

Interactive comment on “The full greenhouse gas balance of an abandoned peat meadow” by D. M. D. Hendriks et al.

D. M. D. Hendriks et al.

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Dear referees,

We would like to thank you for giving these useful remarks and advices with respect to the contents of our article. We have taken all of them into account and provided clarifying answers as well as propositions for changes in the text, tables and figures. Regarding the nature of the remarks and questions we had to take into account some additional data and decided to add the carbon balance of 2006 to the article. Information on this will be found written in the final article together with the results of 2004 and 2005.

Best regards,

On behalf of all authors, Dimmie Hendriks

Response in order of the referee numbers:

Anonymous Referee #1 Although authors measured CH₄ concentrations in the profile, there is no data in the part of Results. Please supplement. Measurements of the CH₄ concentrations in the soil profile are discussed in paragraph 4.4, line 10 to 24. Page 293 line 5-10: CH₄ emission from the tested peat is too strong as compared to other wetland in Europe. Authors could please give some reasons to explain this difference. The following explanation is proposed at page 293, line 9 to 16: The Horstermeer site has relatively high soil water levels, and relatively eutrophic soil conditions. In similar conditions elsewhere also high CH₄ fluxes have been measured (Fiedler & Sommer 2000). Additionally, in this research the CH₄ fluxes from water surfaces, which increase the average flux from the area, are taken into account too. In other research this is often neglected.” The tested peat is a sink of atmospheric C as authors measured, authors should also discuss it GWP. The following sentence will be added at page 291, line 29: “ĚĚ, and only a small sink of 71 g CO₂-equiv. m⁻² yr⁻¹ when considered as GWP.”and on page 294 lines 18: “CO₂-equiv. ha⁻¹ yr⁻¹ (71 g CO₂-equiv. m⁻² yr⁻¹) when considered as GWP:”

Anonymous Referee #2 General remark: Scaling up from the point to whole meadow was done by very simple way: categorization and area-weighted multiplication. I could not be sure that such a simple method captured heterogeneity of the peat meadow in temperature, water and nutrient conditions. The flux chamber measurements are done at ten locations which are spread over the research area in a way that is representative for the three land elements (relatively dry land, saturated land and ditches) and cover a variety of vegetation types. By measuring at those different locations we expect to cover the variation in temperature and nutrient conditions.

Specific comments: Page 279, line 12: Add citation for the European peatland CO₂ sink. The sentence will be changed to the following, more general statement "peat lands have formed a large sink of atmospheric CO₂ since the last glacial maximum." Page 281 line 13: Table 1 appears after table 2 This will be corrected: table 2 will

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4, S423–S434, 2007

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Discussion Paper

become table 1 and vice versa. Page, 282 line 1: “then” should be “than” This will be corrected in the text. Page 285, line 14: “Evapotranspiration” may be more appropriate for E We agree that evapotranspiration is more appropriate than evaporation in this case. In the final text evaporation will be changed to evaporation and E will be changed to ET. Page 287, line 23: Why year 2005 showed larger carbon uptake in spite of shorter growing period? After recalculation (see referee #3, remark 3), the NEE of 2004 appeared larger than the NEE of 2005. This is more logical regarding the significantly longer growing season of the year 2004. Correct values will be corrected throughout the whole article. Page 288 line 8: Does the equation 2 use “Arrhenius relation”? Simply exponential? Equation 2 uses the equation form $R = Ae^{Bt}$ which is described by Lloyd & Taylor (1994) and Van ‘t Hoff (1898). The equation describes the exponential dependence of respiration upon temperature, where R is ecosystem respiration, A is an empirical constant and B is related to the Q10 ($B = \ln(Q10)/10$). This is not an Arrhenius type of relation and the text on lines 7 and 8 will be changed to: “Respiration is exponentially dependent upon temperature and will be described by the following exponential relation (Lloyd & Taylor, 1994 and Van ‘t Hoff, 1898):” Page 290 line 9: Fig. 5 may be Fig. 7 This will be corrected in the text. Page 293 line 29: Explanation for low N₂O flux is not adequate. Discuss more. We propose the following addition to paragraph 3.3 at line 14 to 16: “Fluxes of N₂O appeared to be negligible small with respect to the GHG balance (between -0.0001 and 0.00001 g m⁻² hour⁻¹) and contained measurement errors of more than 70% on average. Therefore we conclude that the N₂O fluxes are not detectable” Additionally, the discussions and conclusions (page 294, line 29 to 37) will be complemented with the following text: “From the undetectable N₂O fluxes, we can draw two conclusions. First such small fluxes cannot be measured properly with the INNOVA 1312 gas monitor. Second, the N₂O fluxes make a negligible contribution to the GHG balance at the site. The formation of N₂O is normally enhanced by an increase in available mineral nitrogen. Since the site has not been fertilised for more then 10 years, the enhancing effect of fertilisation has probably been diminished and the N₂O emission is reduced to insignificant proportions.” Table 4: This

