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*Supplement of*

# Impacts of climate and reclamation on temporal variations in $CH_4$ emissions from different wetlands in China: from 1950 to 2010

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**Supplementary materials for manuscript entitled**: Impacts of climate and reclamation on temporal variations in $CH_4$ emissions from different wetlands in China: From 1950 to 2010.

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**Supplementary material S1: Estimate $CH_4$ emissions from lakes and rivers**

In this paper, we totally followed Chen's method (Chen *et al.*, 2013) to calculate regional $CH_4$ emissions from lakes and rivers across China. Lakes can be found in five major regions in China: the plains of eastern China, the Qinghai-Tibetan Plateau, the Yunnan-Guizhou Plateau, the Mongolia-Xinjiang Plateau, and the Northeast China Plain (Wang & Dou, 1998). The followed equation was used to calculate regional $CH_4$ emissions from lakes:

$$CH4_{regional} = \sum_i \sum_j \sum_k f_{ijk} \times A_{ijk} \times D_{ijk} \quad \text{(S1.1)}$$

Where $i$ is the lake region, $j$ is the growing season and non-growing season (between the different regions), and $k$ is the different zones (pelagic zone and/or littoral zone). $f_{ijk}$ is the seasonal mean $CH_4$ fluxes under conditions of $i$, $j$, and $k$ (listed in Table S1). $A_{ijk}$ is the lakes' area, and $D_{ijk}$ is the duration of the growing and non-growing season or the unfrozen season. $CH4_{regional}$ is the regional $CH_4$ emissions from lakes.

The average area-weighted $CH_4$ flux was calculated as followed:

$$CH4_{flux} = \frac{CH4_{regional}}{\sum_i \sum_j \sum_k A_{ijk}} \quad \text{(S1.2)}$$

Uncertainties of the estimation were come from the fraction of the littoral zones of the lakes, which was assumed at 5% to 12% for all lakes in China based on a preliminary estimate (Chen *et al.*, 2009). More details about this method please see Chen *et al.* (2013).

When used [Eqn. (S1.1)] to calculate regional $CH_4$ emissions from rivers, $f_{ijk}$ is assumed to equal to the value in the pelagic zone, since no available data present.

Table S1 Measurements of $CH_4$ fluxes from lakes in China, from Chen *et al.* (2013).

| Location | Zones | $CH_4$ flux (mg $m^{-2}$ $h^{-1}$) | Sampling season | References |
|---|---|---|---|---|
| | | Eastern Plain | | |
| Lake Donghu | Pelagic zone | 0.97±0.78 | Apr. 2003 to Mar. 2004 | Xing *et al.*, 2005 |
| Lake Taihu | Littoral zone[a] | 0.4±0.9 | Aug. 2003 to Aug.2004 | Wang *et al.*, 2006 |
| | Littoral zone[b] | 10±23.0 | Aug. 2003 to Aug.2004 | |
| | Pelagic zone | 0.5 ±1.9 | Aug. 2003 to Aug.2004 | |
| Lake Boyang | Pelagic zone | 0.82±0.22 | Dec. 2004 to Jan.2005 | Chen *et al.*, 2007 |
| Lake Dongting | Pelagic zone | 0.2±0.64 | Dec. 2004 to Jan.2005 | Chen *et al.*, 2007 |
| Lake Caohu | Pelagic zone | 0.021 ±0.012 | Dec. 2004 to Jan.2005 | Chen *et al.*, 2007 |
| Lake Nansihu | Pelagic zone | 0.034 ±0.020 | Dec. 2004 to Jan.2005 | Chen *et al.*, 2007 |
| Lake Hongzehu | Pelagic zone | 0.019 ±0.010 | Dec. 2004 to Jan.2005 | Chen *et al.*, 2007 |
| Three Gorges Reservoir Region | Littoral zone | 6.7 ±13.3 | Jul. to Sep.,2008 | Chen *et al.*, 2009a |
| | Pelagic zone | 0.26 ±0.38 | Jan. to Dec., 2009 | Chen *et al.*, 2011 |
| | Littoral zone | 0.22 ±0.26 | the inundated season | Yang *et al.*, 2012 |
| | | Qinghai-Tibet Plateau | | |
| Lake Huahu | Littoral zone | 15.1 | Jun. to Aug. 2006 and 2007 | Chen *et al.*, 2009b |
| | | Mongolia-Xinjiang Plateau | | |
| Lake Wuliangsu | Littoral zone[b] | 15.28 | Apr. to Oct.2003 | Duan *et al.*, 2005 |
| | Littoral zone[c] | 2.16 | Apr. to Oct.2003 | |
| | | Yunnan-Guizhou Plateau | | |
| Lake Fuxianhu | Pelagic zone | 0.012 ±0.029 | Dec. 2004 to Jan.2005 | Chen *et al.*, 2007 |
| Lake Erhai | Pelagic zone | 0.044 ±0.15 | Dec. 2004 to Jan.2005 | Chen *et al.*, 2007 |
| Lake Dianchi | Pelagic zone | 0.16±0.035 | Dec. 2004 to Jan.2005 | Chen *et al.*, 2007 |
| | | Taiwan Island | | |
| 10 lakes on plateau | Pelagic zone | 0.07 ±0.06 | NS | Wang *et al.*, 1998 |
| 26 lakes on plain | Pelagic zone | 0.11 ±0.19 | NS | Wang *et al.*, 1998 |

