Interactive comment on “A new model of Holocene peatland net primary production, decomposition, water balance, and peat accumulation” by S. Frolking et al.

Response to Anonymous Reviewer comments

We appreciate the anonymous reviewer efforts to work through a long paper. We address their comments below and in changes made in the revised manuscript. *Our responses are italicized.* “New text added to the manuscript is in quotations”.

Anonymous Reviewer #1:

General comment:

The sensitivity analysis seemed rather tedious to read. I’m wondering if some subheadings could help out. Also, I was wondering whether it might be possible to graphically present the results in Table 5. One suggestion I have is for two bivariate plots: (1) of the relative sensitivities of hpd vs. zwt for changes in parameters from the base case, and (2) the relative sensitivities of NPP (or %NPP in peat) vs. peat mass for changes in parameters from the base case. *The sensitivity analysis has been divided into 3 subsections for groups of parameters evaluated (bulk density, vegetation productivity and decomposition, and water balance). We have generated the bivariate plots suggested (see Fig. R1 below on page 5).*

Specific comments:

• *X-axis labels added to Fig. 6a & 6b*

• *mis-spelling corrected.*

Anonymous Reviewer #2:

General comments:

1. Temperature as an important driver: *We agree that including temperature as a driver of impacts is essential for wide-scale application of the model, both to capture temporal dynamics at sites where temperature has varied through the Holocene more than the past 8000 years at Mer Bleue, and to simulate peatlands from the tropics to the sub-arctic. We discuss this in the manuscript near the end of the discussion section (now with a sub-heading: “*Outstanding issues and future directions”). *In developing HPM, we focused first on hydrology in order to address the carbon-water feedback that we think is an essential internal process governing peatland dynamics. In general, we do not think that there is an equivalent temperature-carbon feedback internal to peatlands, except in the special case of permafrost. We are currently working on developing temperature functionality in HPM, and anticipate incorporating temperature effects into the model in the near future.*

2. Plant functional types: *The number of plant functional types to include has been an issue of much discussion within our group, with our ecologists generally urging more PFTs and our hydrologists and biogeochemists wanting fewer. We arrived at our list of 12 by first thinking of some key functional differences: above- and below-ground biomass/NPP; vascular or non-vascular; ombrotrophic or minerotrophic; woody or herbaceous; tissue decomposability). We then divided the ombrotrophic mosses into a range of ‘moisture’ classes (hollow, lawn, hummock sphagnum and feather) as these are often used in paleo-analysis as wetness indicator. In addition, HPM can be used to look at the behavior of individual plant functional types against climatic changes. We are working right now on adding one additional PFT – trees (unless we can persuade ourselves that trees are just large shrubs) -- which we think will be important for many current peatlands (particularly in the tropics), and also to capture the impacts of climate drying on peatlands carbon and water dynamics. We agree that 12 (or more) wetland/peatland PFTs is likely to be more vegetation classes than a global earth system model will be willing to incorporate (e.g., Wania et al. (2009) use only two wetland PFTs in LPJ-Why – flood-tolerant C3 graminoids, and Sphagnum moss). One application for a model like HPM, which has been coded to make addition or removal of PFTs straightforward and requiring only a few*

parameters (Table 1), will be to evaluate/experiment with different sets of PFTs to assess what is gained or lost in terms of model outcomes and model applicability across a range of scales. We have added a paragraph about this in the discussion section:

"HPM uses 12 PFTs to represent the range of vegetation found on many peatlands. This collection of PFTs was determined by first thinking of key functional differences: above- and below-ground biomass/NPP; vascular or non-vascular; ombrotrophic or minerotrophic; woody or herbaceous; tissue decomposability. Ombrotrophic mosses were then partitioned into a range of 'moisture' classes (hollow, lawn, hummock sphagnum and feather), as these are often used in paleo-analysis as wetness indicator. One missing PFT is trees (unless trees can be considered to just be large shrubs); trees are likely to be important for simulating many current peatlands (particularly in the tropics), and also to capture the impacts of climate drying on peatlands carbon and water dynamics. With 12 PFTs HPM could be used to look at the behavior of individual plant functional types against climatic changes. While 12 (or more) wetland/peatland PFTs may seem too few from an peatland ecology point of view, it is likely to be more vegetation classes than a global earth system model will be willing to incorporate; for example, Wania et al. (2009) used only two wetland PFTs in their LPJ-Why model – flood-tolerant C3 graminoids, and *Sphagnum* moss. A series of simulations with HPM would provide a mechanism for evaluating the importance of different PFTs in long-term peatland dynamics and carbon cycling."