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table for water balance may not be necessary. Since the aspect of including carbon fluxes in the water in the green house gas balance is a relatively innovative topic in this field of research, we think it is important to give a good picture of how the calculations of the water balance are done. We therefore propose to keep the table in the article. Fig. 6: GPP occurred in mid-winter. Is this correct or gap-filling error? The vegetation species *Holcus lanatus* L. that grows in the area is evergreen and is therefore able to fix carbon during sunny winter periods. Moreover, the area is seldom covered with snow and temperatures can reach 10 oC during mid-winter. However, since uncertainties in eddy covariance measurements are considerable, the GPP might partly be the effect of gap-filling or other errors.

Anonymous Referee #3 General comments about clarifications, calculations and methods The authors use an INNOVA 1312 for CH₄ and seem to have found a method to overcome the strong interference of CO₂ and water vapor with the CH₄ signal. As the authors measure very high fluxes on some sites, which are almost world record, a very good technical documentation is needed that the flux is real. I therefore suggest to expand the about the INNOVA and to describe in more detail how the drying and scrubbing was made, and that no bias in the measurement was produced due to systematic increases in water vapor and CO₂ during chamber closure. We agree with the referee that the Innova shows interference of CO₂ and CH₄. However, this can be properly reduced by scrubbing CO₂ and H₂O from the gas samples. We added a revision of paragraph 3.3 describing the flux chamber measurements in more detail. See revised paragraph 3.3 below. Annual NEE: The period from 20 August to 1 October 2004 coincides with the end of the growing season, which differed considerably in 2004 and 2005 (Table 5, section 4.3). The cumulated NEE over the period of the gap in 2005 can therefore not be used to fill the gap in 2004 because C uptake is underestimated. Instead, I suggest as an alternative method to calculate light and temperature response curves of the suitable data around the gap in 2004, and using a model to fill the gap (e.g., Bellisario LM, Moore TR, Bubier JL (1998) Net ecosystem CO₂ exchange in a boreal peatland, northern Manitoba. *Ecoscience*, 5(4), 534-541).

We agree that taking the data of 2005 is not a proper option to cover the gaps in the period between 20 August and 1 October 2004 since this period coincides with the end of the growing season. Instead, gaps over the period were filled by the method of Reichstein et al. (2005) described on page 283 (lines 15 to 18), which appeared to be very well possible. This method results in a significant increase in uptake of carbon during the last part of the growing season ($NEE = 456$, $GEP = 13.14$ and $Reco = 8.69$ $gC\ m^{-2}\ yr^{-1}$). These numbers will be replacing the previous yearly totals for the NEE , GEP and $Reco$ in the final version of the article and the graph for 2004 in figure 6 will be rectified (see also reply to specific comment 5 of referee #2). Annual CH_4 regressions: The regression analyses of the CH_4 fluxes should include information about number of data points used and the significance of the regressions. The R^2 of the regressions is low. Consequently, the regressions seem not to be entirely adequate as the only tool for calculating CH_4 fluxes. I suggest to include more variables in the regressions if significant, and to compare the results with alternative interpolation methods (e.g. simple linear interpolations) to demonstrate that the order of magnitude of the calculated CH_4 fluxes is realistic. This particularly for the saturated land and the ditches where occasional very high fluxes may significantly affect the regressions and the annual budget. Information about the number of data points (respectively 294, 34 and 31 for relatively dry land, saturated land and ditches) will be added to table 6. The significance of the regressions is evaluated with the statistical parameters R^2 , F-test, p-value and error variance in table 6. We propose a better reference to this table in text at page 290, line 1. We agree that the significance of the relation between CH_4 fluxes and soil temperature is very low. However, the significance of the relation between CH_4 fluxes and soil water level is even lower and data of other related variables (soil composition, vegetation parameters, hydro chemical parameters, etc.) are not yet available. In the near future such parameters will be studied in more detail and we will report on this separately. A remark on this topic is made in the Discussion and conclusions section, page 293, lines 10 to 11. Finally, according to your advice we performed linear interpolation of the data points for the three land-types. Uncertainties are estimated by

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determination of the variance between the annual totals of the different flux sites. The two methods didn't differ significantly both in yearly totals and uncertainties. To explain this additional analysis, the following text will be added to in paragraph 4.4 (page 290): "Since uncertainties of the regression equations are very large, yearly totals were also determined using linear interpolation of the data points. Uncertainties were estimated by determination of the total variance between the year totals of the different flux sites. The two methods didn't differ significantly both in yearly totals and uncertainties (table 7)." And the table will be added as table 7 on page 306.