[a] Bare littoral zone; [b]Emergent plant zone; [c]Submerged plant zone; NS, not specified.

**Supplementary material S2: Model description, modification and validation**

## S2.1 Description and modification of $CH4MOD_{wetland}$

$CH4MOD_{wetland}$ is a biogeophysical model that aims to simulate $CH_4$ production, oxidation and emission from natural wetlands (Li *et al*., 2010). The model adopted the hypothesis of CH4MOD model (Huang *et al*., 1998, 2004, 2006; Zhang *et al*., 2011), and made modifications based on the supply of methanogenic substrates in natural wetlands that differs significantly from that in rice paddies. Model inputs include daily soil temperature, water table depth, the annual above-ground net primary productivity (*ANPP*) and soil texture. The outputs are daily and annual $CH_4$ production and emissions. In principle, $CH4MOD_{wetland}$ is possible to simulate $CH_4$ emissions from several kinds of natural wetlands, since it was validated against independent field measurements of $CH_4$ fluxes from different wetland sites across China, Canada and USA (Li *et al*., 2010). More details about $CH4MOD_{wetland}$ are well documented in the previous studies (Li *et al*., 2010; 2012).

In $CH4MOD_{wetland}$, the environmental factors that influence $CH_4$ production and emission in natural wetlands include soil temperature, soil texture and soil redox potential. Previous studies (Atkinson & Hall, 1976; King & Wiebe, 1978; Bartlett *et al*., 1985; 1987; Magenheimer *et al*., 1996) indicate that methane emissions from various coastal salt marshes in the temperate zones vary with salinity. In order to provide the capability of simulating methane emissions from coastal wetland, we adopted the relationship between salinity and methane fluxes according to Poffenbarger *et al*. (2011).

$$f(s) = 10^{a \times s} \quad \text{(S2.1)}$$

where *f(s)* represents the effect of salinity on $CH_4$ production. *s* is the salinity (psu, practical salinity unit). *a* is an empirical constant.

## S2.2 Description of TOPMODEL for simulating water table depth

Following previous research (Bohn *et al*., 2007; Kleinen *et al*., 2012; Lu & Zhuang *et al*., 2012; Zhu *et al*., 2013), this study is based on the topographic wetness index (TWI) $ki = \ln(\alpha_i / \tan\beta_i)$ to represent the spatially distributed water table depth for a 1 km sub-grid within a grid of 0.5°, where $\alpha_i$ is the upslope contributing area above point $i$, $\tan\beta_i$ is the local surface slope at that point. The central equation of TOPMODEL is

$$zi = z - m \times (ki - \lambda) \quad \text{(S2.2)}$$

where $zi$ is the local water table depth in a 1 km pixel, $z$ is the average water table depth in the 0.5° grid, $m$ is the scaling parameter, $ki$ is the local topographic wetness index (TWI) in the 1 km pixel, $\lambda$ is the average of $ki$ over the 0.5° grid cell. The value of $z$ is calculated by the soil moisture content in a 0.5° grid cell. More details about calculating the average water table depth please see the previous study (Letts, *et al.*, 2000; Lu & Zhuang *et al*., 2012). For the scaling parameter $m$, we followed Kleinen *et al*. (2012) that it described the capability of transmissivity with depth for each soil type, and was classified by the soil texture.

After acquiring the local water table depth ($zi$) for each 1 km pixel, we used an approach of (Zhu *et al.*, 2013). The water table depth $z_{wet}$ of wetland in a 0.5° grid cell is calculated as

$$z_{wet} = \frac{\sum_{i=1}^{i=n} z_i}{n} \qquad \text{(S2.3)}$$

where $n$ is the number of 1 km wetland pixels within each 0.5° grid cell, and the value of $n$ is derived from the GLWD-3 data set, within each grid cell.

