Chapter 6
Methane Emissions from China's Natural Wetlands: Measurements, Temporal Variations and Influencing Factors

Xiaoke Wang, Fei Lu, and Le Yang

Abstract Natural wetlands received increased attention for their ecosystem services and high methane (CH_4) emissions. In China, the total area of wetlands is about 38 million ha (M ha), accounting for about 4% of the land. Natural wetlands include peatlands (35.6%), coastal wetlands (15.4%), rivers (21.3%), lakes (21.7%) and reservoirs (6.7%). Human activities and settlement development have drastically reduced wetland areas worldwide. A recent estimate showed that 33% were lost between 1978 and 2008, and land reclamation accounted for more than 70% of the total loss in China. Effects of human activities on wetlands in China were studied at 16 sites across the country, i.e., 6 peatlands, 3 coastal wetlands, 5 lakes and 2 reservoirs. The mean CH_4 emissions were 6.0 (range 1.0–15.6) mg CH_4 m^{-2} h^{-1} for peatlands, 1.6 (0.5–2.4) mg CH_4 m^{-2} h^{-1} for coastal wetlands, 3.1 (0.9–9.7) mg CH_4 m^{-2} h^{-1} for lakes and 0.2 (0.1–0.3) mg CH_4 m^{-2} h^{-1} for reservoir. The annual CH_4 emissions from natural wetlands in China was estimated to be 10.5 Tg CH_4 $year^{-1}$ (1 Tg = 10^{12} g), which accounted for 7.3% (145 Tg CH_4 $year^{-1}$) of the global emissions from wetlands and 171% (6.147 Tg CH_4 $year^{-1}$) of the CH_4 emission from rice paddies in China. The significant contribution of CH_4 emission from natural wetlands should be taken into account in national greenhouse gas inventory.

Keywords Methanogensis • Peatlands • El Nino • Labile organic carbon • Landsat thematic mapper • Greenhouse gases • Atmospheric carbon pool • Aquatic systems • Ethane emission • Natural wetland • Lake • Reservoir • China • Northeast Asia • Tibetan Plateau • Photosynthesis • Hydrophytes • Coastal wetlands • Meadows • Methane emissions • Temporal variations in CH_4 emission • Solar radiation • Hydrology • Water table • Vegetation

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Abbreviations

ATCM	Atmospheric Transport and Chemical Model
CCICED	China Council for International Cooperation on Environment and Development
ENSO	El Nino Southern Oscillation
GHG	greenhouse gas
LOC	labile organic organic
ETM+	Landsat Enhanced Thematic Mapper plus
TM	Landsat Thematic Mapper
NPP	net primary production
SFA	State Forestry Administration

6.1 Introduction

Methane (CH_4) is the second most important anthropogenic greenhouse gas (GHG) in terms of radiative forcing to global warming after carbon dioxide (CO_2). Although its residence time in the atmosphere is short (about 12 years), the ability of CH_4 to absorb infrared radiation makes it 20–30 times more efficient than CO_2 in trapping energy (Weaver 2011). CH_4 is also an important atmospheric constituent by influencing the cleansing capacity [concentration of hydroxyl radicals (OH)], and the formation of ozone (IPCC 2007). The global atmospheric CH_4 concentration has increased from a pre-industrial level of about 715–1,732 ppb in the early 1990s, and further to 1,774 ppb in 2005 (Zhuang et al. 2009). Growth rates have declined since the early 1990s, consistent with trends in CH_4 emissions (sum of anthropogenic and natural sources) being nearly constant during this period. It is very likely that the observed changes in CH_4 concentration are due to anthropogenic activities, predominantly agriculture and fossil fuel use, but relative contributions from different source types are not well determined (IPCC 2007). A recent estimate of annual global CH_4 emission was 582 Tg CH_4 year^{-1} (1 Tg = 10^{12} g, IPCC 2007), of which 70% was released from biogenic sources. These sources include wetlands, rice agriculture, livestock, landfills, forests, oceans and termites. Natural wetland has been proposed to be the single largest CH_4 source based on recent estimates combining bottom-up and top-down fluxes, and global observations of atmospheric CH_4 concentrations in a three dimensional Atmospheric Transport and Chemical Model (ATCM) simulation (Chen and Prinn 2005, 2006). Bastviken et al. (2011) compiled CH_4 emissions from 474 freshwater ecosystems including lakes, impoundments, and rivers and estimated CH_4 emissions to be 103 Tg CH_4 year^{-1} based on recent data on area and distribution of inland water bodies. Expressed as CO_2 equivalents (eq), this emission corresponds to 0.65 Pg CO_{2eq} year^{-1} (1 Pg = 10^{15} g) or 25% of the estimated land greenhouse gas (GHG) sink, assuming that 1 kg of CH_4 corresponds to 25 kg of CO_2 over a 100-year period (Bastviken et al. 2011).

Although most wetlands accumulate organic carbon (C) and are important sinks for atmospheric C, the high global warming potential of CH_4 makes wetlands net sources of GHGs. The mean CH_4 emission rates for wetlands are about 200 kg CH_4 ha^{-1} $year^{-1}$ (Mitra et al. 2005), which would mitigate a C sequestration of 1.5 Mg C ha^{-1} $year^{-1}$ (1 Mg = 10^6 g). This value is slightly higher, but in the same order of magnitude of what can be derived as average C sequestration (0.2–1.4 Mg C ha^{-1} $year^{-1}$ based on a global estimate by Wojick 1999). With the increasing number of field measurements and significant improvement of biogeochemical models, global and national CH_4 budgets have been improved significantly. However, the range is still large from 100 Tg CH_4 $year^{-1}$ (Wuebbles and Hayhoe 2002) to 231 Tg CH_4 $year^{-1}$ (Fletcher et al. 2004). A median was reported by Chen and Prinn (2006) with an estimate of 145 Tg CH_4 $year^{-1}$ emitted 1996–2001. With the increasing availability of regional and national CH_4 budgets, the uncertainties can be reduced significantly. For instance, CH_4 emissions were 9 Tg CH_4 $year^{-1}$ from wetlands in North America with an uncertainty greater than 100% (Bridgham et al. 2006), 5.2 Tg CH_4 $year^{-1}$ from European wetlands and water bodies (Saarnio et al. 2009), and 1.8 Tg CH_4 $year^{-1}$ from natural wetlands in China based on field measurements during 1995–2004 (Ding et al. 2004a).

With more field measurements conducted, the processes and factors controlling CH_4 emissions were investigated in detail. It has been recognized that the key processes are fermentation, methanogenesis, and sulfate, iron, and nitrate reduction in the anaerobic zone (Kayranli et al. 2010). The main factors controlling CH_4 emissions from wetlands are soil temperature (Christensen et al. 2003), water table depth (Moore et al. 1998), and the amount and quality of decomposable substrates (Christensen et al. 2003). However, the diverse combination of environmental factors and processes specific to sites make it difficult to predict CH_4 emission accurately. Although CH_4 emissions from wetlands can be estimated based on their areas and emission rates, in fact, wetland area and CH_4 emission rates are not easy to be determined for a country because of significant temporal and spatial variability.

Although available reviews (e.g., Kayranli et al. 2010) have analyzed the processes and factors influencing CH_4 emissions worldwide, few investigations carried out in China have been included because of the difficulty to access to those reports written in Chinese. In recent years, field measurements of CH_4 emissions from wetlands have been conducted covering different types and locations of wetlands. Considering that China is the largest global CO_2 emitter and most populous country with rapid economic development and significant changes in land use, it is required to review CH_4 emissions from wetlands in China. In this study, the area and CH_4 emission rates of wetlands in China were reviewed, and a national estimate of CH_4 emissions from wetlands was carried out based on the best data available.