Specific comments Abstract and introduction: The study includes the water balance and the C losses by water. This is interesting extra information, which lacks in most studies and could be included in the abstract. We propose the following additional sentence in the abstract after line 19 at page 278: "The water balance of the area is dominated by precipitation and evaporation and therefore fluxes of carbon through seepage, infiltration and drainage are relatively small (18 g C m⁻²)." Page 278, lines 14-18: Values should be rounded to significant digits. The rounding of values will be adjusted in final abstract text, which is one digit behind the comma. Page 278, line 23: Should the unit be g CO₂-equiv. m⁻² yr⁻¹? Yes, this will be corrected in the final text. Page 279, line 3: Please quote references for the CH₄ and N₂O statements Reference (IPPC TAR, 2001) will be added. Page 279, line 27: Please specify what 'reducing management' means: extensification? Restoration? Reducing management here means both extensification and restoration depending on decisions of the policy-makers at a certain location. This will be added to the final text: "Plans exist to convert these agricultural areas into wetland nature by raising the water tables and reducing agricultural use both through extensification and restoration, depending on the area." Page 280, line 8: Year round measurements of CH₄ and CO₂ have been published, e.g. for N₂O: Regina et al., European Journal of Soil Science, September 2004, 55, 591-599. The paper mentioned by the reviewer is studied and will be taken up as reference (page 280, line 8 and References, page 296). Additionally, the papers by Treat et al. (2007) and Alm et al. (1999) in which year-round measurements of CO₂ and

CH₄ are presented will be added as reference (page 280, line 8 and References, page 296). Page 280, line 10: Better quote original papers that did the comprehensive studies. Roulet et al. (2007) recently did such a comprehensive study; this will be added as reference (page 280, line 10 and References, page 296).

Site description: Please include a link to table 1 and the following information: soil classification according to World reference Base (FAO), C/N ratio of the peat, the temporal course of the water levels at the sub-sites (or in results section), and, if available, the fractional cover of the dominant vegetation functional groups. The water table information is critical to understand and interpret the results. Details mentioned by reviewer are available and will be added to this table.

Methods and instrumentation: The method for TOC analysis is not described. Was dissolved inorganic carbon determined as well? Dissolved inorganic carbon was measured too; therefore TOC will be replaced by TC in the final text. Method for TC analyses will be added in paragraph 3.1, page 282: "Water samples were taken from the pore water in the clayey peat, the groundwater from the sand aquifer and from the ditch water to determine total carbon (TC) in the three water types. TC was determined as the sum of total organic carbon (TOC), total inorganic carbon (TIC). Sampling was done using glass filters, installed in the soil or ditch water at 0.2 m depth intervals, and connected to the surface using small diameter Teflon tubes. In the soil these filters were installed in a small diameter borehole, separated from each other by bentonite plugs. The soil filters were installed at three locations, the ditch filters at two locations. Samples were taken using a syringe for drawing up the water, after which the sampling tube was connected to a vacuum exetainer using a three-way stopcock. All sampling is done anaerobe. The sum of TOC and TIC is analyzed in with a Dohrmann DC-190 TC analyzer. Dissolved CH₄ in the samples was analyzed by gas chromatography (Hewlett Packard 5890A, Avondale PA, USA) of the gas-filled headspace of the exetainers. The total CH₄ concentration in the sampled volume was calculated using the gas-water solubility coefficient." Page 282, lines 2-11: What else did you measure in

