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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Annual variation of methane emissions from forested bogs in West Siberia (2005–2009): a case of high CH_4 and precipitation rate in the summer of 2007" *by* M. Sasakawa et al.

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Comment; Abstract: Remove abbreviations and detailed research project and location data; these belong in the introductory sections of the article.

Reply; We have modified the abstract accordingly.

Comment; p. 27762 line 6: What is meant with a 'semi-climatological CO2 flux'? Please explain.

Reply; In response to the above comment, we have modified Section 2.2 as shown below: "2.2 Three-hourly CO2 flux and CH4 flux calculation We calculated daily CH4 flux with measured concentrations of CH4 and CO2, and "semi-climatological CO2 flux" from a model. The latter variable is obtained as follows. Three-hourly terrestrial biosphere CO2 fluxes were generated from the monthly Net Ecosystem Production (NEP) flux of the Carnegie–Ames–Stanford Approach (CASA) ecosystem model (Randerson et al., 1997) on a 1° × 1° grid using a procedure similar to that of Olsen and Randerson (2004). Whereas Olsen and Randerson (2004) used the National Center for Environmental Prediction (NCEP) as the source of meteorological fields, we used the data from the JMA Climate Data Assimilation System (JCDAS; Onogi et al., 2007). First, the 3-hourly downward short-wave radiation was calculated by fitting the 6-hourly JCDAS data to a theoretical clear-sky solar radiation function. Then the 3-hourly Gross Primary Production (GPP) within each month was estimated by distributing the monthly GPP (Net Primary Production (NPP)×2) according to the radiation data. Thereafter, the monthly respiration (Re) is distributed within each month according to: Re(t) = Re,0 × Q10((T(t)-T0)/10) (1) where Q10 was set at 1.5 and T was obtained from 2-m JCDAS temperature. Then, Re,o was adjusted so that the monthly NEP (GPP-Re) approached the same values as the original CASA NEP data, with zero mean annual biospheric flux at every grid point (i.e., a neutral biosphere flux). In order to estimate the actual daily CH4 flux from the CASA 3-hourly CO2 flux normalized with the observed CH4 and CO2 accumulation on a certain day (day x), we used the average of three midnight data between 20:00 LST (day x) and 5:00 LST (day x+1) as CO2 flux (FCO2). Daily CH4 flux was then calculated with the following Equation: FCH4 = FCO2 × ΔCH4/ΔCO2. (2) Here we define gas accumulation (ΔCO2 and ΔCH4) as the measured concentration difference between the concentration at 21:30 LST and the elevated concentration at early next morning (4:30 LST). The CH4 flux calculated from this Equation reflects averaged emissions from the surface inside the targeted rectangular area around each tower. It should be noted that the calculated CH4 flux turned out to be the minimum estimated value because some wetlands showed higher CH4 flux during the daytime than during the nighttime (e.g. Hargreaves and Fowler, 1998, Long et al., 2010). However, the elevated CH4 flux during the daytime was not always observed (Long et al., 2010) and it has been shown that, at some wetlands, a diurnal cycle of CH4 flux was not observed (Werner et al., 2003; Rinne et al., 2007).

Comment; line 20: Give more explanation on the CH4 semiconductor sensor. Reference to an article is not sufficient here; the reader should know basic information, at least on the measurement principles, manufacturer and precision of the instrument.

Reply; The methane system was originally developed by Suto and Inoue (2010). We have added the following sentence in Section 2.1. "Measurement precision was $\pm$0.3 ppm and $\pm$3 ppb for CO2 and CH4, respectively (Sasakawa et al., 2010)."

Comment; p. 27763 line 8: More explanation is needed on the CASA model. Why was this rather old model used here? line 9: which variability is referred to here?

Reply; As already shown, we have modified Section 2.2. The CASA model has been widely used to calculate biosphere CO2 flux. For example, an international collaborative activity for carbon cycle transport model intercomparison (TransCom) has used the output from CASA as providing a relatively reliable estimate of biospheric flux (e.g. Law et al., TransCom model simulations of hourly atmospheric CO2: Experimental overview and diurnal cycle results for 2002. Global Biogeochem. Cy. 22, doi:10.1029/2007GB003050, 2008). In our study we employed a similar model simulation procedure as in various TransCom exercises, employing CASA.

