Reply of Comment on gmd-2021-280
Referee comment on "Assessing methane emissions for northern peatlands in ORCHIDEEPEAT revision 7020" by Elodie Salmon et al., Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2021-280-RC1, 2021

We thank the reviewer for his/her constructive comments. Our manuscript has been significantly improved through addressing the reviewer's comments.
Below, comments have been numbered and a response is exposed for each of them. Line numbers correspond to the Preprint version. Modifications are highlighted in blue in the present document.

Anonymous Referee #1

Comment 1.1: This paper presents a land surface model with an explicit representation of northern peatlands, ORCHIDEE-PCH4. The model simulations are compared to data from 14 wetlands. This paper focuses on methane emissions and refers to previously published work for peat carbon accumulation and carbon balance. The authors use the root mean square difference between simulated and observed methane emissions to optimize 7 model parameters. They first perform the optimization separately for each of the 14 sites, then perform a multi-site optimization.

General comments:
The paper is well written. The introduction, the model description and the site description are very clear. The optimization method is very hard to understand (although I am not a specialist). The results are sometimes hard to follow with very small figures. The discussion and conclusion are clear.
Response: We thank reviewers for positive comments and are glad that our work and conclusions are well understood. By addressing reviewer comments and suggestions below we hope that the optimized method section will be easier to understand.

Comment 1.2: My main comment is related to the representation of some processes in the model. From what is shown by the authors it seems like for most sites, methane emissions are pretty much independent of the water table depth. It is particularly obvious for the sites with multiple years of data. Fr-Lag for instance has a simulated high water table the first summer followed by two summers and autumns with very low water tables. Methane emissions are low the first summer and increase the two following ones (contrary to the observed fluxes). This behavior can also be seen at DE-Sfn, Fi-Lom, Pl-Kpt, and to a lesser extent at DE-Hmm and Dk-Nuf. This contradicts most of the existing literature on observations showing a strong correlation between water table depth and methane emissions (the higher the water table, the higher the emissions).
Response: As we pointed out at the beginning of the discussion section L524-527 "Sensitivity analyses were previously performed to assess methane emission models responsiveness to parameters values (Meng et al., 2012; Riley et al., 2011; Spahni et al., 2011a; Wania et al., 2009; Zhu et al., 2014). These studies (Van Huissteden et al., 2009; Riley et al., 2011)

suggested that temperature dependency of methanogenesis is the most influential parameter affecting methane production whereas methane emissions are mostly sensitive to oxidation and plant transport." Indeed, by definition (equation 3, L175-177) "the rate of methanogenesis (k_i in s^{-1}) depends on soil temperature and moisture according to the same function as for the heterotrophic respiration (Qiu et al., 2019)". And our results displayed in the manuscrit, Figure 2 to 5 and in supplementary document, Figure S3, show that methane emissions are correlated with optimum when both simulated soil temperature and moisture conditions are the highest. Besides, in our model, as explained L493-495 "the simulated water table position is a prognostic variable defined by the cumulative amount of soil water content over the soil column (Fig. S2 and Fig. S3)." We also demonstrate for two sites, at US-Los and DE-Spw, in the supplementary document Figure S4 and S5 and discussed in the manuscript L495-496 that above the simulated water table position, soil moisture is still higher than 80% which is sufficient for methanogenesis to occur in the model. This explains that the correlation between the simulated water table position and simulated methane emissions is not as strong as the one observed in the field.

Comment 1.3: In terms of processes, for a same site a higher water table is related to a higher soil moisture content and a lower oxygen concentration over the whole peat column, which favors methanogens (and also limits methanotrophs). It is particularly important to correctly represent the link between peat water content and methane emissions for a model designed to be used in climate change studies. I would request the authors to at least clearly discuss this issue in the paper and modify their conclusions accordingly.
Response: As explained in the response to comment 1.2, we demonstrate in the manuscript (L175-177, L493-495, L524-527) and with additional figures in supplementary materials (Fig. S3) that our methane model is correlated with simulated soil temperature and moisture conditions. Indeed, Fig S3 shows a strong correlation at each site of methanogenesis maximum with both soil temperature and moisture maximum. We also discussed in the manuscript (L493-495) with additional figures in the supplementary (Fig. S2, S4 and S5) that our prognostic water table position defined from simulated soil moisture content is not well correlated to the observation water table positions measured on sites. We added a few sentences in the conclusion to highlight these results L707: "Our results show that as in previous methane emissions models (Meng et al., 2012; Riley et al., 2011; Spahni et al., 2011a; Wania et al., 2009; Zhu et al., 2014), simulated methanogenesis is strongly correlated to simulated soil temperature and moisture content whereas methane emissions are more strongly correlated to plant mediated fluxes and to soils methane oxidation proportion. We have to point out that in our model, a weak correlation has been established between the observed water table positions and the prognostic water table positions established from simulated soil moisture content. A correlation between soil moisture content and water table position in the field is needed to improve representation of the water table position in models."