6.2 Wetland Area and Changes in China

Wetland can be defined as an area of land whose soil is saturated with moisture either permanently or seasonally at the interface between terrestrial and aquatic systems (http://en.wikipedia.org/wiki/Wetland). Wetland areas may also be covered partially or completely by shallow pools of water. A boarder definition was given under the Ramsar International Wetland Conservation Treaty, i.e., wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water whose depth at low tide does not exceed 6 m. In China, more people prefer to the definition of wetlands made by the Ramsar Treaty, which includes swamps, peatlands as well as lakes and reservoirs (Niu et al. 2009). The rice paddy or other agricultural used wetlands are excluded.

There are different estimations of wetland area in China, ranging from about 26 to 66 million ha (M ha) (Zhang et al. 2008). In 2004, the State Forestry Administration (SFA) issued a report stating that the total area of wetlands individually larger than 100 ha is about 38 M ha which is about 4% of total land area. These estimations include natural and constructed wetlands. The later occupy about 3 M ha or 7.8% of total wetland area. Natural wetlands include coastal (5.9 M ha, 15.4%), riverine (8.2 M ha, 21.3%), lakes (8.4 M ha, 21.7%) and peatlands (13.7 M ha, 35.6%). The area of reservoirs is estimated to be 2.56 M ha, about 6.7% of total wetland area. A recent mapping of the China's wetlands using Landsat Enhanced Thematic Mapper plus (ETM+) data indicated that a total of 35.9 M ha wetlands are of non-agricultural use, of which 33.9 M ha are inland wetland, 0.28 M ha are non-agricultural artificial wetland, and 1.76 M ha are coastal wetland (Niu et al. 2011). The late estimate is similar to that by the SFA with a difference of only 13%. However, the area of coastal wetland surveyed by SFA is three times the area reported by Niu et al. (2009), because single-date remote sensing data cannot capture the land in the intertidal zone and its underwater part (Niu et al. 2009).

In China, peatlands are concentrated in the northeastern and southwestern regions. Sanjiang Plains and Zoige are the two largest peatlands. Other small peatlands are widely distribute in alpine regions such as Qiang-Tibet Plateau and in boreal regions such as Daxing'an and Xiaoxing'an Mountains. Coastal wetlands occur in eastern China along the Pacific Ocean with sandy and muddy beds, and rich vegetation in the northern part and rocky beds in the southern part. Lakes can be divided into five regions according to the differences in climate and topography, i.e., Eastern Plains, Inner Mongolia and Xinjiang Plateau, Yun-Gui Plateau, Qing-Tibet Plateau and Northeastern Plains (Liang et al. 1999). Reservoirs are generally smaller except some big dams, i.e., Three Gorge Reservoir, and are located mainly in southwestern China.

Human activity and settlement development have drastically reduced wetland area not only worldwide but also in China. It was reported that there were abundant wetlands in ancient China reaching 65.7 M ha in coverage. With the increasing demands for grains production, and industrial and residential uses, wetlands have been vanishing for a long period of time. In China, the most intensive wetland reclamation occurred in Ming and Qing Dynasties (1368–1911), and 1950–1990. After the foundation of the People's Republic China in 1949, wetland area in was drastically reduced. In Sanjiang Plains, northeastern China, where the largest peatlands are located, croplands have increased from about 78 M ha in 1949 to 366 M ha by a factor of 4.2, mostly conversion from peatlands (Zhao and Gao 2007).

Another report indicated that 1.36 Mha of wetlands disappeared on the Sanjiang Plain between 1950 and 2000 with a decrease in area from about 52% to 16% of the total area (Hou et al. 2006). In the middle and low reaches of the Yangtze River, the cover of lakes larger than 15 ha had decreased by 43.5% from 1950s to 1980s. Coastal wetland area decreased by 50% or 2 Mha (Zhao and Gao 2007). A recent report by the China Council for International Cooperation on Environment and Development (CCICED), a joint Chinese and international advisory board to the government, indicated that 57% of the country's coastal wetlands have disappeared since the 1950s, largely due to land reclamation (Qiu 2011).

A recent estimate indicated that 33% of wetland area was lost between 1978 and 2008, and land reclamation accounted for more than 70% of the loss (Niu et al. 2011). Based on Landsat Thematic Mapper (TM) images from 1987 to 1992, and (ETM+) images from 1999 to 2002, the wetland distribution in China was mapped between 1990 and 2000, respectively (Gong et al. 2010). In 1990, the total wetland area was 35.5 Mha whereas in 2000 it decreased to 30.5 Mha with a net loss of 5.0 Mha. During 10-year period, inland wetlands were reduced in cover from 31.8 to 25.8 Mha, coastal wetland area decreased from 1.4 to 1.2 Mha, but artificial wetland area increased from 2.3 to 3.5 Mha. The greatest natural wetland loss occurred in Heilongjiang, Inner Mongolia, and Jilin with a total loss of over 5.7 Mha. In western China, over 1.3 Mha of wetlands were created in Xinjiang, Tibet, and Qinghai. About 1.2 Mha of artificial wetlands were also created for fish farms and reservoir constructions.

6.3 Methane Emissions from China's Wetlands

Because of the large area covered by rice paddies in China, CH_4 emissions have been measured since the 1980s while measurements of emissions from natural wetlands or reservoirs began later. since the 1990s, CH_4 emissions from natural wetlands were measured in Sanjiang Plain in 1995 (Cui 1997) and in Tibet-Qinghai Plateau in 1996–1997 (Jin et al. 1999). Since then, additional measurements of CH_4 emissions were made. Review of the published literature showed that the measurements were carried out in at least 16 sites across the country, i.e., 6 peatlands, 3 coastal wetlands, 5 lakes and 2 reservoirs (Fig. 6.1). All measurements for at least one growing season were compiled in Table 6.1, except some measurement data measured for a short period that were designed for specific studies. For example, Duan et al. (2006) reported CH_4 emissions for 3 days to investigate their responses to hydrophyte photosynthesis. Hirota et al. (2005) measured CH_4 emission for two clear days to investigate their response to grazing in an alpine wetland on the Qinghai-Tibetan Plateau. Although there are large variations in CH_4 emission rate across sites (Fig. 6.2) depending on vegetation, and environmental conditions, it can be summarized that the mean CH_4 emissions were 6.0 (range 1.0–15.6) mg CH_4 m^{-2} h^{-1} for peatlands, 1.6 (0.5–2.4) mg CH_4 m^{-2} h^{-1} for coastal wetlands, 3.1 (0.9–9.7) mg CH_4 m^{-2} h^{-1} for lakes, and 0.2 (0.1–0.3) mg CH_4 m^{-2} h^{-1} for reservoirs (Table 6.1).

