Response to Anonymous Referee #2
Received and published: 1 March 2018

We thank the reviewer for his thoughtful comments. In the following, the reviewer's comments and suggestion are typeset normally, our replies to these comments and suggestions are written in **bold,** and the changes applied to the article are written in blue.

Thank you for the opportunity to review the paper by Largeron et al.
I believe the paper is worthy of publication once all the referee comments have been addressed to the satisfaction of the Editor. Largeron et al. added a fixed grid cell fraction to represent northern peatlands to ORCHIDEE. They then evaluated the impact of this new set of processes at site and regional scale. In general, the arguments are quite convincing, but I feel they could be made much more solid with the addition of some extra information (detailed below), and a little extra analysis. For I feel that this lack of detail in certain key places is the main drawback of the paper. I have chosen to divide my comments into General and Specific categories in the following. The comments below refer, where possible, to specific pages and lines or ranges of lines. I'm looking forward to reading a revised version.

General Comments and Questions
————————————

1. The problems with the treatment of snow sublimation, mentioned in many places throughout the text, is vital to be able to understand and trust the results shown here. Please provide more detail.
In the version of ORCHIDEE-MICT used here, the snowmelt runoff bias due to snow simulation bias has been documented by Gouttevin et al (2012). Developments concerning a new representation of snow have been made with a multi-layer snow scheme (Wang_2013, Guimberteau_2017). However, this scheme could not be used when we started this study because it caused a non-conservation of water.
These explanations have been added in P15 L24 and P17 L4 as specified in specific comments. Added also In:
P3 L6-10 (in the modelling section): This scheme represents the changes of thermal and hydrological soil properties during periods of freezing and melting. This improves the latent heat exchange, water suction and the heat capacity depending on the ice content and the volumetric ice content (Gouttevin et al 2012}. The single-layer snow scheme in this model version supposes a constant snow density of 330 kg/m3 and is known to underestimate the snow cover depth as well as the snow water equivalent (Gouttevin et al 2012, Wang et al 2013}.
P17 L28: This trend is due to the same shift of the contribution of the modelled TWS, linked to the snowmelt that occurs about one month too early (Wang_2013).
P21 L6-8: The underestimate of flooded peatlands can be explained by an overestimate of snow sublimation as well as by an underestimate of the snow depth which leads to insufficient runoff from snow melt \citep{(Gouttevin_2012b, Wang_2013).
P22 L30-32: "The model underestimates the WTD in winter for the Siikaneva and Fajemyr site. This can be explained by the overestimate of snow sublimation and the underestimate of the snow melt runoff known in this version of the model (Wang_2013)."
P22 L32-33: because the snow scheme used here underestimates the snow melt runoff in boreal regions (Wang_2013).
P23 L29-30: by the overestimation of the simulated snow sublimation and the underestimation of the snow water equivalent in this version of the model (Wang_2013, Gouttevin_2012).

2. How are the peatland fractions of the cells parameterized? You mention that they have a texture, but is this the same as the remaining fraction of the cell, i.e. more representative of mineral soils? What is the porosity? What is the depth of the bucket? How is evaporation treated?
The fractions of peatlands are inserted in the vegetation map of ORCHIDEE based on the peatland map of Yu et al. Concerning the properties of the soil, we have determined the properties of peatlands based on Letts et al 2000. However, the texture of organic soils that characterizes peat has not been taken into account since this version of ORCHIDEE used the dominant texture based on FAO. Therefore, peatland-specific textural parameters are applied only where peatlands are dominant. The depth of the soil is 2m and split in 11-layers (De Rosnay et al 1999). The water balance is calculated for each type of soil where the evaporation of the peatlands soils is treated as a function of the soil moisture of the peatlands soils only. We then used a resistance factor R to

