Response to Anonymous Referee #1:

Implementing northern peatlands in global land surface mode: description and evaluation in the ORCHIDEE high latitude version model (ORC-HL-PEAT).

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.

This paper discusses the addition of peatlands into ORCHIDEE. There are two components for this a vegetation component and a hydrology component. The vegetation component is mainly a modification of parameters. However the hydrology component involves the addition of some processes. These need to be described in more detail. I think more detail is required on the snow component which is frequently referred to in the results section but not discussed in the modelling section.
The vegetation is modified and there is a brief evaluation at the three FLUXNET sites. However it would be good to see the large scale effects of these changes. Also, since the snow seems to be a reason for many of the differences shown it would be good to maybe evaluate the snow component a little more.
It would be interesting to see a map of the observed peatlands and the different types.
I thin they authors should separate experimental design, observations used, model description and results more clearly. There are lots of slightly different experiments included, which is a bit confusing. There needs to be more consistency (particularly of terminology and experimental design) throughout the paper to make the story easier to understand.
Section 3.3.2 needs to be more focused on the key results given the question of how adding peatland affects the hydrology of northern high latitudes.

To clarify the model experiments section, this has been split in 2 sections: Site simulations and large-scale simulations. The section 3.3.2 has been rewritten with fewer details and more clearly. We have added more details concerning snow component with explanations below:

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.
In accordance with the Reviewer 2, we have added more details concerning the explanation of the bias of the snow representation. The following sentences have been added:
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 L11: "The new multi-layer snow scheme from Wang et al (2013), Guimberteau et al (2017), 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)"
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 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).

Minor comments

P2.L5 "The characteristics..." - sentence needs re writing.
Peatlands have specific properties concerning vegetation, hydrology as well as carbon.
P3. L14 What is the depth of the soil column and the approximate layer thicknesses?
This information has been added L20 P3:
The transport of water in the soil is described by the 11-layer scheme of (DeRosnay et al 1999). The thickness of each layer increases geometrically with depth, from 1 mm in the top-soil to 1 m thickness at the standard 2 m total depth. Heat diffusion and moisture transport is calculated between each soil layer.

P3. Section 2.2 – Paragraph 1 needs to go later. The first part of the section should discuss the site simulations, then the next part the large scale simulations. These should be more clearly separated.
In addition and maybe more importantly, there is no experimental design for the large scale simulations despite several different experiments being included later.
The first part of the section explains the experimental design for large scale simulations. This has been put at the end of the section with the following introductory sentence:
The impact of the inclusion of peatland in the model has been studied at large spatial scales, considering all northern peatlands above 45° North.
P3. L1 There is no discussion of how the soil respiration is calculated used for the NEE.
It is unfortunately unclear to us what section this comment refers to.

P6. L30 What hydraulic properties are used for peat soils?
We have tested peatland-specific van Genuchten parameters as given in Table 1. We therefore write:
P7 L31-32: We aimed at improving the representation the hydraulic properties of relevant large-scale peat soils by using appropriate Van Genuchten parameters of organic peat soils as described in Table 1.
However, the hydraulic properties used in the model are unique for each grid cell, and the value used is based on the dominant mineral soil present in the cell. Therefore the hydraulic properties adapted for organic soils are not applied.

P7. L3 – How much runoff from the other PFT soil columns?
All the runoff is reinfiltrated into the peat soils. When this rate is too high, the runoff occurs in the next time step of the model with the column of soil of peatlands. Revised article:
P8 L2: To represent these processes, we choose to infiltrate into the soil column of peatlands the entire runoff generated in the non-peatlands tiles of the same grid box at the same time step.

P7. L7 How is the drainage blocked?
The flux of water at the bottom of the layer has been set to zero. This has been added to this sentence:
P8 L7-8: To prevent water lost by the drainage, we choose to block the deep drainage at the deepest soil layer, with applying a zero-flux of the bottom drainage, because peatlands usually have no deep drainage.

P7. Is there an equation or two that can be included to show how the hydrology was modified?
We have added two equations in the section 2.3.3:

P8 L8: with applying a zero-flux of the bottom drainage ($q_N = 0$)

P8 L17-20: The water supply W_{supply} of peat soils is summarised in the equation (Eq), T_F is the throughfall, S_{runoff} the runoff coming from non-peat soils and $R_{stagnant}$, the water from the reservoir.
$W_{supply} = T_F + S_{runoff} + R_{stagnant}$

Fig 1. What is the depth of the soil?
The depth of the soil is 2 m as diagnosed in the standard configuration of ORCHIDEE. This information has been added in the caption of the Figure.