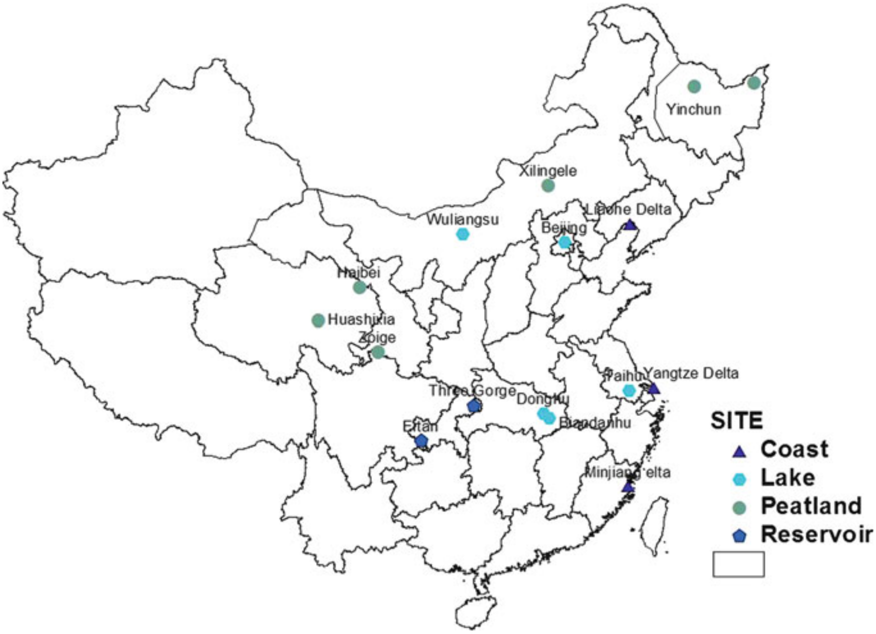

Fig. 6.1 The wetland CH_4 measurement sites in China

6.3.1 Peatlands

Although there is wide distribution of peatlands across China, large area of peatlands are concentrated in Sanjiang Plain, northeastern China and Qinghai-Tibetan Plateau, western China. In both regions, the climate is characterized by cold, long winters and short, cool summers with relatively high precipitation The annual mean air temperature and precipitation were 2.52°C and 558 mm in Sanjiang Plain (Song et al. 2009) and 1.7°C and 650 mm in Qinghai-Tibet Plateau (Chen et al. 2009), respectively. In summer, the relatively humid climate supports high plant productivity, which induces a large input of organic C to the soil. As the low temperatures and high soil moisture regimes are not favorable to decomposition, organic C accumulates in soils, and builds up large quantities of peat, which are prone to anaerobic CH_4 production. Since 1990s, the measurements of CH_4 emissions have begun in these two regions.

The Sanjiang Plain was probably the largest wetland in China. It covered 5.3 million ha in the early 1950s (Liu and Ma 2000). Unfortunately, wetland area shrunk very quickly with development of agriculture. CH_4 emissions were measured during the plant growing season typically from May through October over 1 or 2 years period (Cui 1997; Ding et al. 2004b; Hao et al. 2011; Yang et al. 2004, 2006a; Wang et al. 2006a; Zhang et al. 2007), and 4 years period (Song et al. 2009). High CH_4 emissions were reported during a short summer period (Cui 1997). In this study, the

Table 6.1 The field measurements of CH_4 from wetlands in China

Type	Location	Treatment	Period	Frequency	Mean	Reference
Peatland	Tongjiang	*Carex lasiocarpa*	July and Sept., 1995, May 1996	Twice a month	20.67	Cui (1997)
		Glyceria spiculosa			28.92	
		Carex schmidtii			13.19	
		Calamagrostis angustifolia			18.81	
		Phragmites communis			39.28	
		Carex lasiocarpa	2 years	Twice a week	19.60	Ding et al. (2004b).
		Carex lasiocarpa	May–Aug., 2001	Twice a week	17.30	
		Carex lasiocarpa	May–Aug., 2002	Twice a week	22.00	
		Carex lasiocarpa	Jun–Aug	3 consecutive days/month	20.06	Ding et al. (2004b)
		C. meyeriana	June–Aug.		17.60	
		Forest patch	June–Sept., 2003	1–weeks	0.05	Yang et al. (2004)
		Carex lasiocarpa	June–Sept., 2003	Once a week	10.80	Yang et al. (2006a)
		Carex pseudocuraica			11.40	
		Deyeuxia angustifolia			1.59	
		Carex lasiocarpa	2002–2005	2×/week, early May-late September	4.50	Song et al. (2009)
		Deyeuxia angustifolia			0.50	
		Shrub		1×/month, non-growing season	0.02	
		Corex lasiocarpa	Non-growing	Twice per week	2.43	Song et al. (2009)
			Growing		23.46	
			2002–2003		25.89	
			Non-growing		1.70	
			Growing		47.57	
			2003–2004		49.27	
			Non-growing		–0.17	
			Growing		43.20	
			2004–2005		43.03	
			Growing (2005–2006)		32.30	
			Annual mean		39.40	

(continued)

Table 6.1 (continued)

Type	Location	Treatment	Period	Frequency	Mean	Reference
		Deyeuxia angustifolia	Non-growing		0.39	
			Growing		6.09	
			2002–2003		6.45	
			Non-growing		0.18	
			Growing		5.65	
			2003–2004		5.82	
			Non-growing		−1.00	
			Growing		0.90	
			2004–2005		0.81	
			Growing (2005–2006)		0.00	
			Annual mean		4.36	
		Shrub	Non-growing		0.06	
			Growing		0.21	
			2002–2003		0.27	
			Non-growing		0.20	
			Growing		0.14	
			2003–2004		0.34	
			Non-growing		−0.04	
			Growing		0.06	
			2004–2005		0.02	
			Growing (2005–2006)		0.00	
			Annual mean		0.21	
		Corex Lasiocarpa	June–Oct., 2002		11.90	Hao et al. (2004)
		Deyeuxia angustifolia			8.50	
		Shrub			0.75	

Peatland	Haibei	*Kobresia tibetica*	June-Sept., 2003	Twice a week	1.10	Hu et al. (2005)
		Corex pamirensis			6.92	
		Corex Lasiocarpa	June-Oct., 2001		17.29	Wang et al. (2003)
	Haibei, Qinghai	*Potamogeton pectinatus*	July-Sept., 2002	2 weeks	1.38	
		Hippuris vulgaris			8.92	
		Scripus distigmaticus			4.57	
		Carex allivescers			8.19	Hirota et al. (2004)
	Zoige	*Carex muliensis*	May–Sept., 2001	Twice a week	2.87	Wang et al. 2002
		Carex meyeriana			4.51	
		Open fen on hills	June–Sept., 2006	Monthly	2.21	Chen et al. (2010a)
		Smooth littoral wetland			0.65	
		Steep riparian zone			0.00	
		Natural meadow			0.00	
		Steep littoral wetland			11.95	
		Mead			0.00	
	Huashixia	*Kobresia humulis*	July–Aug., 1996	Once a month	1.80	Jin et al. (1999)
		Batrachium trichophyllum			0.54	
		Hippuris vulgaris			–0.01	
		Kobresia tibetica			1.91	
		Kobresia humulis	Apr.–Sept., 1997		0.56	
		Batrachium trichophyllum			0.28	
		Hippuris vulgaris			2.47	
		Carex atrofusa			2.91	
	Yichun	*Alnus sibirica swamp*	June-Oct., 2007	10 days	0.64	Song et al. (2009)
		Betula platyphylla			0.03	
		Larix gmelinii-Carex schmidtii			–0.04	
		Larix gmelinii-moss			–0.04	
		Larix gmelinii-Sphagnum			2.34	

(continued)

Table 6.1 (continued)

Type	Location	Treatment	Period	Frequency	Mean	Reference
		Corex schmidtii	June–Oct., 2007		*1.85*	Song et al. (2009)
		Shrub			0.09	
		*Larix gmelinii*_10yr_R			0.01	
		*Larix gmelinii*_20yr			–0.07	
		*Larix gmelinii*_10yr_D			0.10	
		*Larix gmelinii*_20yr			0.06	
	Yichun	*Carex schmidtii*	June–Oct., 2007	10 days	1.88	Sun et al. (2009b)
	Xilingele	Hummock_upper site	July–Aug., 2003	4 days	5.51	Wang et al. (2005)
		Hollow_upper site			10.18	
		Hummock_middle site			4.53	
		Hollow_middle site			20.32	
		Hummock_lower site			1.18	
		Hollow_lower site			16.85	
		Drained			–0.08	
Coast	Minjiangkou	*Spartina alterniflora*			2.35	Tong et al. (2008)
	Liaohe Delta	*Phragmites australis*	Apr.–Nov., 1997	Monthly	0.52	Huang et al. (2001b)
	Changjiangkou	*Scirpus mattfeldianus*_M	May 2004–Apr. 2005	Monthly	2.06	Yang et al. (2007)
		*Scirpus mattfeldianus*_L			0.04	
Lakes	Wuliangsu	*Phragmites australis*-H	2003	2× month	17.93	Duan et al. (2007)
			2004		19.13	
		Phragmites australis-L	2003		12.67	
			2004		14.87	
		Potamogeton petinatus –H	2003		2.09	
			2004		4.26	
		Potamogeton petinatus-L	2003		2.32	
			2004		4.20	

