

## Response to interactive comments from Anonymous Referee #2 (bg-2018-456)

We would like to express our sincere gratitude to Anonymous Referee #2 for helpful comments and corrections. Our responses to specific comments (reprinted in bold) are given below.

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### Major points

**1. If the authors want to prove that the increase of CH<sub>4</sub> emission in 2012 and 2013 was due to reduced condition after high precipitation in 2011, the authors should show the precipitation data in the preceding years before 2009 (e.g. 2007 and 2008, if possible) to prove that low CH<sub>4</sub> emission in 2009 and 2010 was observed under long lasting oxic condition (although there is no GWL data). By showing it, readers can convince more easily the authors' hypothesis.**

*Reply:* The precipitation and air temperature data for 2007 and 2008 have been added to the manuscript (Fig. 2) from the same data source as 2009–2013 (WMO weather station 21946, GHCN-Daily). Annual precipitation was persistently low at 162–173 mm from 2007 to 2009, compared to 211–421 mm from 2010 to 2013 (in hydrological year, i.e. from October in the previous year to September in the current year). This suggests dry soil conditions during our flux observations from 2009 to 2010, considering characteristically high air temperature and low precipitation in July 2010. We have revised Sect. 3.1 in our manuscript accordingly.

As we have added to the section, “Parmentier et al. (2011) reported that water level was lower in summer 2009 than the previous two summers at a tundra research station (Kytalyk) in the vicinity, approximately 30 km to northwest of Chokurdakh.” In addition, although we did not observe water level from 2009 to 2010 in our study area, we saw a drastic change in soil wetness conditions from 2010 to 2011, especially in sedge\_V. We found no surface water even in the wettest area (sedge\_V, containing some amount of cotton-sedge cover as will be described below in relation to the definition of wet area) in 2010, and we observed a high water level (10–14 cm) above the ground surface in 2011.

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**2. In Figure 4 and 5, isotopic data of CH<sub>4</sub> are shown in different colors for different year (not for each sampling site). Therefore, readers cannot see the spatial difference of these isotopic values. Please revise the figures (in the same manner as Figure S1). By doing so, the reader can judge if the difference in dD is due to spatial difference or not. In addition, are there any temporal changes in dD values at 10 cm in 2011? If there is any relationships between higher dD values and environmental factors (i.e. drop with GWL or**

**precipitation in summer), this can be important information to understand the effect of CH<sub>4</sub> oxidation or diffusion on variation in  $\delta D$ .**

*Reply:* We have added spatial information to Fig. 4 and 5 (though we also wonder if you meant corrections of Fig. 5 and 6, we hope readers can see spatial variations in  $\delta D$  and  $\delta^{13}C$  of dissolved CH<sub>4</sub> from Fig. 5, and that in dissolved CH<sub>4</sub> concentration from Fig. 4). In summer 2011, three of all the four wet areas (sphagnum\_K, sedge\_V, and sedge\_B) showed low  $\delta^{13}C$  or high  $\delta D$  values apart from the convergence values ( $\delta^{13}C \cong -50\text{‰}$ ,  $\delta D \cong -408\text{‰}$ ) seen in deep soil layer or under high dissolved CH<sub>4</sub> concentration (Fig. 5). In this way, it does not appear that the large variations in  $\delta^{13}C$  and  $\delta D$  of dissolved CH<sub>4</sub> in 2011 were limited to one special location.

We have added individual values of water level and  $\delta D$  of dissolved CH<sub>4</sub> observed on each date in 2011 at 10 cm depth in wet areas to the supplement (Table S4). We found increases in water level during summer 2011. However, we could not find clear temporal change in the  $\delta D$ , although we only have  $\delta D$  data for late July in 2011. We did not find clear temporal change in the delta values of dissolved CH<sub>4</sub> in 2012 and 2013, either.

Truly, it would be our important future task to conduct detailed investigation of the temporal variation in CH<sub>4</sub> dynamics regarding precipitation and water drainage within one summer, although this study found large interannual variations in CH<sub>4</sub> flux and dissolved CH<sub>4</sub> concentration, and those in isotope ratios of dissolved CH<sub>4</sub> to some extent.

### **3. Results of phylogenetic composition should be presented in the main text and as a main figure.**

*Reply:* We have added results of phylogenetic composition to Sect. 3.4 in the main text, and moved the data figure from the supplement to the main manuscript (Fig. 8).

