Authors' response: Interactive comment on **"CH_4 and N_2O dynamics in the boreal forest–mire ecotone"** by **B. Ťupek et al., BGD, 11, 8049–8084, 2014, boris.tupek@helsinki.fi, 26 September 2014**

Please, find our response *in italic font* and proceeded by # symbol.
Suggested text for the manuscript uses same font as our BGD paper.
We thank Referees for the valuable comments on the manuscript.

Anonymous Referee #1

Received and published: 26 June 2014
Review of Tupek et al, 2014, BGD, 11, 8049–8084 CH4 and N2O dynamics in the boreal forest–mire ecotone
General comments: This paper examines the production of CH4 and N2O through a transitional landscape region commonly found in boreal environments. The paper uses the closed chamber method for 2-3 years over nine locations on an ecotone gradient. The paper finds minimal spatial patterns in N2O due to the generally low fluxes while CH4 fluxes tended to follow a soil-wetness gradient. The authors did not detect any evidence for "hot moment" fluxes of either gas and also found relatively stable fluxes from year-to-year despite different wetness conditions in these years. I found the paper well put-together and interesting in its presentation of the data. The paper helps to fill a gap in current knowledge of these common transitional landscapes. It cites many interesting papers and helps to contextualize its results through a comparison to these other studies. I find the paper worth publishing in Biogeosciences after some revisions and additions to the content as detailed below.
 # Thank you!

Suggestions: The paper would benefit from a stronger description of site differences, including pH and CN ratios for the different landscape units. It seems that the pH is not measured with each flux estimate, which is a pity in such a study. Especially with a discussion of microbial communities and the lag-time in response to changing water tables, pH can be a particularly useful indicator of CH4 production potential. If you have such data for the sites (it is unlikely to change so greatly through the year) it would be nice to see it. Likewise some information about the site CN ratios would be useful for understanding both CH4 and N2O fluxes.
 # We agree with the Referee that results on pH and C/N ratios would help the reader to understand individual site potential CH_4 and N_2O fluxes. We analysed our remaining data and suggest extending the manuscript for pH of soil water solution and soil properties (bulk density and C/N ratios):

2 Material and methods
2.1 Study site characteristics
Page 8054, after Line 4

We measured pH during summer campaign 2005 from soil water data collected on all sites by suction-cup lysimeters. Three lysimeters were installed in 10 cm and one in 30 cm depth below the soil surface in each site. Detailed description of the lysimeters and sampling procedure can be found in Starr (1985). The pH was measured on the day of water sampling in the laboratory by pH meter equipped with a glass electrode. The mean acidity level of the

sites of forest-mire ecotone was gradually increasing from pH 5.6 in uplands (CT) to 4.4 in transitions (KR), whereas mires were less acid than transitions with pH 5.1 and 4.8 (VSR1 and VSR2 respectively) (Table 1). Collected soil water from 30 cm depth showed generally higher pH than soil water pH at 10 cm depth. Three soil cores for each plot were taken in July 2006 from the top soil (0-10 cm) in upland forests and from the two profile depths (0-10 cm, 10-30 cm) in forest mire transitions and in peatlands. The volume of samples was measured before the oven drying at 70 °C to determine the bulk density. The bulk density of the upper organic layer ranged from 0.24 gcm^{-3} (KR) to 0.48 gcm^{-3} (MT) and was approximately half of the bulk density of the organic layer from 10-30 cm depth (mean of transitions and mires 0.77 gcm^{-3}) (Table 1). The C/N ratio was determined once for each plot from the soil organic matter analysed by dry combustion with Leco CNS-1000 (Leco Corp., USA). The C/N ratio was wider in the 0-10 cm profile (mean 37) than in the 10-30 cm profile (mean 27). The highest N content and lowest C/N ratio along the ecotone was found in forest-mire transitions OMT+ and KgK (Table 1).

Table 1. Site soil water solution pH and soil properties.

