessary for this merge."

289: This is the first mention of this site specifically, and it really comes out of nowhere. Consider introducing the site before this.

We agree with this observation, and have added in the following sentence at the end of the Introduction (line 264-267).

"*The choice of the Lena River basin in Eastern Siberia as the watershed of study for model evaluation owes itself to its size, the presence of floodplains and mountain areas which allow us to test the model behavior for contrasting topography, the relatively low impact of damming on the river, given that ORCHIDEE only simulates undammed fluvial 'natural flow', and its mixture of continuous and discontinuous permafrost with tundra grassland in the north and boreal forests in the south, and is described in greater detail in Part 2 of this study*"

430: Typo 437: typo

Extra full-stop removed.

444-446: Confusing. This sounds like a lake or pond

The section you refer to is: "Further, in modelled frozen soils, a sharp decline in hydraulic conductivity is imposed by the physical barrier of ice filling the soil pores, which retards the flow of water to depth in the soil, imposing a cap on drainage and thus potentially increasing runoff of water laterally, across the soil surface (Gouttevin et al., 2012). In doing so, frozen soil layers overlain by liquid soil moisture will experience enhanced residence times of water in the carbon-rich upper soil layers, potentially enriching their DOC load."

This refers to the frozen vertical barrier imposed by soil freezing on hydrological transfer to deeper layers. This is why they are referred to as 'liquid soil moisture' as opposed to water body or some such, as it implies that water increases its residence time in a certain layer above the frozen portion, but does not remain static there nor 'pond' into a water body proper.

We have also added the clarification that frozen water in the form of thick ice wedges that are important for e.g. thermokarst formation, are not simulated by the present model formulation, e.g. " *Note that ice wedges, an important component of permafrost landscapes and their thaw processes, are not included in the current terrestrial representation, but have been previously simulated in other models (Lee et al., 2014)*".

In addition, we found some potentially misleading text in the following segment: "First, in the process of drainage DOC is able to percolate from one layer to another, through the entirety of the soil column, meaning that vertical transport is not solely determined by 11th layer concentrations, given that DOC can be continuously leached and transported over the whole soil column. "

We have adapted this section as follows:
" First, as it water percolates through the soil column, it carries DOC along from one layer to another through the entirety of the soil column, but this percolation is blocked when the soil is entirely frozen, i.e. it is assumed that all soil pores are filled with ice which blocks percolation. This implies that DOC transport is not just determined by what enters from the

top but also by the below ground production from litter, the sorption and de-sorption to and from particulate soil organic carbon in the soil column, , its decomposition within the soil column, and water vertical transport entraining DOC between the non-frozen soil layers using the hydraulic conductivity calculated by the model as a function of soil texture, soil carbon and time-dependent soil moisture (Guimberteau et al., 2018). "

474: typo

This has been corrected.

4780480: confusing

This refers to the following section of the manuscript: "The water residence time in each reservoir depends on the nature of the reservoir (increasing residence time in the order : stream < fast < slow reservoir). More generally, residence time decreases with the steepness of topography, given by the product of a local topographic index and a constant with decreasing values for the 'slow', 'fast' and 'stream' reservoirs."

To clarify this, we have shortened and increased the conciseness of the segment as follows:

"*More generally, residence time locally decreases with topographic slope and the grid-cell length, used as a proxy for the main tributary length (Ducharne et al., 2003; Guimberteau et al., 2012). This is done to reproduce the hydrological effects of geomorphological and topographic factors in Manning's equation (Manning, 1891) and determines the time that water and DOC remain in soils prior to entering the river network or groundwater."*

In addition, to increase the readability of the subsection, descriptions of the hydrological module in the paragraph preceding the segment you refer to are improved upon. The original section reads: **"**The 'slow' water reservoir aggregates the soil drainage, i.e. the vertical outflow from the 11^{th} layer (2 m depth) of the soil column, effectively representing 'shallow groundwater' storage. The 'fast' water reservoir aggregates surface runoff simulated in the model, effectively representing overland hydrologic flow. The 'slow' and 'fast' water reservoirs feed a delayed outflow to the 'stream' reservoir' of the adjacent subgrid-unit in the downstream direction."

The model's hydrology routing scheme is indeed a complex system, and we use the same terminology as that adopted by its architects cited to in the text, which in turn follow the terminology given to these water reservoirs in the model code.

Thus we only try to make clearer the last sentence of the paragraph with the following edit: " *The 'slow' water reservoir aggregates the soil drainage, i.e. the vertical outflow from the 11^{th} layer (2 m depth) of the soil column, effectively representing 'shallow groundwater' transport and storage. The 'fast' water reservoir aggregates surface runoff simulated in the model, effectively representing overland hydrologic flow. The 'slow' and 'fast' water reservoirs feed a delayed outflow to the 'stream' reservoir' of the next downstream sub-grid quadrant."*

498-490: Justification for this approach would be helpful (add supporting references)

We assume this refers to lines 498-500 and not 498-490. This segment reads:
"Active DOC flows into a Labile DOC hydrological export pool, while the Slow and Passive DOC pools flow into a Refractory DOC hydrological pool (Fig. 2b)."