	Donghu	I	Apr. 2003–May 2004	Monthly	1.12	Xing et al. (2005)
		II			0.88	
		III			1.14	
	Biandanhu	I	May 2003–Apr. 2004	Monthly	0.62	Xing et al. (2006)
		II			0.70	
		III			1.31	
	Taihu	Eulittoral	Aug. 2003–Aug. 2004	Once a week	2.60	Wang et al. (2006a)
		Pelagic			0.50	
		Infralittoral			0.40	
		Supralittoral			0.10	
	Beijing	Urban	2009	2× month	2.61	Ai et al. (2009)
Reservoir	Ertan	Open water	May 2008–Apr. 2009		0.12	Zheng et al. (2011)
	Three Gorge	Sandouping	2010	2× month	0.28	Yang et al. (2012)
		Zigui			0.12	
		Wushan			0.26	
		Yunyang			0.59	

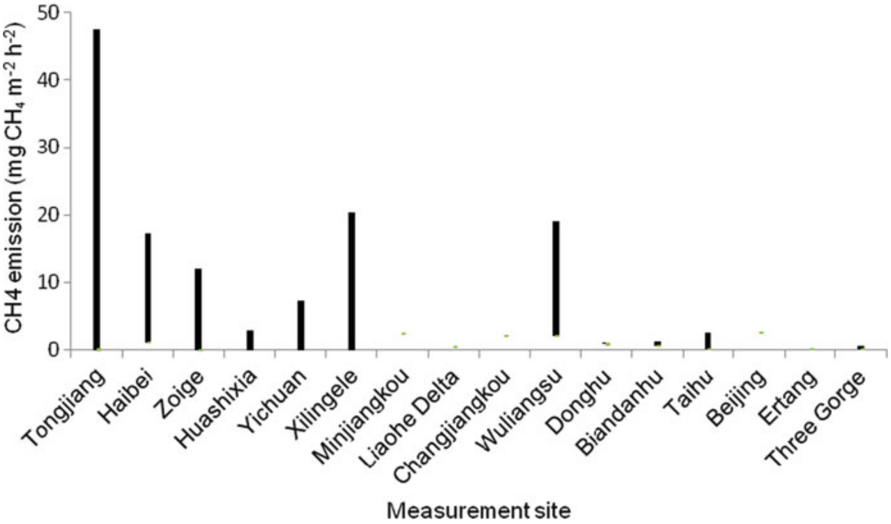

Fig. 6.2 The ranges of CH_4 emission from different wetland sites in China

effects of vegetation, cutting and water depth on CH_4 emission were assessed with a limited data. The 2-year mean emission was 19.6 ± 12.8 mg CH_4 m^{-2} h^{-1} from *Corex lasiocarpa* EHRH from May to August 2001 and 2002 (Ding et al. 2004b). The effects of plant species and cutting on CH_4 emission were also assessed (Ding et al. 2004c, 2005). Since 2002, Song et al. (2008, 2009) has monitored CH_4 emissions from three wetlands [permanently inundated wetland (PI), seasonally inundated wetland (SI) and shrub swamp (SS)] for a period of 4 years. The mean CH_4 emissions were 6.0 ± 1.0 mg CH_4 m^{-2} h^{-1} for PI, 0.7 ± 0.3 mg CH_4 m^{-2} h^{-1} for SI, and 0.03 ± 0.02 mg CH_4 m^{-2} h^{-1} for SS, respectively (Song et al. 2009). Substantial interannual variation of CH_4 fluxes were reported due to significant climatic variability. There was another study of CH_4 emissions carried out by Yang et al. (2004) from June to September 2003 in similar types of wetlands located 10.9 km from the measurement site of Song et al. (2009). The mean CH_4 emissions were 10.8, 11.4 and 1.6 mg CH_4 m^{-2} h^{-1} for *Corex lasiocarpa*, *C. pseudocuraica* and *Deyeuxia angustifolia* peatlands, respectively (Yang et al. 2006a). It is important to note that CH_4 fluxes from a forest patch within a peatland were also measured from June 1 to September 28 of 2003 in Sanjiang Plain, and were in the range of −0.03 to 0.04 mg CH_4 m^{-2} h^{-1} depending on the water level (Yang et al. 2004).

Large areas of peatland are located in Qinghai-Tibetan Plateau with an estimated total area of 13.3 Mha. Previous measurements conducted in a transect across four types of peatlands in Huashixia Permafrost region in 1996 and 1997 (Jin et al. 1999) indicated that CH_4 emissions were in the range of −0.01 to 1.91 mg CH_4 m^{-2} h^{-1} from July to August 1996, and 0.27–3.00 mg CH_4 m^{-2} h^{-1} from April to September 1997, respectively. In Haibei, CH_4 emissions were measured from June 30 to September 4, 2003, along a moisture gradient from 38.5% to 100% (v/v), and at

Potentilla fruticosa scrub meadow, *Kobresia humilis* meadow, *Koresia tibetica* meadow to seasonal wetland. The mean values varied from −0.03, −0.03, 1.10–6.92 mg CH_4 m^{-2} h^{-1}, respectively (Hu et al. 2005). In the same region, CH_4 emissions were measured in three emergent-plant zones, dominated by *Carex allivescers* (ZCar), *Scirpus distigmaticus* (ZSci), or *Hippuris vulgaris* (ZHip), and one submerged plant zone dominated by *Potamogeton pectinatus* (ZPot) along a gentle gradient of shallow to deep water. The smallest CH_4 fluxes were 0.5–2.8 mg CH_4 m^{-2} h^{-1} at ZPot. The highest were 4.4–12.3 mg CH_4 m^{-2} h^{-1} at ZHip. ZSci and ZCar had intermediate values from 1.1 to 6.5 mg CH_4 m^{-2} h^{-1} and 1.9 to 10.6 mg CH_4 m^{-2} h^{-1}, respectively (Hirota et al. 2004).

Zoige peatland, located at the eastern edge of Qinghai-Tibetan Plateau, is one of the largest peatlands in China with an area of about 0.4 Mha (Wang et al. 2002). From May to September 2001, CH_4 emissions were measured at two types of peatlands. One is a *Carex muliejsis* marsh and the other a *C. meyeriana* marsh. CH_4 emissions were 0.5–8.2 mg CH_4 m^{-2} h^{-1} with an average of 2.9 mg CH_4 m^{-2} h^{-1} from the *C. muliejsis* marsh and 0.4–10.0 mg CH_4 m^{-2} h^{-1} with an average of 4.5 mg CH_4 m^{-2} h^{-1} from *C. meyeriana* marsh, respectively (Wang et al. 2002). In 2005, a short-term (from mid-June to mid-August and mid-June to mid-September) measurement of CH_4 emissions at Zoige Plateau was conducted to assess the effects of vegetation on CH_4 emission (Chen et al. 2010a). The mean CH_4 emission was 2.5 mg CH_4 m^{-2} h^{-1}, with the highest emission rate of 12.0 mg CH_4 m^{-2} h^{-1} from steep littoral wetlands, and the lowest flux rate of −0.007 mg CH_4 m^{-2} h^{-1} in steep Riparian zones. Significant difference may occur among microsites even under the same vegetation, and water tables which are important factors controlling CH_4 emissions from peatlands (Chen et al. 2010a).