	CT		VT		MT		OMT		OMT+		KgK		KR		VSR1		VSR2	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
pH 10 cm	5.57	0.36	5.14	0.42	5.24	0.08	4.68	0.39	4.58	0.30	4.46	0.14	4.37	0.22	5.06	0.39	4.80	0.44
pH 30 cm	6.20	0.06	6.18	0.02	5.91	0.13	5.30	0.11	5.53	0.04	4.91	0.10	4.55	0.08	5.32	0.15	4.79	0.19
Bulk density 0-10 cm	0.37	0.09	0.28	0.04	0.48	0.03	0.27	0.09	0.31	0.13	0.33	0.05	0.24	0.02	0.40	0.12	0.40	0.12
Bulk density10-30cm									0.92	0.07	0.31	0.12	0.85	0.03	0.90	0.07	0.90	0.07
Tot C (%) 0-10 cm	43.17		24.22		49.63		47.09		45.36		48.68		50.30		45.76		48.20	
Tot C (%) 10-30 cm									21.76		53.31		48.33		47.70		49.97	
Tot N (%) 0-10 cm	1.02		0.61		1.18		1.59		2.19		1.47		1.12		1.29		0.96	
Tot N (%) 10-30 cm									0.96		1.95		1.45		1.87		1.81	
C/N 0-10 cm	42.32		39.70		42.06		29.62		20.71		33.12		44.91		35.47		50.21	
C/N 10-30 cm									22.67		27.34		33.33		25.51		27.61	

2 Material and methods

2.4 Statistical analysis

Page 8058, after Line 6

To examine correlations between CH_4 and N_2O fluxes and pH, and soil properties we preformed the Pearson's correlation tests.

3 Results

Page 8063, after Line 2

3.6 Effects of pH and soil properties on CH_4 and N_2O flux

The site specific momentary CH_4 and N_2O fluxes did not show significant correlation with varying soil water pH (except for one correlation coefficient $r = -0.45$, $p = 0.02$ on MT for N_2O and pH at 10 cm). No correlation was found between CH_4 momentary data on the ecotone level. Although, for the CH_4 data including group of upland forest and forest-mire transitions (excluding mires) Pearson correlation between momentary CH_4 fluxes and soil water pH was significant ($r = -0.32$, $p < 0.001$). Mean values of summer 2005 CH_4 of upland forests and forest-mire transition were negatively correlated with mean pH (CH_4 = 129.35 −

33.36*pH, r^2 = 0.49, Fig. 8a). The ecotone N_2O fluxes of the summer 2005 pH campaign were significantly correlated with pH (r = 0.174, p = 0.004). The mean N_2O values of sites increased with mean pH (N_2O = −117.07 + 27.33*pH, r^2 = 0.32, Fig. 8b). However, the post-hoc Tukey differences of mean N_2O fluxes from forest floor for the pair-wise comparisons of forest/mire types were not significant for 31 pairs and mean N_2O flux differences were significant only for 5 pairs (KgK-CT, VSR1-KgK, VSR1-KR, VSR1-MT, VSR1-OMT, Figure 9). We did not find significant correlation between site specific mean CH_4 and N_2O flux and bulk density and/or C/N ratio.