**S2.3 Model validation**

Two simulations were made to test the model performance at the site scale and the grid scale. To begin with, we used the site-specific measurements of air temperature, soil temperature, water table depth, aboveground net primary productivity (ANPP) and the observed plant phenology to drive $CH4MOD_{wetland}$ to simulate site-specific daily $CH_4$ fluxes at each site (Table S2). We compared these daily simulated $CH_4$ fluxes with the measurements. Fig S1 (a, b, d, e, g, i and k) and Fig S2a shows the comparisons of the seasonal variations and the monthly amount between the modeled and observed $CH_4$ fluxes.

Moreover, in order to test the performance of the integrated model framework ($CH4MOD_{wetland}$/TEM/TOPMODEL) (Fig. 1) at the grid level, we also compared the observed monthly $CH_4$ fluxes in the wetland sites (Table S2) and the simulated monthly $CH_4$ fluxes at the 0.5°×0.5° grid. We used the gridded data of climate, soil and vegetation to drive the integrated model framework (Fig. 1) on a monthly step. Field measurements in the wetland show that there are large uncertainties in the ANPP, standing water depth and the plant phenology. For example, in the Sanjiang Plain, the range of ANPP ranges from 422 to 530 g $m^{-2}$ (Hao, 2006; Li *et al.*, 2012); The average standing water depth during the growing season ranges from 1 to 10 cm (Song *et al.*, 2007); The mature period of the plant ranges from mid-July to mid-August (Hao, 2006). We made 8 sensitivity experiments with differing ANPP, standing water depth and the plant mature period. The range of input ANPP, standing water depth and the plant mature period are from the observed data at each wetland sites (Table S3). Variations of half the range in ANPP, standing water depth and the plant mature period on the basis input data were used as the maximum and minimum values of the input. Error bars in Fig. S1 (c, f, h, j, l) and Fig. S2b are determined by the sensitivity experiments.

Table S2 Site description

| Site name | Location | Wetland type | Plant speices | Experiment period | References |
|---|---|---|---|---|---|
| Sanjiang Plain (SJ) | 47°35′ N,133°31′E | marsh | *Carex & Deyeuxia* | 2003-2005 | Hao (2006);<br>Song *et al*., (2007) |
| Ruoergai Plateau (REG) | 32°47′N,102°32′E | peatland | *Carex* | 2001 | Ding *et al*., (2004) |
| Haibei alpine marsh (HB) | 37°29′N,101°12′E | marsh | *Carex* | 2002 | Hirota *et al*., (2004) |
| Zhalong wetland (ZL) | 46°52′N -47°32′N,<br>123°47′E- 124°37′E | floodplain | *Phragmites* | 2009 | Huang *et al*., (2011) |
| Wuliangsu lake (WLS) | 40°47′ -41°03′ N,<br>108°43′-108°57′ E | floodplain | *Phragmites* | 2003 | Duan *et al*., (2005) |
| Liao river delta (LRD) | 40°40′-41°25′N,<br>121°35′- 122°55′E | coastal wetland | *Phragmites* | 1997 | Huang *et al*., (2005) |
| Chonging island (CMI) | 31°00′ -31°30′ N,<br>121°00′ -122°00′ E | coastal wetland | *Scirpus* | 2004 | Yang *et al*., (2007) |

Table S3 Site-specific parameters and model inputs of $CH4MOD_{wetland}$

| Parameters and inputs | Description | Value | | | | | | | Unit |
|---|---|---|---|---|---|---|---|---|---|
| | | SJ | REG | HB | ZL | WLS | LRD | CMI | |
| VI* | Vegetation index | 2.4[a)1], 2.8[b)1] | 2.4[1] | 2.4[1] | 1[1] | 1[1] | 1[1] | 1[1] | dimensionless |
| ANPP^ | Aboveground net primary productivity | 485[a)2], 450[b)2] | 340[c)3], 290[d)3] | 380[4] | 1200[5] | 1860[e)6], 2520[f)6] | 1200[5] | 692[7] | $g\ m^{-2}\ yr^{-1}$ |
| $f_{root}$* | Proportion of below-ground to the total production | 0.6 [a)8], 0.5 [b)8] | 0.6 [c)d)9] | 0.5[9] | 0.5[9] | 0.5[9] | 0.5[9] | 0.5[9] | dimensionless |
| $P_{ox}$* | The fraction of $CH_4$ oxidized during plant mediated transport | 0.5[1] | 0.5[1] | 0.5[1] | 0.9[1] | 0.9[1] | 0.9[1] | 0.9[1] | dimensionless |
| $T_{veg}$* | The fraction of plant mediated transport was available | 1[1] | 1[1] | 1[1] | 1[1] | 1[1] | 1[1] | 1[1] | dimensionless |
| SAND^ | Soil sand fraction | 56.0[a)10,11] ,47.0[b) 10,11] | 66.0[10,11] | 80[12] | 47[12] | 80[12] | 30[12] | 65[12] | % |
| SOM^ | Concentration of soil organic matter | 70[a) 10,11] ,246[b) 10,11] | 520[10,11] | 146[13] | 222[13] | 133[13] | 103[13] | 212[13] | $g\ kg^{-1}$ |
| ρ ^ | Soil bulk density | 1.00[a) 10,11] ,0.74[b) 10,11] | 0.75[10,11] | 1.73[13] | 1.40[13] | 1.52[13] | 0.9[13] | 1.55[13] | $g\ cm^{-3}$ |