This formulation follows on from prior published developments made to the model code, but is unpacked more explicitly in the section by adding the following content:

"*However, because the terrestrial Slow and Passive DOC pools (Camino-Serrano et al., 2018) are given the same residence time, these two pools are merged when exported (Lauerwald et al., 2017): Active DOC flows into a Labile DOC hydrological export pool, while the Slow and Passive DOC pools flow into a Refractory DOC hydrological pool (Fig. 2b), owing to the fact that the residence time of these latter soil DOC pools is the same in their original (ORCHIDEE-SOM) formulation (Camino-Serrano et al., 2018), and retained and merged into a single hydrological DOC pool in Lauerwald et al. (2017). The water residence times in each reservoir of each subgrid-scale quadrant determine the decomposition of DOC into CO_2 within water reservoirs, before non-decomposed DOC is passed on to the next reservoir in the downstream subgrid quadrant.*"

In addition, to improve contextual understanding, in Section 2.3 (paragraph 1) we have added the following (in red) to this section: " *The non-respired half of the litter feeds into 'Active', 'Slow' and 'Passive' free DOC pools, which correspond to DOC reactivity classes in the soil column in an analogous extension to the standard CENTURY formulation (Parton et al., 1987).*"

508-525: These water pool names are really confusing.
527-534: I'm having a difficult time following this
Here we combine your two above comments into an adaptation to the paragraph as follows. We believe the confusion arises from our description of the fast, slow and stream reservoirs with respect to headwaters. The paragraph has been adapted as follows:

" Note that while we do not explicitly simulate headwaters as they exist in a geographically determinant way in the real world, we do simulate what happens to the water before it flows into a water body large enough to be represented in the routing scheme by the water pool called 'stream', representing a real-world river upwards of roughly stream order 4. The 'fast' reservoir is thus the runoff water flow that is destined for entering the 'stream' water reservoir, and implicitly represents headwater streams by filling the spatial and temporal niche between overland runoff and the river stem. "

528-540: seems like there would be less organic matter to leach from on higher slopes.

Yes, certainly an omission here. We have added in the line:
"*In addition, places with higher elevation and slope in these regions tend to experience extreme cold, leading to lower NPP and so DOC leaching.* "

Equation 2: needs units, what does 12.011 represent? A carbon unit conversion?

This has now been altered to:

"*Where the pCO_2 (atm.) of a given (e.g. 'stream', 'fast', 'slow' and floodplain) water pool (pCO_{2POOL}) is given by the dissolved CO_2 concentration in that pool* $[CO_{2(aq)}]$, *the molar weight of carbon (12.011 g mol^{-1}) and K_{CO2}*."

Equation 3, 4, 6, ditto. If these are empirically derived parameters there needs to be a reference.

For Eq. 3 we add in the text: "Water temperature (T_{WATER}, (°C)) isn't simulated by the model, but is estimated here from the average daily surface temperature (T_{GROUND}, (°C)) in the model (Eq. 3*), a derivation calculated for ORCHILEAK by Lauerwald et al. (2017) and retained here*."

For Eq. 4, the Schmidt number that is calculated is entirely from Wanninkhof, and cited therein in the following segment: " With our water temperature estimate, both K_{CO2} and the Schmidt number (*Sc,* Eq. 4) from Wanninkhof (1992) can be calculated, allowing for simulation of actual gas exchange velocities from standard conditions.

For Eq. 6, we follow the standard CENTURY soil carbon pool formulation (Parton et al., 1987) in which rates enter black boxes of soil carbon for each grid cell and are then re-divisible over desired quantities (area/volume etc), which is why for these we did not give units, as it is simply a discrete mass over discrete time.

More specifically, the CENTURY carbon pools, rate modifiers are determined based on soil organic dynamic in Parton et al. (1987) and then evaluated on other ecosystems (Eglin et al., 2010, Dimassi et al., 2018) for ORCHIDEE. A slightly modified version of this, with the same CENTURY parameters that now account for the priming effect, was derived by Guenet et al. (2016) and included in this version. The parameters in this equation are derived in the cited references (see Equations 1-8 in Guenet et al. 2016) and repeated in Guenet et al (2018). For clarity, we have made the following edit to the text, reflecting the fact that k is the standard decomposition rate in 1/time, the rate modifiers are zero-dimensional and SOC represents the mass of SOC, represented here by Kg as the SI unit of mass:

" *Where IN_{SOC} is the carbon input to that pool, k is the SOC decomposition rate (1/dt), FOC (Kg) is a stock of matter interacting with this SOC pool to produce priming, c is a parameter controlling this interaction, SOC is the SOC reservoir (Kg), and θ, Φ and γ the zero-dimensional moisture, temperature and soil texture rate modifiers that modulate decomposition in the code, and are originally determined by the CENTURY formulation (Parton et al., 1987) and subsequently re-estimated to include priming in Guenet et al., (2016, 2018).*."

Figure 1. part k. K: assumption of soil C distribution, differences between continuous and discontinuous. Don't know how well supported this is – perhaps some justification could be found in the literature.

Yes, this is only illustrative but can be found in the literature for example the top 1m of soil generally is richer in carbon in continuous over discontinuous regions, with the canonical snapshot of this captured by the NCSCD.

The caption has been edited to reflect this with the following: " *(k) Turbation and soil carbon with depth (e.g. (Hugelius et al., 2013; Tarnocai et al., 2009), (Koven et al., 2015))*;"

Terminology between headwaters, tributary in figure vs. manuscript text are confusing.

The terminology we agree is a bit confusing because of the nomenclature that is used in the model code and in preceding papers cited herein which refer to real-world water pools like streams as 'fast reservoir' and real-world water pools like rivers as 'stream reservoir'. However, as this figure is a cartoon, we feel it appropriate to use real-world terms for bodies such as streams and tributaries that are represented collectively in the model by both the 'fast' and 'stream' pool.

Thus in the caption text we include the following sentence: " *Note that 'tributaries' in the Figure may be represented in the model by either the 'fast' or 'stream' pool, depending on their size.*"