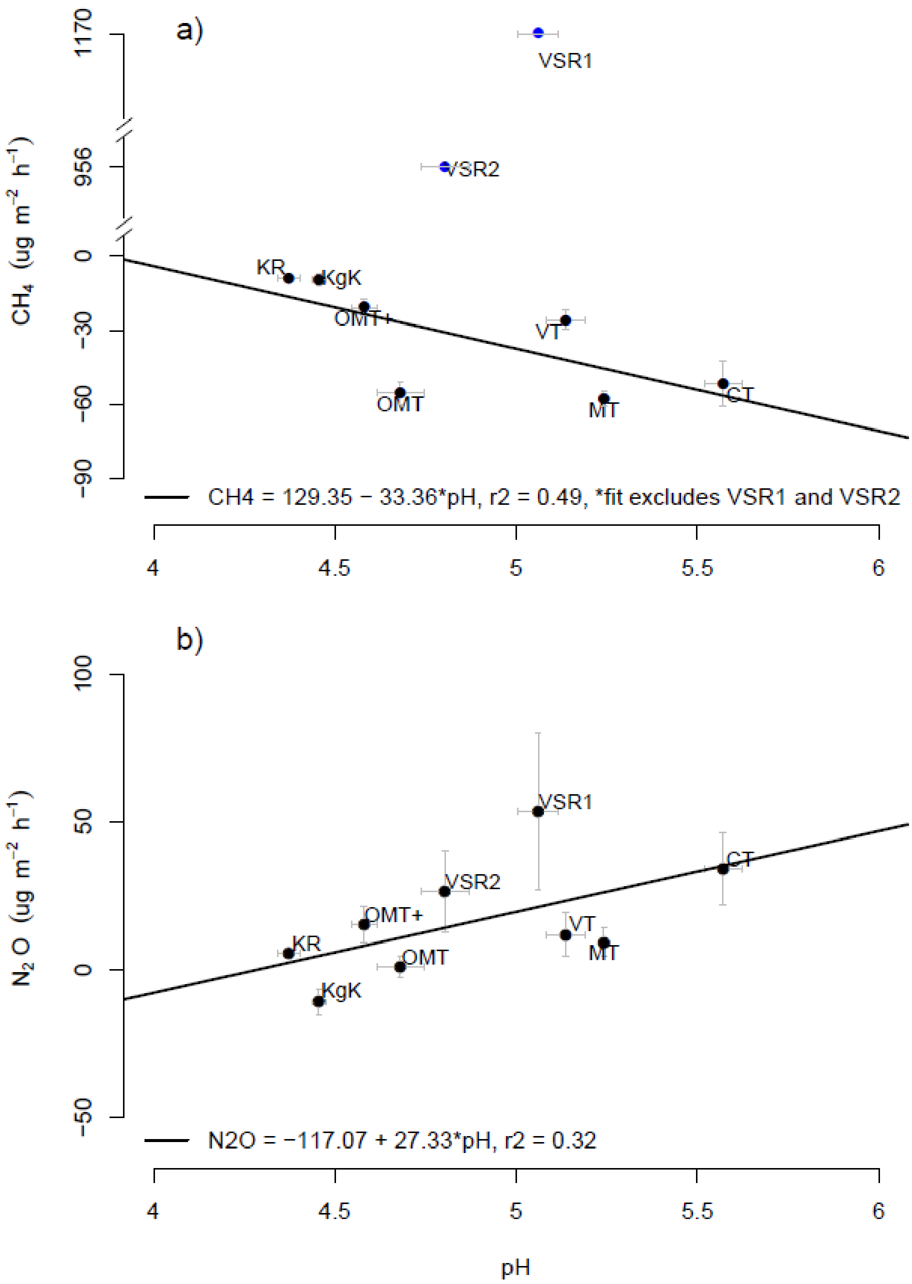


Figure 8. Scatterplot between site specific mean pH and mean flux ($ugm^{-2}g^{-1}$) of a) CH_4 or b) N_2O of summer with intermediate moisture over the period of soil water sampling campaign (July-September 2005).Error bars show standard error. The CH_4 error bars for VSR1 and VSR2 are not shown.