Comment 1.4: The second comment is related to the Dk-Nuf site. I happen to be familiar with this dataset and I noticed some imprecisions in the text (see specific comments), so I would ask each co-author responsible for a site to carefully proofread the manuscript.

Response: We addressed the reviewer's concerns by addressing specific comments below (comment 1.5).

Specific comments:

Comment 1.5: L 243: Dk-Nuf : The methane emissions are measured by automatic chambers on this site. There is a flux tower but it only measured CO2 fluxes (besides turbulent energy and radiative fluxes). Also, the water table depth is not available at this site. Table 1: measurements for Dk-Nuf don't cover 2006-2009 but 2008 – 2014 (actually, the dataset extends to 2019)

Response: We thank the reviewer for noticing this mistake, we carefully checked the observation period of table 1 and modified the one of FI-Lom to 2006-2009 and DK-Nuf to 2008-2013 that were wrong.

Table 1. Sites ecological characteristics summary. Sites identification includes the country initials and the short three letters name of each site, locations of the sites are provided by the country, latitude (Lat) and longitude (Lon) values. Hydrological characteristics are distinguished by the type of ecosystem, fen, bog, tundra and marsh. Y and N indicate presence and absence of snow cover in winter, permafrost soil, forest above the peat. Temporary drawdown of the water table level is specified by presence and absence indicators Y or N. Grey color highlight groups of peatlands organized by amount of methane emissions in ranges 0-10, 10-150, 150-400, 400-600 mg m^{-2} d^{-1}.

Sites	Site name	Country	Lat	Lon	Climatic zone	Types	Observed period (year range)	Monthly mean methane emissions (mg m^{-2} d^{-1}, min, max)	Forest (Y/N)	Drained (Y/N)	Snow (Y/N)	Permafrost (active layer depth in m, Y/N)
US-Los	Lost Creek	United States	46.08	-89.98	temperate	fen	2006	-1.1, 3.6	N	Y	Y	N
DE-Spw	Spreewald	Germany	51.89	14.03	temperate	fen	2011	-1.4, 6.5	Y	N	Y	N
DE-Sfn	Schechenfilz Nord	Germany	47.81	11.33	temperate	bog	2012-2014	4.7, 38.0	Y	N	Y	N
DE-Zrk	Zarnekow	Germany	53.88	12.89	temperate	fen	2013	0, 37.9	N	Y	Y	N
CA-Wp1	AB-Western Peatland	Canada	54.95	-112.47	boreal	fen	2007	0, 49.3	Y	N	Y	N
US-Bog	Bog at Bonanza Creek	United States	64.7	-148.32	boreal	bog	2013	0, 54.4	Y	N	Y	Y (0.5-0.9)
FR-Lag	LaGuette	France	47.3	2.3	temperate	fen	2014-2016	0, 99.2	N	Y	Y	N
DE-Hmm	Himmelmoor	Germany	53.74	9.85	temperate	bog	2012-2014	0, 151.0	N	Y	Y	N
FI-Lom	Lompolojänkkä	Finland	68	24.21	boreal	fen	2006-2009	0, 187.8	N	N	Y	N
DK-NuF	Nuuk Fen	Denmark	64.13	-51.39	arctic	fen	2008-2013	6.1, 232.2	N	N	Y	N
PL-Kpt	Kopytkowo	Poland	53.59	22.89	temperate	fen	2013-2015	2.2, 294.7	N	N	Y	N
PL-Wet	Polwet	Poland	52.76	16.31	temperate	fen	2013	0, 361.6	N	N	Y	N
US-Wpt	Winous Point North Marsh	United States	41.46	-83	temperate	marsh	2011-2013	6.1, 502.9	N	N	Y	N
RU-Che	Cherski	Russia	68.61	161.34	arctic	tundra	2002-2005	0, 565.3	N	N	Y	Y (0.5)