## **25 Minor points**

### **Abstract**

#### **P1, L23 “soil” incubation “emitted” CH<sub>4</sub>**

*Reply:* We appreciate your corrections. We have added “soil” before “incubation” to the sentence. Instead of “emitted”, we have inserted “dissolved”, because we do not show any data of isotopic compositions of the emitted CH<sub>4</sub> to the atmosphere but only those of dissolved CH<sub>4</sub> for in situ observation.

**P1, L25 & L26 CH<sub>4</sub> “emission”**

*Reply:* We have corrected our manuscript accordingly.

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**P1, L28 “in 2011” see Major point 2**

*Reply:* As we described above, we found no clear spatial variation and no clear temporal variation in isotopic compositions of dissolved CH<sub>4</sub>.

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**Introduction**

**P2, L5, Rewrite the sentence.**

*Reply:* We have rewritten the sentence.

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**P2, L9-14 Referencing in the manuscript is incomplete.**

*Reply:* We have corrected our manuscript accordingly.

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**P3, L8 “soil” incubation**

*Reply:* We have corrected our manuscript accordingly.

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**Methods**

**P4, L25 When was GWL measurement conducted in each year? After every sampling? Or just one time?**

*Reply:* Water level was measured after most of the CH<sub>4</sub> flux observations in wet areas from 2011 to 2013. Detailed observation dates of water level are shown in Table S2. We have corrected the sentence accordingly.

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**P5, L3 How many soil incubation samples are prepared for each sampling point and for each initial and final measurement? Please clarify.**

*Reply:* We prepared three soil samples for each sampling point. We collected dissolved CH<sub>4</sub> samples twice from each soil sample, and prepared three dissolved CH<sub>4</sub> samples for each of the initial and final measurements. Only  
5 for sedge\_K, we prepared three replicate soil samples multiplied by four treatments of incubation (12 soil samples in total) to assess vertical variation and effect of incubation temperature. These incubation treatments were 10 cm depth at 5 °C, 10 cm depth at 10 °C, 20 cm depth at 5 °C, and 30 cm depth at 5 °C. We have added all this information to Sect. 2.3 in our manuscript.

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**P5, L9-L12 If the analysis method of phylogenic composition is shown in Methods section, data (figure) should be shown as main figure (not as supplement)**

*Reply:* We have moved the data figure from the supplement to the main manuscript (as Fig. 8). We have also added detailed method of the phylogenic composition analysis to Sect. 2.3 in the main text.

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**P5, L15 Were the samples prepared in quadruplicate for each day of sampling? Or one sample was measured for each location and each sampling day? Please clarify.**

*Reply:* We measured four replicate samples for each location and each sampling day. First, we prepared four  
20 replicate soil samples for each of the two sampling locations (sphagnum\_K and sedge\_K). Second, we collected headspace gas sample for three times (day 0, day 4 and day 8) from each incubated soil sample. We have added all this information to Sect. 2.3 in our manuscript.

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## **Results**

**See the Major point 3.**

*Reply:* As we described above, we have added results of phylogenic compositions to Sect. 3.4.

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**P6, L21, Please clarify the definition of “wet area” in this manuscript.**

*Reply:* The definition is based on vegetation. We defined “wet area” as micro-reliefs with wetland vegetation, namely micro-reliefs covered by sphagnum mosses (*Sphagnum squarrosum*) and those by sedges, especially by some amount of cotton-sedges (*Eriophorum angustifolium*). Because wetland vegetation can be identified visually, “wet area” can be identified easily based on this definition. We found that spatial distribution of the wetland vegetation corresponded to lower elevation in microtopography and higher soil moisture from transect observation (Morozumi et al., in review). We could also confirm from Table 1 in this study that “wet areas” had higher soil moisture than tree mounds. We have rewritten the definition of wet area in Sect. 2.1 accordingly.

10 **P6, L25, Please show the thaw depth of each observation year, in addition to the averaged value.**

*Reply:* We have shown the thaw depth of each observation year as Table S1. In wet area, the thaw depth observed during mid-July became deeper from 2011 ( $22 \pm 4$  cm) to 2012 ( $25 \pm 8$  cm) and 2013 ( $35 \pm 7$  cm). We have added this information to Sect. 3.1, and mentioned it in Sect. 4.2 and the concluding remarks as an alternative explanation of the multi-year effect of wetting on CH<sub>4</sub> emission.