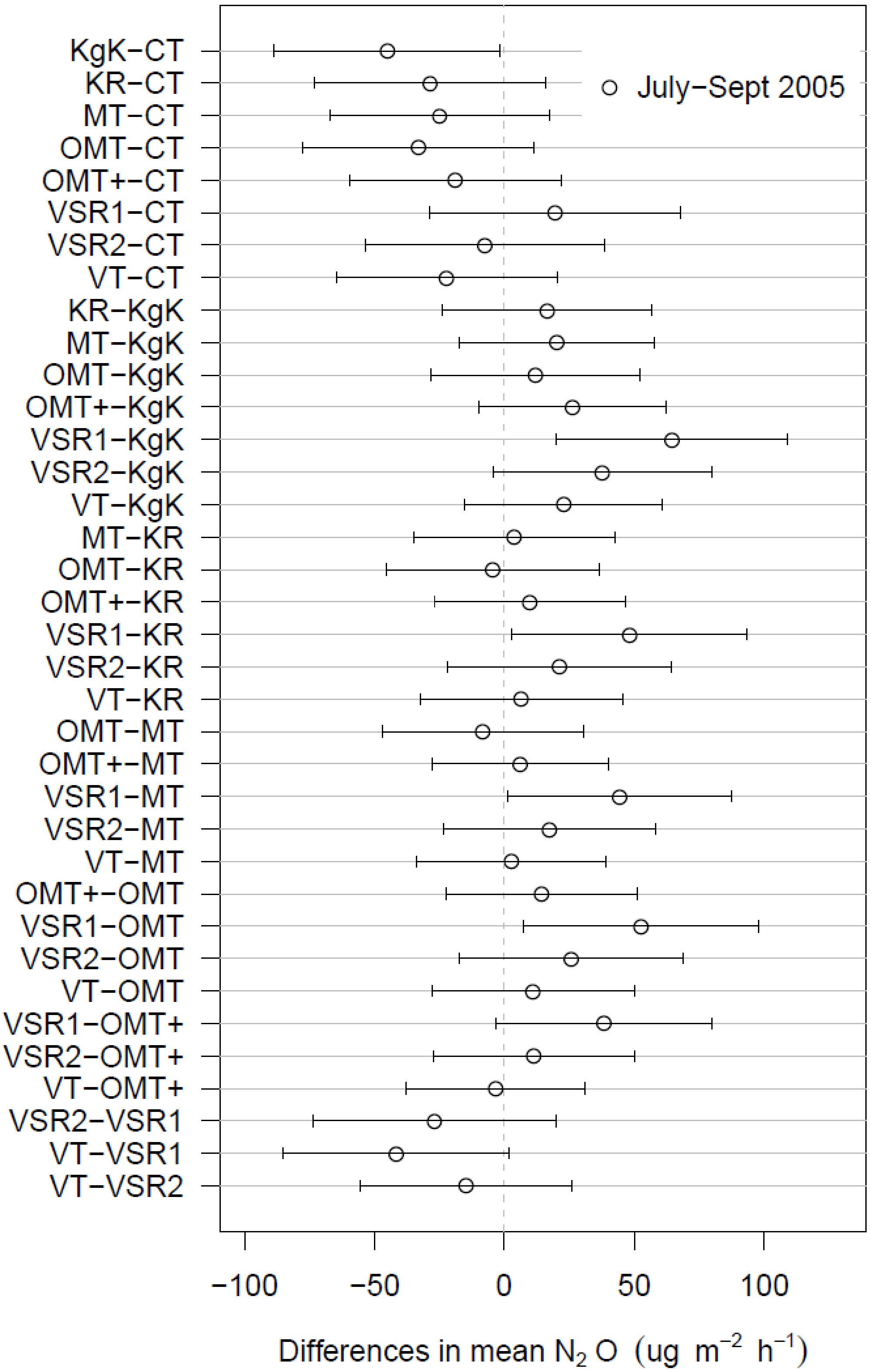


Figure 9. The post-hoc Tukey differences (error bars for 95% confidence intervals) of mean N2O (μgm^{-2} h^{-1}) fluxes from forest floor for the pair-wise comparisons of forest/mire types (uplands - CT, VT, MT, OMT; transitions – OMT+, KgK, KR; and mires – VSR1, VSR2) over the period of soil water sampling campaign (July-September 2005).

4 Discussion

4.1 CH_4 dynamics

added text on Page 8064, after Line 2 and before Line 3

Temporally water saturated soil layers of pristine forest-mire transitions had low CH_4 production partly due to highly acidic pH levels imposing physiological restrictions on soil microbial communities. Methanogenic activity in water saturated organic soils can be reduced by high acidity (e.g. Ye et al. 2012). Small momentary CH_4 emissions (Supplement Fig. 3a) observed in forest-mire transitions also indicated potential for occasionally higher production than consumption/oxidation. Beside microsite differences in soil saturation and microbial populations also plant communities (Fig. 1c) could play important role in explaining enhanced emissions (e.g. Saarnio et al., 1997, Riutta et al., 2007). For example, sedges through aerenchymatic transport interplay with microbes by providing recently photosynthesized carbon downwards and transporting CH_4 from microbial populations upwards (Alm et al., 1997).