Comment 1.6: L 266 : I don't understand the 0.5 degree grid cell. What is actually run at this resolution?
The authors say at line 270 that they impose site level meteorological forcings. They also seem to indicate that the spin-up to reach close to observed peat carbon content and depth was done by using the site specific meteorological data. So is it the texture that is at 0.5 degree or the hydrology? If it is the hydrology to calculate the peatland fraction then what is used to force this calculation? A gridded meteorological forcing or the site specific one ? If a gridded meteorological forcing was used then it should be mentionned. This is a bit confusing.
Response: to improve the description of simulation setup, we modified paragraphs L266: "Each peatland site is a sub-grid area embedded in the 0.5°x 0.5° grid cells whose extent is determined by a fraction of grid area as defined in Table 2. These sub-grid areas enable the representation of ecosystems variability in which a specific scheme simulates soil hydrology, vegetation characteristics and soil carbon cycling for northern peatlands. The fraction of peatlands per grid cell was defined by modifying the prescribed values employed by Qiu et al., (2018) in order to collect enough water to fill the peatland by runoff from the other soil fractions and elevate the water table level for northern peatlands. We employed vegetation phenotype properties and peatland fractions described in (Qiu et al., 2019) and peatlands hydrology and carbon model as described in Qiu et al., (2019). Site simulations were then constrained at the grid cell scale with a half hourly time series of meteorological conditions e.g. air temperature, wind speed, wind direction, longwave incoming radiation, shortwave incoming radiation, specific humidity[ES1] , atmospheric pressure, and precipitation. These time series are flux tower measurements that were gap filled by 6-hourly CRU-NCEP 0.5◦ global climate forcing dataset (Qiu et al., 2018). "

Comment 1.7: Table 2: I am surprised by the value of observed carbon stock at DK-NuF. The only study known to me (Morel et al, Earth Syst. Sci. Data, 2020) gives 36.3 kg/m2. This is much lower than the 54.6 given in the Table.
Response: We added in table 2 citations in which we collected the maximum peat depth and the soil carbon stock. For DK-Nuf we used and refer to measurements from Bradley-Cook and Virginia, (2016)

Table 2. Simulations conditions and framework to constrain peatlands soil carbon stock. Grey color reports the groups of sites with equivalent levels of methane emissions (Table 1).

Sites identification	Peat fraction	Vcmax	Carbon accumulation period	Maximum peat depth		Soil carbon stock		References
				Observed	Simulated	Observed	Simulated	
	fraction	µmol m^{-2} s^{-1}	numbers of years	m	m	kg/m^2	kg/m^2	
US-Los	0.16	65	214	0.5	0.75	27.5	28.0	Sulman et al., 2009; Chason

								and Siegel, 1986
DE-Spw	0.14	89	272	1.2	1.5	84.0	84.2	Dettmann et al., 2014
DE-Sfn	0.18	45	4 544	5	5	372.8	372.5	Hommeltenberg et al., 2014
DE-Zrk	0.9	33	10 060	10	7	696.7	696.6	Zak et al., 2008
CA-Wp1	0.16	38	620	2	2	51.0	51.0	Benscoter et al., 2011; Long et al., 2010
US-Bog	0.27	42	4 305	2	3	207.4	207.7	Manies et al., 2017
FR-Lag	0.22	42	937	1.6	2	121.0	121.4	Gogo et al., 2011; Leroy et al., 2019
DE-Hmm	0.9	35	8 963	3	3	265.0	266.4	Vybornova, 2017
FI-Lom	0.27	28	6 396	3	3	200.3	200.5	Lohila et al., 2010
DK-NuF	0.5	31	8 959	0.75	1.5	54.6	54.6	Bradley-Cook and Virginia, 2016
PL-Kpt	0.14	52	3 819	2.5	3	250.0	250.3	Jaszczynski, 2015
PL-Wet	0.11	52	261	0.5	0.75	37.6	37.8	Milecka et al., 2016; Zak et al., 2008
US-Wpt	0.27	80	32	0.3	0.75	5.3	5.4	Chu et al., 2014
RU-Che	0.05	35	2 968	0.56	0.75	45.8	45.8	Dutta et al., 2006

Comment 1.8: Section 2.3: this is very hard to follow. I am absolutely not a specialist but I wondered if the whole time series of observation was used, and at what time step? (hourly, daily,monthly, yearly?) and why.

Response: Optimization simulations were performed over site-specific observation periods as defined in Table 1. We added these precisions in the sentences L305 “Two types of simulations are performed over the site-specific observation period defined in Table 1: single site (SS) experiment for which parameters are optimized for each site and a multi-site (MS) experiment that aims at refining one set of parameters considering all sites together.”

The timestep of the model is half-hourly but the model output is the mean monthly value. We choose to have the same timescale for the outputs throughout the sites following measurements timescale that we all converted to monthly timescale because it was the timescale of the chamber measurements. We added measurement timescale L284-288: “These sites are a subset of the 30 peatlands sites collected for the calibration of ORCHIDEE-PEAT (Qiu et al.,

2018) for which, in addition of eddy-covariance data and physical variables (water table, snow depth, soil temperature), methane emissions were measured by eddy-covariance at daily time scale at US-Los, hourly timescale at DK-Nuf and otherwise at half-hourly timescale or chamber measurements at monthly timescale for FR-Lag and RU-Che. All methane emissions data were monthly average."

