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Temporal and Spatial Variabilities of the CH_4 Fluxes in Small Ponds and Its Influencing Factors



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Outline

- Background
- Materials and Methods
- Results and Discussion
- Conclusion

Background

- **CH_4** is an important greenhouse gas with warming potential globally about 20 times than CO_2 (Cicerone and Oremland, 1988; Wuebbles and Hayhone, 2002).

- **0.583PgC/yr^{-1}** were omitted from very small ponds globally, and small ponds make up only 8.6% of the global surface area, yet comprise 15.1% of CO_2 diffusion and 40.6% of diffusive CH_4 emissions (Holgerson and Raymond, 2016).

- There are **four** pathways for methane transportation from lake sediment to atmosphere: ebullition, diffusion, aquatic vegetation, storage in water column, where ebullition is the major (Bastviken et al., 2004).

Purpose

- To quantify the ratio of CH_4 ebullition to total CH_4 flux;
- To estimate the average annual emission of CH_4 ebullition flux and the average annual emission of CH_4 diffusion flux.

Materials and methods

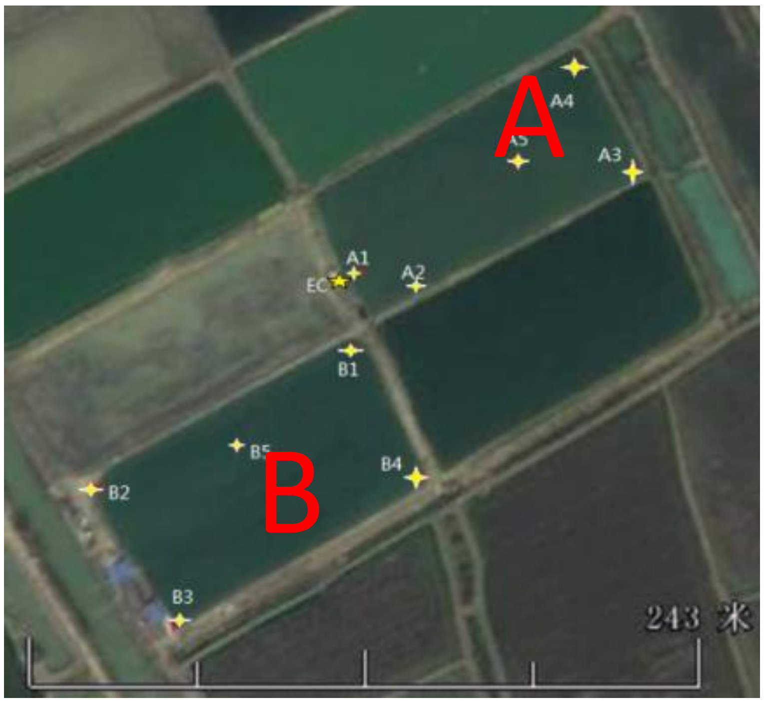


Fig.1 Locations of the 10 observation sites in the two ponds

- ■ Time duration：

2016summer 2016/07/27-2017/08/13
2017spring 2017/05/08-2017/05/21
2017summer 2017/07/18-2017/08/03
2017autumn 2017/10/27-2017/11/10

- ■ Inverted-funnel: (gas samples)

Intensive sampling: 06/12/18/24 LST
Daily sampling: 08-09 LST

- ■ Headspace balance method: (water samples)

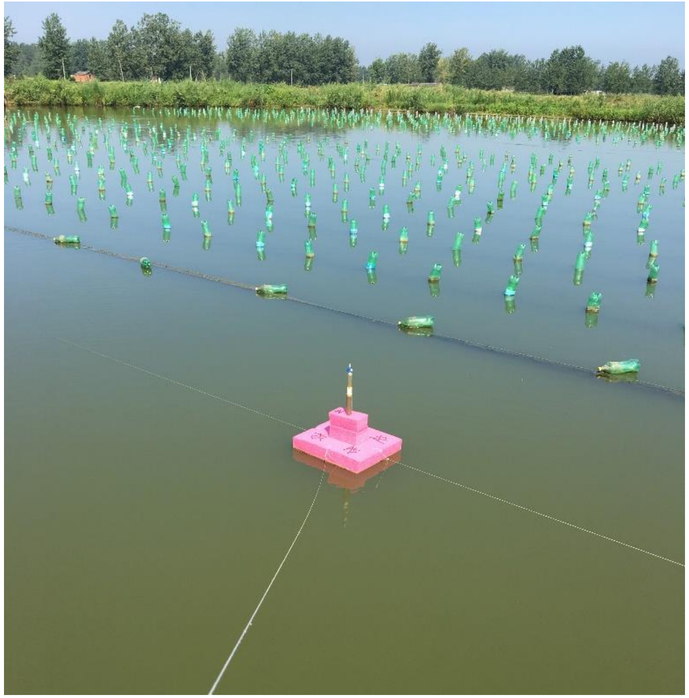
Daily sampling: 12 LST

Methods

Inverted-funnel method

$$F = \frac{C_{\mathrm{CH_4}} \times V \times M}{A \times t \times V_{\mathrm{m}}} \times \frac{1}{1000}$$

(Wik et al., 2013)



Headspace balance method

$$F = K(C_{\mathrm{w}} - C_{\mathrm{eq}})$$

(Cole & Caraco, 1998)

Auxiliary observation

CO_2 gas concentration
CH_4 gas concentration

Air temperature/pressure
Humidity/wind speed and wind direction/ radiation/gradient water temperature