3. <u>Model validation</u>: *We agree that, at this stage, HPM is not sufficiently tested for global (or even regional) application (see responses to comments 1 and 2 above). This manuscript presents the model in detail, and provides the initial test at one site, with the goal of illustrating two things: (1) the nature and scope of what the model simulates, and (2) that the model is potentially applicable to (or testable at) real sites (i.e., meters of peat accumulating in millennia, with varying water table depths generally in a range of 0-0.6 meters, and vegetation transitions during peatland development). By generating an accumulated peat profile that can be used to compare simulated peatland history to contemporary peat cores collectable in the field, HPM is open to detailed testing at a number of sites. Additional modeling work is now underway at unmanaged sites in Finland and northern Quebec, and at a drained site at Mer Bleue, and work is planned for additional development assessment in Alaska and for nutrient addition experiments at Mer Bleue, and for an initial foray into tropical peatlands. We also welcome participation of others who would like to test, modify, or further develop the model at additional sites.*

4 & 5. <u>Manuscript organization</u>: *We added a subsection (3.5 Sensitivity analysis) to the (renamed) Model Description and Simulations section; we divided Section 4.2 (Model Sensitivities) in the results section into 3 sub-sections for groups of parameters evaluated* ("Peat bulk density parameters, vegetation productivity and decomposition rates, and water balance parameters"). *And we divided Section 5 (a single Discussion section in the original manuscript) into 5 sub-sections* ("Vegetation; Hydrology; Decomposition; Carbon balance; and Outstanding issues and future directions").

<u>Specific comments</u>:

• P116, L18: Change "310 kg C" to "310 kg C/m2". Otherwise the figure makes no sense. *Changed*.

• p.117, l3-6: This sentence is a bit confusing, as the figures refer to mass of C, or the compounds (CO2, CH4 and DOC). Clearer wordings may help. For example, change to " they appear to take up CO2 at a rate of between 40 and 80 g C /m2/yr", if that is the case (I think it is the case). For CH4, it is for CH4, not C. *This has been revised to read*: "At present, multi-year field studies indicate that northern peatlands take up CO_2 at a rate of 40 - 80 g C m^{-2} yr^{-1} and lose 10-20 g DOC m^{-2} yr^{-1} to downstream aquatic ecosystems (Roulet et al. 2007; Nilsson et al. 2008; Koehler et al. 2010), while northern peatlands in aggregate 15 - 40 Tg CH_4 yr^{-1} (Makiloff-Fletcher et al. 2004)."

• p.117, l11: Change to "MacDonald" *Changed*.

• p.117, l.21: Do the authors really think that the model with that much detail and with lack of temperature as presented can be coupled to earth system model? How likely would the data required be available on a large or global scale? *See general comments above. We think we are headed in that direction (see reply to comments* *above), but acknowledge that HPM as presented here is only part way there. We have revised the text to reflect that; it now reads: "*In the present study we develop a new model, with the intention that, with further development (see Discussion in Section 5 below) it could be eventually coupled to Holocene climate or earth system models to investigate the climate-carbon-methane interactions over decades to millennia."

• p.118, l8: change subheading to "Background – modeling peatland processes"? (as the model does more than just peat accumulation.) *Changed*.

• p.119, l6: it is not necessary to convert mass to depth in order to discuss depth-age relations, but it is actually preferable to use mass-age curves (depth is expressed as cumulative mass per unit area). *This has been revised to read: to generate a relationship between cumulative mass per unit area and age, or using a constant value for peat bulk density to convert mass to depth, this model generates a concave depth-age profile.*

• p.119, l10: change "Eq. (3)" to "Eq. (2)" *Changed*.

• p. 122, l.15: Change heading to "Model description and simulations"? *Changed*.

• P. 122, l25: change to "The vegetation sub-model in HPM is based on the assumption that . . ..", as I think the word "assumption" is more accurate than "idea" in this context. *Changed*.

• p. 123, l.17-18: It is great that the model can generate species composition on the basis of precipitation and the optima and tolerance formulations. Could this provide another means to test the model performance using modern plant community data (and water table and precipitation data) from peatalnds around the world? *Yes, the model's simulated NPP by PFT at the end of a simulation (i.e., contemporary conditions) could be tested against field data (probably best averaged over a few years – or test model ranges in NPP by PFT over the final 10-100 years of the simulation against observations of temporally variability across a site or interannual variability at a site).*

• p.131, l1: typo, delete "a peat" *deleted*.

• p. 131, l.23: add "respectively" between "organic mater content" and "(Dean, 1974,. . ." *added*.

• p.131, l.25: Does "46%" here refer to C % in organic matter (peat)? Unclear. Reword. *Changed to:* "Turunen et al. (2004) analyzed the top 0.60 m of peat for 48 cores from 24 different bogs in eastern Canada and obtained a mean of 0.46 g C g^{-1}, …"

• p.131, l.27: change "thereafter" to "below that" *Changed*.

• p. 131, l.29: change "dates" to "ages" or "age determinations" *changed to* "age determinations".

• p. 132, l. 3-4: add a new subsection on sensitivity analysis and move and reorganize some materials from subsection 4.2. See general comments above. *Done*.

