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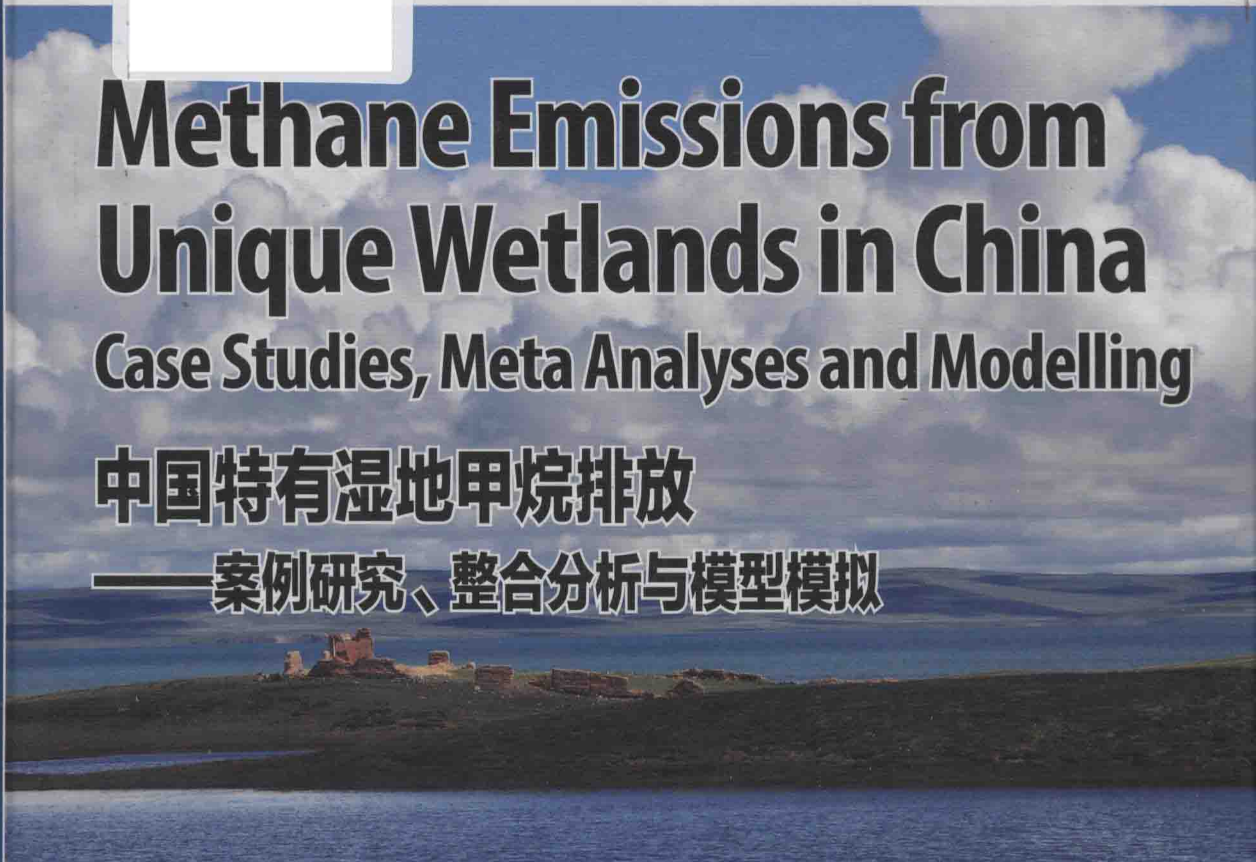

Methane Emissions from Unique Wetlands in China

Case Studies, Meta Analyses and Modelling

中国特有湿地甲烷排放

——案例研究、整合分析与模型模拟

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Preface

The world is undergoing rapid change in many factors, especially climate, especially global warming, that control the structure, function and services of ecosystems. Increasing atmospheric concentration of greenhouse gases is proven to be responsible for global warming. Due to its powerful warming potential, methane (CH_4), has a considerable impact on the earth's climate system second anthropogenic greenhouse gas only to CO_2. Sources of CH_4 become highly variable for countries undergoing a heightened period of development (e.g. China) due to both human activity and climate change. An urgent need therefore exists to understand key sources of CH_4, such as wetlands (rice paddies and natural wetlands) and lakes (including reservoirs and ponds), especially those unique ones in specific countries, which are sensitive to these changes. This book was written to provide a systematic basis for understanding CH_4 fluxes from unique wetlands of China and their sensitivity to environmental and biotic factors.