4.2 N_2O dynamics

added text on Page 8066, after Line 19 and before Line 20

Soil incubation studies under various moisture and temperature regimes (Pihlatie et al., 2004, Szukics et al., 2010) imply that our higher forest floor N_2O emissions during typical summer 2005 than during dry summer 2006 (Supplement Fig. 3b) were probably induced by stimulated N turnover through the soil wetting and drying cycle under favorable temperature. During conditions with intermediate moisture (July-September 2005) we observed also mean N_2O flux of dry pine forest significantly larger than paludified spruce forest (larger CT than KgK), whereas mean N_2O flux of water saturated mire was larger than four sites (VSR1-KgK, VSR1-KR, VSR1-MT, VSR1-OMT) (Fig. 8, Fig. 9) . Therefore during fluctuating soil moisture, we could expect increased N_2O fluxes of normally xeric (CT) and water saturated (VSR1) site due to stimulated nitrification (CT in rewetting phase, and VSR1 in drying phase). During July-September 2005, CT and VSR1 sites were also least acid along the ecotone which could favor nitrification and consequently N_2O emissions through denitrification (Regina et al., 1996, Ste-Marie and Pare´, 1999, Paavolainen et al., 2000). These studies reported that increasing of pH by rewetting could initiate nitrification. In contrast to less acid CT and VSR1, highly acid forest-mire transitions with widest range of water level fluctuations along the forest-mire ecotone ranked into a group of sites with lower N_2O fluxes. Highly acid conditions prevent development of nitrifiers, substrate affinity and nitrification, even if ammonium is available (Ste-Marie and Pare´, 1999, Paavolainen et al., 2000). The fact that net nitrification of acid sensitive nitrifiers positively increases with forest floor pH, whereas acidification reduces it, suggests that nitrifiers in our sites were acid sensitive and not acid tolerant. The lack of nitrate renders denitrification potential to be negligible. Although, if nitrate would be present low pH would enhance N_2O emissions due to inhibiting di-nitrogenoxide reductase and increasing N_2O/N_2 ratio of denitrification (e.g. Weslien et al., 2009).

Page 8066, Lines 20, 21, 22 were reformulated

In pristine peatlands nitrification positively depended on pH and negatively on water level (Regina et al., 1996) in supply of nitrate for denitrification, as the main source of N_2O emissions (Regina et al., 1996; Nykänen et al., 1995; Wray et al., 2007). Thus, during drying-

rewetting periods as in July-September 2005 our sites could initiate short-term significant differences, but for the whole measurement period the lack of a statistically significant difference in N_2O fluxes was probably due to low nitrification potential. Generally low pH and high C/N ratios of our forest floors suggest conditions of low nitrification potential.

References

Alm, J., Talanov, A., Saarnio, S., Silvola, J., Ilkkonen, E., Aaltonen, H., Nykänen, H., and Martikainen, P.J.: Reconstruction of carbon balance for microsites in a boreal oligotrophic pine fen, Finland, Oecologia, 110,423-431, doi: 10.1007/s004420050177,1997.

Paavolainen, L., Fox, M., and Smolander, A.: Nitrification and denitrification in forest soil subjected to sprinkling infiltration. Soil Biol. Biochem., 32, 669-678, doi: 10.1016/S0038-0717(99)00194-7, 2000.

Starr, M.R.: Variation in the quality of tension lysimeter soil water samples from a Finnish forest soil. Soil Sci., 140, 453-461, doi: 10.1097/00010694-198512000-00009, 1985.

Ste-Marie, C., and Pare´, D.:Soil, pH and N availability effects on net nitrification in the forest floors of a range of boreal forest stands. Soil Biol. Biochem., 31, 1579–1589, doi: 10.1016/S0038-0717(99)00086-3, 1999.

Szukics, U., Abell, G.C., Hödl, V., Mitter, B., Sessitsch, A., Hackl, E., and Zechmeister-Boltenstern, S.: Nitrifiers and denitrifiers respond rapidly to changed moisture and increasing temperature in a pristine forest soil. FEMS Microbiol. Ecol., 72, 395-406, doi: 10.1111/j.1574-6941.2010.00853.x., 2010.

Weslien, P., Kasimir Klemedtsson, Å., Börjesson, G. and Klemedtsson, L.: Strong pH influence on N_2O and CH_4 fluxes from forested organic soils. European Journal of Soil Science, 60, 311–320, doi: 10.1111/j.1365-2389.2009.01123.x, 2009.