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**P6, L26- See Major comment 2, please show the environmental data of several years prior to flux measurement in 2009 and 2010.**

*Reply:* We have added precipitation and air temperature data for 2007 and 2008 to Fig. 2, and rewritten Sect. 3.1 accordingly.

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**P7, L2, Again, when was GWL measurement conducted in each year? After every sampling? Or just one time? If the authors measured GWL after every sampling, it can be useful information to understand the CH<sub>4</sub> production and oxidation processes. It may be especially true for summer 2011 when the dynamic GWL change must occur with precipitation.**

*Reply:* As we described above, water level was measured after most of the CH<sub>4</sub> flux observations in wet areas from 2011 to 2013 (each observation date of water level is shown in Table S2), and we have added individual values of water level observed in wet areas on each date in 2011 to the supplement (Table S4). We found increases in water level during July 2011. However, we could not find clear temporal changes in the isotopic compositions of dissolved CH<sub>4</sub>.

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**P7, L11 Take out “active”**

*Reply:* We have taken out “active.”

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**P7, L13 Take out “Interestingly”**

*Reply:* We have taken out “Interestingly.”

10

**Section 3.3 See the Major comment 2. Please show the spatial (and temporal) variations of isotopic values.**

*Reply:* As described above, we have added spatial information to Fig. 4 and 5. We have added data for the temporal variation of delta values at 10 cm within 2011 to the supplement (Table S4).

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**P7, L25 Please show the ranges of concentrations and dD and d13C values of CH<sub>4</sub> in ambient air using for “in situ” dilution.**

*Reply:* We wonder if you mean the air we used for extracting dissolved CH<sub>4</sub> from water samples by headspace method. We preserved this air as a background sample for each day of dissolved CH<sub>4</sub> sampling. As a result of  
20 analyzing the background samples, we obtained 2.0–4.3 ppm for CH<sub>4</sub> concentration, –53‰ to –45‰ for δ<sup>13</sup>C, and –168‰ to –78‰ for δD. We corrected delta values of dissolved CH<sub>4</sub> for the bias from background CH<sub>4</sub> based on mass balance. We have added these ranges to Sect. 2.2 in our manuscript.

25 **P7, L26 similarly “to what?”**

*Reply:* We intended to mention that the range of δ<sup>13</sup>C of dissolved CH<sub>4</sub> was similar among surface water, 10 cm depth, and 20 cm depth. We have taken out “similarly” from the sentence.

30 **P8, L9, L10, Please show statistics.**

Reply: With regards to the sampling depths, CH<sub>4</sub> production rate was  $0.66 \pm 0.15 \mu\text{mol day}^{-1}$ ,  $0.33 \pm 0.06 \mu\text{mol day}^{-1}$ ,  $0.003 \pm 0.004 \mu\text{mol day}^{-1}$  for 10 cm, 20 cm, and 30 cm depths, respectively ( $n = 3$  for all the depths). Difference in the rate values among the depths were significant based on Welch's ANOVA test ( $p < 0.01$ ). Regarding the incubation temperature, production rate was  $0.66 \pm 0.15 \mu\text{mol day}^{-1} \text{gdw}^{-1}$  and  $0.74 \pm 0.14 \mu\text{mol day}^{-1} \text{gdw}^{-1}$  for 5 °C and 10 °C, respectively ( $n = 3$  for both temperatures). Difference in these rate values was not significant based on  $t$ -test ( $p > 0.5$ ). All these rates here were obtained for sedge\_K. We have added all this information to the sentence in our manuscript.

10 **P8, L20- Please add figures showing change of d13C and dD in Figure S2.**

Reply: We have added plots of  $\delta^{13}\text{C}$  and  $\delta\text{D}$  to Fig. S2. As seen in these plots, both  $\delta^{13}\text{C}$  and  $\delta\text{D}$  increased along incubation day. Two headspace CH<sub>4</sub> samples from day 8 could not be analyzed for delta values, because the CH<sub>4</sub> concentration was low ( $< 10$  ppm).

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### Discussion

**P8, L30, L31 Please show the ranges of CH<sub>4</sub> flux both in this site and in the some literature.**

Reply: We have reformulated the sentence as follows; “our CH<sub>4</sub> flux in wet areas ( $36\text{--}140 \text{ mg CH}_4 \text{ m}^{-2} \text{ day}^{-1}$ ) was comparable to that reported for wet tundras ( $32\text{--}101 \text{ mg CH}_4 \text{ m}^{-2} \text{ day}^{-1}$ ) or permafrost fens ( $42\text{--}147 \text{ mg CH}_4 \text{ m}^{-2} \text{ day}^{-1}$ ) in a database across permafrost zones compiled by Olefeldt et al. (2013).”