Results and Discussion-1

Temporal Variabilities of the CH_4 Fluxes

Time series of meteorological factors

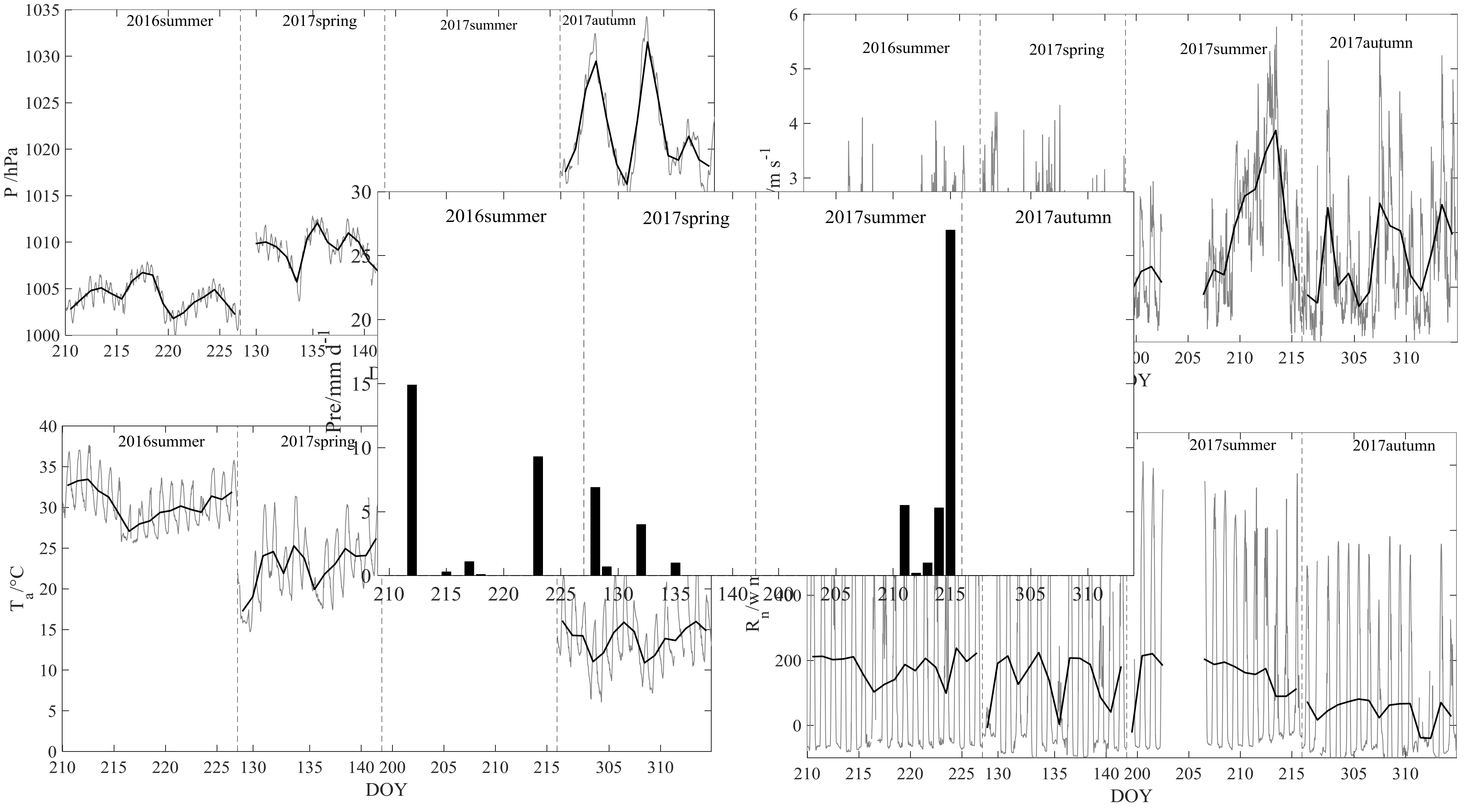
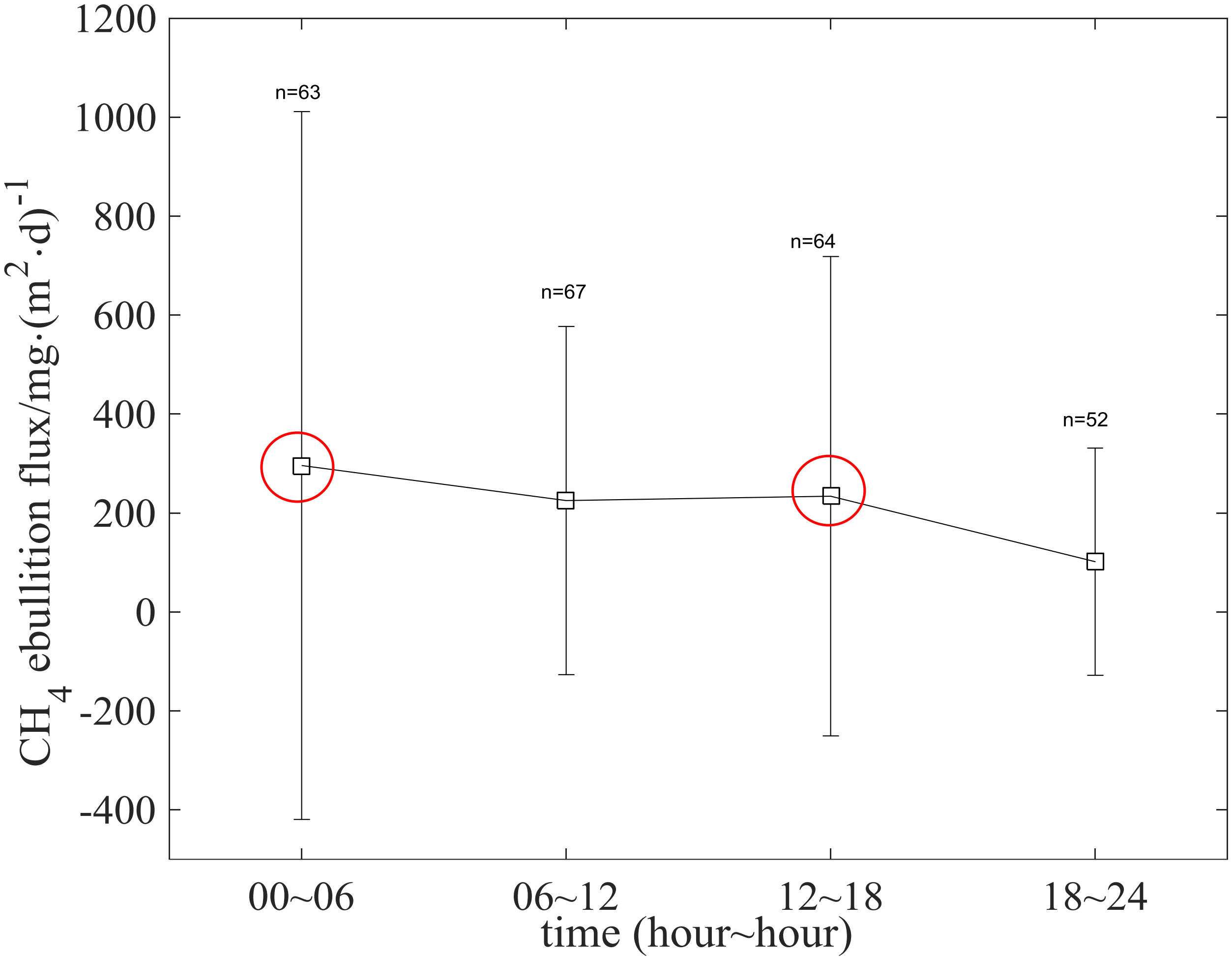