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the water samples apart from CH₄? Please specify the parameters of the gas chromatography analyses. No additional measurements have been done at the time of the TC and dissolved CH₄ measurements. However, measurements of EC and pH of the three water types have been done in all seasons and a yearly average will be given in table with site description. Page 283, line 7: Specify the soil depths in detail. The specific depths (0.01, 0.02, 0.04, 0.06, 0.08, 0.10, 0.15, 0.25, 0.40 and 0.60 m) will be added to the text. Page 284, line 2: How did the relatively tall vegetation described earlier fit in a 30 cm high chamber? Indeed high vegetation did not fit in the chambers totally. When necessary the vegetation was cut back to the size of the chamber during summer period. However, we do not expect a big influence on the CH₄ fluxes. The following sentence is proposed in paragraph 3.3: “To prevent vegetation area was maintained. However, when measurements are done over vegetation higher than 30 cm, it was cut to this size.” (see revised paragraph 3.3 below) Page 283: Closed chamber measurements: Please give details about number of replicates per sub site, timing and measurement frequency (how often, how many per year, and maybe show a graph with measured values through the year if there is a seasonal variation in fluxes.) Details on the amount, time, frequency and locations of the chamber measurements will be added to paragraph 3.3 (see revised paragraph 3.3 below). Additionally, we propose to add graphs with the flux measurements over time (see below), which will be discussed in the text in paragraph 4.4 (see remark 1 from referee #1). Page 284, line 20: please give the time of the biomass sampling. Was this at peak biomass? Biomass was sampled in May and October; this will be added to the text at page 284, line 20.

Results: Page 286, lines 23-26: Give criterium for removal of data points out of this continuous set of half-hourly data. The criterium for the removal of those data points is given in lines 23 to 25, however since this might be not clear enough for readers, we propose the following change in text: “The high values for “LE+H+G” at sunny hours around noon are mainly the result of extremely high apparent G. These high G values are caused by erroneous measurements of the upper soil heat sensors due to over-

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heating during periods with a lot of sunlight. When these data points with erroneous G values are removed from the data set, the regression line has a slope of 0.996 and an R2 of 0.82.” I suggest that C transport to water and results of water analyses are reported in a separate section. A separate section for C transport through water might make the structure of chapter four more clearly. We will insert an extra paragraph (4.5) for this purpose following the paragraph on Methane. Consequently the paragraph “A full green house gas balance” will become paragraph 4.6. Page 288, line 28: it is unclear what the reference stands for and how they relate to your findings (better leave them for the discussion). Reference will be deleted here and only mentioned in the discussion. Page 289, lines 1-5: are the 28 measurements different times, how many replicates? For what periods, how many times were the saturated land and ditches sampled? In all seasons? (see comment above) All details will be given in paragraph 3.3 “Flux chamber measurements” (see below). Page 289, line 13/14: As you work on a managed peatland the water table may be manipulated to certain levels and therefore not follow the typical seasonal pattern observed elsewhere. Please specify (see comment above). The water level in the ditches is managed, but does follow a seasonal pattern for most of the land surface due to the seasonal evaporation cycle and the low permeability of the peat (this will be taken up in table 1, see above). However, the aspect of management makes no difference for the correlation between CH4 flux and water level at a time scale of hours. Generally it is assumed that CH4 emissions are high with high water tables and vice versa, but this relation cannot be found at the Horstermeer site until present.

Editorial comments: Sort the tables and figures in the order of the first mentioning in the text. This will be rectified in final paper: table 2 will be table 1 and vice versa; table 7 will be table 6 and vice versa; figure 6 will be figure 5 and vice versa. Do not repeat numbers displayed in tables in the text (e.g., page 285, line 15-23, page 288, line 10-17). Numbers will be removed from text and reference to table will be added in necessary on page 285, line 15-23, page 288, line 10-17 and page 290, line 2-4). Use consistent units, preferably g C m⁻² yr⁻¹, do not mix m⁻² with ha. All units in the text