**Section 4.2 Need more reference.**

25 Reply: We have added references (Woo, 2012; Nassif and Wilson, 1975) to three sentences about hydrological processes in Sect. 4.2.

**P9, L15, If the authors do not show the ORP data, take out “remarkably”.**

30 Reply: We have taken out “remarkably”.

**P9, L26, Again, please check if these higher dD values are not associated with sampling point and sampling time.**

5 *Reply:* As we described above, we found no clear spatial variation and no clear temporal variation (Fig. 5, Table S4).

**P9, L32, Here, I recommend showing the equilibrium concentration of dissolved CH<sub>4</sub> with atmospheric CH<sub>4</sub>, to exclude the possibility that CH<sub>4</sub> exchange can effect on isotopic values.**

10 *Reply:* We have added the following after the sentence in our manuscript. “The effect of CH<sub>4</sub> exchange between surface dissolved CH<sub>4</sub> and atmospheric CH<sub>4</sub> can be excluded, because all the dissolved CH<sub>4</sub> observed in this study was highly oversaturated ( $> 0.3 \mu\text{mol L}^{-1}$ , Fig. 4) compared to the equilibrium concentration of atmospheric CH<sub>4</sub> (4-5 nmol L<sup>-1</sup>, assuming 1–10 °C water temperature and 2 ppm atmospheric CH<sub>4</sub> concentration; Yamamoto et al., 1976).”

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**P10, L1 In addition, heavy precipitation may supply O<sub>2</sub> to surface layer of wet area.**

*Reply:* We have included this thought to the sentence; “shallow layers are provided with O<sub>2</sub> from the atmosphere and precipitation.”

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**Section 4.3 See the Major point 3. I think that the results of microbial analysis agree well with isotopic variation and, therefore, are should be shown in main text.**

25 *Reply:* I truly appreciate your positive comment. We have moved the data figure of microbial analysis from the supplement to the main manuscript (as Fig. 8), and added description of the results to Sect. 3.4 in the main text. We have also modified Sect. 4.3 accordingly.

Being more confident with the interpretation, we have added the following sentence to the abstract; “delayed activation of acetoclastic methanogenesis following soil reduction could have also contributed to the enhancement of CH<sub>4</sub> production.”

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## **Concluding remarks**

### **P11, L18-19 Add reference.**

*Reply:* We have added references (Sugimoto and Wada, 1993; McCalley et al., 2014; Itoh et al., 2015).

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### **Figure 2 Please show the precipitation and temperature data in the preceding years before 2009. GWL data of sphagnum moss in 2013 seems missing.**

10 *Reply:* We have added precipitation and temperature data for 2007 and 2008 to the figure. As we have added to the figure caption, “water level was very low ( $< -12$  cm) in the wet area of sphagnum in 2013, and could not be measured.”

### **Figure 3, Add statistical information (yearly difference) in the figure.**

*Reply:* We have added statistical information to the figure.

### **Figure 7, Please represent the symbols for different sampling site by different colors.**

20 *Reply:* We have revised the figure accordingly.

### **Figure 8, Are the d13C & dD data averaged value? Please clarify.**

25 *Reply:* The  $\delta^{13}\text{C}$  and  $\delta\text{D}$  data are individual values from each incubation syringe and each day. Nevertheless, all the data points were plotted on one line. We have corrected the figure caption accordingly (Figure 9 in our revised manuscript).

We have also corrected the ranges of both axes in the figure to include all the data points (we missed one data point with  $\delta^{13}\text{C} = -6.6\text{‰}$  and  $\delta\text{D} = +507\text{‰}$  in our previous manuscript).

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### **P25, L5 “in the bottom left corner”? Please rewrite.**

*Reply:* We have rewritten the sentence as follows; “initial isotopic compositions of the headspace CH<sub>4</sub> were −66‰ to −65‰ for δ<sup>13</sup>C and −167‰ to −162‰ for δD.”

5 **Figure S2, Please add figures showing change in d13C and dD.**

*Reply:* We have added the figures.

**Table S2, Please show isotopic values and number of samples.**

10 *Reply:* We have added isotopic values and number of samples to the table (Table S3 in our revised manuscript).