• p. 133, l.16: change "more then" to "more than" *Changed*.

• p.134, l.9-11: Here the difference between total NPP and total decomposition is referred as NECB, while in Fig. 5c it is referred as NEE. Perhaps the authors want to be consistent throughout the manuscript, as both terms refer to different ecosystem processes, though the simulations cannot tell them apart (as CH4, DOC and other fluxes are not explicitly considered). *We agree; the figure was mis-labeled. We have changed the Fig. 5c to read NECB, as NEE typically refers to CO_2 only, and this is not what the model is simulating.*

• p. 138, l.17: Add subsections in Section 5? With last subsection focusing on uncertainties and outstanding issues, etc. See general comments above. *Done*

• p. 139, l. 17: Change "300 kg" to "300 kg/m2", otherwise the figure makes no sense. The cumulative mass per unit area and depth in m should be interchangeable with bulk density information. *Changed. Cumulative mass per unit area and depth are interchangeable with bulk density, however, it is important to note that bulk density is a dynamic state variable in HPM, and also that it is an independently measured property of peat cores, so final state simulated bulk density profiles can be tested against field data.*

• p.139, l. 19-20: It is kind of unusual that simulations at 1-yr timestep are less variable than the observed peat-core data that were sampled at much lower resolution. Could that be due to the smoothed precipitation time series, even with added random variability? Fig. 4a shows that the reconstructed annual precipitation ranges from 0.8 to 1.1 m over the last 8000 years. How that range compares with the instrumental records in Montreal or Ottawa? If similar, should we expect to see much larger magnitude of precipitation change during the Holocene? If so, what impacts of the reduced precipitation driver variability on the results? *This is an interesting question. In terms of carbon accumulation (Fig. 5b), the difference in variability between the model and the core may be overstated, and it is important to bear in mind the (unreported) uncertainty in the measured record of carbon accumulation. In terms of vegetation composition of remaining peat (Fig. 6 c & d), it does seem that the model is less variable then the core (as reported here, which as a general, not a high resolution analysis of a single core, no replicates). The model, for vascular PFTs, does use a 10-yr smoothed water table to account for some inertia in vegetation dynamics. This was not stated in the submitted manuscript and has been added in Section 3.1 (added text:* "For vascular plants, the calculation in Eq. 6 uses a 11-yr mean water table depth (simulation year and 10 previous years) to account for inertia in vegetation response to moisture changes; non-vascular plants use the current simulation year water table depth for the calculation in Eq. 6."). *Nonetheless, this discrepancy between model and core may indicate that PFT dynamics in HPM are more stable than they should be. We also think that it is likely that there were much larger precipitation changes during the Holocene than in the recent record. The annual precipitation range at Montreal (1940-1995) was 0.75 – 1.2 m/y. One of us (PJHR) is trying to better quantify Holocene precipitation through paleo-analyses at sites in southern Quebec. Note that HPM seems to be much more sensitive to long period variations in precipitation (i.e., a dry century or two) than to interannual variability. It is also possible that seasonal changes in precipitation may be more important for peatland carbon cycling than mean annual values (e.g., Charman (2007) Holocene, 17, 217-227), and these may also have been variable through the Holocene. In its current formulation, HPM does not resolve seasonal precipitation (we address this briefly in the Discussion).*

• References from p. 146: There are some errors in the references cited. Below are just a few examples. The authors should check thoroughly. *Done*

• Dise: Should be published in year 2009 in Science, not 1998. Re-order references around Forrest and Fraser, between other Frolking refs. McGuire 2009. The journal should be "Ecological Monograph", not "Ecological Appl." Yu 2003. The co-authors may not be correct for that cited paper. *These were corrected and we checked the entire list again.*

• Table 1. Superscripts for some terms may be confused with the terms themselves. Spell out the terms in the footnotes? For example, for (a): NPPmax are the maximum NPP values. *changed*.

• Table 2: Footnote b: "-25" needs unit (per mil) *added*

• Fig. 2: need pane label for c. *fixed*.

• Fig. 6: Add appropriate x-axis labels for all panels? *X-axis labels added to Fig. 6a & 6b*

New References Cited

Wania, R., Ross, I., Prentice, I.C.: Integrating peatlands and permafrost into a dynamic global vegetation model: 2. Evaluation and sensitivity of vegetation and carbon cycle processes. Global Biogeochem. Cycl., 23, GB3015, doi:10.1029/2008GB003413, 2007.

Figure R1: HPM sensitivity to various parameters (see Table 5), represented as (a) total simulation NPP vs. % of total simulation NPP remaining as peat at end of simulation, and (b) final peat depth vs. final peat water table depth. Black circles represent mean baseline simulation with standard deviations (see Table 5), and solid line in panel (a) represents a constant final peat mass equal to the mean of the base runs.