Comment 1.9: L326-327: this is very strange. If zroot is increased to 0.75m then, if I am not mistaken, froot=0 (I am assuming zsoil=0.75m since this is the peat depth), so that fpmt=0. If zsoil is not equal to 0.75m, increasing zroot decreases fpmt (in absolute value). Is this wanted? Similarly, why increase the rate of methanotrophy to get higher methane net emissions?
Response: Indeed, as in Walter and Heimann (2000), froot is decreasing with depth meaning that proportion of root decreases with depth. Nevertheless, since the plant mediated transport scheme is limited to layers containing roots by increasing zroot we increase the number of layers that will be involved in methane transport. Concerning the rate of methanotrophy, when the rate is higher, a lower proportion of methane is oxidized which leads to higher content of methane in the soil that will eventually be emitted. We modified the sentence L324: "Three parameter ranges were modified for DK-Nuf, the minimum value of q_{MG} was lowered to 7.0, z_{root} maximum is increased to the maximum peat depth at 0.75m in order to consider plant mediated transport in all the peat layers, the maximum value of T_{veg} was increased to 40.0 and the maximum rate of methanotrophy k_{MT} was enlarged up to 8 d^{-1} to decrease the methane oxidation and to obtain in the simulation methane emissions higher than 150 mg CH_4 m^{-2} d^{-1}. "

Comment 1.10: Another question: what did the authors do with missing data for methane emissions? There are very few winter measurements of methane emissions at Dk-Nuf. Did the authors gap-fill the data and then optimized their parameters on this? It should be clearly stated.
Response: To clearly explain data availability and timescale, we added fews sentences L243 : "For the optimization simulations, at DE-Sfn, DE-Hmm, FI-Lom, PL-Kpt, PL-Wet, and US-Wpt, year-round data were available and zero values were filled for the first and the last month of years at the beginning and the end of the observation period. Otherwise, winter months were filled with zero and during spring, summer and fall months missing data were filled gapped using a linear regression."

Comment 1.11: L327: to be coherent with the rest I believe Table 4 should have values in parenthesis for qMG at PL-Wet site (4 is outside the range given in table 3)
Response: PL-Wet out site range has been added under parenthesis to table 4:

Table 3. List of parameters driving the methane production, oxidation and transport scheme in ORCHIDEE-PCH4.

Sites	q_{MG}	k_{MT}	M_{rox}	Z_{root}	T_{veg}	wsize	mxr_{CH4}
	proportion	1/d	fraction	m	proportion	m	fraction

US-Los	9.9	1.92	0.994	0.057	3.8	0.0319	0.306
DE-spw	9.9	1.00	0.595	0.188	0.003	0.0005	0.530
DE-Sfn	10.5	1.98	0.493	0.399	0.01	0.0010	0.377
DE-Zrk	10.0	1.98	0.756	0.418	9.8	0.0015	0.259
CA-Wp1	10.2	2.99	0.471	0.122	0.45	0.0059	0.193
US-Bog	9.2	2.45	0.500	0.173	4.4	0.0098	0.117
FR-Lag	10.7	1.74	0.857	0.291	0.5	0.0085	0.463
DE-Hmm	9.4	3.94	0.147	0.118	3.7	0.0011	0.164
FI-Lom	9.5	3.97	0.491	0.174	5.7	0.0040	0.140
DK-NuF	8.5 (7.0, 11.0)	4.38	0.068	0.677 (0.01,0.75)	23.6 (0.0, 40.0)	0.0255	0.203
PL-Kpt	10.3	1.32	0.541	0.071	9.1	0.0030	0.061
PL-Wet	4.0 (1.0, 11.0)	1.95	0.165	0.328	6.0	0.0110	0.136
US-Wpt	7.9 (7.0, 11.0)	5.25 (1.0, 8.1)	0.035	0.304	22.3 (0.0, 40.0)	0.0023	0.120
RU-Che	9.8	1.36	0.004	0.404	8.4	0.0171	0.294
Uncertainty	0.8 (1.6)	1.6 (2.8)	0.4	0.196 (0.296)	6.0 (16.0)	0.0398	0.192

Comment 1.12: Figure 2-5 a): why not give the observed water table depths when available
Response: The observed water table depths when available are already provided in the supplementary document Figure S2 and overlapped with simulated water table depth. More details about correlation between observed and simulated water table depth are available in the response to comment 1.2 and 1.3.

Comment 1.13: L 459: how does permafrost explain a deeper simulated water table position ? explain.
Response: The simulated water table position is defined as the accumulation of water content height in each soil layer. When a soil layer, or part of it, is frozen water infiltration is reduced involving reduction of soil moisture in the deepest soil layers and a lower water content height and consequently a lower water table position. We modified the sentence L458: "Indeed, both sites are underlaid with permafrost which limit water infiltration to the deepest soil layers and can explain these deeper simulated water table positions."