P8. L1– Please rephrase this first sentence.

This sentence has been modified:
P9 L7: Peatland soils are flooded for part of the year, which leads to a vegetation saturated with water during this time.

P8, L13 – any tests of the calibration of R for other sites? Maybe more details?
We have added in Fig 1b the turbulent latent heat flux for the Siikaneva site in accordance with the comments of the other reviewer.

Fig 2. Looks a bit weird. In terms of the x-axis – there seems to be two days in a month. Results look very comparable though! The peatland pft has made a good change
To improve the readibility, we have chosen to plot the diurnal cycle with a 10-day running mean filter. In fact, there is on average 3 composite diurnal cycles per month.

Fig 2. Do the observed NEE represent 100% peatland?
We consider peatland sites to be composed only by peatlands.

P9. L19. This says despite the missing processes we are getting the right answers? Surely this is unexpected?
Good point, the idea here is to show that it is almost sufficient to represent quite well the WTD. This can be due by a low water supply from runoff.
This has been changed as following: Model results for the minerotrophic sites (Degero and Siikaneva) show that the water supply from precipitation only is almost enough to reproduce the observed water table position.

P9. L22. Now it says Degero WTD is underestimated.....
This has been changed as following:
Results from the Degero fens site slightly underestimate the WTD during the summer. This small bias…

Fig 3. Does Degero really have no winter precipitation? Maybe it is just too small to see? The axes could be adjusted? **Yes, the winter precipitation of Degero is not zero but very small. The axis have been chosen to be optimised for the 3 sites.**

Fig 3. I think these WTD results look pretty good for the summer. I think the winter differences need clear justification, see next comment.
Fig 3. Does the standard version of ORCHIDEE simulate a water table depth? If it does it would be good to see how the improved representation of peatland affects this.
The standard version of ORCHIDEE does not simulate a water table depth. This water table depth can be used only for wetland areas since the standard depth of soil is 2 m. We have added the calculation of the WTD for peatlands. In the case of peat soils, the drainage flux at the bottom of the soil has been blocked since there is no deep drainage in peat.
See sentence P8 L7-8.

P10. L2. We have learned very little about snow up to now. Why can't the infiltration of snow occur?
Good point, this occurs when the soil is frozen. This sentence has been modified as follows:
P11 L3: Since infiltration of snowfall is blocked when the soil is frozen, the water content is underestimated.

Fig 4. How does this compare with observations?
Due to the lack of large-scale information on the distinction between peatland types, we have chosen to create a map in order to discern minerotrophic to ombrotrophic hydrological behaviour. The distinction between the type of peatlands could be made only with peatlands site.
We have added this information P11 L17-18:
P11 L17-18: Since we cannot separate bogs and fens at the spatial scales relevant here, we consider in the model that all peatlands are fed by runoff. Due to the lack of large-scale information on the distinction between peatland types, we have chosen to create a map in order to discern the hydrological behaviour of the different type of peatlands. Due to the lack of large-scale information on the distinction between peatland types, we have chosen to create this map in order to discern the hydrological behaviour of the different types of peatlands.

Fig 5. How much does lack of snow infiltration affect things?
To quantify the lack of snow infiltration, this study would need to be again evaluated with a version of the model that includes the new snow scheme. This is unfortunately beyond the scope of this study.

Section 3.2 This is a long section. Maybe I am missing the point but it seems to be telling us that minerotrophic peatlands are more sensitive to precipitation than ombrotrophic peatlands. This is expected? Is it the ability of the model to determine the difference between the two the novel result here? How much is this affected by the lack of representation of snow infiltration? It would be good to explicitly state the usefulness of these results for other applications.
Peatlands are very sensitive to precipitation. However, minerotrophic peatlands receive both direct precipitation and runoff, which indirectly depends on the precipitation of surrounding environments. This additional factor lets us suggest that minerotrophic fen could be more sensitive to precipitation. The lack of the representation of snow infiltration here could enhance an underestimation of peatlands considered as ombrotrophic bogs.
This has been added in the section: Moreover, the total area of ombrotrophic bogs can be underestimated due to the lack of the snowmelt runoff in the version of the model (Wang et al 2013, Gouttevin 2012?).