This book is intended to introduce CH_4 fluxes from wetlands to climate managers, policy makers, practicing scientists, modellists, advanced undergraduate students, beginning graduate students from a wide array of disciplines, such as ecology, climatology, geography, forestry, microbiology, etc. We also provide access to the rapidly expanding literature in CH_4 fluxes of wetlands in China that contribute to fully understanding of the budget of CH_4 fluxes of wetlands in China and their trends.

The first chapter of the book (by Huai Chen, Ning Wu, Yanfen Wang, Changhui Peng) provides the context for understanding CH_4 fluxes from wetlands. We introduce the importance of CH_4 as a greenhouse gas and wetlands as the important source of CH_4, then briefly review the studies about CH_4 fluxes from wetlands in China. We show why we chose Zoige alpine wetlands and Three Gorges Reservoir as the case studies in the book and list our objectives. The second chapter of the book (by Huai Chen, Ning Wu, Yanfen Wang, Dan Zhu, Yongheng Gao), we fully describe spatial (from habitats, ecosystem to landscape) and temporal variations (from diurnal, seasonal to inter-annual) of CH_4 emissions from Zoige wetlands at different scales. The third chapter of the book (by Huai Chen, Xingzhong Yuan, Yixin He), we put our pioneer results about CH_4 emissions from littoral wetlands and the surface of the Three Gorges Reservoir. The fourth chapter of the book (by Jianqing Tian, Huai Chen, Yanfen Wang), we discuss about methanogens and methanogensis in Zoige wetlands, as well as their changes responsive to vegetation types and climate change. The fifth chapter of the book (by Huai Chen, Changhui Peng, Qiu'an Zhu, Ning Wu, Yanfen Wang, Gang Yang), we review references in relation to CH_4 emissions from rice paddies, natural wetlands, and lakes in China and then re-estimate the total amount based upon the review itself. In the last chapter of the book (by Qiu'an Zhu, Changhui Peng, Huai Chen), we try to model methane emissions from wetlands and a case study in China.

Primary funding for this book was came from the National Basic Research Program of China (2013CB956602), the International S&T Cooperation Program of China (S2013GI0408), 100 Talents Program of the Chinese Academy of Sciences, Program for New Century Excellent Talents in University (NCET-12-0477), and the National Natural Science Foundation of China (No. 31100348). Many individuals have contributed to the development of this book. We would like to show our gratitude to Ms. Wan Xiong, Dr. Chuan Zhao, Ms. Wei Li, Mr. Lile Zeng, Mr. Wei Zhan, Mr. Erxiong Zhu, Mr. Xinwei Liu, Ms. Dan Xue, Ms. Lifan Xiao, Mr. Xinhua Jiang, Mr. Ben Miller and Ms. Xinya Huang for their great help in editing. We particularly thank our family and their patience makes this book possible. We also thank the great many friends and colleagues who helped us by commenting on our book draft.

Comments and suggestions for improvement are welcome and will be gratefully appreciated.

Huai Chen
Chengdu, China

Contents

Chapter 1

Methane is an Important Greenhouse Gas

Huai Chen, Ning Wu, Yanfen Wang, Changhui Peng

1.1 Methane as an Important Greenhouse Gas

A distinguished Victorian scientist, John Tyndall FRS (1820–1893), was one of the first to appreciate that trace gas constituents within the atmosphere act as so-called "greenhouse gases" (GHG). Methane (CH_4) is an important GHG that possesses power beyond carbon dioxide (CO_2) to influence warming within the atmosphere by an approximate magnitude of 21 on a per mole basis [1]. Moreover, CH_4 exerts a strong influence on chemistry of the troposphere, stratosphere and many other greenhouse gases including ozone (O_3), hydroxyl radicals (—OH), and carbon monoxide (CO) by the way of photochemical reactions [2]. A study has recently reported that gas-aerosol interactions substantially alter the relative importance of various GHG emissions. This is especially true for CH_4 emissions that have larger overall impacts than current carbon-trading schemes or those found within the Kyoto Protocol, which modified its radiative forcing from +0.48 W m^{-2} to +0.90 W m^{-2} [3,4]. CH_4, therefore, has a considerable impact on the earth's climate system second only to CO_2. Atmospheric CH_4 is primarily emitted from biological sources and, this accounts for more than 70% of the global total [5]. CH_4 is consumed primarily through oxidation by way of ·OH within the troposphere [5,6]. Since the preindustrial era (1750), its atmospheric concentration has increased from 700 ppb to almost 1,800 ppb [7]. Moreover, a renewed growth in CH_4 atmospheric concentration occurred around the beginning of 2007 [7,8] following a near zero-growth decade. The existing state of the global CH_4 budget must therefore be addressed without delay.