Comment 1.14: L 562: I couldn't agree more with the authors comment on the need for more data on vascular plants in peatland
Response: This sentence is: "While a significant number of studies provide insight on gas exchanges through vascular plants, densities of vascular plants with aerenchyma in peatlands is poorly characterized."

Comment 1.15: L 590-591: I am not sure the authors really showed that these 2 sites were limited in methane substrate. It is likely the case in the model, but is it the case in reality ? Because it seems that this model result might be related to the partitioning between active, slow and passive C pools.
Response: We agree with the reviewer that for these 2 sites methane substrate is limited in our model. We modified the sentence to specify this L590: "Only two values have been defined above 10 at US-Wpt and DK-Nuf which are two sites that are limited in methane substrates in the model which explains these high values of T_{veg}. "

Comment 1.16: L 727: I couldn't agree more with this last sentence.
Response: This sentence is: "This demonstrates the complexity of interactions of the methane cycle with environmental conditions considered at various scales and the need for more detailed on-site studies."

Technical comments:
Comment 1.17: L103: Qiu et al, missing year
Response: We added citation year L103 "Recent developments of ORCHIDEE land surface model lead to simulate soil hydrology, permafrost thermodynamic and carbon cycle in the northern latitudes (Guimberteau et al., 2018) and in the northern peatland specifically (Qiu et al., 2018), including peat carbon decomposition controlled by soil water content and temperature as well as CO_2 production and consumption processes (Largeron et al., 2018; Qiu et al., 2018)"

Comment 1.18: L 285 : there is something strange with the end of the sentence "… and driven"
Response: Words ' and driven' have been removed, the sentence read now L285: "Then during the site-specific measurement periods (Table 1), methane variables are calibrated against observed monthly average methane fluxes times series."

Comment 1.19: L316 : reached instead of reach

Response: The sentence read now : "Successive runs serve to ensure that the minimum reached is not a local minimum."

Comment 1.20: L318 : that emits instead of that emitting
Response: L318 'One of these four sites, DE-Spw, is among the sites that emits the fewest amount of methane (up to 7 mg m^{-2} d^{-1}) and features a larger stock of carbon of 84 kg C / m^2 than at US-Los that features 27 kgC / m^2 and emits up to 4 mg m^{-2} d^{-1}. "

Comment 1.21: L357 : "discharged" is not the right verb here
Response: The verb has been removed, sentence L 357 read now "At sites that emitted between 10 and 150 mgCH_4 m^{-2} d^{-1}, RMSD values fluctuate between 4 and 26 and when methane fluxes were between 150 and 400 mgCH_4 m^{-2} d^{-1}, RMSD is of 38 - 80."

Comment 1.22: L365 : "significantly lower" : that is quite an understatement
Response: L365: "The temporal and the average magnitude are equivalent than in measurements except for the US-Wpt and RU-Che for which simulated emissions are much lower than observed emissions."

Comment 1.23: L 385 : "simulated diffusion of atmospheric methane" instead of "diffusion of simulated atmospheric methane"
Response: L385:"This explains the negative methane flux (Figure 2c) produced in winter by the model via simulated diffusion of atmospheric methane in the snow cover. "

Comment 1.24: Figure 2, 3, 4 and 5: b and c : the units of the flux should be mg/m2/d on the Y axis e : on the Y axis on the right
Response: Units of Figures 2 to 5 line b,c and e have been modified to mg/m2/d for the Y axis.