Although forest swamps are widely distributed in northeastern China including Daxing'an and Xiaoxing'an mountainous regions, CH_4 emissions were not measured until very recently. During June to October 2007, Sun et al. (2009a) measured CH_4 emission from different swamps in Yichun of Xiaoxing'an Mountains at 10 days interval. The CH_4 emissions during the growing season were 2.3 ± 8.4, 0.6 ± 0.6, 0.03 ± 0.04, −0.04 ± 0.07 and −0.04 ± 0.1 mg CH_4 m^{-2} h^{-1} for *Alnus sibirica* swamp, *Betula platyphylla* swamp, *Larix-Carex schmidtii* swamp, *L. gmelinii*-moss swamp and *L. -Sphagnum* spp. swamp, respectively. In their another report, Song et al. (2009) reported CH_4 emissions during the growing season from a marsh, a swamp, and 10- and 20-years—old plantations were 1.9 ± 2.3 mg CH_4 m^{-2} h^{-1}, 0.09 ± 0.09 g CH_4 m^{-2} h^{-1}, 0.01 ± 0.11 g CH_4 m^{-2} h^{-1} and −0.07 ± 0.06 g CH_4 m^{-2} h^{-1}, respectively. Sun et al. (2009b) reported a mean CH_4 emission of 1.9 mg CH_4 m^{-2} h^{-1} in a *Carex schmidtii* marsh from June to October 2007 measured in the same region.

In semiarid grasslands, plenty of small patches of wetlands in areas of low relief and poor drainage regions are scattered which may be CH_4 sources (Wang et al. 2005). Field measurements of CH_4 emissions were carried out in riparian mires and adjacent uplands on the Xilin River basin in 2004. Mean emission was 9.8 mg CH_4 m^{-2} h^{-1} during the growing season, but varied by 2–3 orders of magnitude (Wang et al. 2005).

6.3.2 Coastal Wetlands

In the eastern part of China, wetlands are widely distributed along the coast of the Pacific Ocean. CH_4 emissions from coastal wetlands have been measured in Liaohe Delta (northeastern China), Yangtze Delta (Municipality of Shanghai) and Minjiang Delta (Fujian Province). CH_4 emissions were −1.0 to 2.7 mg CH_4 m^{-2} h^{-1} from reed wetlands in Liaohe Delta (Huang et al. 2001a), 2.1 mg CH_4 m^{-2} h^{-1} in middle flat and 0.04 mg CH_4 m^{-2} h^{-1} in low flat wetlands, respectively, in the Chongming east intertidal flat (Yang et al. 2007), and 13.1 and 12.9 mg CH_4 m^{-2} h^{-1} from *Spartina alterniflor* before flood and after ebb in Minjiang Delta, respectively (Tong et al. 2008).

6.3.3 Lakes

In China, CH_4 emissions from lakes have been measured in field since 2003. A 2-year measurement during two growing seasons from April to October 2003 and 2004 indicated that the mean CH_4 emission rate from *Potamogeton pectinatus* (submerged macrophyte) growing zones was 3.4 ± 1.6 mg CH_4 m^{-2} h^{-1}, 78% lower than that from *Phragmites australis* (emergent macrophyte) in Wuliangsu Lake, Inner Mongolia (Duan et al. 2007). The average CH_4 emission was 23.3 ± 18.6 mg CH_4 m^{-2} h^{-1} with strong seasonal variation in Donghu lake, Hubei Province (Xing et al. 2005), and 0.6 ± 0.4, 0.7 ± 0.4, and 1.3 ± 0.6 mg CH_4 m^{-2} h^{-1} from three replicates, respectively, in Biandantang lake, Hubei Province (Xing et al. 2006). In hypereutrophic Meiliang Bay of Taihu Lake, measurements showed that the macrophyte-covered infralittoral zones were the "hotspots" of CH_4 emission with large temporal variations for CH_4 fluxes, ranging from about −2 to 131 mg CH_4 m^{-2} h^{-1} in the macrophyte-covered littoral zone (Wang et al. 2006a).

6.3.4 Reservoirs

The debate about the effect of energy generation by hydropower on climate is related to emissions of CH_4 from reservoir constructed for electricity production. In 2008, the first reported all-year measurement of CH_4 emissions from the newly established reservoir in Ertan showed that the surface of the reservoir was a net source of CH_4 during the sampling period with a mean CH_4 flux of 0.12 ± 0.06 mg CH_4 m^{-2} h^{-1} (Zheng et al. 2011). Measurements conducted at the Three Gorge Reservoir, one of the largest reservoirs in the world, showed that CH_4 emissions from the water surface were 0.3 ± 0.1 mg CH_4 m^{-2} h^{-1} during summer (Lu et al. 2011).

6.3.5 *Geographical Variation in Methane Emissions*

It is difficult to depict a clear geographical distribution of CH_4 emission from wetland because the available data are relatively limited, and many factors (e.g., vegetation, water table) also influence CH_4 emissions. The two largest peatlands in China are located in Zoige Plateau and Sanjiang plain. Although there are remarkable variations in CH_4 emission in a region because of vegetation and measurement sites, available results show that CH_4 emissions in Sanjiang peatland are higher than those in Zoige peatland (Table 6.1). The simultaneous measurements showed that the average value of CH_4 emissions from Sanjiang peatland was 4.7 times more than that of Zoige peatlands due to different water and temperature regimes (Wang et al. 2003). In coastal wetlands, CH_4 emissions were the lowest in the northern region (e.g., Liaohe Delta) and higher in the southern region (e.g., Mingjiang Delta), which may be related to temperature differences. The annual air temperature were 8°C in Liaohe Delta (Chen et al. 2011) and 19.7°C in Minjiang Delta (Li et al. 2009), respectively. In lakes, higher CH_4 emissions were reported in northwestern China (e.g., Wuliangsu Lake) than in other regions which may be mainly driven by higher vegetation biomass (18.6–25.5 $Mg\,ha^{-1}$ for reed, Duan et al. 2007) in the Wuliangsu Lake.

6.4 Temporal Variation in Methane Emissions

6.4.1 *Diel Variation*

Understanding the diel variation in CH_4 emissions is of importance to designing the temporal sampling strategy for estimating the amount of CH_4 emissions and to investigating environmental variables controlling CH_4 emission. Although diel variations of CH_4 emissions have been observed at various sites, no consistent pattern has emerged. CH_4 emissions from *Corex lasiocarpa* and *Deyeuxia angustifolia* freshwater marsh in Sanjiang Plains exhibited a unique peak at 9:00 in the morning, lagging about 4 h behind sunrise and the lowest CH_4 emission at 0:00 midnight about 5 h after sunset. Both plant species showed higher daytime emissions than during nighttime. However, the diel variation in CH_4 emission was much smaller at the *D. angustifolia* than the *C. lasiocarpa* site (Ding et al. 2004c). Correlation analysis showed that CH_4 emissions were not significantly related to air temperature and soil pore water temperature at 0–35 cm depth (Ding et al. 2004c).

In peatland of Zoige, there was an apparent diurnal variation pattern in CH_4 emission with one minor peak at 06:00 in the morning and a major one at 15:00 in the afternoon. The sunrise peak was consistent with a two-way transport mechanism for plants (i.e., convective at daytime and diffusive at nighttime). The afternoon peak could not be explained by diurnal variations in soil temperature, but may be attributable to changes in CH_4 oxidation and production driven by gas transport mechanisms within the plants (Chen et al. 2010b).