1.2 Methane Emission Processes in Wetlands

CH_4 emissions that occur in wetlands (natural or constructed) and aquatic ecosystems are the result of interactions between several biological, chemical and physical processes that primarily include CH_4 production, oxidation and transportation (see Fig.1.1 for a summary of these processes). Certain studies have indicated that CH_4 is also aerobically produced and emitted by plants [9-11]. Anaerobic conditions can also produce CH_4 as an end product of organic matter degradation by the way of acetoclastic and hydrogenotrophic methanogenic archaea [12]. CH_4 produced under these conditions is then partly oxidized by methanotrophic bacteria within oxidized zones (the rhizosphere, the lower part of culms, the soil-water interface, and submersion water) [13-15]. For understanding CH_4 emissions from wetlands or lakes, it is essential to understand CH_4 transportation. There are three major mechanisms existed that drive CH_4 transportation: molecular diffusion, bubble ebullition [16,17], and plant-mediated transportation [18,19]. The CH_4 transportation mechanism is quite variable within various wetlands and lake zones. Due to this, CH_4 emissions from wetlands and lakes are an inherently complex biogeochemical process in which the physical factors involved in the three processes mentioned above can influence emissions. The primary factors that influence CH_4 emissions include temperature, the quantity and quality of the methanogen substrate, the water regime, the soil redox potential, pH, salinity, sulfate concentration, etc.[6,15,20]. Although the knowledge concerning CH_4 emissions and their regulations is un-

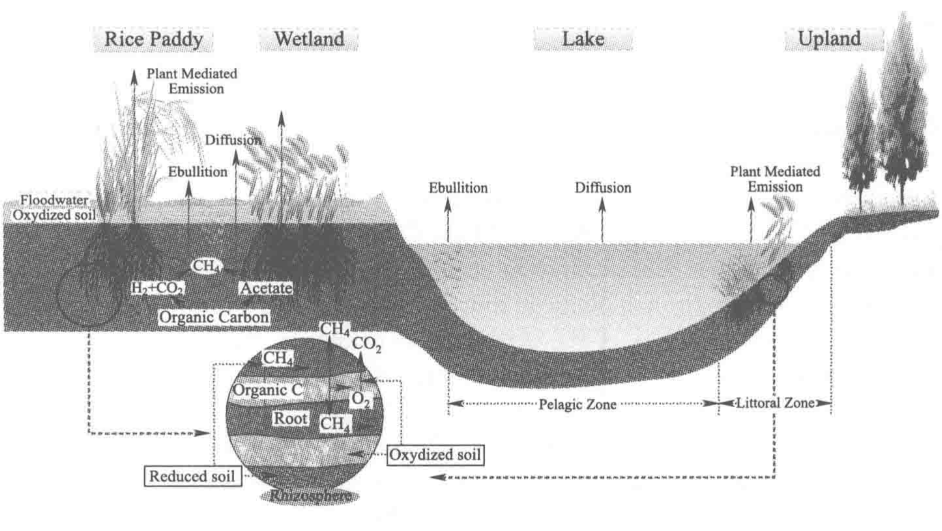

Fig. 1.1 A simplified illustration of CH_4 emissions from rice paddies, natural wetlands and lakes.

derstood, expansive studies in remote regions and more details concerning its processes (especially microbial processes) are needed to upscale and increase the overall knowledge base.

