Supplement of

Evaluation of CH4MOD_{wetland} and Terrestrial Ecosystem Model (TEM) used to estimate global CH₄ emissions from natural wetlands

Tingting Li et al.

Correspondence to: Yanyu Lu (ahqxlyy@163.com) and Lingfei Yu (yulf@ibcas.ac.cn)

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Supplementary material S1 Model calibration of CH4MOD\textsubscript{wetland}

We used the independent datasets from the literature and the field measurements for model calibration. The vascular plants provide an effective mechanism by which CH\textsubscript{4} can be transported to the atmosphere (Chanton et al., 1992; Schimel, 1995; Shannon et al., 1996). According to previous study (Walter et al., 1996; Zhang et al., 2002), grasses and sedges are good gas transporters, but shrubs and trees are poor ones. \(T_{\text{reg}}\) ranges from 0 (plants without aerenchyma) to 1 (plants with well-developed aerenchyma). For herbaceous plants and woody plants, \(f_1\) was the average value of several observed proportion of BNPP to the total NPP derived from the data sets compiled from the amount of literatures (Gill and Jackson, 2000; White et al., 2002). \(F_N\) was calculated by the initial concentrations of nitrogen and lignin (g kg\(^{-1}\)) in the plant litter (Li et al., 2010). The nitrogen and lignin concentration of the above-ground and below-ground litter for grass and forest were from the global data set developed by the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL-DAAC) (White et al., 2002; Gordon and Jackson., 2003). \(VI\) and \(P_{\text{at}}\) are calibrated using the CH\textsubscript{4} measurements from three wetland sites (Table 1). CH\textsubscript{4} measurements from the Sanjiang Plain, China in year 2002 (Hao, 2006; Song et al., 2009; Yang et al., 2006) and from the Wuliangsu lake, China in year 2003 (Duan et al., 2005) were used to make calibration for the wetland dominated by the herbaceous plants. CH\textsubscript{4} measurements from Sarawak, Malaysia (Table 1) (Melling et al., 2005) in year 2002 were used to make calibration for the wetland dominated by the woody plants. The calibration was done by running CH4MOD\textsubscript{wetland} for the observation period driven with the local climate, soil and vegetation data at each site. By setting the increment of 0.1 for \(VI\) and \(P_{\text{at}}\), the model was run for all combinations of \(VI\) within the range of 0.5-3.0 and \(P_{\text{at}}\) within the range of 0.1-1 until the root-mean-square error (RMSE) between the daily simulated and observed CH\textsubscript{4} fluxes was minimized. After setting \(VI\) and \(P_{\text{at}}\), the empirical constant of the salinity influence (\(\alpha\)) is calibrated as -0.025 by minimizing the RMSE between observed fluxes and simulated fluxes at the coastal wetland in Chongming island, China in year 1997 (Li et al., 2016). Table 2 shows the main parameter values for different wetland types. Site-level parameters were extrapolated to the 0.5°×0.5° pixel of the global natural wetland map.

Supplementary material S2 Model calibration of TEM

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In this study, the vegetation and soil data sets were used to assign vegetation- and soil-specific parameters to each grid cell globally. The methane emission in wetland simulated in TEM was mainly
controlled by the following parameters, which include the ecosystem-specific maximum potential \( \text{CH}_4 \) production rate \( (M_{\text{go}}) \), the dynamic \( Q_{10} \) coefficient indicating the dependency of \( \text{CH}_4 \) production to soil temperature \( (D_{Q_{10}}) \), the reference temperature used in the \( Q_{10} \) function for simulating the effects of soil temperature on methanogenesis \( (T_{\text{REF}}) \), and maximum daily NPP for a particular ecosystem \( (\text{MaxFresh}) \). These parameters are calibrated using the \( \text{CH}_4 \) measurements from 5 sites (Table 1). \( \text{CH}_4 \) measurements from Toolik Lake, USA in year of 1992 and 1993 (Schimel et al., 1994; 1995), from Saskatchewan, Canada, in year of 1995 (Sellers et al., 1997), from the Sanjiang Plain, China in year 2002 (Hao, 2006; Song et al., 2009; Yang et al., 2006), from Sarawak, Malaysia (Melling et al., 2005) in year 2002, from the coastal wetland in Chongming island, China in year 1997 (Li et al., 2016) was used to calibrate parameters for tundra, peatland, marsh, swamp and coastal wetland. We used the Monte-carlo approach to calibrate parameters for each wetland type (Zhuang et al., 2004). Specifically, the intervals of each parameter were firstly determined according to the former studies (Lu and Zhuang, 2012; Zhu et al., 2013; Zhuang et al., 2004). Then, the parameters were randomly sampled within the intervals based on uniform distribution. Consequently, the \( \text{CH}_4 \) emission simulated by TEM with these parameters was compared with the observed by using the coefficient of determination and RMSE. These steps were repeated 5000 times to obtain the set of optimized parameters which made the model simulation closest to the observation. (Table S2 described the main parameter values of TEM model)

**Supplementary material S3: Equations used to calculate the statistics**

The RMSE was used to measure the coincidence between the measured and the modeled values.