Fig.2 Time series of meteorological variables during the observation period

Diurnal variation of CH_4 ebullition flux



Mean in daytime: 229.61 $mg \cdot (m^2 \cdot d)^{-1}$

Mean in nighttime: 198.86 $mg \cdot (m^2 \cdot d)^{-1}$

Fig.3 Diurnal variation of methane ebullition flux during the intensive campaign

Seasonal variation of CH_4 ebullition flux

Summer>autumn>spring

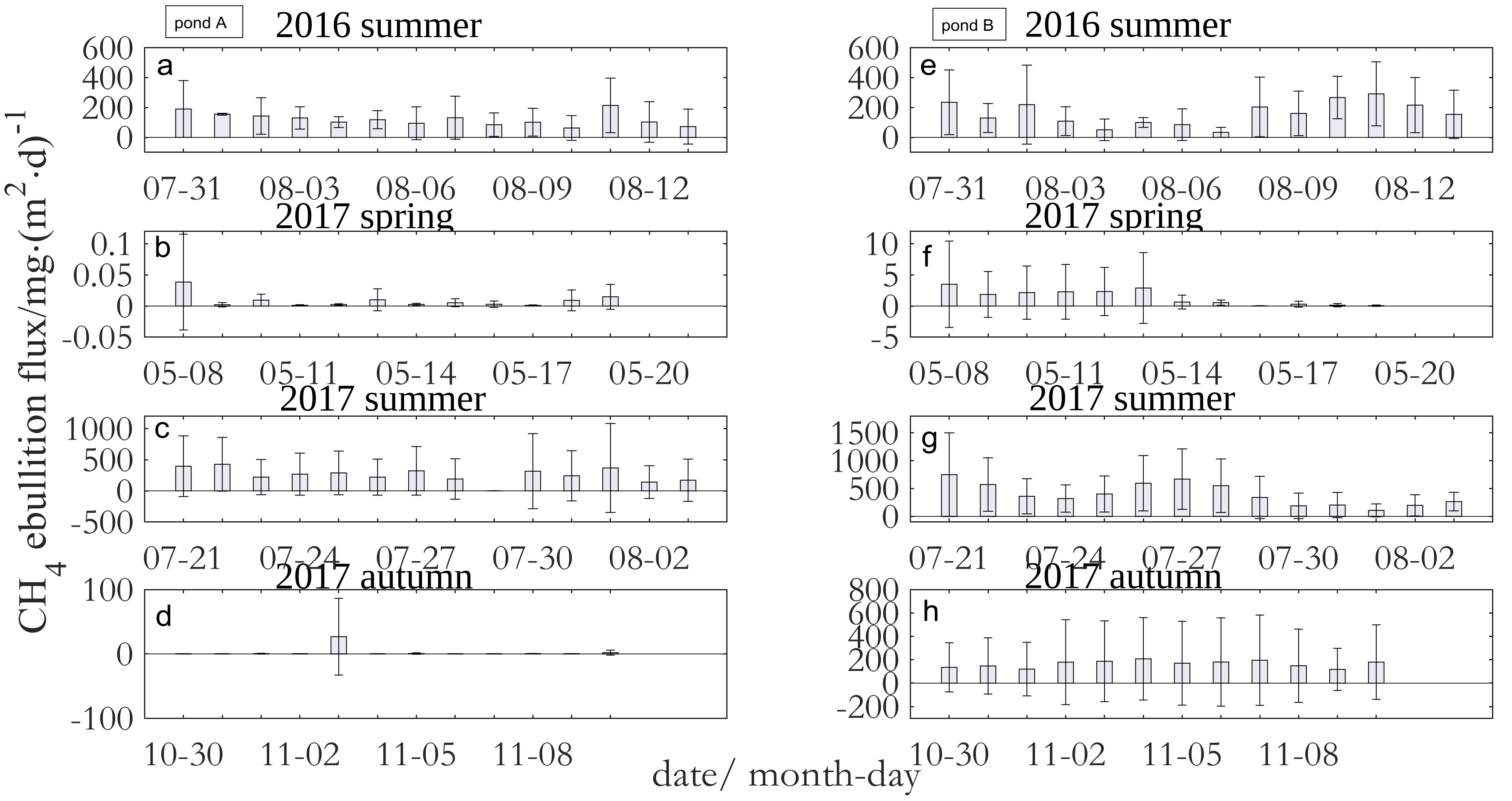


Fig.4 Seasonal variation of methane ebullition flux during the daily campaign

Seasonal variation of CH_4 diffusion flux

Summer>spring>autumn

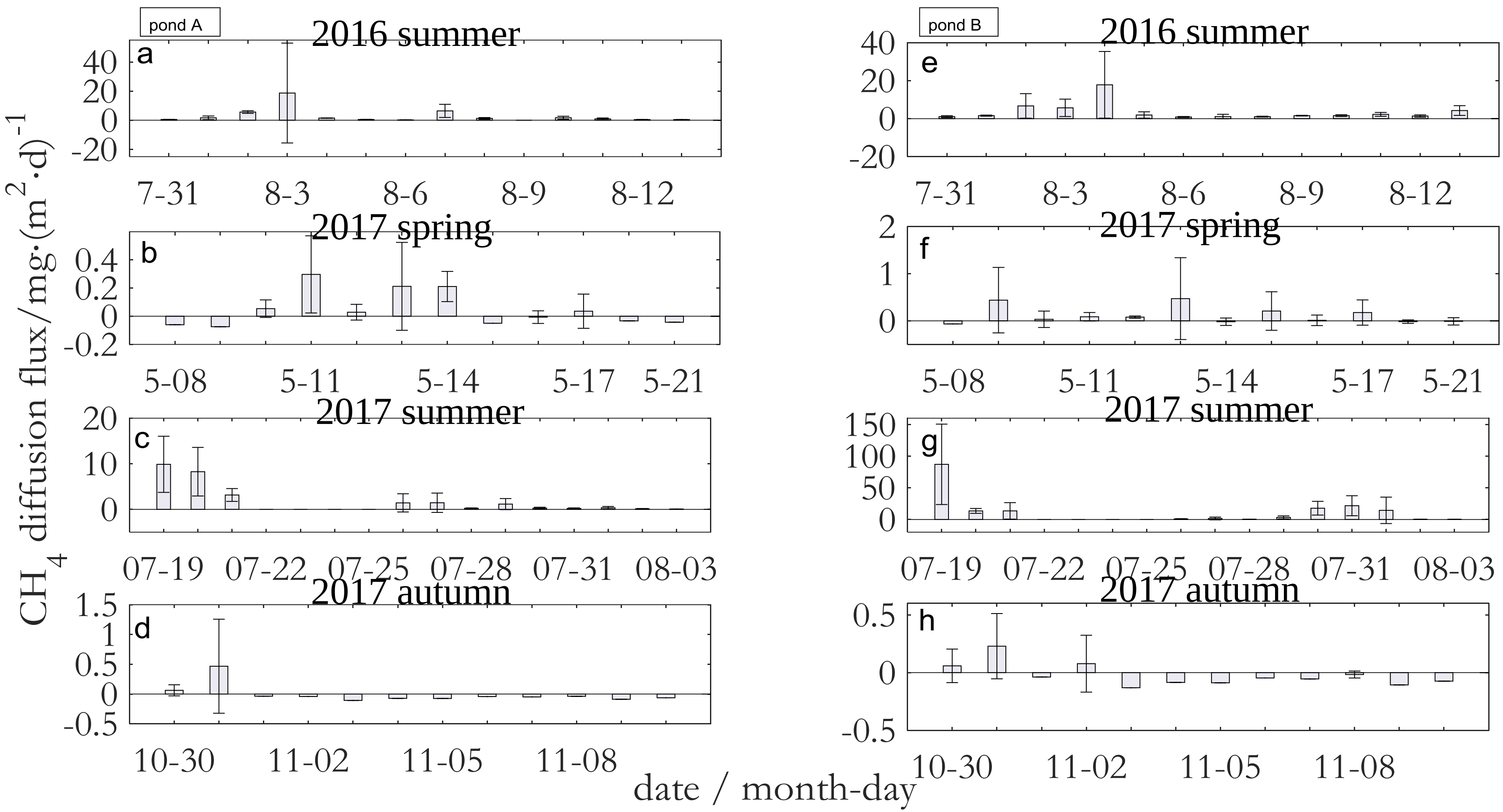


Fig.5 Seasonal variation of methane diffusion flux during the daily compaign

Seasonal variation of CH_4 bubble ratio

Table 1 Ratio of CH_4 ebullition flux to the total CH_4 flux in different seasons

Time		Pond A					Pond B			
	/n	Ebullition Flux	Diffusion Flux	Total Flux	Bubble Ratio		Ebullition Flux	Diffusion Flux	Total Flux	Bubble Ratio
	day	$/mg\cdot(m^2\cdot d)^{-1}$			/%		$/mg\cdot(m^2\cdot d)^{-1}$			/%
2016 summer	14	121.78	3.38	125.16	97.30		161.08	3.79	164.87	97.70
2017 spring	12	0.71	0.14	0.85	83.64		120.31	0.19	120.50	99.84
2017 summer	14	255.07	0.85	255.92	99.67		330.82	7.43	338.25	97.80
2017 autumn	12	2.54	0.26	2.80	90.78		186.01	0.13	186.14	99.93