1.3 Wetlands as an Important Source of Methane

Wetlands are the single largest source of atmospheric CH_4 emissions due to the prevalence of waterlogged and anoxic conditions, accounting for approximately 148 Tg CH_4 yr^{-1} (1 Tg = 10^{12} g) compared to natural wetlands and 112 Tg CH_4 yr^{-1} compared to rice paddies [5,21]. These ecosystems contribute more than 40% of the total global CH_4 emissions to the atmosphere [22]. Large CH_4 emissions coming from lakes have also caused the increasing interest of lates in the scientific community. This source has recently been estimated to contribute from 8 to 48 Tg CH_4 yr^{-1} [23]. Moreover, several studies have designated northern thaw lakes as recognized CH_4 emission "hotspots" with an estimated source strength of approximately 24.2 ± 10.5 Tg CH_4 yr^{-1} [24-28]. Wetlands and lakes remain important CH_4 sources within the global CH_4 budget, but considerable uncertainties in relation to their emission output still exist. Such uncertainty primarily arises from the large spatiotemporal variation that occurs for different scales and the limited range of observational conditions [5,29]. It, therefore, would be highly desirable to procure estimates of CH_4 emissions from wetlands and lakes on national, regional as well as global scales — a topic that has been highlighted in many other studies [23,27,30]. The increased knowledge concerning CH_4 emissions from wetlands and lakes in China is important to understand the CH_4 budget of China as well as the CH_4 budget of the world at large. Estimating CH_4 emissions from Chinese wetlands and lakes, however, is extremely difficult to accomplish owing to the great expansive area of wetlands and lakes, its complex distributional patterns, the many different types of wetlands and lakes that exist in the country, and the complex dynamics that takes place in wetlands and lakes as a result of land use changes that occur in countries undergoing heightened periods of development.

1.4 Briefly Advances in Studies about Methane Emissions from Wetlands in China

Multiple studies on rice paddies CH_4 emissions in China have already been carried out [31-39], and some have even made efforts to estimate the total emission rate for the country [34,40-43]. Recent studies on natural wetland CH_4 emissions in China have been published [44-50] that offer preliminary national estimates [51]. Although CH_4 emission data from lakes and reservoirs are important to the national CH_4 budget [23], especially with regard to lakes undergoing thawing or experiencing eutrophication [27,52], only a few studies have related directly to China [53-55]. The above-mentioned studies were primarily carried out in northeastern, southeastern and southwestern China (Fig.1.2).

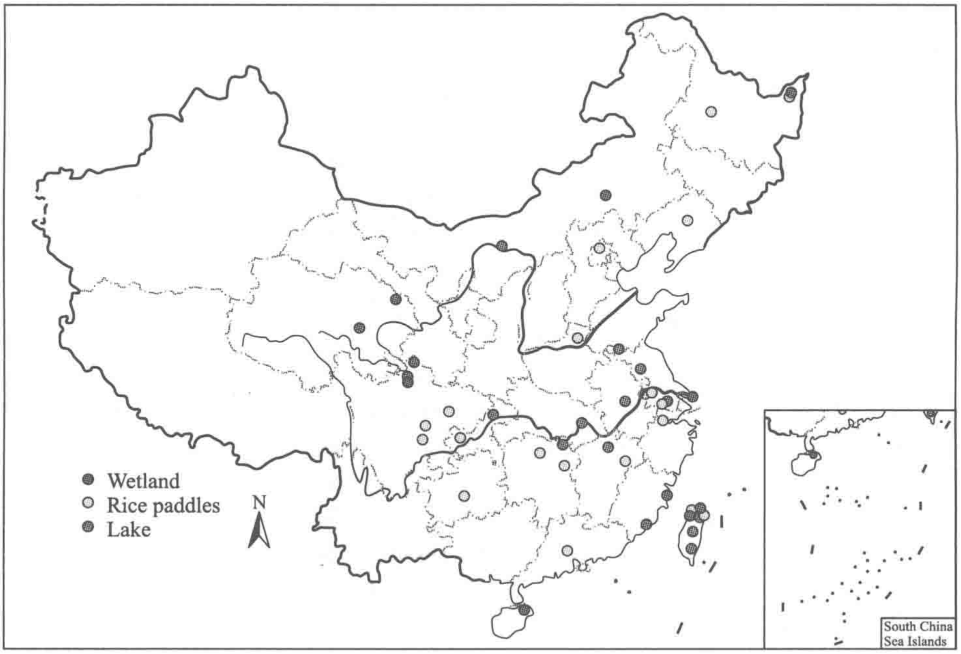

Fig. 1.2 Main CH_4 emission study sites from rice paddies, wetlands and lakes in China. Outline download website: https://219.238.166.215/mcp/index.asp (GS (2008) 1464). (see also colour figure)

No synthesis study investigating CH_4 emissions that have commented on a comprehensive CH_4 budget for both cultivated wetland areas (rice paddies) and non-cultivated wetlands and lakes in China exists thus far to the best knowledge of the authors of this study. Therefore, (i) studying methane emissions from unique wetlands, furthermore, and (ii) carrying out systematic analyses on studies concerning CH_4 emissions from rice paddies, wetlands, and lakes in China are urgently needed to arrive at a total CH_4 emission estimate from sources such as these. It is of great importance to the international scientific community to obtain a reasonable and comprehensive picture of CH_4 emissions from unique wetlands in China and how this contributes to the global CH_4 budget.

