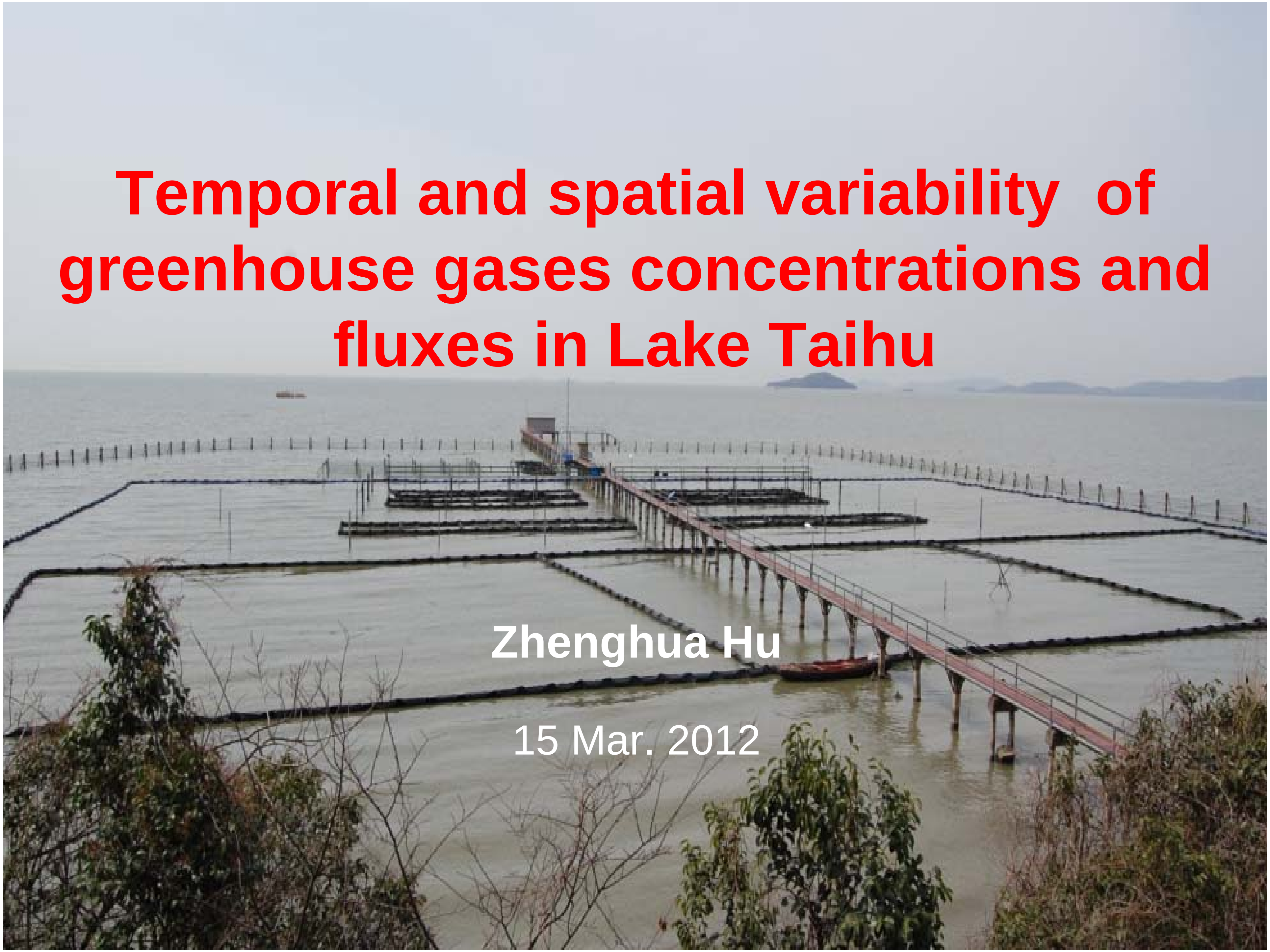


Temporal and spatial variability of greenhouse gases concentrations and fluxes in Lake Taihu

Zhenghua Hu

15 Mar. 2012

Outline

1 Background
2 Questions/Objectives
3 Methods
4 Results
5 Discussion
6 Conclusion

1 Background

- Mostly lakes (boreal, temperate, and tropical lakes) are typically supersaturated with CO_2, and act as sources of CO_2 and CH_4 emissions to the atmosphere (Cole et al. 1994; Schrier-Uijl et al. 2011).