Results and Discussion-2

Spatial Variabilities of the CH_4 Fluxes

Spatial patterns of CH_4 ebullition flux

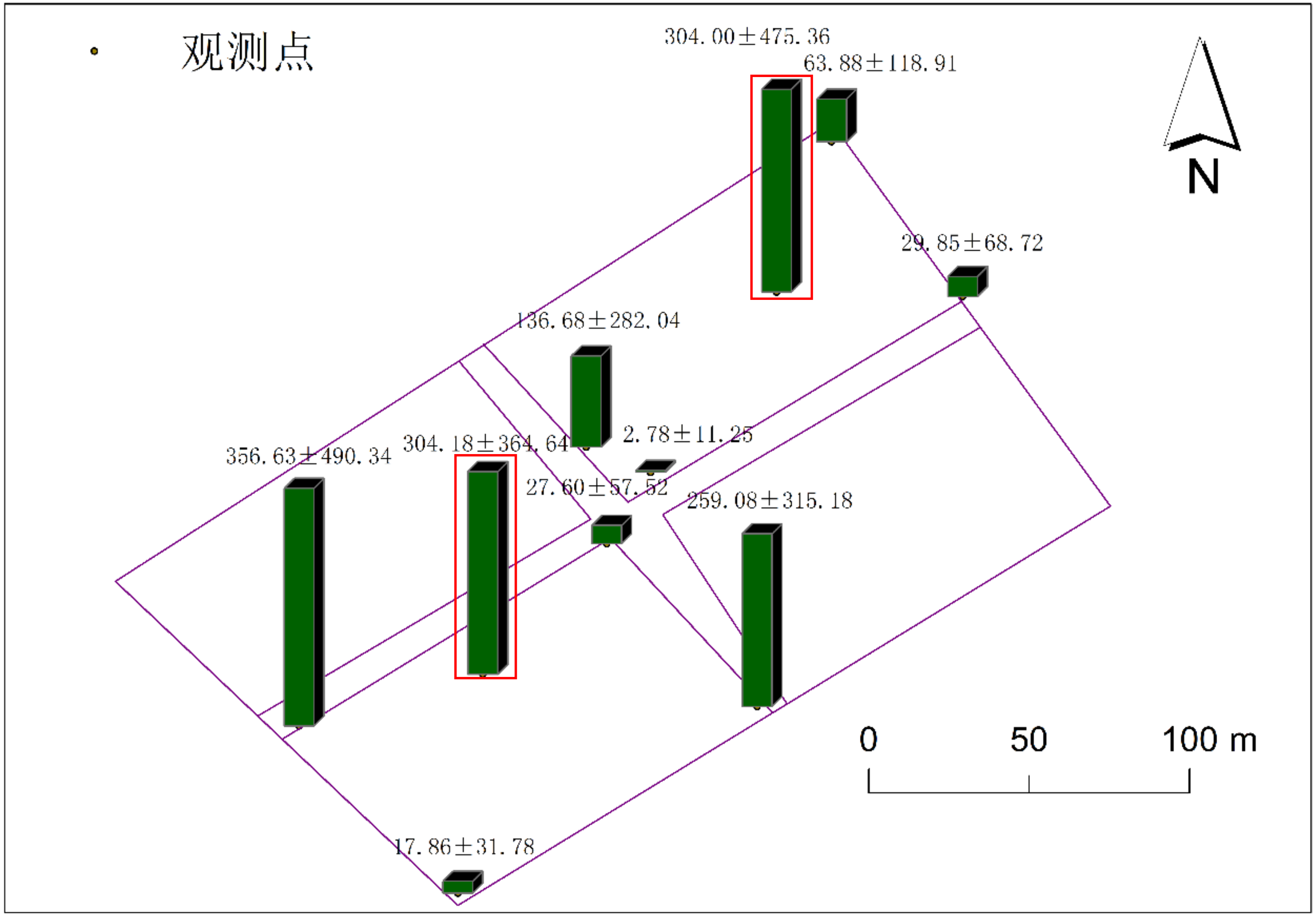


Fig.7 Spatial patterns of the CH_4 ebullition flux at the sampling locations

Spatial patterns of CH_4 diffusion flux

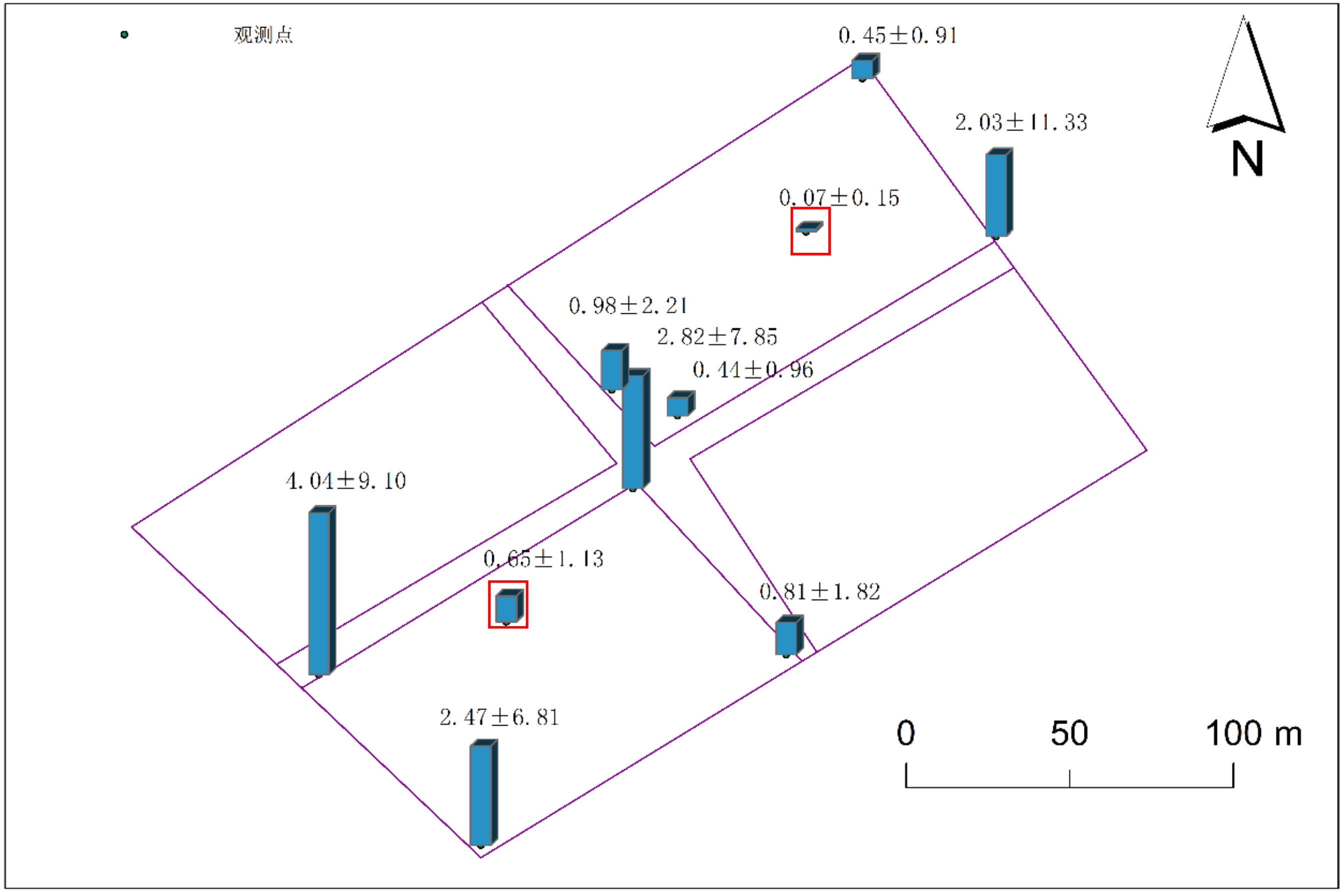


Fig.9 Spatial patterns of the CH_4 diffusion flux at the sampling locations

Spatial patterns of CH_4 fluxes

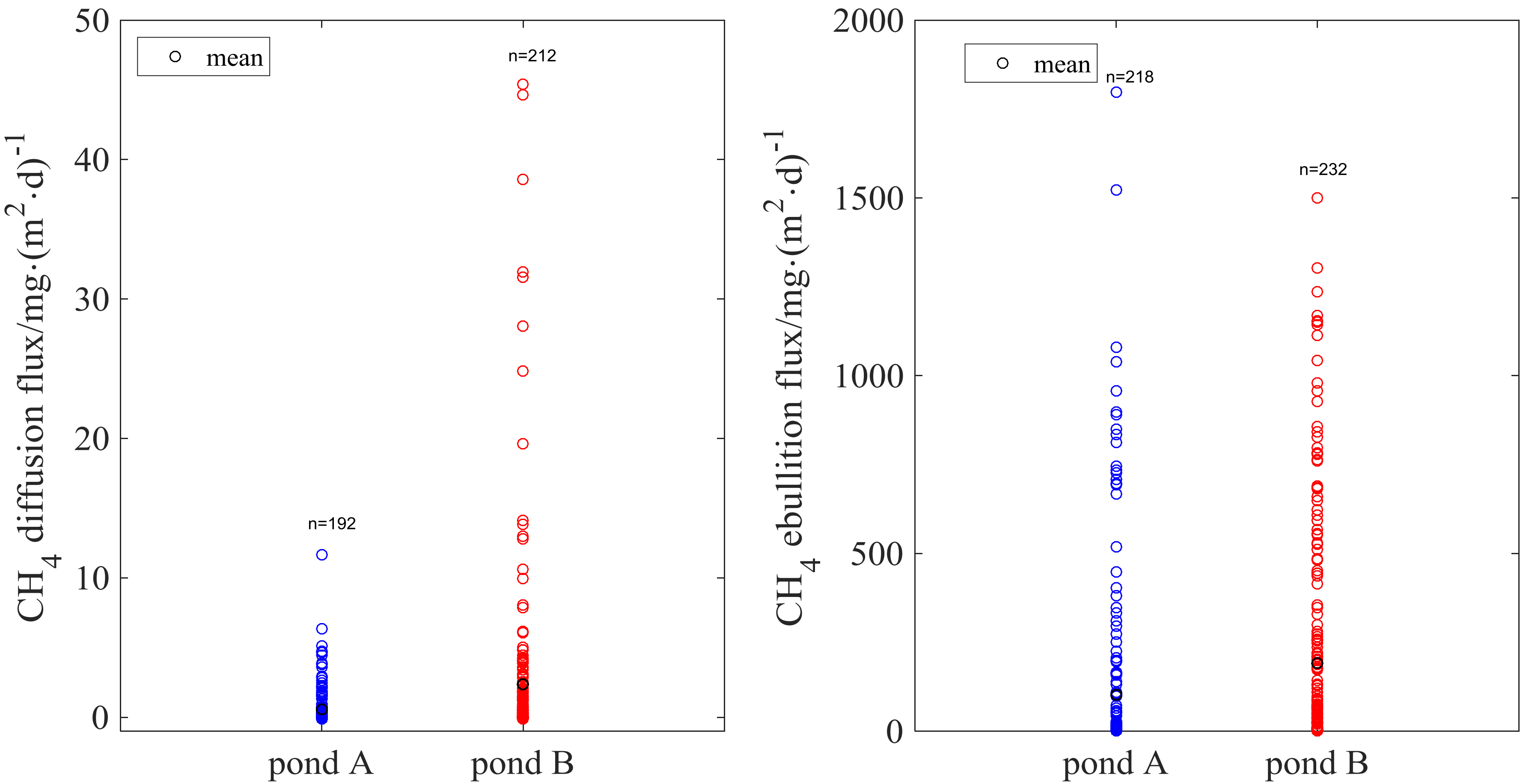


Fig.10 Spatial patterns of the CH_4 fluxes in the two ponds

Annual emission of CH_4 ebullition flux and diffusion flux

Table 2 annual emissions of CH_4 ebullition flux and CH_4 diffusion flux

	Ebullition Flux /mg·$(m^2 \cdot d)^{-1}$	**Diffusion Flux /mg·$(m^2 \cdot d)^{-1}$**	**Total Flux mg·$(m^2 \cdot d)^{-1}$**
2016 summer	143.36	2.61	145.97
2017 spring	58.11	0.061	58.17
2017 summer	331.97	4.14	336.11
2017 autumn	11.13	NaN	11.13
annual average	102.30	1.72	103.45