Comment; line 24: The GLWD has various resolutions, which one was used? Also, wetland extent may differ among wetland databases and models, see Petrescu et al., 2010.

Reply; We obtained and used the GLWD 1-km resolution data to capture the fine-scale heterogeneity, and then aggregated them into a 0.5-deg resolution. We agree that the wetland data sets differ in their extent, leading to estimation uncertainty. Therefore, our model estimation was compared with those obtained by the GISS study using different

wetland data.

Comment; p. 27764 line 0-5 For estimation of the inundation fraction the data of Prigent et al., 2007 are used. However, considerable processing of the data is included which is not properly clarified in the text. Explain: what is considered as unrealistic monthly fluctuation, what is the baseline inundation fraction and how is it derived. Also the average water tables that are selected on the basis of these data are quite arbitrary: 0 cm for inundated, -25 cm for drained. These choices should be explained, and their effects on flux modelling assessed. CH4 fluxes measured in the field, and in the model which is used here (Walter-Heimann) are highly sensitive to water table fluctuations in the range of 0 to -25 cm. So selecting arbitrary values has large effects on methane flux estimations.

Reply; We have addressed these issues in the modified Section 2.3 as follows; "2.3 Ecosystem model Monthly CH4 fluxes from wetlands were estimated with VISIT (Inatomi et al., 2010; Ito, 2010) to evaluate the variation of gas fluxes responding to weather and biological conditions. Fig. 1 shows a schematic diagram of the CH4 exchange processes employed in VISIT. The model consists of carbon, nitrogen, and water cycle sub-schemes, each of which is composed of several functional compartments such as leaves, stems, roots, dead biomass, and organic soil. Plant photosynthetic CO2 uptake, allocation, biomass growth, and mortality are simulated in the carbon cycle as part of an ecophysiological process (Ito and Oikawa, 2002). Wetland CH4 flux is simulated using a semi-mechanistic scheme (Walter and Heimann, 2000), in which three processes of CH4 flux emission are considered: physical diffusion, plant-mediated transportation, and ebullition. The physical diffusion rate depends on the CH4 concentration gradient between the surface and soil air, which is affected by CH4 production and oxidation within the soil. In the soil, the CH4 production rate is determined by microbial activity and substrate supply from plants, producing sensitivity to temperature variability that leads clearly to seasonal cycle in the CH4 emission. Spatial heterogeneity in diffusivity through soil pore spaces is determined on the basis of sand/clay composition data (Hall et al., 2006) and water table depth. The plant-mediated transport of CH4 is dependent on the plant growing stage determined by the cumulative temperature and biome-specific rooting depth (typically, 20 cm for wetlands). The ebullition flux occurs only when the CH4 concentration exceeds 500 μmol liter–1 (Walter and Heimann, 2000). Wetland distribution is determined on a 0.5° $\times$ 0.5° grid based on Global Lakes and Wetland Database (GLWD, Lehner and Döll, 2004) (Fig. 2). A distribution of natural vegetation type including both uplands and wetlands is derived from the global data set (Olson et al., 1983; Ramankutty and Foley, 1999). For performing broad-scale simulations, wetland soils are stratified into 20 layers of 5 cm thickness each. To include the spatial heterogeneity of wetlands, CH4 fluxes are separately estimated for flooded (i.e., inundation) and non-flooded fractions of the ground surface, each of which has different water table depths. Thus, the total CH4 emission (E) for each grid cell is obtained as: E = w $\times$ (finund $\times$ Einund + fdrain $\times$ Edrain) (3) where w represents the wetland fraction in each grid cell, and f and E denote the land fraction and CH4 exchange flux of inundation and drainage parts (subscripts), respectively. Monthly average inundation fraction (finund) is derived from a passive microwave Special Sensor Microwave/Imager (SSM/I) observation for 1993–2000 (e.g., Prigent et al., 2007). Because we estimate the inundation fraction on the basis of seasonal variation for each grid cell, snow cover and extensive flooding after snow melting could in some cases affect the base line. To avoid these apparent variations (e.g., too much severe drying after a spring flood) during the growing-period (May–August), we have decided to use the average inundation fraction derived from the SSM/I observation during the period. The baseline water table depths of the inundation and drained wetland surfaces are assumed as 0 and -25 cm, respectively, on the basis of an observation at West Siberian wetlands (Bohn et al., 2007). At layers lower than the water table, CH4 production is estimated as a function of temperature and plant carbon supply, which is obtained from the vegetation production scheme of the model. We also evaluated the influence of precipitation rate on the CH4 emission from wetlands. Inter-annual variability in the water table depth was estimated from the cumulative pre-