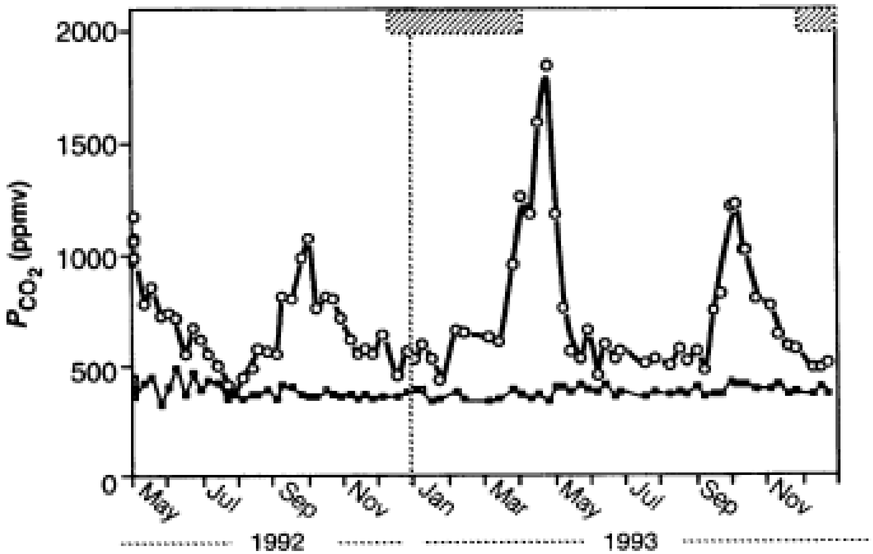
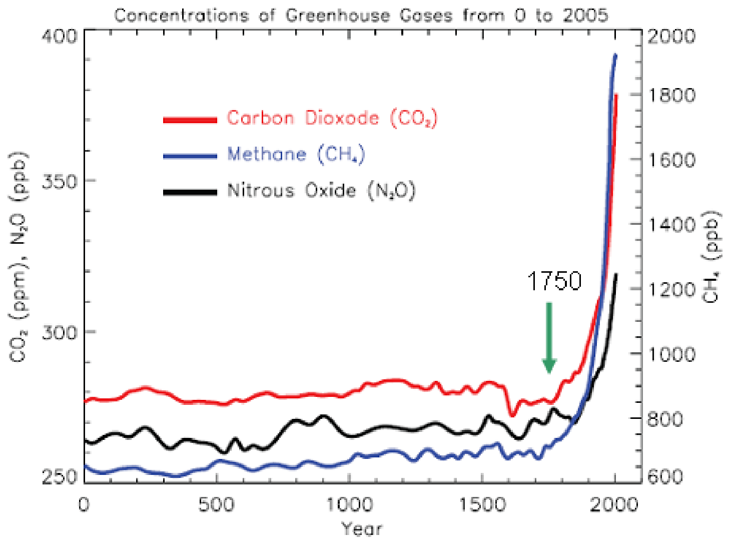


Fig. 1. Seasonal cycle of direct measurements of the P_{CO_2} in the surface water of Mirror Lake (circles) and in the overlying air (squares), showing persistent supersaturation. Mirror Lake is a soft water lake in New Hampshire (15); ppmv, parts per millic The hatched areas cover.