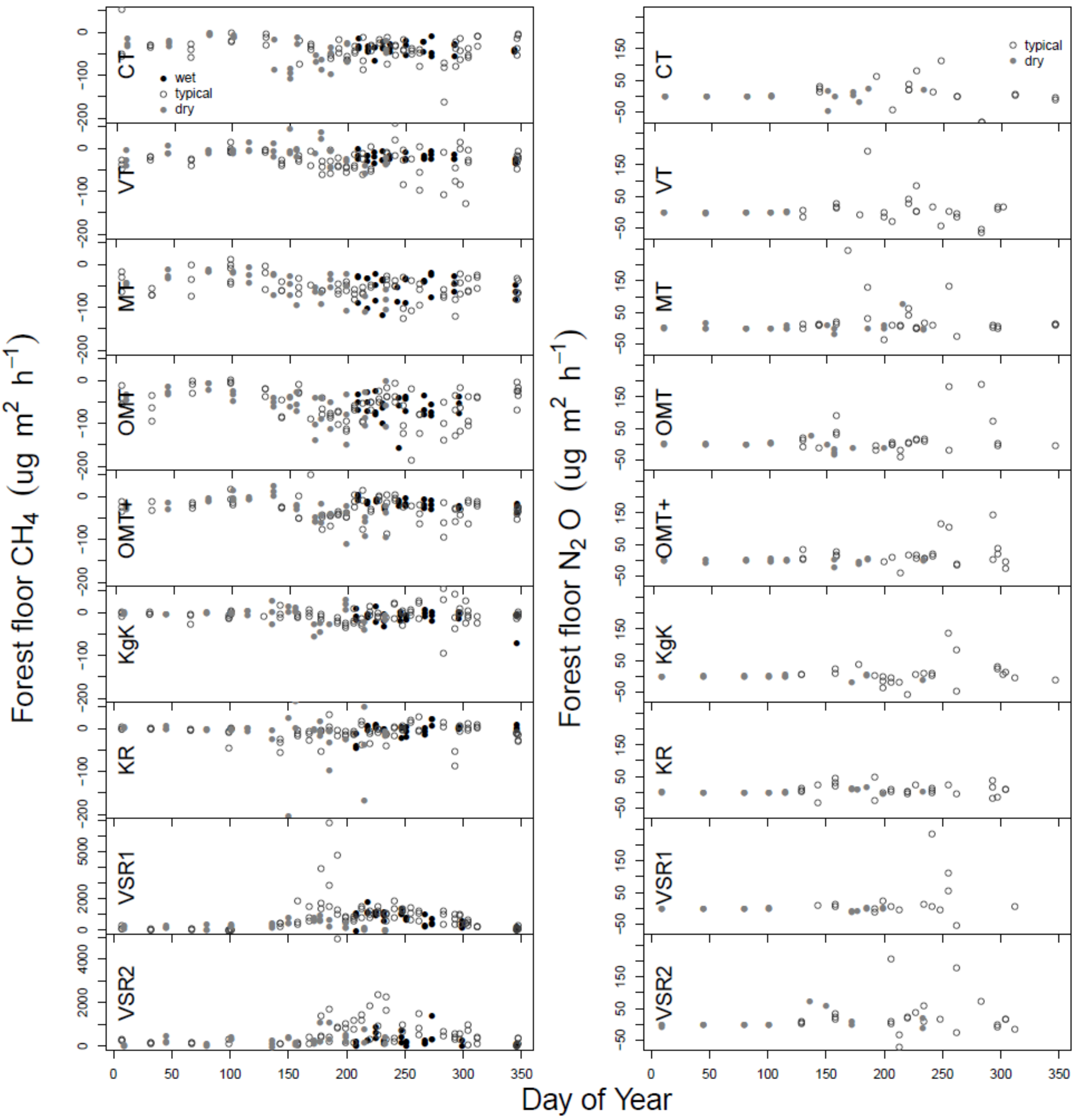
Ye, R.Z., Jin, Q.S., Bohannan, B., Keller, J.K., McAllister, S.A., and Bridgham, S.D.: pH controls over anaerobic carbon mineralization, the efficiency of methane production, and methanogenic pathways in peatlands across an ombrotrophic-minerotrophic gradient. Soil Biol. Biochem., 54, 36–47, doi:10.1016/j.soilbio.2012.05.015, 2012.

Acknowledgements, Page 8068, Line 24

We also thank Jukka Laine, Jukka Alm, Mike Starr and Frank Berninger for valuable discussions; Mike Starr for providing suction cup lysimeters;

The paper would benefit from a more complete time series of the fluxes for each site – something like Figure 2 for each gas flux (or another style of presenting this information – even the daily values). Otherwise it is hard to visualize how the time series may look, how seasonal and interannual shifts may or may not occur, etc., from only the fluxvariable relationships in Figs 4 and 7 and the overviews in Figs 3 and 5. This new figure could indeed replace or supplement figures 3 and 5. Alternatively such a presentation could be given as a supplemental on-line figure.

 # In order to visualise the seasonal and inter-annual shifts in CH_4 and N_2O fluxes we provide the time series of daily momentary values (Supplement Fig. 3).