Results and Discussion-3

CH_4 Ebullition Flux of Influencing Factors

CH_4 ebullition flux and sediment temperature

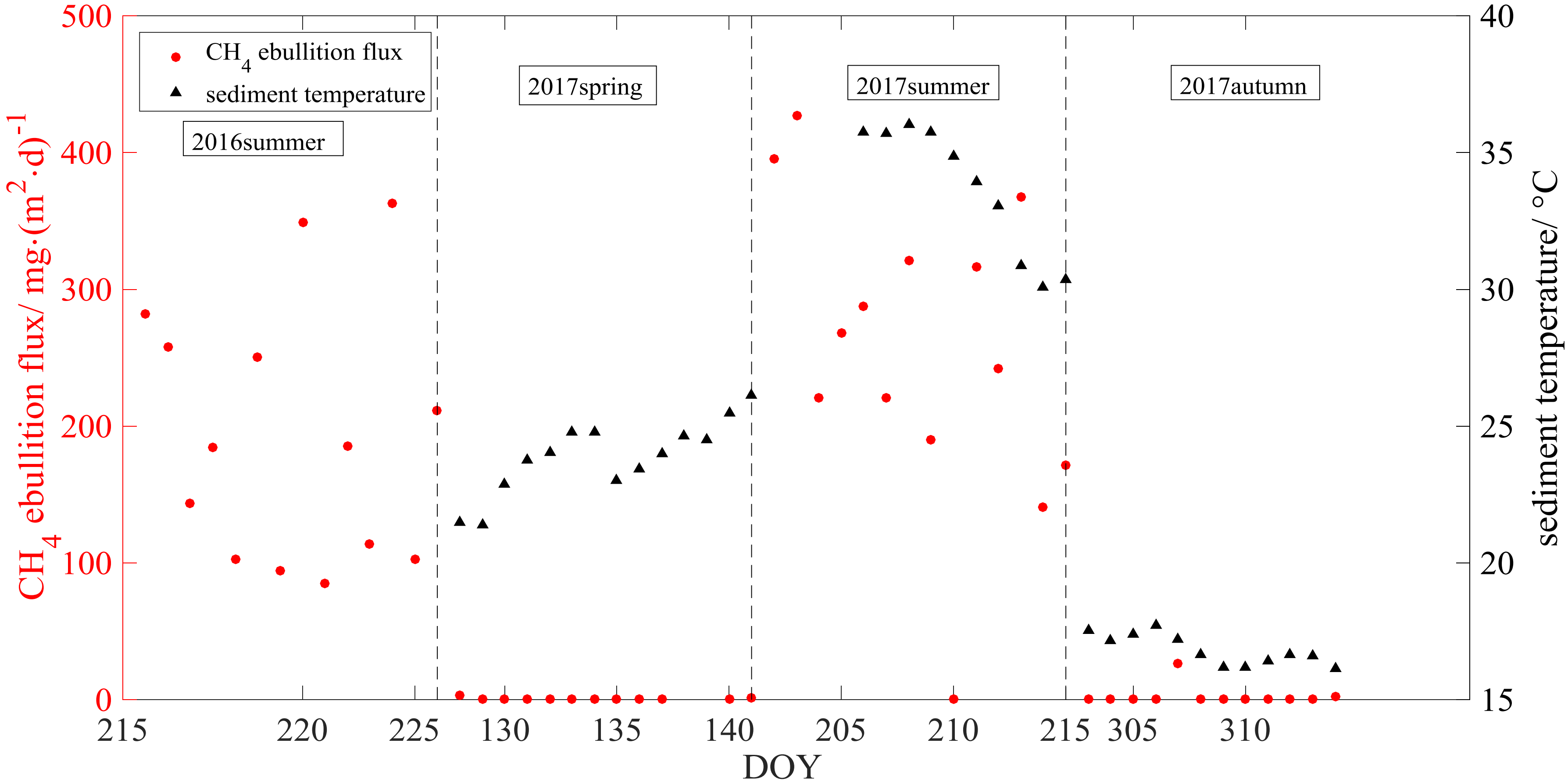


Fig.11 Time series between CH_4 ebullition flux and sediment temperature

CH_4 ebullition flux and sediment temperature

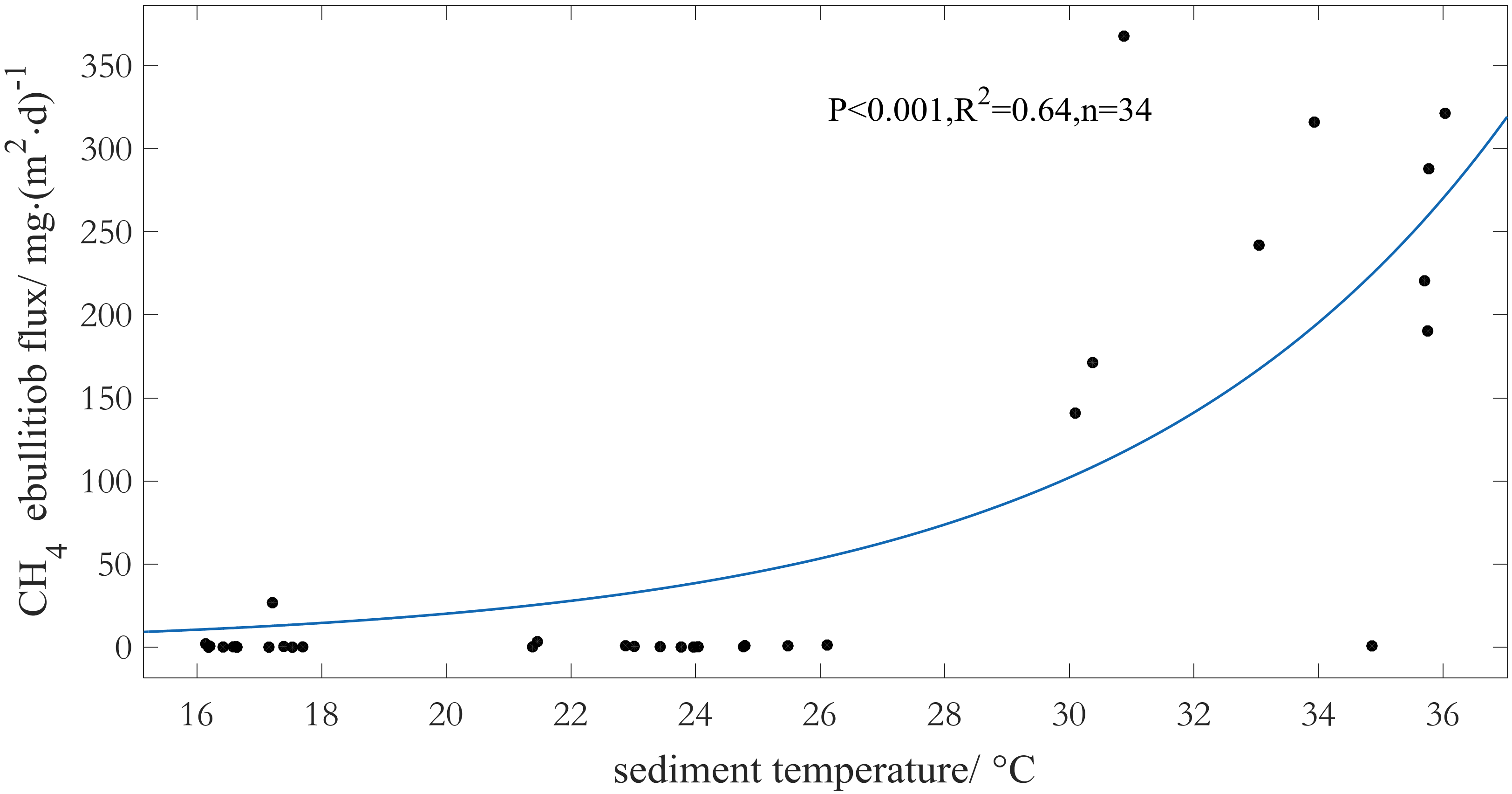


Fig.12 Relationship between CH_4 ebullition flux and sediment temperature