cipitation anomaly at each model grid as deviation from the 2001–2009 mean, which was obtained from the NCEP/NCAR reanalysis data (Kalnay et al., 1996). To assess the possible range of estimation, a high (+1mm water table depth/+1mm precipitation anomaly) and a low (similarly, +0.2 mm/+1 mm) response cases were examined. To validate the CH4 flux estimated by VISIT, we compared the model output with a widely used climatological CH4 flux distribution map of the wetlands (bogs, swamps, and tundra) published by the NASA Goddard Institute for Space Studies (GISS) (Fung et al., 1991).

Comment; line 14-15 The Walter Heimann model needs tuning of some of its parameters on observation data, and should be applied cautiously for upscaling (see e.g. Van Huissteden et al., Biogeosciences, 2010). Where there any site flux observation data on which the model could be tuned? Please specify your choices for the parameter values, in particular the parameters that affect methane generation, transport and oxidation rate during transport.

Reply; In fact, the model in Walter-Heimann (2000, hereafter WH2000) contains several empirical parameters. We selected these values within the range of their original paper. For example, a parameter for the quality of plant-mediated transport (Tveg) was assumed to be 6 and 4 for flooded and non-flooded wetland, respectively; these values are close to those at Sphagnum moss fen in Minnesota (cf. Table 2 of WH2000). Similarly, maximum CH4 oxidation rate was assumed to be 20 μ-mol per hour. The same temperature sensitivity of CH4 production (Q10) that was used in WH2000 (6.0) was also assumed in this study. Parameter calibration using field data at West Siberia, however, remains for our forthcoming study.

Comment; line 23-26 You cannot ignore completely the diurnal variation of CH4 emission. Several recent studies of wetland CH4 emission using eddy covariance show a clear diurnal emission regime. You should consider how this may affect your emission estimates.

Reply; No diurnal cycle of CH_4 flux was observed at some wetlands (Werner et al., 2003; Rinne et al., 2007). Other wetlands showed higher CH_4 flux during daytime than during nighttime (e.g. Hargreaves and Fowler, 1998, Long, et al., 2010). However, the elevated CH_4 flux was not always obvious. For example, the elevated CH_4 at a northern Canadian peatland was pronounced only in July (not in May, June, August, and September) (Long et el., 2010). This suggests that our emission is estimated at minimum values because we used the accumulation of CH_4 during nighttime. We have added an explanation in Section 2.2 as follows; "It should be noted that the calculated CH_4 flux turned out to be the minimum estimated value because some wetlands showed higher CH_4 flux during the daytime than during the nighttime (e.g. Hargreaves and Fowler, 1998, Long et al., 2010). However, the elevated CH_4 flux during the daytime was not always observed (Long et al., 2010) and it has been shown that, at some wetlands, a diurnal cycle of CH_4 flux was not observed (Werner et al., 2003; Rinne et al., 2007)."

Comment; p. 27765 'Figure 2 does not indicate any clear increase in the nighttime CO_2 concentration while the daytime CO_2 concentration from 2005 to 2009 shows a general increase': This is difficult to read from the figure. This may be solved by adding an extra figure showing the maximum nighttime fluxes and minimum daytime fluxes plotted against year.