Supplement Figure 3. The momentary forest floor gas fluxes (µgm^{-2} h^{-1}) of a) CH_4 and b) N_2O in forest/mire types (uplands CT, VT, MT, OMT, transitions OMT+, KgK, KR, and mires VSR1, VSR2) as measured during the years with exceptional moisture (wet, typical, and dry). The top–down arrangement of sites mimics the locations on the slope (see Fig. 1).

Minor suggestions

Page 8050, Line 4 omit “the”

Page 8050, Line 20 “upscaling” Not “up scaling”

Page 8051, line 25 change richer to rich

Page 8052, line 24 promotes to promote

Page 8052, line 28 saturate to saturated

 # comments above were followed as suggested

Page 8055, line 9: Model number? (and/or supply more details about column and mesh materials, gas flow rates and column temperature to allow for a reproducible study)

 # gas chromatograph (Hewlett-Packard, USA) model number HP-5890A was added into the sentence

Page 8055, line 18: add “the” before “gas chromatograph”
Page 8056, line 21: remove the comma and “which” and replace with “that”
Page 8057, line 8: replace “case” with “observation”
Page 8058, line 5: replace “the” with “a”
Page 8059, line 18: add “the” before “forest floor”
Page 8061, line 9: change “like” to “as”
- Lines 10-11: “was for uplands. . .” change to “was relatively low for uplands (10%) and transitions (15%) and slightly higher for mires (22%).”
- Line 15: “fluxes” to “flux”

 # comments above were followed as suggested

- Line 23: it would be nice to add the uncertainty range on the 18 cm estimate, as this parameter value is the type of result of particular interest to upscaling and larger, regional modeling studies (also the 14 oC result found in line 26)

 # we added uncertainty ranges and reformulated these sentences

… sigmoidal response with lower CH_4 fluxes towards the extreme ends. The optimum water level for CH_4 effluxes was at 18 cm (se 2.2) below the surface with 16.6 cm tolerance which is deviation of water level up to 60% of CH_4 flux maximum (Figure 4, $p < 0.001$, WT_{opt} and WT_{tol} in Table 2). Optimum near surface peat temperature for the CH_4 emissions was found at 13.9 °C (se 1.4) with 6.4 °C tolerance (Figure 4, $p < 0.001$, T_{opt} and T_{tol} in Table 2).

Page 8062, line 10: change “momentarily” to “momentary”
- Line 12: move “lower” to immediately after “were”
Page 8063, line 11 add “m” after 450
- Line 13 change “whereas” to “Alternatively”
- Line 14 awkward start to the sentence – I suggest “we have complemented the few studies. . .” and “. . .have lowered the likelihood. . .”

 # comments above were followed as suggested

Page 8065 the first paragraph needs more context and sign-posting to clarify that it introduces the following two paragraphs. Please improve the transitions & outlining on this page (perhaps “first, . . . “ and “second. . .” and more in this first paragraph).

#we reformulated the paragraph

In our upland forests the role of soil physiochemical and microbiological drivers may have contributed to the fact that the temperature and moisture significantly explained just 10% of the variation. Although our mean CH_4 data did not show significant correlations with bulk density, the porous organic horizon is known to enable larger diffusion and CH_4 oxidation (Nakamo et al. 2004, Ullah and Moore 2011).

- Line 21 do you mean “flark” instead of “flurk”?

 # yes, it should be “flark”

Page 8066, Line 1: omit “with”
- Line 9, change “sometime” to “sometimes”, line 10 difference to differences.
Page 806, Line 2, remove parentheses from degrees-C
- Line 6, change “fast” to “quickly”

- Line 17, are you referring to a formal categorization system or emission-factor methodology? If not I suggest “considered”.

 # comments above were followed as suggested

Page 8078, Fig 1: In caption B can you add the site numbers after xeric, etc., to indicate which categories belong with which sites?

 # site numbers were added into the figure caption

Page 8080, Fig 3: It seems to me better to remove the VSR1 and mires data-axis labels from the inset boxes since they are not presented (but seem to have some flux observations within the range shown on these plots).