CH_4 ebullition flux and temperature at 20cm

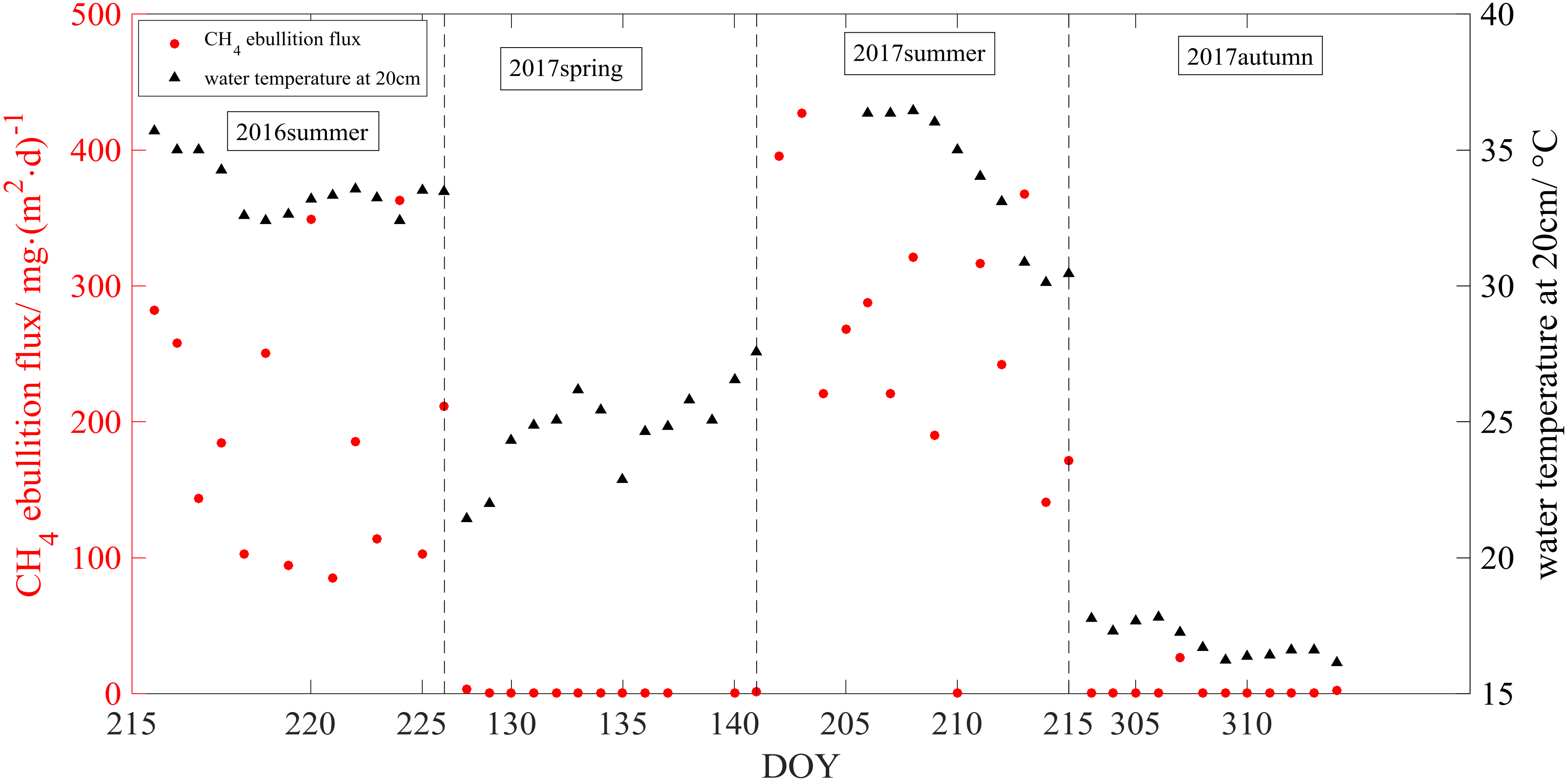


Fig.13 Time series between CH_4 ebullition flux and temperature at 20cm

CH_4 ebullition flux and temperature at 20cm

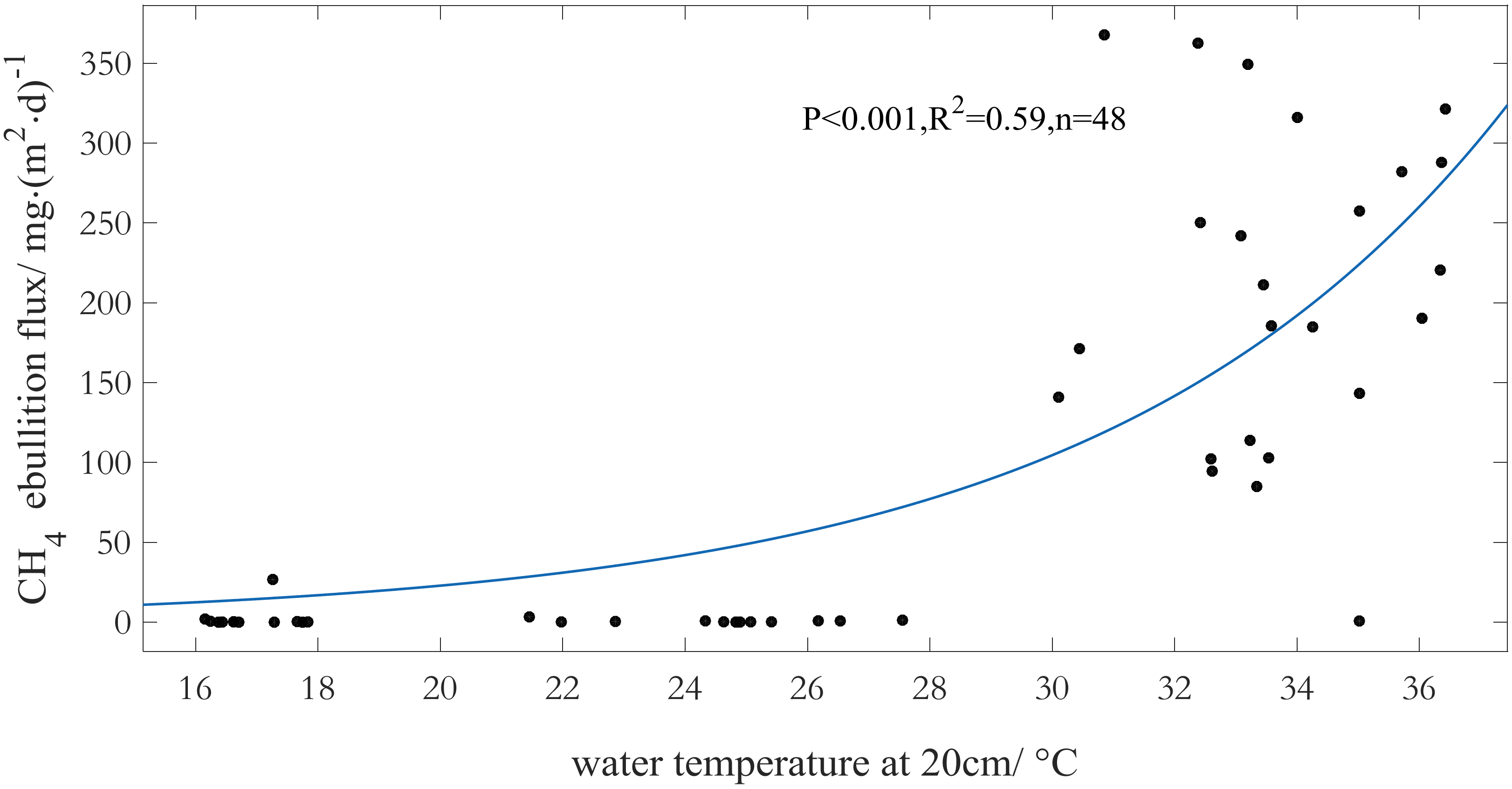


Fig.14 Relationship between CH_4 ebullition flux and temperature at 20cm

CH_4 ebullition flux and water depth