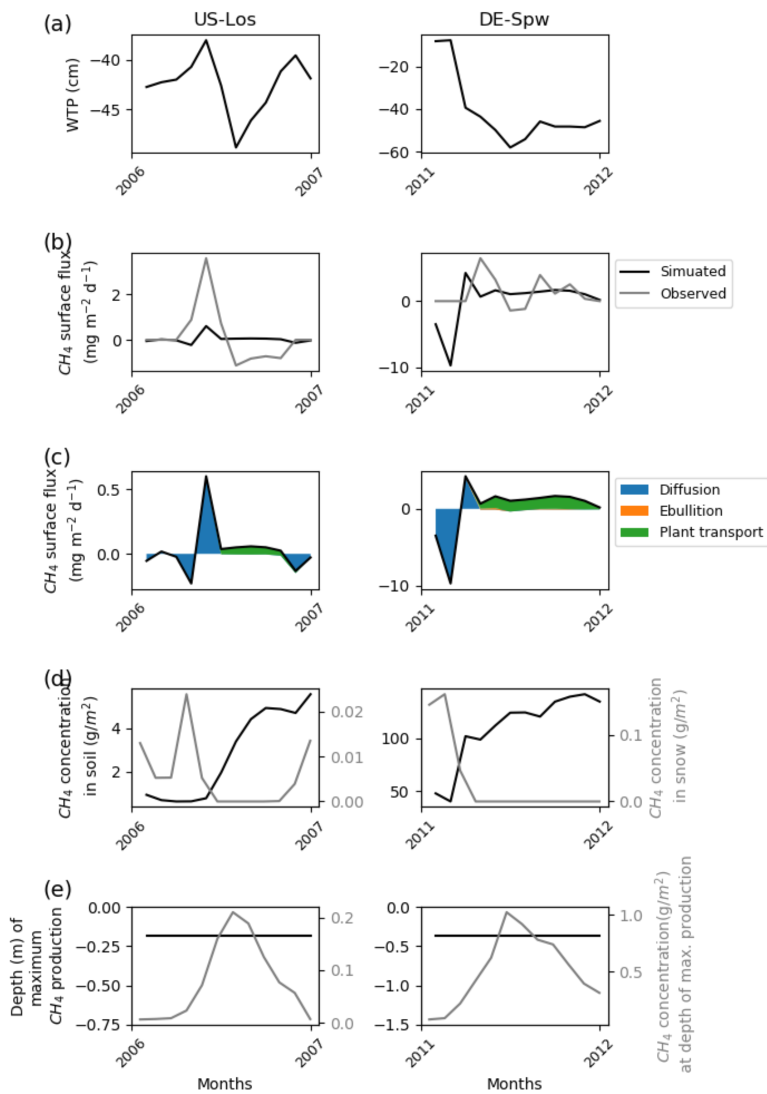

Figure 2: Temporal distribution of methane at sites emitting less than 10mg CH_4 m^{-2} d^{-1}. (a) Simulated water table position estimated from the soil water content; (b) Simulated (dark line) and observed (gray line) methane emissions released to the atmosphere; (c) Cumulative amount of simulated methane emitted by diffusion, plant mediated transport and ebullition; (d) Methane concentration in the soil layers (dark line) and in the snow layers of the model (gray line); (e) On the left, depth at which simulated methane production is the highest in the soil, scaled to the maximum peat depth. On the right, the amount of simulated methane produced at these depths.