will be changed to $\text{g C m}^{-2} \text{ hour}^{-1}$ or $\text{g C m}^{-2} \text{ yr}^{-1}$. Explain abbreviations when they occur first (e.g. GWP, PAR) Global warming potential (GWP) will be explained on page 278, line 8; Greenhouse gas (GHG) will be explained on page 278, line 10 and Net ecosystem exchange (NEE) will be explained on page 287, line 2 (instead of on page 288, line 1). Page 285, line 7: remove “is” “is” will be removed on page 285, line 7. Page 285, lines 14, 15: Should “E” be ET and “transpiration” Evapotranspiration? We agree that evapotranspiration is more appropriate than evaporation in this case. In the final text evaporation will be changed to evapotranspiration (page 285, line 4, 8, 14, 15) and E will be changed to ET (page 285, line 14). Page 290: best show results in a table. It is difficult to get a good overview of the data out of this text. Results will be shown in table 7, together with the results of the linear interpolation method (see above). Figure 7: include measured values, or show the model fit elsewhere. This figure is a bit trivial as it mainly shows temperature response of CH₄ from the sub sites. Showing the model fit to the observations and the annual balances may be more appropriate. Measured values will be shown in two graphs: one for results of measurements on the relatively dry land and one for the results of measurements on the saturated land and the ditches. Graphs will be discussed in the text in paragraph 4.4: ‘Measured CH₄ fluxes observed at the relatively dry land vary from -0.0011 to $0.0152 \text{ gC m}^{-2} \text{ hour}^{-1}$ with a mean value of $0.0017 + 0.0002 \text{ gC m}^{-2} \text{ hour}^{-1}$, while fluxes observed at saturated land vary from -0.0084 to $0.0485 \text{ gC m}^{-2} \text{ hour}^{-1}$ with a mean value of $0.0138 + 0.0022 \text{ gC m}^{-2} \text{ hour}^{-1}$. CH₄ fluxes from the ditches vary from 0.0004 to $0.0184 \text{ gC m}^{-2} \text{ hour}^{-1}$ with a mean value of $0.0068 + 0.0009 \text{ gC m}^{-2} \text{ hour}^{-1}$ (fig. 7).’ Page 291, line 5: give reference for GWP Reference is IPCC TAR, 2001

3.3 Flux chamber measurements (revised) Closed flux chamber measurements of CH₄ and N₂O fluxes were performed using a Photo Acoustic Field Gas-Monitor (INNOVA 1312) connected with tubes to closed, dark chambers (non-transparent PVC, 45 x 45 x 12 or 30 cm). The INNOVA detection limit and precision is dependent on the less detected value (LDL-value) of the optical filter used for a specific gas. Reliable measurements can be done from 1.0 ppm for CH₄ and 300 ppb for N₂O with a precision

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of 2 ppb and 0.6 ppb respectively. A fan was installed in the chambers to mix the air and increase the representativeness of the measurements. The software of the gas monitor compensates for cross-interference of CO₂ and water vapour. Additionally, to minimize any possible effect of the interference of those gases, the air was filtered before measurement with a Sodalime filter and a silica gel filter respectively (Van Huissteden et al, 2005). CO₂ and water vapour concentrations remain stable during the flux measurement procedure when the filters are used. The soda lime filter reduced the CO₂ concentrations below 100 ppm. The Sodalime filter was replaced when the INNOVA gas monitor indicated concentrations higher than 100 ppm CO₂ while filtering the air for CO₂. The silica gel (Riedel-de Haen, Germany) contains moisture indicating pearls and was replaced at least after every ten measurements or when pearls indicated saturation. To prevent vegetation disturbance, chambers with a height of 30 cm are used. Vegetation was not removed preceding the flux measurements, to maintain the representativeness of the chamber measurements for a larger area. However, when measurements are done over vegetation higher than 30 cm, it was cut to this size. During each measurement soil temperature and local water table were determined. On land, at eight fixed locations stainless steel frames with a water-filled gutter were used to seal the chamber from the ambient air during measurement. Six of the locations are positioned in the relatively dry part of the area evenly spread over the various vegetation types. At each of those six locations, fluxes were measured 49 times between January 2004 and December 2006. The two other locations are in the part of the area with saturated soils and were measured 17 times each. On the ditch water surface, measurements were done at two locations. For this purpose a rectangular floater was used allowing the chamber to rest on the water. Between January 2006 and December 2006, fluxes were measured 17 times on the ditch at the east side and 14 times at the ditch at the west side of the research area. At all sites the flux measurements were performed approximately once every 4 weeks during winter and once every two weeks during summer. For each flux measurement five measurements were done at two-minute intervals. The series of concentration measurements done with

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the flux chamber technique are calculated into fluxes by determining linear regression lines from the concentration changes over time. Air pressure and temperature from the moment of measuring are taken into account in the calculations. Data were checked for outliers that may result from instrument error, chamber leakage or irregular ebullition events. Fluxes of N₂O appeared to be negligible small with respect to the GHG balance (between -0.0001 and 0.0001 g m⁻² hour⁻¹) and contained measurement errors of more than 70% on average. Therefore, the N₂O flux measurements are not considered in further analyses.

Interactive comment on Biogeosciences Discuss., 4, 277, 2007.

BGD

4, S423–S434, 2007

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