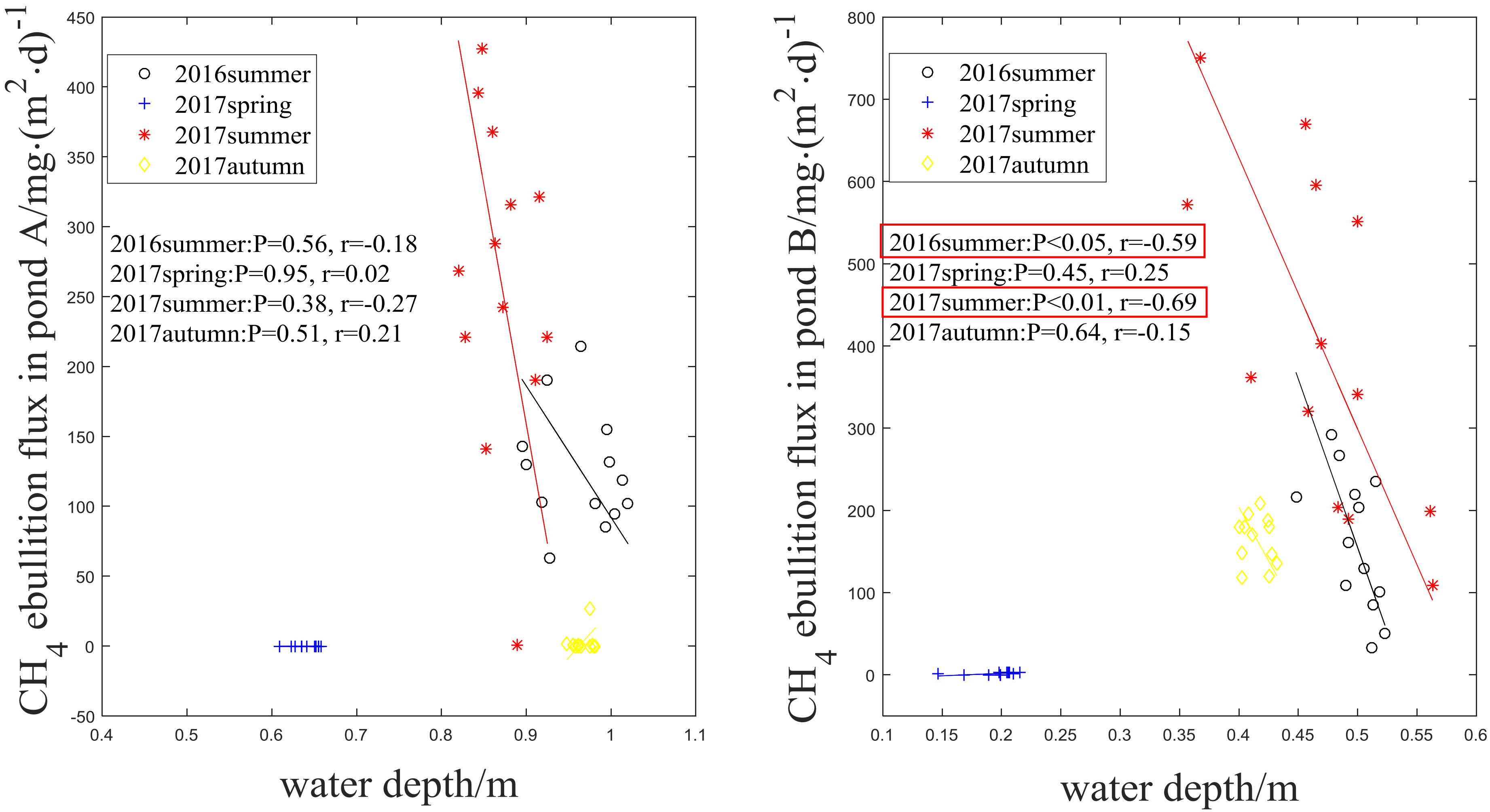


Fig.15 Relationship between CH_4 ebullition flux and water depth

CH_4 ebullition flux and wind speed

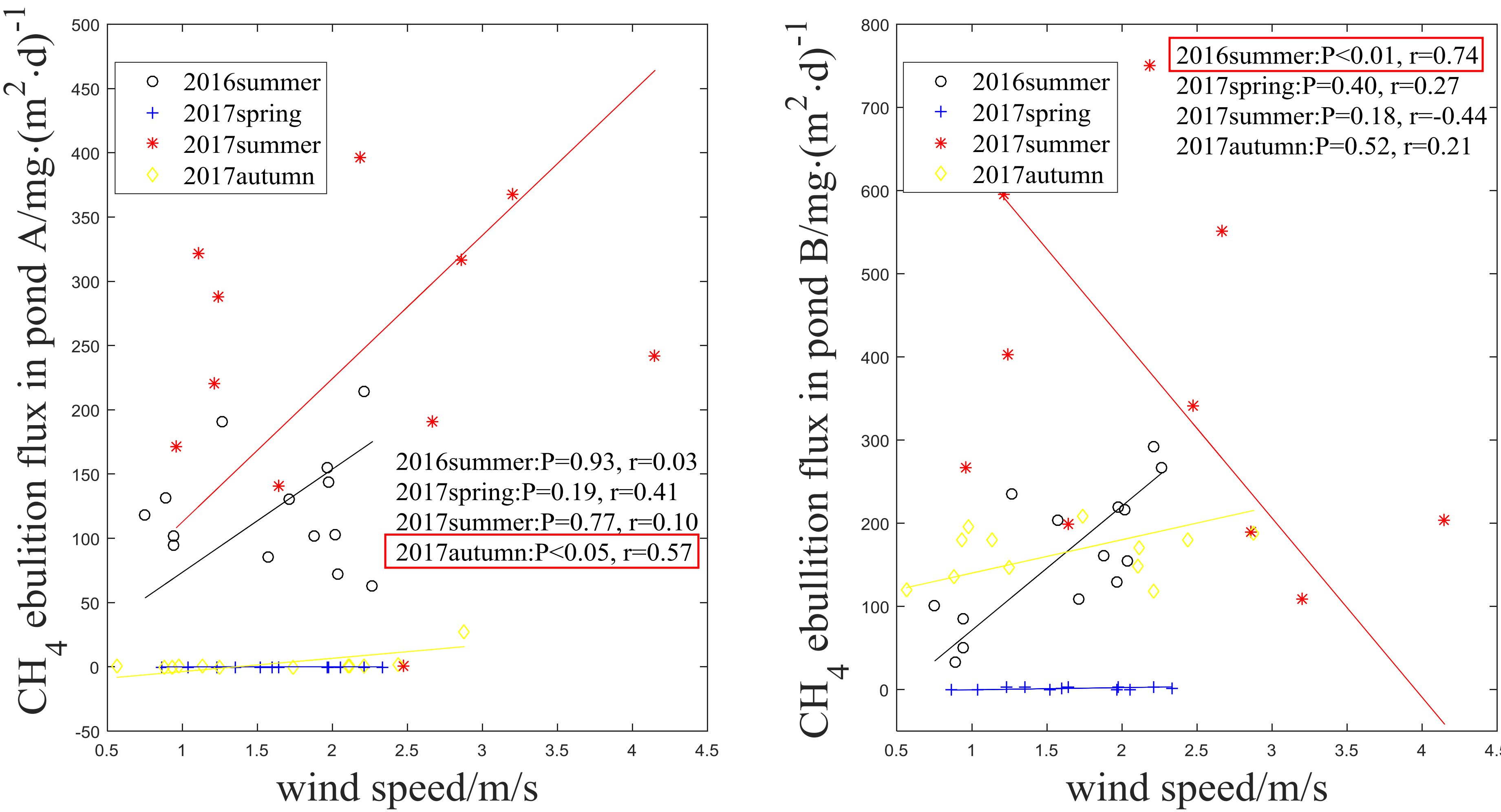


Fig.16 Relationship between CH_4 ebullition flux and wind speed

Comparison with other studies

Table3 Comparisons of the CH_4 ebullition flux in the inland water bodies in different regions