Reply; Although we appreciate the comment by the reviewer, it is our feeling that the present figure is adequate to support our statement.

Comment; p. 27766 Line 7: You state that remarkably high _CH4/_CO2 ratios were observed in August 2009. Can this also be attributed to weather conditions?

Reply; We think so. It is shown in p. 27768 Line 10–11.

Comment; Line 13-14: Why is the source area for the emissions rectangular? I would not expect the footprint area of the towers to be rectangular.

Reply; We use the minimum grid size of the CASA for the latitude. To make the length the same, the range for the longitude is longer. We cannot change the region since this is the minimum size.

Comment; p. 27767 line 5-19: I miss flux data measured by Repo et al (Tellus, DOI: 10.1111/j.1600-0889.2007.00301.x, 2007)

Reply; We have made reference to the paper.

Comment; p. 27768 line 13-14: 'In which the dimension of the flooded area was assumed to expand proportionally to the monthly precipitation anomaly rates': here, the accuracy of the model input is strongly overstated. In section 2.3, the flooded area is derived from Prigent et al., 2007, with strongly simplified assumptions on the water table! line 20: Here, low and high response cases are introduced without any further explanation. How are the low and high response cases defined in terms of the model parameters? Describe these high and low response cases.

Reply; As already noted above, we have modified Section 2.3 and added the necessary explanation.

Comment; Supplement: I wonder why this figure is not included in the paper. It makes no sense to add supplemental information for just one figure. I suggest to use the supplement for adding information on the models.

Reply; We have moved the figure into the main paper as new Figure 6.

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 27759, 2010.

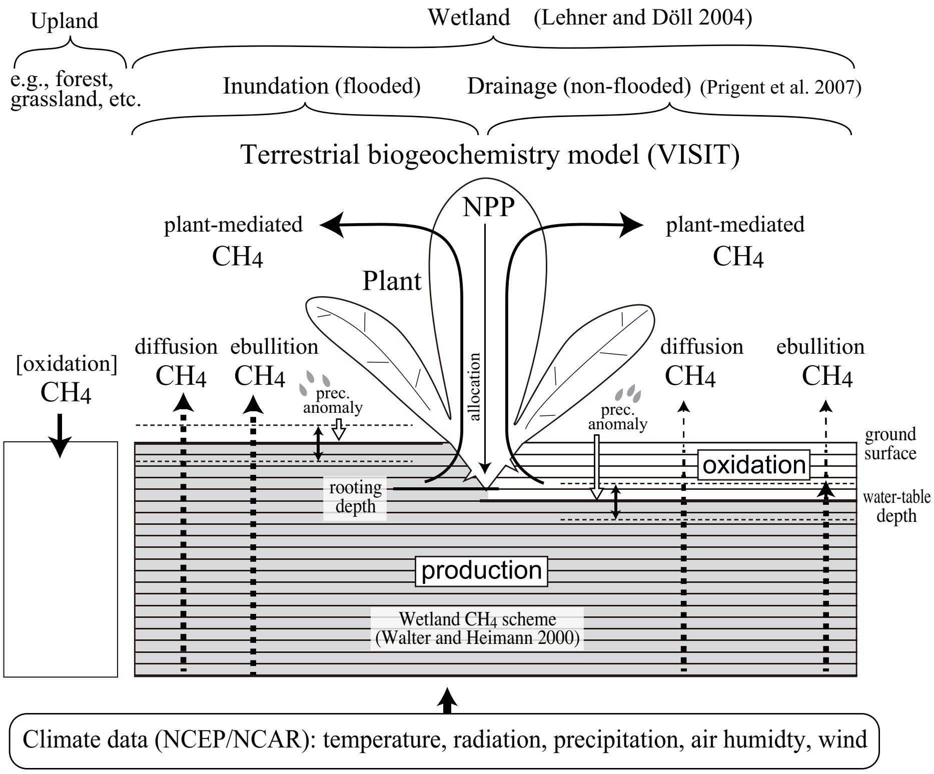

Fig. 1. A schematic diagram of the CH4 exchange scheme used in this study.