Field measurements have been conducted in the Inner Mongolia marshes to compare the diurnal CH_4 fluxes between summer and winter, between a sandy site and an organic site, and between a wet meadow and a waterlogged habitat at each site (Wang and Han 2005). The results indicated that during summer apparent diurnal patterns in CH_4 emissions with unique peaks at sandy sites and plant photosynthesis greatly affected the processes of CH_4 production, oxidation and transport. This resulted in a diurnal variation of CH_4 emission with a peak in the late afternoon and the lowest value immediately prior to next day's sunrise. At the OM-rich site, plant-mediated CH_4 transport together with the absence of a significant relationship between CH_4 flux and environmental variables indicated that diurnal CH_4 flux was determined by vascular plants (Wang and Han 2005).

Distinct trends were observed based on measurements of CH_4 emissions from Wuliangsu Lake as in July and August. However, significant differences in CH_4 emissions between day and night were observed which may be related to irradiation during the growing season (Duan et al. 2005). The CH_4 emissions from Pondweed-dominated plots were low during the nighttime, increased in the morning and reached a maximum primarily in the afternoon between 14:00 and 18:00 when the sediment temperature was the highest (Duan et al. 2005).

The diurnal CH_4 fluxes followed the same trends during the wet and dry seasons reported at the Ertan Reservoir (Zheng et al. 2011). The fluxes peaked during early afternoon and then gradually declined. The maximum CH_4 flux occurs during the afternoon at 14:00 in the wet season and at 16:00 during the dry season (Zheng et al. 2011).

6.4.2 Seasonal Variation

In general, CH_4 emissions are higher during summer or the growing season than those during winter or the non-growing season. The apparent seasonal pattern appears in a sinusoidal shape with the vertex around August and nadir around January for CH_4 emission at the Sanjiang Plain (Song et al. 2009). Actually, the monthly CH_4 emissions from three kinds of wetland start increasing from March or April when plant growth begins, and peaks when plant biomass reaches its maximum. CH_4 emissions during the entire growing season (April to October) account for more than 90% of the annual flux (Song et al. 2009). Although there were measurable CH_4 emissions (0.1–2.3 mg CH_4 m^{-2} h^{-1}) in the freshwater marsh during winter (November through March), it was only about 3.8%, 5.5%, and 2.2% of the annual emissions 2003, 2004, and 2005, respectively (Song et al. 2009). During the freeze–thaw period (April–June), CH_4 emissions increased significantly, and were about 31%, 21%, and 216% of the annual emissions 2003, 2004, and 2005, respectively (Yang et al. 2006b).

Similar seasonal variations in CH_4 fluxes were also apparent at reed-dominated lakes. The CH_4 flux increased from early April when the shoots began to emerge from the water, reached its maximum in summer, and then declined. The CH_4 fluxes were positively correlated with soil temperature in reed-dominated lakes with an exponential correlation. In contrast, there was only a small seasonal variation in CH_4 release from the pondweed dominated plots but the highest emission rate was observed in August (Duan et al. 2005).

In Donghu Lake, Hubei, the mean CH_4 emission rates for all stations remained low during spring, autumn and winter, while they markedly increased during summer. The CH_4 emissions were positively correlated to net primary production (NPP), chlorophyll a concentrations, and water and sediment surface temperatures in shallow lakes (Xing et al. 2005).

The seasonal variation in CH_4 emissions during wet and dry seasons were of minor importance at Ertan Reservoir as emission rates were low all year round (Zheng et al. 2011).

6.4.3 Inter-annual Variation

As most measurements of CH_4 emissions are conducted during only 1 year, the available data on multiple-year variation are inconclusive. For example, 2-year measurements of CH_4 emissions from Wuliangsu Lake showed that emissions from reed dominated wetlands was larger in 2004 than in 2003 because of higher reed biomass 2004. The flux from pondweed dominated wetlands in 2004 was lower than that 2003 due to blooming of blue algae which limited pondweed growth. Song et al. (2009) conducted measurements of CH_4 emissions in Sanjiang Plains from 2002 to 2005. The CH_4 emission varied significantly year by year. The biggest change was more than one order of magnitude. For example, the CH_4 flux from shrub swamp wetland ecosystems in 2004 was nearly 17 times that of 2005. The CH_4 flux from seasonally inundated wetland ecosystems in 2003 was about eight times that of 2005 (Song et al. 2009), which may have resulted from the lower precipitation in northern China caused by the relatively strong El Nino Southern Oscillation (ENSO) (Song et al. 2009).

6.5 Environmental Variables and Their Effects on Methane Emissions

The CH_4 emissions are depending on three processes namely production, oxidation and transport. All processes depend on variety of climate, hydrology, soil and vegetation. In order to estimate and predict CH_4 emissions from wetlands, studies about the effects of varying environmental factors are important. During the measurements of CH_4 emission from various wetlands in China, factors influencing emissions were also monitored and analyzed simultaneously. The main results are discussed in the following section.

6.5.1 Solar Radiation

Solar radiation provides nearly all energy to all living organisms. As increasing photosynthesis stimulates roots to exude more organic compounds providing substrates for methanogenic bacteria to produce CH_4, there is a close relationship between photosynthesis and solar radiation. Thus, the increase in solar radiation, especially photosynthetically active radiation (PAR), results in increasing CH_4 production. Duan et al. (2005) reported that diurnal variations in CH_4 emissions were related to irradiation, and during growing stage, higher emissions occurred during sunny days in reed dominated plots at Wuliangsu Lake. When PAR was blocked by covering (e.g., chamber covered with black clothe), CH_4 emissions declined significantly (Duan et al. 2006) assuming the chamber effect on air temperature and humidity were minor.

Diurnal changes in CH_4 flux in three types of peatlands in Haibei, Qinghai-Tibet Plateau, dominated by *Scirpus distigmaticus*, *Hippuris vulgaris* and *Potamogeton pectinatus*, respectively, were significantly correlated with changes in PAR, especially in the late season (Hirota et al. 2004). The chambers were covered with sheets of aluminum foil for light–dark experiments which suggested the presence of stomatal control of CH_4 fluxes (Hirota et al. 2004).

6.5.2 Temperature

Temperature is an important factor influencing microbial activities which may produce CH_4 in anaerobic environments. Thus, CH_4 emissions were positively and exponentially related to soil temperature in reed-dominated wetlands in Wuliangsu Lake (Duan et al. 2005), to water surface and sediment temperature in a shallow hypereutrophic subtropical lake (Xing et al. 2005), and to soil temperature in 5-cm depth during the growing season in freshwater marsh in northeast China (Song et al. 2008). To accurately quantify the sensitivity of gas fluxes to air temperature, Song et al. (2009) used Q_{10} as the index to monitor the increases in gas fluxes when the air temperature increased from 10°C to 20°C, and reported that Q_{10} for CH_4 emission from peatlands in Sangjiang Plain was 1.9–2.7, indicating global warming may stimulate CH_4 emissions from wetlands.

6.5.3 Hydrology

Methane is produced under anaerobic environment controlled by water depth or soil moisture regime. Duan et al. (2005) compared CH_4 emission rates from wetlands with different depth and found that a relatively high mean emission rate was observed in reed-dominated plots with the deepest standing water depth., Ding et al. (2002) reported that CH_4 emissions from *Carex lasiocarpa*, *Carex meyeriana* and *Deyeuxia angustifolia* marshes in the Sanjiang Plain in Northeastern China increased as standing water depth increases from 5 to 20 cm. In Yichun of Xiaoxing'anling Mountains, average CH_4 emission rates were higher with deeper water table among the forested swamps, except for *Larix gmelinii—Sphagnum* spp. Swamp (Song et al. 2009). A critical point of water table for atmospheric CH_4 source or sink in Xiaoxing'an mountains was reported to be at 34.5–30.8 cm, below which the peatlands turn into atmospheric CH_4 sinks (Song et al. 2009). In Ertan hydroelectric reservoir, shallow-water areas emitted more CH_4 than deep-water regions. The reasons are (1) higher CH_4 fluxes in shallow areas probably resulting from higher CH_4 production in the sediments due to OM inputs in the littoral zone and (2) the nutrients in runoff from the catchment apparently accelerate OM accumulation and plant productivity in the littoral zone, thereby boosting CH_4 emissions (Zheng et al. 2011).