Latitude	Wetland	Region /Country	Sampling Time	Ebullition Flux /mg·(m²·d)⁻¹	Number /n	Bubble Ratio /%	Reference
60º~90ºN	3 lakes	Stordalen mire/Sweden	2009-06~2009-09, 2012-06~2012-09	10.0~22.6	572~1253	—	[20]
30º~60ºN	Ponds	Hubei/China	2013-07~2013-10	—	—	91.7~99.7	[43]
	5 ponds	Yichang/China	2014-11~2015-10	106.1~417.8	—	98.3~99.3	[17]
	Pond	YIchang/China	2013-07-22~2013-07-24	595.2	—	96.4~99.7	[18]
	2 ponds	Anhui/China	2016-07~2017-11	102.30	450	83.6~99.9	This study
	Hua lake	Qinghai–TIbetan/China	2006-06~2007-08	362.4	—	—	[44]
	Wuliangsuhai lake	Neimenggu/ China	2003~2004	53.0~408.0	—	—	[27]
	Priest Pot	The United Kimdom	1997-05~1997-10	192	—	96	[15]
	Catchment	Seberia	2014-07~2014-08	15.4	—	—	[45]
	Thermokarst lake	Seberia	2003-04~2004-05	46.7	—	—	[46]
	10 Shallow lakes	Qu ébec/ Canada	2011-06~2011-08, 2011-10	73.8	98	—	[19]
	3 lakes	Qu ébec/ Canada	2012-05~2012-0511, 2014-07~2014-09	17.6	139	—	[19]
	Beaver pond	Thompson/ Canada	1994-05-01~ 1994-09-15	83.8	—	—	[25]

(continued)

Latitude	Wetland	Region /Country	Sampling Time	Ebullition Flux /mg·(m²·d)⁻¹	Number /n	Bubble Ratio /%	Reference
0~30ºN	**Orinoco River**	**Venezuela**	**1991-07~1992-10**	**114**	**—**	**65**	**[47]**
	Lago Loiz lake	Puetro/ Panama	1994-07-26~ 1994-07-27	8~24	—	—	[26]
	Gatun lake	Panama	1988-02~1988-05	5~1088	—	—	[16]
0~30ºS	Peatland lake	Panama	1988-11~1988-12	40	40	—	[48]
	Manaus lake	Amazon	1988-01~1988-12	44.8	90	59~73	[48]
	Calado lake	Amazon	1986-09	164.8	—	69	[49]
	16 lakes	Pantanal	2006-09, 2006-12, 2008-11	131.8~216	24	91	[29]
	Miranda river	Pantanal	2004-03, 2004-06, 2004-09, 2004-12, 2005-03	142.4	—	90	[50]

CH_4 ebullition flux with latitude

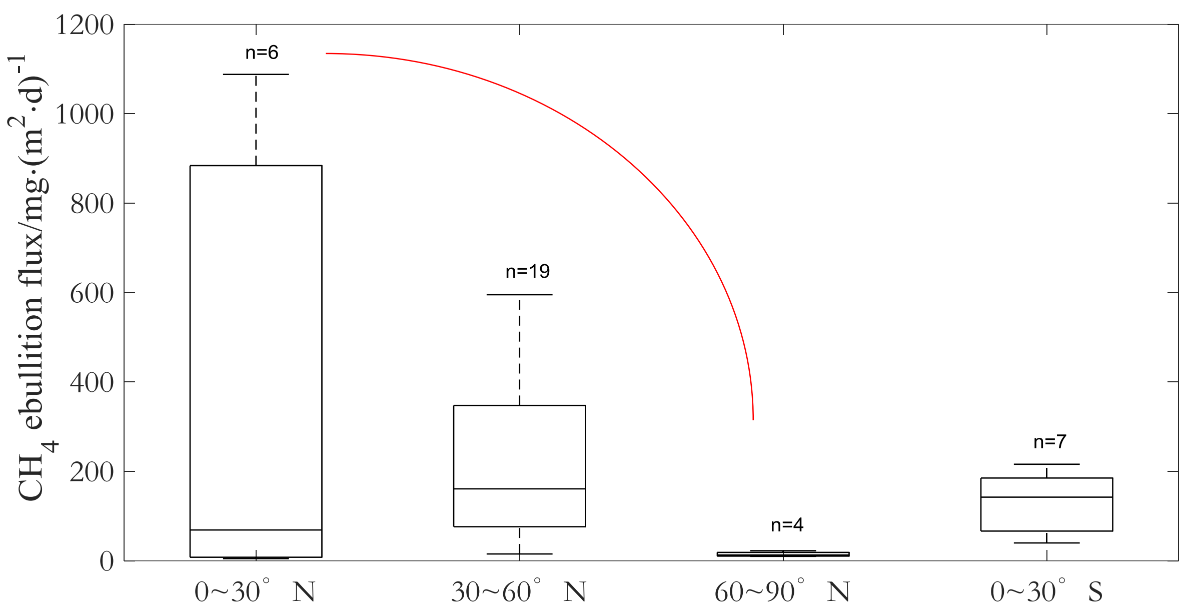


Fig.18 The CH_4 ebullition fluxes in different latitude ranges

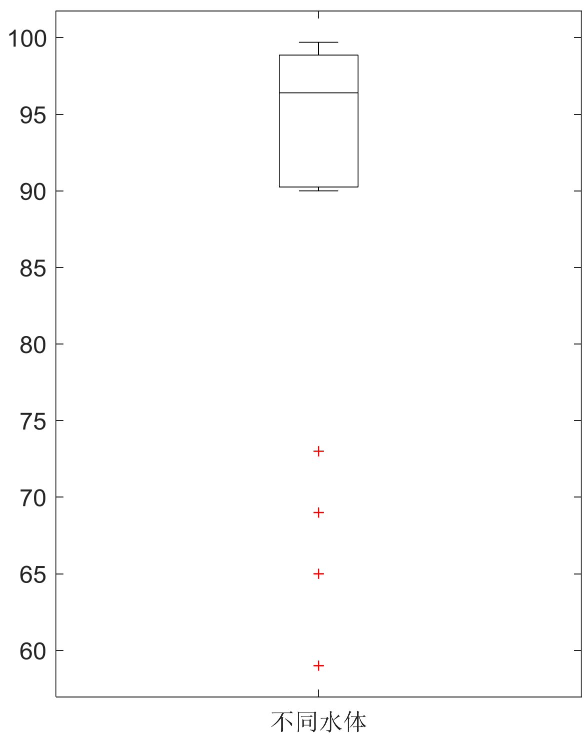


Fig.19 The CH_4 bubble ratios of different inland water bodies

Conclusion

- There were significant **temporal** (seasonal and inter-annual) **variability** and **spatial patterns** for the CH_4 ebullition flux and CH_4 diffusion flux, and also diurnal variation for the CH_4 ebullition flux.
- In the four observation periods, average CH_4 ebullition flux was 102.30 $mg \cdot (m^2 \cdot d)^{-1}$, annual CH_4 diffusion flux was 1.72 $mg \cdot (m^2 \cdot d)^{-1}$, and the ratio of the CH_4 ebullition fluxes to the total CH_4 fluxes was always higher than **83%**, which indicated bubbling was the main pathway of CH_4 emission from small ponds.
- The main controlling factors for the temporal variability of the CH_4 ebullition flux were **sediment temperature**, **water temperature at 20 cm depth**, **water depth and wind speed**.

Thank you for your attention!

Have a good day~