a) For *Carex lasiocarpa* site; b) For *Deyeuxia angustifolia* site; c) For *Carex meyeriana* site; d) For *Carex muliensis* site; e) For *Phragmites australis* site1; f) For *Phragmites australis* site2; * Defined as model parameters; ^ Defined as model inputs.


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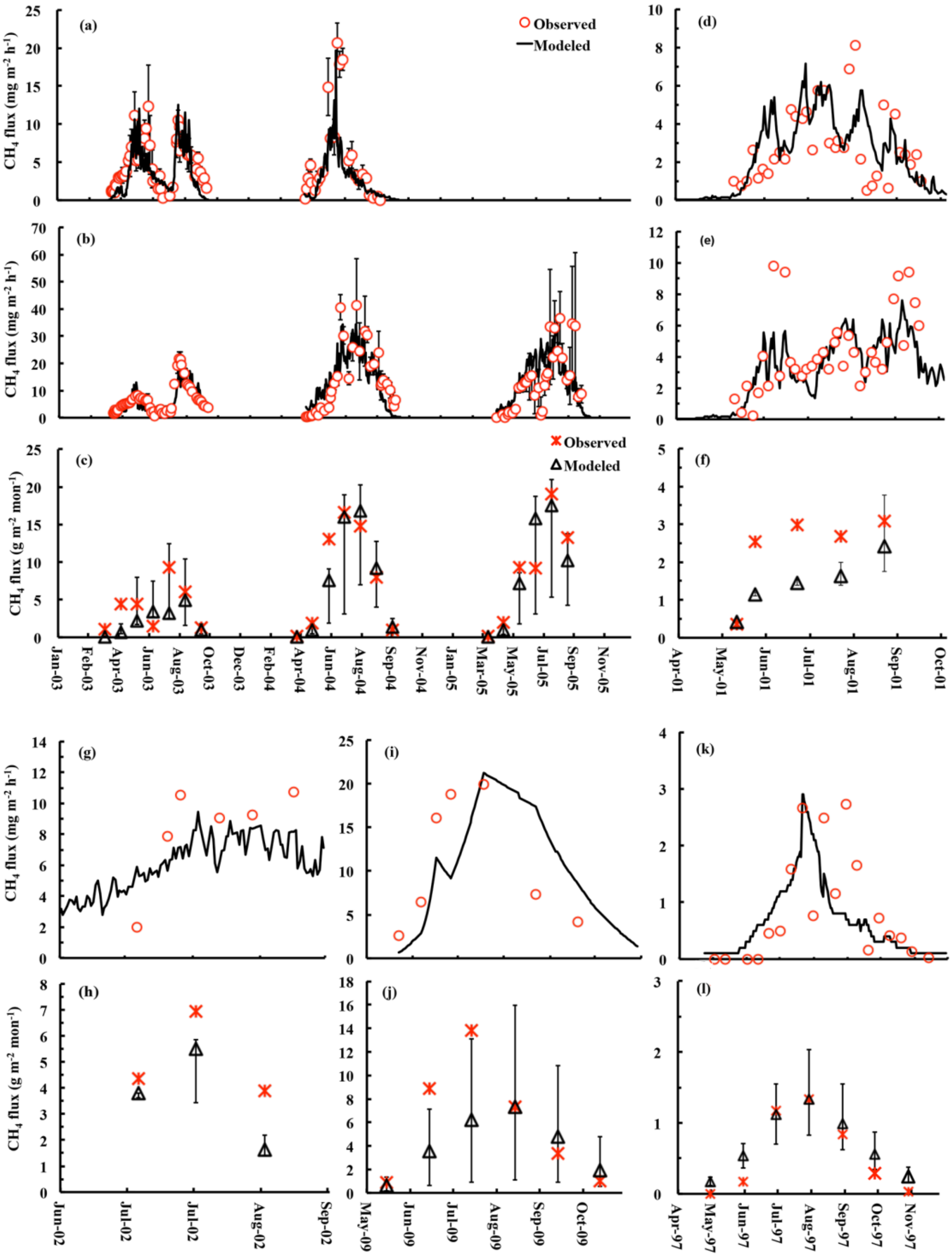