 # mires data-axis was removed from the inset box

Anonymous Referee #2

Received and published: 30 June 2014

This manuscript presents CH4 and N2O fluxes measured along a forest-mire ecotone using the closed chamber technique. The manuscript closes an important knowledge gap as many studies on CH4 and N2O fluxes have been conducted at typical forest sites and also in peatlands but I am solely aware of two published studies on CH4 and N2O fluxes from a forest-mire transition zone. These two published studies were conducted in Canada. So this study would be the first from the European continent. It has been suggested before that such transition zones might be a hot spot of CH4 emissions. This study could show at different meteorological conditions that this hypothesis is quite unlikely. The topic of the manuscript is well within the scope of the journal and is particularly suitable for the special issue: “Towards a full GHG balance of the biosphere”. The paper meets a basic scientific quality, it is well structured. The applied closed chamber method is for sure the right one to achieve the goals of the study, results are presented in a clear way and discussion is comprehensive. I highly recommend that manuscript to be published in Biogeosciences Discussions.

 # Thank you!

Minor suggestions:

Page 8059, Line 24

Unfortunately, neither Fig. 2 nor Fig 3 shows the correlation between CH4 flux and ground water level, please include a new figure to show that correlation.

 # In response to similar requests of you and Referee#1 and in order to help visualize the relation between temperature, moisture and water table level dynamics (Fig. 2), and forest floor CH_4 and N_2O fluxes (Fig. 3), we agree with adding Supplement Fig. 3 with the momentary CH_4 and N_2O flux measurements (page 7 of this document).

Page 8061, Line 7

Just to clarify: which parameter shows the mean level of CH4 fluxes in Table 1?

The mean level of CH_4 fluxes of upland and transitional forests differed (Table 1, parameter “group bi”), …

Page 8065, Line 21

change flurk to flark

 # changed to “flark”

Page 8068, Line 2 Why do you put _C in parenthesis?

 # parenthesis were deleted

Figure 3: please explain in the labelling of the figure what does 3a) and 3b) show
Figure 6: reference for that figure is missing in the text
 # The Fig.6 reference can be found on page 8062, line 14 and line 20.

General comment to figures: it might be better to use consistent designation for parts of one figure, either a), b) or right panel, left panel
 # to ensure consistency we changed designations for Fig. 6 and Fig. 7 to a) and b).

Anonymous Referee #3
Received and published: 29 June 2014
General comments: The manuscript studies the question if CH4 and N2O dynamics in transition zones between boreal forest and peatland are similar or different from those, considering that vegetation and hydrology change spatially and temporally between years. While carbon and nitrogen cycling in both boreal forests and peatlands are well studied, the transition zone has been less investigated. This can be an important factor for up-scaling to regional scales.
The authors report results from static chamber measurements along a 450m transect for the climatically different years 2004, 2005 and 2006. Statistical analyses (ANOVA, Tukey tests) are used to test differences between locations and years. Environmental controls are analyzed by fitting linear regression models to the flux data. Generally, substantial CH4 fluxes only occur in the peatlands, while in forest soil and transition zones mostly CH4 oxidation (neg. CH4 fluxes) occurs. N2O emissions are small along the entire transect. The authors conclude that these transition areas are likely no hot spots for CH4 and N2O emissions.
The paper is well written and fits into the scope of 'Biogeosciences'.
 # Thank you!

Minor comments: It looks like that the three forest-mire transition types (at least KgK and KR) are more similar in their CH4 emissions to the upland forest than to the mires (N2O emissions are similarly low), even though soil organic matter content and soil moisture are higher than in the mineral forest soils.
The authors discuss that during the few occasions when the water table rises in the transition zones, a 'slow' response of the microbial communities prevent higher methane fluxes. I suggest to add vegetation characteristics in this discussion: e.g. sedges can both enhance methane production by supplying 'fresh' carbon substrate to methanogens as well as provide transport to the atmosphere via their aerenchyma.

 # In response to your comment on vegetation characteristics we suggest adding additional information on CH_4 flux of transitions.
4 Discussion
4.1 CH_4 dynamics, Page 8064 before Line 3

Small momentary CH_4 emissions (Supplement Fig. 3) observed in forest-mire transitions also indicated potential for occasionally higher production than consumption/oxidation. Beside microsite differences in soil saturation and microbial populations also plant communities (Fig. 1c) could play important role in explaining enhanced emissions (e.g. Saarnio et al., 1997, Riutta et al., 2007). For example, sedges through aerenchymatic transport interplay with microbes by providing recently photosynthesized carbon downwards and transporting CH_4 from microbial populations upwards (Alm et al., 1997).