The RMD was calculated to evaluate the model for any systematic bias (Brisson et al., 2002). A positive EF value indicates that the simulated values describe the trend in the measured data better than the mean of the observations, while a negative value indicates that the simulated values describe the data less well than the mean of the observations (Smith et al., 1997) The CD is a measure of the proportion of the total variance in the observed data that is explained by the predicted data (Smith et al., 1997).

We first calculated RMSE as follows:

\[
\text{RMSE} = \frac{100}{\delta} \sqrt{\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2}
\]  

(1)
where $\bar{O}$ represents the average value of the observations. $P_i$ and $O_i$ represent the simulated and observed values, respectively. $n$ represents the number of observations.

We then decomposed the RMSE into three components:

$$\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2 = (\bar{P} - \bar{O})^2 + (S_P - rS_O)^2 + (1 - r^2)S_O^2$$

(2)

where $\bar{P}$ is the mean modeled value, and

$$S_P^2 = \frac{1}{n} \sum_{i=1}^{n} (P_i - \bar{P})^2$$

(3)

$$S_O^2 = \frac{1}{n} \sum_{i=1}^{n} (O_i - \bar{O})^2$$

(4)

$$r = \frac{\sum_{i=1}^{n} (P_i - \bar{P})(O_i - \bar{O})}{\left( \sum_{i=1}^{n} (P_i - \bar{P})^2 \sum_{i=1}^{n} (O_i - \bar{O})^2 \right)^{1/2}}$$

(5)

The first component, $(\bar{P} - \bar{O})^2$, measures the bias in the simulation procedure. In this study, if the simulation consistently overestimates or underestimates the CH$_4$ fluxes, this component will have a large value. If the value of the second component, $(S_P - rS_O)^2$, is zero, the regression between the simulated and observed CH$_4$ fluxes has a slope of 1. This component often occurs in subjective forms of simulation where the simulations are biased upward if the observed CH$_4$ fluxes are low but are biased downward when the observed CH$_4$ fluxes are high. The third component, $(1 - r^2)S_O^2$, can be considered to be a measure of the error due to random disturbances.

Finally, we normalized the above components by dividing each component by $\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2$.

The ultimate proportions of the errors were thus defined as:

$$U_M = \frac{(\bar{P} - \bar{O})^2}{\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2}$$

(6)

$$U_R = \frac{(S_P - rS_O)^2}{\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2}$$

(7)

$$U_E = \frac{(1 - r^2)S_O^2}{\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2}$$

(8)

And hence

$$U_M + U_R + U_E = 1$$

(9)
RMD, EF and CD were calculated as follows:

\[ RMD = \frac{100}{n} \sum_{i=1}^{n} \frac{P_i - \bar{O}_i}{\bar{O}_i} \]  

(10)

\[ EF = 1 - \frac{\sum_{i=1}^{n} (P_i - \bar{O}_i)^2}{\sum_{i=1}^{n} (\bar{O} - \bar{O}_i)^2} \]  

(11)

\[ CD = \frac{\sum_{i=1}^{n} (O_i - \bar{O})^2}{\sum_{i=1}^{n} (P_i - \bar{O})^2} \]  

(12)

**Supplementary material S4 Spatial pattern of annual mean CH$_4$ fluxes**

The simulated latitudinal contributions of CH$_4$ fluxes were consistent between the two models (Fig. 5a and 5b). Large fluxes were modeled in tropical regions. CH4MOD wetland simulated a peak flux of 30.18 g m$^{-2}$ yr$^{-1}$ in the 10°S–0° latitudinal band, followed by fluxes over 20 g m$^{-2}$ yr$^{-1}$ in the 20°–10°S latitudinal band and 0°–20°N latitudinal band (Fig. 5a). A peak flux of 30.61 g m$^{-2}$ yr$^{-1}$ was simulated in the 0°–10°N latitudinal band, followed by fluxes over 20 g m$^{-2}$ yr$^{-1}$ in the 20°S–0° latitudinal band and 10°–20°N latitudinal band (Fig. 5b). Lower fluxes under 15 g m$^{-2}$ yr$^{-1}$ were modeled in the 40°–80°N latitudinal band by CH4MOD wetland and in the 50°N–80°N latitudinal band by the TEM (Fig. 5a and 5b).