P13. L10 This first paragraph is model description.
First paragraph: The transport scheme of ORCHIDEE (Ngo-Duc et al., 2005) stores the water from the runoff and the drainage in 3 reservoirs with different residence times. Since the implementation of the peatlands in the model leads to the redirection of runoff from the other soil columns to the peat soils, one might expect some impact on the simulated river discharge. This impact is evaluated here for the Ob basin, which represents one of the largest boreal basins (above 45° N). This watershed is located in abundant peatland areas, particularly north of 60_ N. Although the average percentage of peatlands remains less than 10% per grid cell at 0.5° resolution, more than half of the grid cells have a non-zero fraction of peatlands. Above 60° N, peatlands are present on more than 96% of the grid points of the Ob basin.
The first sentence has been moved to model description of ORCHIDEE.
This paragraph has been modified and added to model experiments. Revised version:
The impact of peatland on the river discharge has been evaluated for different catchments. Here, we present the results with the Ob basin, which represents one of the largest boreal basins above 45°° N. This watershed is located in abundant peatland areas, particularly north of 60N. Although the average percentage of peatlands remains less than 10% per grid cell at 0.5° resolution, more than half of the grid cells have a non-zero fraction of peatlands. Polewards of 60° N, peatlands are present on more than 96% of the grid points of the Ob basin.
This sentence has been added to the second (becomes first) paragraph of the section 3.3.1:
The implementation of the peatlands in the model leads to the redirection of runoff from the other soil columns to the peat soils. Here, we evaluate its impact on the simulated river discharge.

Fig 7. These subplots need a title. STD runoff is missing. **This change has been made in the Figure**

Fig 7. there is an interesting timing difference on the peaks between the observations and the model.
It is unclear to us what this remark refers to. We see a maximum in June in both cases.

P14. L1 – Why is the STD version not the HL version aha it is (confusing!)?
To avoid confusion ORCHIDEE-HL has been added in the caption of Fig 7 and in following sentence:
The standard simulation (STD) corresponds to the version of ORCHIDEE-HL which includes soil freezing \citep{Gouttevin_2012} and excludes the peatland scheme.

P14. L3. This is the first time PEAT-LOWET has been introduced. It needs to go in the experimental design.
Thank you. This has been added in the hydrological processes section 2.3.3:
In this study, we made two peatlands simulations: The first one, referred to as PEAT-LOWET in the following, includes the resistance to evaporation. In the second one, referred to as PEAT, no such resistance is applied.

P14. L6 to P15. L5. This information can also go in the experimental design.

The first paragraph has been moved in the model experiments.
The GRDC observations is remind in the section as following:
P16 L6: The GRDC (Fekete et al 1999) observed river discharge is shown as a dotted red line in Fig. 7a.

P15. L30 GRACE should be discussed earlier in a "materials and methods" section.
This paragraph has been moved in the model experiments section.

Fig 8 – What is HIGHLAT representative of – is this the same as STD? GRACE needs to be the same in each subplot. What do we learn from Fig 8a?
The term HIGHLAT has been added in the caption: variations of latitudes over 45° N (HIGHLAT).
The importance of snow in TWS is shown in Fig 8a: In the model, the accumulation of snow represents three-quarters of the total increase of TWS north of 45° N between Autumn and Spring.

Fig 8. Do we learn anything from such a long time series or would a climatology for 1 year be better?
The long time series study was shown to avoid wrong conclusions due to an atypical year.

P16. L4 We have no "top panel" in fig 8.
This has been changed with adding a, b and c in the Figure.

Fig 9. I don't understand the units?
The units correspond to the peatland area (km2) per grid cell of 0.5° resolution. This has been added in the caption: Extent of flooded areas (in km^2) for each 0.5° grid cell…

Section 3.4 In section 3.2 there is quite a discussion of bog vs fen. Can this be referred back to in this section? How well does the model represent the flooded areas of bog vs fen? This would tie the relevant sections together.
In the map, the flooded peatlands in summer are located in regions defined as bogs (because of the definition which say that WTD is <30 cm). This has been added P20 L15:
The flooded peatlands areas coincide with the regions defined as ombrotrophic bogs (Fig. 4b). This can be explained by the definition of the bogs we used, that is, where their WTD does not exceed 30 cm depth for at least 4 consecutive months.

Fig 10 – it seems the differences in timing in Figure 10 are caused by the snow. It might be good to show some snow results to demonstrate this? **This is unfortunately not possible to demonstrate this. This study has started when the new snow scheme in ORCHIDEE was not implemented yet. A demonstration such this one requires to merge the peatlands scheme development in a version that includes the new snow scheme.**