1.5 Zoige Alpine Wetlands and Methane Emissions

Recently, there are increasing number of studies measuring the methane emission rates from various wetlands all over the world [56-60]. But our knowledge of methane emissions from alpine or sub-alpine wetlands is far from sufficient to scrutinize the source strength of alpine wetlands, despite sporadic studies reported which were mainly located in the Rocky Mountains in American continent [46,61-64]. Hereupon detailed and informative data from other alpine regions all over the world, e.g. Zoige Plateau, will lead to a precise understanding of the global alpine budget of methane.

Zoige Plateau (av. 3,400 m a.s.l.), the major methane emission hotspot in the eastern edge of Qinghai–Tibetan Plateau (av. 4,000 m a.s.l.) [47], is a complete and orbicular plateau surrounded by a series of alpine mountains (av. 4,000 m a.s.l.). The landscape of Zoige Plateau is special and dominated by numerous hills (the average relative height is 70–150 m) and the alluvial plateau flat, on which flow two branches of the Yellow River, named the Black River and the White River [65]. The plateau covers an area of 2.8×10^4 km^2. Numerous alpine wetlands and lakes have developed on the plateau, accounting for 17.8% of the plateau coverage [66]. And these ubiquitous alpine wetlands on the plateau were formed during the Early Holocene (9355±115BP) [67]. However, the research on the CH_4 emission in Zoige alpine wetlands has lagged behind, so has systematic investigation on them. To scrutinize the CH_4 efflux in Zoige wetlands, more research is urgently needed.

1.6 Three Gorges Reservoir and Methane Emissions

Large dams have always played an indispensible role in human development all over the world. They are usually used to provide drinking water, control floods, irrigate crops, facilitate navigation, and generate electricity. People used to think large dams represented progress in hydraulic engineering. But they gradually recognized the harm of such dams to environment in the past several decades [68,69]. Dams have resulted in not only large-scale habitat fragmentation [70], but also emission of greenhouse gases to the atmosphere [71,72], especially methane (CH_4). This is because anoxic conditions prevailing at the bottom of the reservoir favor production of CH_4 and its possible emission into the atmosphere [73]. Moreover, the seasonally exposed bottom of the reservoir may play a more important role in CH_4 emission [74]. In fact, during the last 2,000 years, ancient large-scale water-management projects might have altered atmospheric CH_4 in China and India [75]. Therefore, the clean and green image of dams may have been overstated [76].

Among the large dams in the world, the Three Gorges Dam (TGD) with 2,335 m long and 185 m high on the Yangtze River of China is the biggest and thus a good example. It has a great drawdown area of about 350 km^2, approximately one third of the dam lake when fully operating. The Three Gorges Reservoir Region (TGRR) is about 660 km long and 58,000 km^2 in watershed area, greater than Switzerland [70,77]. When operating at full capacity, the total inundated area in the TGRR is estimated to be about 1,080 km^2 [69].

1.7 Objectives

In light of the rationale explained above, the overall goal of this research is to advance the knowledge in methane emissions from unique wetlands (Three Gorges Reservoir and Zoige alpine wetlands) in China and preliminarily estimate total methane emissions from wetlands in China. The spatiotemporal variation of methane emissions from Zoige alpine wetlands is based on measurements from 2004 to 2009. The methane emission from the Three Gorges Reservoir was firstly measured since 2008. Finally, a meta-analysis is introduced to review and analyse the methane emission from wetlands and its budget in China.

The objectives in detail are to:

i. Understand the temporal variation of methane emissions in Zoige alpine wetlands and find out the key factors influencing the temporal variations of methane emissions.
ii. Understand the spatial variation of methane emissions in Zoige alpine wetlands and find out the key factors influencing the spatial variations of methane emissions.
iii. Understand the CH_4 emission and its controlling factors in the drawdown area of the Three Gorges Reservoir(TGR).
iv. Probe the CH_4 emission and its controlling factors from the surface of the TGR.
v. Explore implications of methane emissions for the TGR and other large dam reservoirs.
vi. Review and analyze existing studies on CH_4 emissions from rice paddies, natural wetlands, and lakes in China.
vii. Provide new estimates and maps of the total CH_4 emissions from wetlands and lakes in China based upon above-mentioned review and analyses.