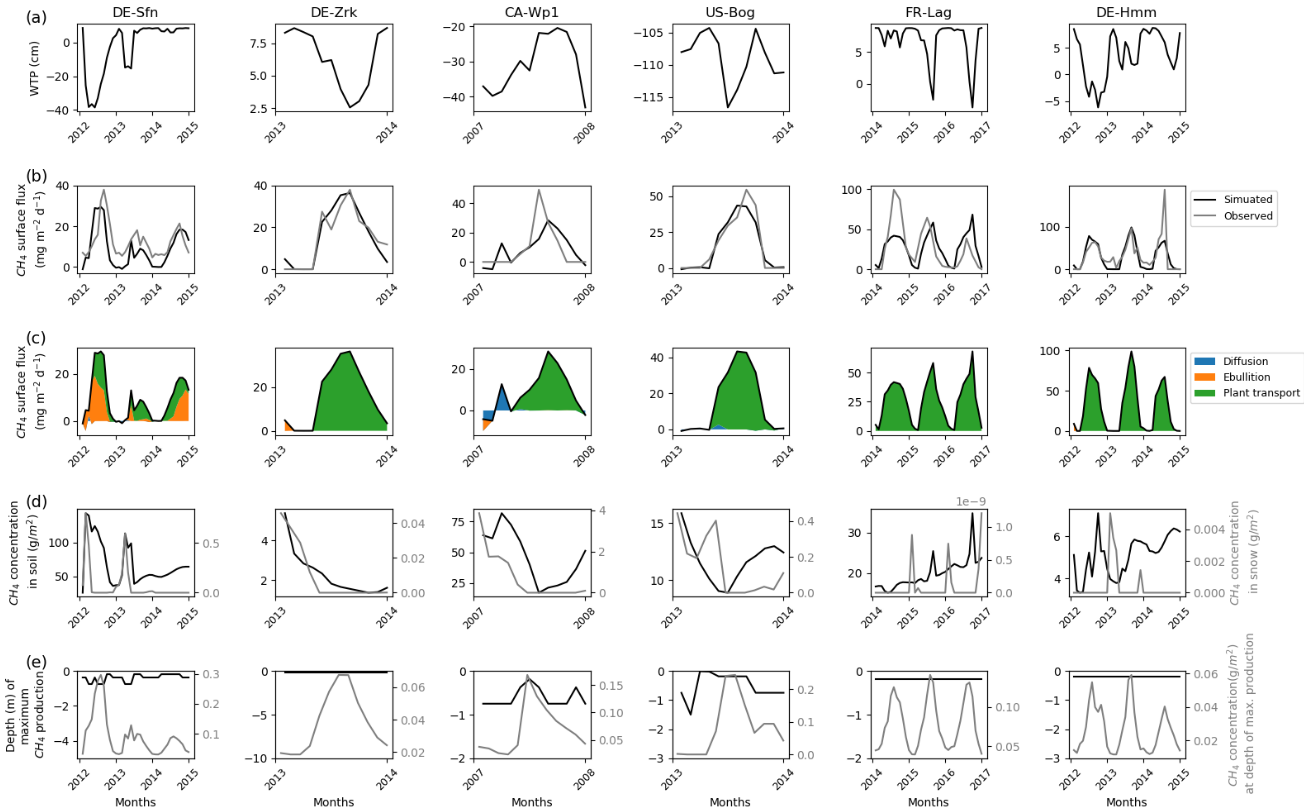

Figure 3: Temporal distribution of methane for sites emitting between 10 and 150 mg CH_4 m^{-2} d^{-1}. (a) Simulated water table position estimated from the soil water content; (b) Simulated (dark line) and observed (gray line) methane emissions released to the atmosphere; (c) Cumulative amount of simulated methane emitted by diffusion, plant mediated transport and ebullition; (d) Methane concentration in the soil layers (dark line) and in the snow layers (gray line) of the model; (d) On the left, depth at which simulated methane production is the highest in the soil, scaled to the maximum peat depth. On the right, the amount of simulated methane produced at these depths.