reduce evaporation for peatlands soils to counterbalance the fact that the (assumed) water holding capacity and infiltration of mineral soils used in the model for peat is lower than the one of actual peat soils and that the ability of mosses to retain water is not represented.
This explanation is described in the model description in section 2.1 as following (the sentence added is written in bold):
The transport of water in the soil is described by the 11-layers scheme of (DeRosnay et al 1999), **where the layer thickness of each layer is increasing with depth, from 1 mm to 1 m depth with the standard 2 m total depth scheme.** The heat and moisture transport is calculated between each soil layer. The water balance of the soil is defined separately as a function of class of vegetation and clustered for bare soil, trees and grasses. Each of these three soil types has a separate water balance. The fraction of the area of each soil type is calculated as a function of the fraction of the area of the corresponding PFT. However, the soil porosity is defined only as a function of the dominant soil texture in the grid cell, based on textural classification data from the global Food and Agriculture Organization map (FAO, 1978). Only one soil parameter is defined per grid cell, which describes hydraulic conductivity, residual and saturated water content as well as the Van Genuchten parameters, which describe the hydrological properties of the soil. »
In order to clarify this in the paper we have added the following sentence to remind this in the hydrological processes section of peatlands:
P7 L3-6: "This leads to a separation of the water balance of peatlands soils that is crucial to represent the water content of these soils. The calculation of evaporation is therefore separated for these soils, where an adjustment can subsequently counterbalance the non-representation of the mosses often present in these environments, which have a significant capacity to retain water."

3. For the FLUXNET site evaluation: how was the WFDEI forcing combined with the climate at the site? What were the other components of the C flux, e.g. GPP, and do they compare to site observations?
For the site evaluation, flux tower meteorology is used to prescribe precipitation to the model. However other meteorological forcing (wind, air humidity, pressure…) comes from WFDEI. The observed eddy covariane NEE flux is then compared to modelled NEE at each sites.
This sentence has been modified as following: (P4 L27-29)
The site evaluation was performed using WFDEI meteorological forcing at the 0.5° grid cell containing each site, excepted for precipitation that was prescribed from flux tower observations (FLUXNET data).

4. Maps: Can you provide a map of your peatland fractions, described in Sec 2.3.1, or combine it with Fig 4? Can you highlight the Ob catchment on Fig. 4?
In the Fig 4 are represented all the grid cells where the fraction of peatland is greater than zero.
A map of the fraction of peatland is added in Figure 4 with a highlight over the Ob catchment with the following title: (a) map of peatlands fraction inserted in the model vegetation map at 0.5° resolution. The red domain highlights the Ob catchment.
Added in the text: P5 L21 peatland map… in order to obtain a fraction of peatland fpeat_Yu for each grid cell as shown in Fig. 4(a). P14 L7: This impact is evaluated here for the Ob basin (represented in red in Fig 4a)
5. Productivity and decomposition: you reduce Vcmax based on Degerö observations, but how is the regional GPP affected by this change? Was the ORCHIDEE decomposition changed too? A lot of effort is put into a study of the effects on the regional water balance, but how do these peatland changes alter the regional C balance and fluxes? How does the peatland vegetation behave, e.g. in terms of LAI, NPP, biomass etc.?
Good point. Yes, we have applied a lower decomposition of active carbon for peatlands soils based on the soil moisture of the peatlands soils.
This paper has mainly focused on the hydrological effects of peatland and the changes made to carbon were not described in this paper. Another study has further improved the carbon budget of peat based with additional adaption of the peat hydrology described in our study (Qiu et al 2018).

6. Little mention is made of the effect of the soil freezing and thawing processes. E.g. I suspect that the active layer depth is greater in your peatland cells than in reality, if the texture you use corresponds to mineral soils.
The active layer thickness is reduced with organic soils compared to mineral soils. Unfortunately, this mechanism is not accounted for in our model.