The simulation of meridional annual mean CH$_4$ fluxes showed the largest peak at approximately 60°–80°W and a secondary large peak at approximately 20°–30°E (Fig. 5a and 5b).
| ID | Annual mean temperature (℃) | Annual Precipitation (mm) | Water table depth (cm) | Salinity | CH₄ emissions (g m⁻² yr⁻¹) | Measurement method | Reference |
|----|-----------------------------|---------------------------|------------------------|----------|-----------------------------|------------------|-----------|
| 1  | -13.6                       | 319                       | -10.0                  | --       | 2.64, 3.15                  | Chamber & EC     | Wille et al., 2008; Wagner et al., 2003 |
| 2  | -13.4                       | 200                       | No data                | --       | 1.26                        | Chamber          | Nakano et al., 2000 |
| 3  | -12.4                       | 200                       | 11.8                   | --       | 8.40                        | Chamber          | Nakano et al., 2000 |
| 4  | -10.5                       | 220                       | 2.0–15.0               | --       | 2.63, 2.27, 1.42            | EC               | Parmentier et al., 2011 |
| 5  | -10.3                       | 223                       | -45.0–4.0              | --       | 9.55, 6.70, 9.07            | Chamber          | Christensen et al., 2000; Joabsson and Christensen, 2001 |
| 6  | -0.2                        | 263                       | -35.0–3.0              | --       | 0.45                        | Chamber          | Svensson et al., 1999 |
| 7  | -2.2                        | 397                       | -3.6–7.0               | --       | 5.50                        | EC               | Aurela et al., 2002 |
| 8  | 2.3                         | 600                       | 5.3                    | --       | 28.10, 53.20, 55.00         | Chamber          | Song et al., 2008; Song et al., 2009 |
| 9  | 7.3                         | 650                       | 0.9                    | --       | 11.65                       | Chamber          | Wang et al., 2002 |
| 10 | 17.7                        | 188                       | 46.0                   | --       | 63.30                       | Chamber          | Kang et al., 2016; Duan et al., 2005 |
| 11 | 12.3                        | 490                       | 14.3                   | --       | 15.20                       | Chamber          | Song et al., 2015; Hirotta et al., 2004 |
| 12 | 12.7                        | 625                       | 27.0                   | --       | 30.20                       | Chamber          | Huang et al., 2011 |
| 13 | 10.9                        | 625                       | 18.0                   | 7.2      | 3.81                        | Chamber          | Huang et al., 2005 |
| 14 | 18.1                        | 1004                      | 7.0                    | 6.9      | 6.52, 8.29, 5.05            | Chamber          | Gao et al., 2010; Li et al., 2014 |
| 15 | 22.8                        | 1582                      | 15.7                   | 12.5     | 25.37                       | Chamber          | Kang et al., 2008 |
| 16 | 24.5                        | 1670                      | 0.0                    | 15.2     | 0.91                        | Chamber          | Ye et al., 2000 |
| 17 | 27.4                        | 2015                      | -44.0                  | --       | 0.01                        | Chamber          | Melling et al., 2005 |
| 18 | 25.5                        | 2528                      | -80.0–20.0             | --       | 1.36                        | Chamber          | Jauhiainen et al., 2005 |
| 19 | 20                          | 1500                      | -20.0–40.0             | --       | 32.00                       | Chamber          | Coyne et al., 2005; Tathy et al., 1992 |
| 20 | 20                          | 1500                      | -20.0–40.0             | --       | 16.00                       | Chamber          | Tathy et al., 1992; Coyne et al., 2005 |
| 21 | No data                     | No data                   | No data                | --       | 49.00                       | Chamber          | Alvalá and Kirchhoff, 2000; Melack et al., 2004 |
| 22 | No data                     | No data                   | No data                | --       | 69.00                       | Chamber          | Crill et al., 1988 |
| 23 | No data                     | No data                   | No data                | --       | 40.00                       | Chamber          | Devol et al., 1988 |
| 24 | No data                     | No data                   | 0.0–130.0              | --       | 29.20                       | Chamber          | Belger et al., 2011 |
| 25 | -1.4                        | 406                       | No data                | --       | 3.70                        | Chamber          | Bartlett et al., 1992 |
| 26 | -1.4                        | 406                       | No data                | --       | 0.49                        | EC               | Fan et al., 1992 |
|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
|   |   |   |   |   |   |   |
| 27 | No data | No data | No data | -- | 11.20 | Chamber | Sebacher et al., 1986 |
| 28 | No data | No data | -10.0 – 15.0 | -- | 3.50, 5.10, 4.80 | Chamber | Whalen and Reeburgh, 1992 |
| 29 | 12.8° | 3240° | No data | -- | 21.70 | EC | Suyker et al., 1996; Sellers et al., 1997 |
| 30 | No data | No data | No data | -- | 37.00, 37.00, 55.00 | Chamber | Shannon et al., 1996 |
| 31 | 15.1° | 126° | No data | -- | 3.35 | Chamber | Christensen, 1993; Schimel et al., 1994; 1995 |
| 32 | 10.8κ | 479κ | -35.0 – 100.0 | -- | 4.57 | Chamber | Moore et al., 1994 |
| 33 | No data | No data | -80.0 – 20.0 | -- | 7.18 | Chamber | Moore et al., 1990 |
| 34 | No data | No data | 4.0 – 25.0 | -- | 47.7, 38.8 | Chamber | Koh et al., 2009 |
| 35 | 15.1 | 335 | -80.0 – -50.0 | -- | 4.4 | EC | Hatala et al., 2012 |
| 36 | 3.7 | 584 | -14.0 – -24.0 | -- | 15.73, 16.00 | EC | Olson et al., 2013 |
| 37 | 6.0 ± 0.8 | 943 | -65.0 – -28.0 | -- | 8.00 | EC | Moore et al., 2011 |
| 38 | No data | No data | 15.0 – 20.0 | -- | 3.24 | EC | Harazono et al., 2006 |
| 39 | No data | No data | No data | -- | 8.10 | EC | Harazono et al., 2006 |
| 40 | 3.0 | 344 | -15.0 – 20.0 | -- | 13.04, 9.26, 12.13 | EC | Hanis et al., 2013 |
| 41 | No data | No data | -13.0 – 10.0 | -- | 1.48 | EC | Zona et al., 2009 |
| 42 | 2.1 | 504 | -62.0 – -38.0 | -- | 3.20 | EC | Long et al., 2010 |
| 43 | 16.6 | 1330 | -50 – 60.0 | -- | 3.47 | EC | Morse et al., 2012 |