Water table influences CH_4 emissions not only directly by changing the anaerobic environment where CH_4 is produced but also indirectly by determining the distribution of hydrophytes. For example, emergent macrophytes, *Scirpus acutus* and *Typha latifolia* grow in the shallow zone of Wuliangsu Lake while *Phragmite australis* appears in the zones where the water depth is under 2 m with higher CH_4 emissions (Duan et al. 2005). Ding et al. (2002) also reported that standing water depth determined the type of marsh plants, which governed CH_4 transport, and the amount of plant litter, which resulted in the difference in labile organic organic (LOC) for methanogenesis among marshes in Sanjiang Plains.

6.5.4 Vegetation

In recent years, vegetation has been recognized as key factor influencing spatial variation in CH_4 emissions. Vegetation properties, such as density, life form, and species composition, affect three processes—production, consumption, and transport of CH_4—and, thus, interfere with emissions from wetlands. Through litter production and root exudates, plants can provide substrates for methanogenesis. Aquatic plants provide gas conduits which transport both CH_4 from waterlogged soils to the atmosphere and oxygen from the atmosphere to the soil. The measurements in Wuliangsu Lake indicated that mean CH_4 emissions from submerged plant (*Potamogeton pectinatus*) growing zones were 2.2 mg CH_4 m^{-2} h^{-1} which was 86% lower than that from emergent macrophyte (*Phragmites australis*) growing zones (Duan et al. 2005). In Liaohe Delta, CH_4 emissions from the wetland dominated with reeds were 15 times that without reed (Huang et al. 2001a). The emergent plants can transport CH_4 to the atmosphere directly whereas CH_4 emission from the submerged plants was only distributed to the water column, and its emission was controlled by ebullition and diffusion from plants and sediment surfaces.

In Sanjiang plains, CH_4 emissions from *Carex lasiocarpa* dominated wetlands was significantly higher than those of *Deyeuxia angustifolia* dominated and shrub wetlands (Song et al. 2009). Measurements of CH_4 emissions in six different littoral zones of Huahu Lake on the Qinghai-Tibetan Plateau in the peak growing season 2006 and 2007 indicated that emergent plant zones (*Hippuris vulgaris* and *Glyceria maxima* stands) had the highest CH_4 flux rates. The CH_4 emission in the floating mat zone of *Carex muliensis* was significantly lower than those of emergent plant zones. CH_4 fluxes in the floating leaved zone of *Polygonum amphibium* and bare lakeshore showed no significant difference and was low, only higher than that of a littoral meadow (*Kobresia tibetica*) (Chen et al. 2009). In Haibei of Qinghai-Tibet Plateau, there were three emergent-plant zones (*Hippuris*-dominated; Scirpus-dominated; and *Carex*-dominated) and one submerged-plant zone (*Potamogeton*-dominated). The lowest CH_4 emission (seasonal mean 1.4 mg CH_4 m^{-2} h^{-1}) was observed in the *Potamogeton* dominated zone, which occupied about 74% of the total wetland area . The highest CH_4 flux (seasonal mean 8.9 mg CH_4 m^{-2} h^{-1}) was observed in the *Hippuris*-dominated zone, also the second deepest water area (Hirota et al. 2004). In Yichun of Xiaoxing'an mountain, varying CH_4 emission rates were reported among vegetation from CH_4 sink to source during the growing season (Song et al. 2009)

6.5.5 Other Factors

Human activities influence CH_4 emissions from wetlands in many ways. The most common is to drain wetlands or convert them into cropland which may significantly reduce CH_4 emissions and even turn the converted land into a CH_4 sink. Other practices also influence CH_4 emissions. For example, Hirota et al. (2005) investigated the effect of grazing on CH_4 emissions in Haibei at the Qinghai-Tibet Plateau. After grazing for about 3 months, ecosystem CH_4 emissions were remarkably greater than under non-grazing conditions. This increased CH_4 emissions resulted mainly from the flux increase within the gas-transport system of grazed plants (Hirota et al. 2005). Zhang et al. (2007) reported that exogenous applied N significantly enhanced the mean seasonal CH_4 emission rates by 181% (application rate 6 gN m^{-2}), 254% (12 gN m^{-2}) and 155% (24 gN m^{-2}), respectively (Zhang et al. 2007).

It is evident from this study that processes controlling CH_4 emissions from wetlands are highly complex and vary with climate, vegetation and human activities. Thus, no single environmental variable can explained variations in CH_4 emissions entirely. Process-based biogeochemical models are therefore helpful tools. Huang et al. (2010) developed a CH_4 MOD model which had been validated by CH_4 emissions data from peatlands in Sanjiang Plain and Zoige. The model consists of 20 basic functions. Methanogenic substrates derived from plants via root exudates, from the decomposition of above- and below-ground plant litter and from SOM are simulated. Plant growth and senescence, CH_4 production and emission, and the influence of environmental factors on CH_4 production and emission are simulated. However, this model has not yet been used to estimate CH_4 emissions from wetlands on a national scale.

6.6 Regional and National Estimates of Methane Emission

The regional and national CH_4 emissions are generally estimated based on limited numbers of field measurements by summing-up the product of area and its CH_4 emission for each habitat. Up to now, the CH_4 emissions have been estimated for Qinghai-Tibet Plateau, Zoige peatland, Sanjiang peatland, Wuliangsu Lake, and Donghu Lake (Table 6.2). Due to significant variations in CH_4 emissions among different habitats, regional CH_4 emissions are not attributed proportionally to land area of each source. For example, 85% of the CH_4 emissions were from a *Phragmites australis* community dominated area with less than 50% of total area cover of Wuliangsu Lake (Duan et al. 2007). Although the riparian mires cover only 0.4% of the Xilin River basin, their CH_4 emissions were about half of the amount of CH_4 consumed by the upland grassland which covered 89.7% of the land (Wang et al. 2006b).

The annual CH_4 emissions from peatlands in China were estimated to be 1.8 Tg CH_4 $year^{-1}$ (Ding et al. 2005) and 1.7 Tg CH_4 $year^{-1}$ (Ding and Cai 2007) based on measurements at peatlands in Qinghai-Tibet Highland and the freshwater marsh in Sanjiang Plain 2001 and 2002, and measurements 1995–2004, respectively. Jin et al. (1999) reported CH_4 emissions of 2.0 Tg CH_4 $year^{-1}$ in Qinghai-Tibet Plateau based on field measurement at Huashixia, Maduo, Qinghai. Based on the data in this study, the annual CH_4 emission is 10.5 Tg CH_4 $year^{-1}$ with a range between 2.5 and 33.1 Tg CH_4 $year^{-1}$ in China (Table 6.3), of which 69% occurs in peatlands, 8% in coast wetlands, 22% in lakes, 0.4% in reservoirs and 1.4% in rivers, respectively.