7. Section 3.2. Did you force the model with precip and NO runoff first in order to identify bogs and fens?

After that, runoff transfer is switched off in cells with bogs? Please clarify.
Yes, that is right.
To model bogs we made a simulation switching OFF runoff transfer from other PFTs and defined peat in a grid cell as bog if the water table in this grid cell was not deeper than 30 cm for at least 4 consecutive months. After that simulation, we switched OFF runoff transfer for all bogs and other peat grid cells are defined as fen.
This has been added in the corresponding paragraph as presented below:
"We modelled ombrotrophic bogs, i.e. peatland fed only by rainfall that do not receive input from other soil columns, in two steps. First, we made a simulation switching off runoff transfer from other PFTs and defined peat in a grid cell as ombrotrophic bog if the water table in this grid cell was not deeper than 30 cm (in accordance with observations \citep{Booth_2005}) for at least 4 consecutive months in the mean year, for the 1990-2010 period. After that simulation, we continued to switch off runoff transfer for all ombrotrophic bogs, while the water balance of all other peat grid cells defined as minerotrophic fen is simulated with runoff transfer being switched on. Usually the ombrotrophic bog condition tends to be fulfilled between January and April."
8. Discussion. Can this approach be used to represent tropical wetlands? What is needed to do so? How about seasonally inundated wetlands? Will you add a CH4 submodel?
This approach may possibly be used for tropical peat but its limitation is that runoff is only received from PFT in the same grid. If a tropical peat system is connected to large-scale hydrological network with water routing connecting grid-cells, then our approach cannot be used. However, the validation and the evaluation have been done only at high latitudes and would need to be studied for tropical wetlands. This model might be better for tropical wetlands since there are no issues related to snow. However, the reduction of the evaporation might be not adapted for tropical conditions. We have adapted the model of methane emission from Walter et al 2001, which is very sensitive to the variation of WTD. The results concerning methane emission are not presented in this study.

This paragraph has been added at the end of the discussion:
This approach may possibly be used for tropical peatlands but its limitation is that runoff is only received from PFT in the same grid. If a tropical peat system is connected to large-scale hydrological network with water routing connecting grid-cells, then our approach cannot be used. Moreover, this would need to be evaluated for tropical peatlands.

We have added a CH4 sub-model adapted for peatlands, which takes into account the variation of the WTD. This has been made from the flux density model of Walter et al 2001 and the reintroduction of this model with simplification from Ringeval et al 2010.
To explain this we have added the following sentence:
P21 L7-10: For this, an adaptation of the CH4 sub-model for flooded wetlands by (Ringeval et al 2010) has been implemented which takes into account the variations of WTD. It is based on the methane flux density model of Walter et al 2001 and used to evaluate the methane emission from peatlands as described in this study (Largeron, 2016). However, the methods and results of the methane emission are not shown in this paper.
9. Language: Finally, please consider getting a native English speaker to go through your paper before it is published. The language is mostly fine, but there are quite a few places where the readability and grammar could be improved. I have identified some, but not all, below.

Specific Comments ————————
Page 1: Line 3. The sentence "These are considered..." doesn't make sense. "These"
are peatlands. These peatlands are represented as a new Plant Functional Types (PFT)
Line 9. "at" or "for" instead of "according to" at different spatial and temporal scales
P2: L3. Sentence "Moreover, ..." is too general, and anyway seems out of place here.
This sentence has been deleted
L11. Same thing for "Peatlands..." **This has been deleted**
L15. Remove "a large" : **This has been deleted in the text.**
L30. "peatland density" **This has been changed in the text.**
P3: L4. "MICT" ??? **ORCHIDEE-MICT used here is a preliminary version of Guimberteau et al 2017} This has been clarified in the text**.
L5. "latitude" L30. "as" to "to" **changed in the text.**
P4: L6. I suggest: "... with site measurements from the FLUXNET ..." **This has been changed in the text.**