* May to October
° Summer period
κ June to October
| Parameter   | Description                                                                 | A   | B   | C   | References                                      |
|-------------|------------------------------------------------------------------------------|-----|-----|-----|------------------------------------------------|
| VI          | Vegetation index                                                            | 2.4 | 1   | 1   | This study                                      |
| $T_{veg}$   | The fraction of plant mediated transport was available                       | 1   | 1   | 0.1 | Walter and Heimann, 2000                       |
| $P_{ox}$    | The fraction of CH$_4$ oxidized during plant mediated transport              | 0.5 | 0.9 | 0.9 | This study                                      |
| $f_{c}$     | Proportion of below-ground NPP to the total NPP                             | 0.5 | 0.5 | 0.45| Gill and Jackson, 2000; White et al., 2002      |
| $F_{N\_shoot}$ | Fraction of nonstructural component in above-ground litter                   | 0.8 | 0.8 | 0.3 | White et al., 2002; Gordon and Jackson., 2003 |
| $F_{N\_root}$ | Fraction of nonstructural component in below-ground litter                   | 0.5 | 0.5 | 0.2 | White et al., 2002                             |

A for the wetland dominated by herbaceous plant calibrated by CH$_4$ measurements from the Sanjiang plain, China, year 2002.
B for the wetland dominated by herbaceous plant with high productivity (annual aboveground biomass $>1000$ g m$^{-2}$ yr$^{-1}$), calibrated by CH$_4$ measurements from the Wuliangsu lake, China.
C for the wetland dominated by woody plant, calibrated by CH$_4$ measurements from Sarawak, Malaysia.
| Parameter | Description | Prior interval | Optimized value | Unit |
|-----------|-------------|----------------|-----------------|------|
| MGO       | Maximum potential CH₄ production rate | [0, 2]          | 1.45 1.03 0.8 0.10 0.48 | μmol L⁻¹ h⁻¹ |
| DQ₁₀      | Dependency of CH₄ production on soil temperature | [1, 6]          | 1.11 1.07 2.82 1.60 1.45 | unitless |
| TREF      | Reference temperature in Q₁₀ function | [-6, 2]         | -3.13 1.98 1.55 0.72 -3.41 | °C |
| MaxFresh  | Maximum daily NPP for a particular ecosystem | [2, 20]         | 12.03 8.70 8.83 4.97 11.73 | g C m⁻² day⁻¹ |
Fig. S1 Simulated seasonal patterns of CH₄ emissions by CH4MOD_wetland (a) and TEM (b) based on the average monthly CH₄ emissions from 2000–2010.
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