Fig. S1: Comparison of simulated and observed seasonal $CH_4$ variations. SJ: the "site-scale" validation (a, b), the "grid-scale" validation (c); REG: the "site-scale" validation (d, e), the "grid-scale" validation (f); HB: the "site-scale" validation (g), the "grid-scale" validation (h); ZL: the "site-scale" validation (i), the "grid-scale" validation (j); LRD: the "site-scale" validation (k), the "grid-scale" validation (l). Error bars in a and b are the standard errors from 3 sampling replicates. Error bars in c, f, h, j and l are the uncertainties from the heterogeneities of ANPP, standing water depth and the plant mature period in the grid.

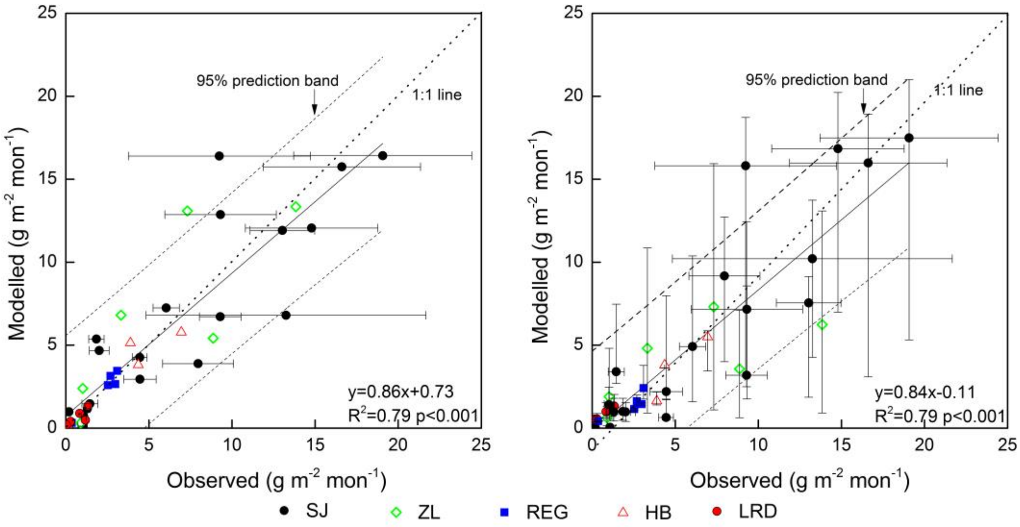


Fig. S2: Observed vs. simulated monthly $CH_4$ emissions from 5 wetland sites. (a) site-scale validation; (b) grid-scale validation. Dashed line is 1:1. The horizontal bars represent standard errors from 3 sampling replicates in SJ. The vertical bars are the uncertainties from the heterogeneities of ANPP, standing water depth and the plant mature period in the grid. For the wetland where two micro-sites locate (SJ and REG), the average observed/simulated values were used to represent the average $CH_4$ emissions at that site.

**Supplementary material S3: Division of the inland wetlands in China**

Chinese inland wetlands are divided to 5 regions (Fig. 2) (Lang & Zu, 1983). They are distributed unevenly and primarily occur in in northeastern China (30%) (Region I; Fig. 2) and the Qinghai Tibetan Plateau (50%) (Region II; Fig. 2) (Ding *et al*., 2004). Marshes (dominated by *Carex*, *Phragmites*, *Cyperus*, *Blymus*, and *Deyeuxia*) and the swamps (dominated by *Alnus* and *Larix*) are widely distributed in the northeast China. Peatlands (dominated by *Carex*, *Pedicularis*, and *Scirpus* species) are the mainly type in Qinghai Tibetan Plateau. In Region III (Fig. 2) (Inner Mongolia and northwestern China) and Region IV (Fig. 2) (North China plain and the Middle-Lower Yangtze Plain), marshes and floodplains dominated by *Phragmites australis* are the important landscape. Peatlands (dominated by *Carex and Sphagnum*) and marshes (dominated by *Phragmites australis*) are the main types in Region V (Fig. 2) (southern China).

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