L18. "shallow" vegetation? Do you mean low? **Yes, low vegetation. This has been changed in the text.**
L21. Västerbotten **changed in the text**
L28. remove final "of" **deleted in the text**
P5: L23: I suggest "in reasonable agreement with" instead **This has been changed instead of in adequacy**
L30-32: Mention that some models do have this stress, e.g. LPJ-WHyMe
In peatlands, the vegetation can survive in saturated areas. The representation of inundation stress is taking into account in some models such as LPJ-WHy \citep{Wania_2009b}.
P7: L4-7: I'm confused, was a simple bucket approach used, or did the infiltration etc follow STD ORCHIDEE? Eqns. 1 & 2. Do the Beta factors depend on vegetation type/PFT?
In this study, we used the standard 11 layers described by De Rosnay 1999. However, the WTD is diagnosed by taking into account all the water contained in each layer previously diagnosed, as if it were transferred to a bucket.
The parameter B_{inter} and $B_{transpir}$ is calculated for each PFT. However, B_{evap} is calculated only per grid cell. This explains why we applied the reduction factor R only in function of the fraction fpeat.
To avoid confusion, the following sentences has been added P7 L14: "In this study, we use the standard 11-layers scheme of ORCHIDEE as described by \citet{DeRosnay_1999} to represent the hydrology of peatlands."
P7 L35 P8 L1: The parameters B_{inter} and $B_{transpir}$ are calculated for each PFT. However, the evaporation capacity B_{evap} is calculated only in function of the grid cell
P8: - In general, I'd recommend you use "soil moisture" instead of "humidity" in the text. - R is described as a resistance and a reduction. - Eqn 3: so does this mean that when fpeat = 1, R = 1, so there is NO evaporation from the peatland? Is that justified?
We choose a <u>resistance</u> R in accordance with the soil <u>moisture</u>. I changed reduction into resistance and soil moisture instead of humidity. When fpeat=1 (almost never the case) the evaporation is not reduced. This sentence has been added in the text:
"The reduction of evaporation does not occurs when $f_{peat}=1$. "
L10-12. show the improved latent heat flux! **The figure has been added with the Figure 1. Caption**: (b) Observed (black) and modelled (green) turbulent latent heat flux (LE) in W/m2 of the peatland site of Siikaneva
P9: Fig.2 - is PFT grass simply the same simulation without the Vcmax reduction? **PFT grass doesn't have the Vcmax reduction and doesn't have the hydrological processes applied to the PFT peatland.**
L14. "snowfall and rainfall" **changed in the text**
P10: L1. evidence for "may"? **I have changed the following sentence:** This bias can be explained by the amount of water from groundwater, which is not represented in the model. The opposite is observed at the Siikaneva site and could come from an outgoing flow as a small drainage rate.
L1-2. unclear what's meant here. **This has been modified in the text as following:** "The opposite is observed at the Siikaneva site where the WTD is overestimated. This could come from an outgoing flow as a small drainage rate."
L3-5. But didn't you force Fajemyr with observed precipitation? If so, the WTP reduction on Feb/Mar should also be seen in the observations. Is the problem frozen soil? If so, where is the soil water coming from in reality? Is there justification for the sensitivity test described in Lines 9-10? **The modelled WTD of peatlands are diagnosed from the FLUXNET precipitation of this site. 2005 is a dry years and could explain why the modelled WTD is deeper than observations. In reality, there might be different properties of the soil as well as presence of mosses that can hold water.**
This has been added in the text:
"The specific vegetation at the Fajemyr site such as mosses helps to hold the water which can then be infiltrated into the soil. The underestimation of the modelled WTD can be explained in part by the absence of the representation of mosses in the model."
P11: Fig 5. Describe the zoomed section in caption. **Sentence added to the caption:**
The region of western Siberia (zoomed area) has been used for a sensitivity study of peatland to precipitation.
P12: L1-2. Obvious? Sec. 3.3.1 - please identify the Ob basin in a Figure. **This has been added in Fig 4a**
P13: Fig 7. There is no "center". Please identify with a, b and c, as in Fig 8. **This has been changed**
L8. "first show" - but both are in Fig 7! **This sentence has been deleted**
P15: L10. "reduction" instead of "difference" **changed in the text**
L24. RE snow - more detail needed. **This has been added in the text: (now P17-L11)** "The new multi-layer snow scheme, not included in the model version used here, better represents snow depth and snow water equivalent (SWE), which were previously both underestimated in ORCHIDEE. This corrects the