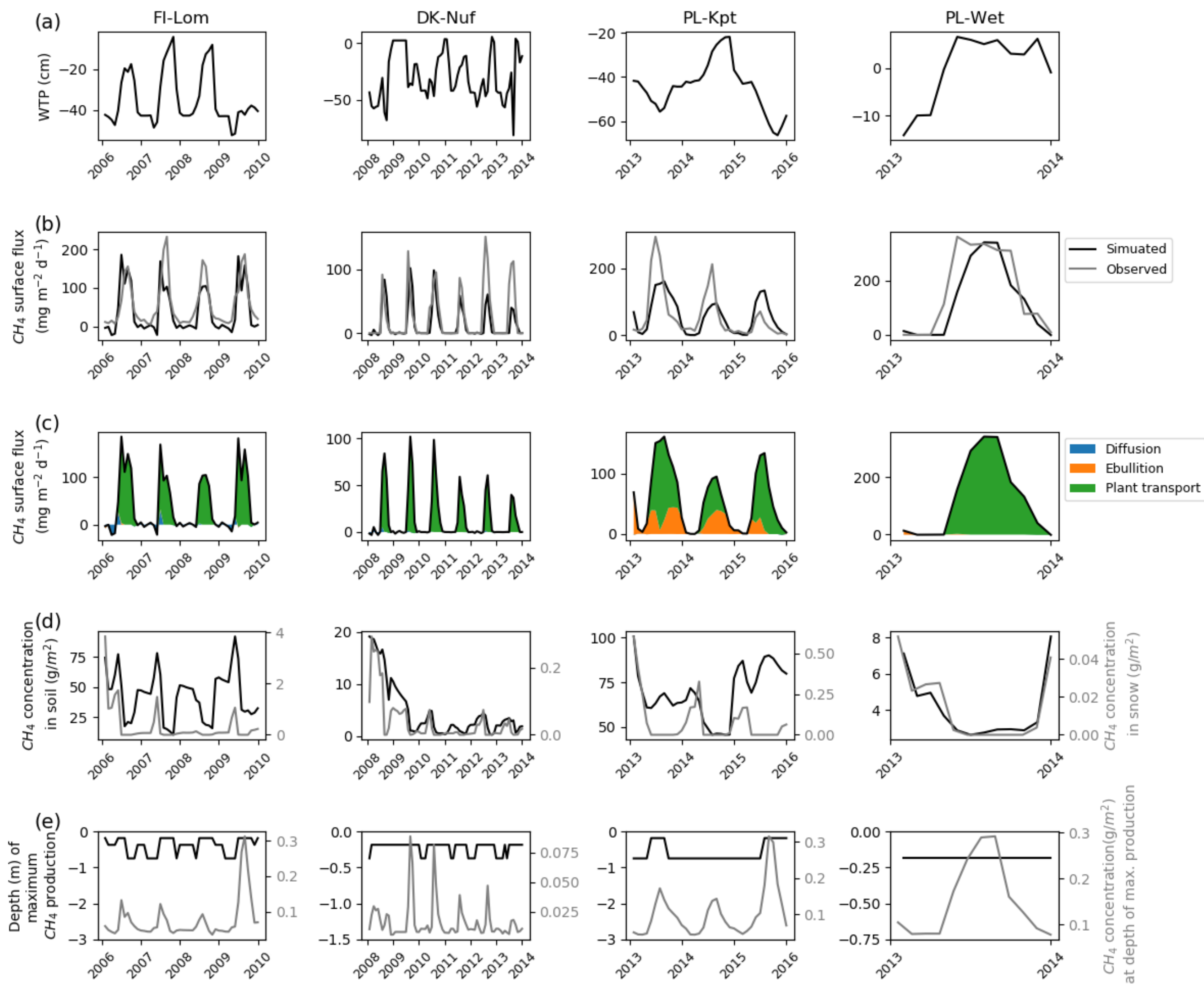

Figure 4: Temporal distribution of methane for sites emitting between 150 and 400 mg CH_4 m^{-2} d^{-1}. (a) Simulated water table position estimated from the soil water content; (b) Simulated (dark line) and observed (gray line) methane emissions released to the atmosphere; (c) Cumulative amount of simulated methane emitted by diffusion, plant mediated transport and ebullition; (d) Methane concentration in the soil layers (dark line) and in the snow layers (gray line) of the model; (e) On the left, depth at which simulated methane production is the highest in the soil, scaled to the maximum peat depth. On the right, the amount of simulated methane produced at these depths.

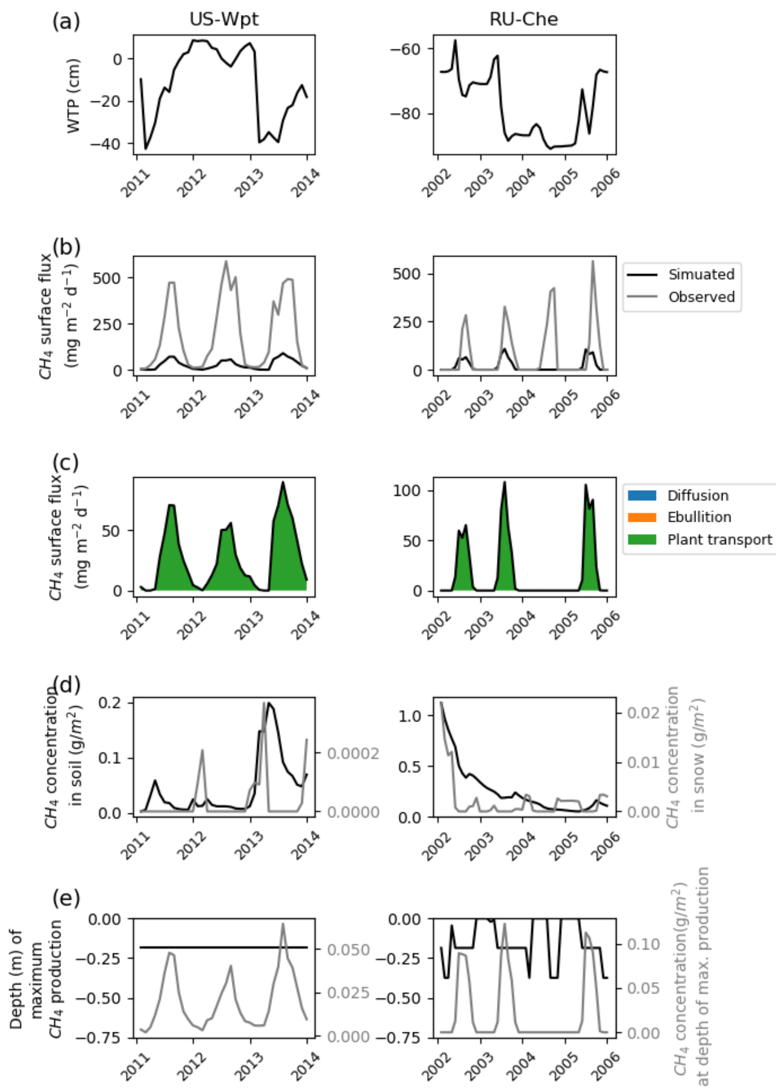

Figure 5: Temporal distribution of methane for sites emitting more than 400 mg CH_4 m^{-2} d^{-1}. (a) Simulated water table position estimated from the soil water content; (b) Simulated (dark line) and observed (gray line) methane emissions released to the atmosphere; (c) Cumulative amount of simulated methane emitted by diffusion, plant mediated transport and ebullition; (d) Methane concentration in the soil layers (dark line) and in the snow layers (gray line) of the model; (e) On the left, depth at which simulated methane production is the highest in the soil, scaled to the maximum peat depth. On the right, the amount of simulated methane produced at these depths.

Comment 1.25: L 482: Table 6 instead of 5

Response: We modified the table number, the sentence now reads L482: “Multi-site optimized parameters values acquired by using average values of parameters defined at each site and the initial ranges (Table3) are shown in Table 6. ”