Table 6.2 Regional and national estimates of CH_4 emission from wetland in China

Wetland	Area (km^2)	CH_4 emission (Mg $year^{-1}$)	Reference
Sanjiang	11192.9	0.9607	Cui (1997)
Northeastern China	2.4×10^4	1.36	Huang et al. (2010)
Zoige Peatlands	4,038	0.052	Wang et al. (2002)
Qinghai-Tibet Plateau	13.3×10^4	0.79	Jin et al. (1999)
Wuliangsu Lake	293	0.0012	Duan et al. (2005)
Donghu Lake	19.03	0.00016	Xing et al. (2005)
Country (peatlands)	9.4×10^4	1.76	Ding et al. (2004b)
	9.4×10^4	1.7	Ding and Cai (2007)
Country	25×10^4	2.0	Jin et al. (1999)
	38.4×10^4	9.97	This study

Table 6.3 CH_4 emission from different wetlands in China

Type	CH_4 emission (mg m^{-2} h^{-1}) Mean	Max	Min	Area (10^3 km^2)	CH_4 emission (Tg $year^{-1}$) Mean	Max	Min
Peatland	6.00	15.63	1.02	137.00	7.20	18.76	1.22
Coast wetland	1.64	2.35	0.52	59.40	0.86	1.22	0.27
Lake	3.09	9.68	0.88	83.52	2.26	7.08	0.64
Reservoir	0.21	0.31	0.12	22.56	0.04	0.06	0.02
River	0.21			82.02	0.15	6.00	0.32
Sum				384.50	10.51	33.13	2.48

Note: The CH_4 emission for river is deployed the same figure as that for reservoir because of lack of field measurement data

6.7 Conclusions and Outlook

Natural wetlands have received increased attention because of their importance for ecosystem services and CH_4 emissions. In China, the total area of wetlands is about 38 Mha accounting for about 4% of the total land area. Natural wetlands include peatlands (36%), coastal wetlands (15%), river (21%), lakes (22%) and reservoirs (7%)**.** Human activities and the development of settlements have drastically reduced the wetland area. A recent estimate indicated that 33% of wetlands were lost between 1978 and 2008, and land reclamation accounted for more than 70% of this loss.

CH_4 emissions from natural wetlands are measured in Sanjiang Plain since 1995 and in Tibet-Qinghai Plateau since 1996–1997. Based on previous studies, measurements of CH_4 emissions were carried out at 16 sites across the country, i.e., six peatlands, three coastal wetlands, five lakes and two reservoirs. The mean CH_4 emission rates were 6.0 (range 1.0–15.6) mg CH_4 m^{-2} h^{-1} for peatlands, 1.6 (0.5–2.4) mg CH_4 m^{-2} h^{-1} for coastal wetlands, 3.1 (0.9–9.7) mg CH_4 m^{-2} h^{-1} for lakes, and 0.2 (0.1–0.3) mg CH_4 m^{-2} h^{-1} for reservoirs.

Although diel variations of CH_4 emissions have been observed at many sites, there is no consistent pattern. In general, CH_4 emissions are higher in summer or during the growing season than that in winter or non-growing seasons. Because of the difference in site characteristics, seasonal patterns of CH_4 emissions change with vegetation, freeze-thaw periods, and climate types. Inter-annual variations of CH_4 emissions are significant because of changes in vegetation growth and precipitation.

CH_4 emission are generally determined by three processes, i.e., CH_4 production, oxidation and transport. The processes depend on changes in climate, hydrology, soil properties and vegetation type and production. CH_4 emissions increase with increase in solar radiation, especially at diurnal scales. Further, CH_4 emissions were positively and exponentially correlated with air or soil temperature in many wetlands. Water table influences CH_4 emissions not only directly by changing the anaerobic environment where CH_4 is produced but also indirectly by determining the distribution of hydrophytes. Vegetation has been recognized as a key factor affecting spatial variation in CH_4 flux by providing methanogenic substrates and conduits for CH_4 transport. In addition, human activities influence CH_4 emissions from wetlands in many ways, such as reductions in emission by wetland drainage and intensification of grazing.

The regional or national CH_4 emissions are estimated based on a limited number of field measurements which indicate that regional CH_4 emissions are not attributed proportionally to land area of each source. The annual CH_4 emission rates from natural wetlands in China are 10.5 Tg CH_4 year^{-1}, accounting for 7% (145 Tg CH_4 year^{-1}) of global emissions from wetlands, and is 171% (6.1 Tg CH_4 year^{-1}) of the CH_4 emissions from rice paddies in China.

Field measurements are essential for more accurate estimations of CH_4 emissions from natural wetlands of China. To date, there are three measurement methods available, i.e., the chamber method, the air-water interface method and the eddy covariance method. Up to now, only chamber methods have been used in China. However, chamber effects may influence temperature, photosynthesis and transpiration. Although black chambers coated by isolative material can prevent the temperature rise within the chamber, the reduction in photosynthesis will reduce root exudation which supplies important substrates to methanogenic bacteria. In addition, CH_4 emission is monitored discontinuously, and CH_4 fluxes at night or during rapid changes in water levels are generally not monitored. Also, very few measurements of CH_4 emissions have been carried out during the winter season.

To reduce the uncertainty in estimating CH_4 emissions from wetlands, process-based biogeochemical models are valuable tools. The models can capture the main processes controlling CH_4 emissions with regard to high temporal and spatial resolution of environmental factors. There are some biogeochemical models employed to estimate CH_4 emissions from wetlands, e.g., Wetland-DNDC (Zhang et al. 2002), PEATLAND (van Huissteden et al. 2006). With the increasing number of field experiments conducted in China, more critical parameters embedded in biogeochemical models will be available, which will promote the development of biogeochemical models specific to China's wetland. CH_4MOD developed by Huang et al. (2010) has been verified in China and will soon be used to estimate CH_4 emissions.

It is crucial to quantify CH_4 emissions from different types of wetlands and to determine the driving factors. CH_4 emission into the atmosphere is the result of production, oxidation and transportation driven by temperature, hydrology, and vegetation. These driving factors vary by location. The resolution of vegetation distribution is critical to improve accurate estimations of CH_4 emissions because there are significant differences in CH_4 emissions among vegetation covers and their distribution depending on hydrology, which is also important for CH_4 emissions. The relationship between CH_4 emission and NPP is important for estimating CH_4 emissions from remote sensing data which are used for large scale NPP estimations.

It is well known that water depth is a very important factor controlling CH_4 emission, and CH_4 source and sinks greatly depend on water level which varies seasonally, and even hourly. Unfortunately, the information of water depth is generally not available because of its considerable temporal and spatial variation. Continuous monitoring and remote sensing data would be valuable for accurately measuring water depth.

Climate change is one of the most threatening forces that will affect future CH_4 emissions because climate influences temperature, evapotranspiration, water level, distribution of aqueous vegetation, and growing season length. The recent drought affecting wetlands and lakes on the Qinghai-Tibetan Plateau caused a change in vegetation zones from submerged plants to emerged plants as result of a rapid decrease in water depth. This change in plant community composition may decrease CH_4 fluxes from alpine wetlands in the future. The prolonged drying of many wetland regions in the world as a result of drainage and climate change may have resulted in a reduction in CH_4 emissions . Thus, it is also necessary to investigate CH_4 emissions under a future climate change.

Although occupying only about 3% of the world's land area, wetlands provide many important ecosystem services. Costanza et al. (1997) estimated the total global value of services provided by coastal areas and wetland ecosystems to be 15.5 trillion US$ per year or 46% of the total value of services global ecosystems provide. The major functions of wetlands are water storage and groundwater recharge, flood control, shoreline stabilization, water quality control, moderating climate and community structure, biodiversity and wildlife support. Unfortunately, wetlands have historically been the in the center of large-scale drainage efforts for agricultural and real estate developments, or flooding for creating recreational lakes. Drainage to cropland will turn wetlands from a CH_4 source into sink. The important issue is how to deal with tradeoffs between ecosystem service and mitigation of wetland CH_4 in decision making.

Reducing CH_4 emissions from natural wetland is one of the important measures to mitigate climate change. Based on the available investigations, the following measures may be considered: (1) wetlands can be flooded by intermittent management which will mitigate CH_4 emission as well (Huang et al. 2001b). (2) Invasion by vascular plants such as weed (for lowering water table) and eutrophication should be prevented because they stimulate CH_4 emission. (3) Climate change should be mitigated because the rise of temperature will stimulate CH_4 emissions.

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