underestimation of snow melt runoff, and consequently improves the modelled river discharge in northern high latitudes (Guimberteau et al 2017)"
P16: L4. "top panel" - use (a) instead. **This has been changed**
P17: L4. RE snow - more detail needed. **This has been added in the text**: (now L28-29 P17)
"This trend is due to the same shift of the contribution of the modelled TWS, linked to the snow melt that occurs about one month too early \citep{Wang_2013}."
L6 & L11. Fig 8a **This has been added.**
L14-17 - remove/move this paragraph? **This has been removed.**
L22. Why north of 40N? I thought you ran the model for north of 45N. **For this study, each reservoir has to be calculated explicitly. The routing scheme in the model is used here. However, the routing scheme cannot run at 45°N because the scheme need information from the whole river basin information**.
L18-29. This whole section is unclear. **This whole section has been modified as described below:**

Modelled TWS in Fig 8a has the same phase than in the GRACE observation, but the annual amplitude is underestimated by 27% in the model. The simulation of TWS is improved by the soil freezing and snow parameterization introduced by Gouttevin et al (2012). In the model, the accumulation of snow represents three-quarters of the total increase of TWS north of 45°N between Autumn and Spring (blue curve in Fig 8a). In addition, the soil freezing parameterization keeps a mass of water stored as ice in the soil pores (green curve in Fig 8a) instead whereas in absence of freezing, liquid water losses from runoff and drainage would decrease TWS. By contrast, the three free water reservoirs corresponding to water being routed to the ocean (red, orange, pink curves in Fig 8a) have a small seasonal variation and thus do not contribute to the amplitude of TWS.
In our model, peatlands store a fraction of runoff water that is not transported to the ocean.
To evaluate the impact of peatlands on the variation of TWS, we selected only the grid-cells containing some peat (non-zero peat fraction) and performed two simulations. We have evaluated the contribution of the SOIL reservoir both for all column of soil (Fig. 8 b) and for the column of soil of peatland only (Fig. 8 c). The results shown in Fig. 8b indicate that the additional storage of water contributed by the peat fraction in the selected grid cells is negligible (the curves with and without peatlands are merely distinguishable).
In this case, the TWS changes are reduced by 0.10 cm due to the lower variation of soil humidity with the peatland scheme, where the inter-annual variations are low. Moreover, the inter-annual variability of TWS in the regions of northern peatlands only is better represented than for the whole boreal regions.
However, the TWS change in northern peatlands is higher when only the soil column of peatland is considered (Fig. 8c) and reaches an increase in mass gain up to 2 cm in 2009. However, more water storage only occurs in the column of peat soil and not in the other column of soil of a grid cell. When the column of peat soil only is considered (Fig. 8c), the TWS change is higher and reaches an increase in mass gain up to 2 cm in 2009. This is the reason why we show in Fig 8c simulated TWS averaged over the area covered by peat only (column of peat soil) compared to a simulation where the same area is covered by grass. Local TWS remains lower in summer with peat than with grass, with a mean difference of 1.30 cm.

P19: L1. ice on the observed or modelled soil? **Modelled soil: Since satellite observations do not retrieve flooded areas being frozen we consider flooded area during the thaw season.**
Revised text: P20 L5: "The comparison with satellite flooded area was restricted to the thawing season, because of no satellite retrieval of flooded area being frozen »
L12. Could also mention the discrepancy near Finland. **This has been added in the text.**
L28-30. Not sure what this sentence means. **This sentence has been modified:** « In western Siberia, the model underestimated the flooded peatlands of 0.04 Mkm2 in summer compared to observations. This means that the model represents only 66% of the observed extent of flooded peatland in this region »
P20: L6. "methane emissions to hydrological variations", perhaps? **Yes, that's right. This has been changed in the text.**
P21: L17. meteorological **This has been corrected in the text**
L31-32. Unclear "34% in average" of what? **This sentence has been modified:**
"The variations of water mass linked to soil moisture of all soils contribute to 34\%\ of the annual mean TWS."
P22: L8. Which Fig 8 - a, b or c? **Comparison between Fig 8 a and b:** (Fig. 8 (a) and (b)).
L14. Underestimated. **This has been corrected in the text**