Cole et al. 1994



- It has been estimated that lakes annually emit 513 Tg C CO_2 (Cole et al. 1994), and 8-48 Tg CH_4, which is 6-16% of the global natural CH_4 emissions (Bastviken et al. 2004; St. Louis et al. 2000).

1 Background

- CO_2 is produced by respiration and biological processes in sediments and water.
- CH_4 emission is the balance of two counteracting processes: methanogenesis in anoxic conditions and the oxidation of the generated CH_4 (Minkkinen and Laine 2006; Schrier-Uijl et al. 2011). Most of the CH_4 that remains unoxidised will be emitted by diffusive flux to the atmosphere.

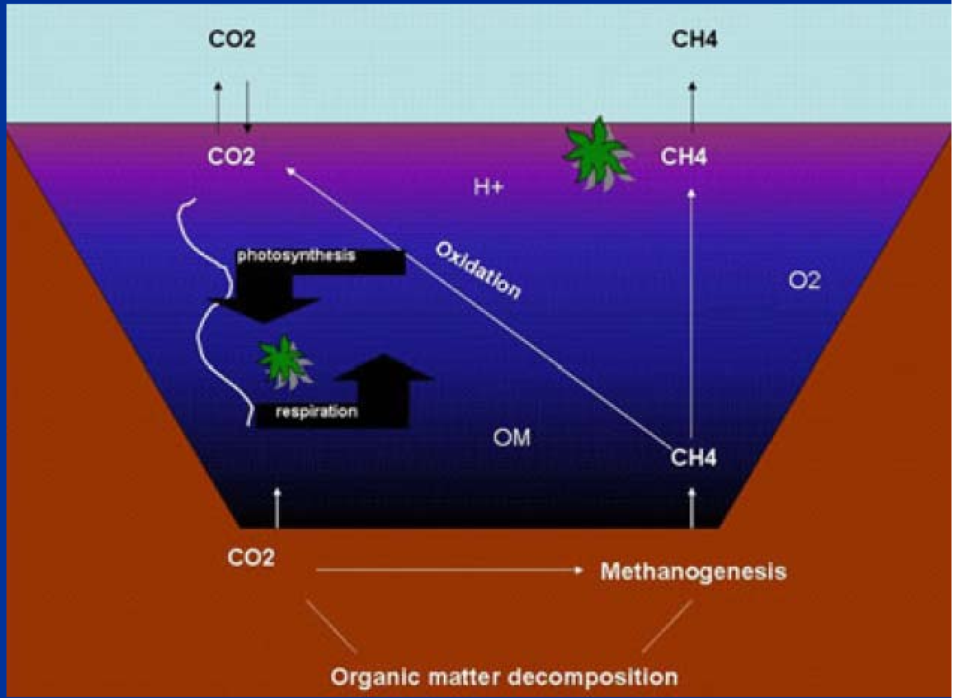


Fig. Simplified illustration of CO_2 and CH_4 dynamics in water bodies (OM,organic matter) (Schrier-Uijl et al. 2011).

1 Background

- N_2O generation in lakes generally requires steep oxygen gradients allowing sequential aerobic nitrification and anaerobic denitrification to take place (Seitzinger 1990).
- The eutrophic lakes could be supersaturated with N_2O and act as sources of N_2O to the atmosphere. While, the shallow lakes are not large sources for atmospheric N_2O (Huttunen et al. 2003).
- The freshwater lakes are only moderate sources of N_2O (Mengis et al. 1997).

- Yet though it is likely that lakes with organic-rich sediment contribute especially significantly to regional greenhouse gas balances, they are poorly studied and very little is known about their underlying biogeochemical processes (Saarnio et al. 2009).
- More data are needed from lakes situated in different geographical regions to obtain a better estimate of the atmospheric importance of natural lakes (Huttunen et al. 2003).

1 Background

- Lakes have not been incorporated in previous regional or global greenhouse gas budgets.

2 Questions

- How to quantify shallow freshwater lakes contribute to the greenhouse gas.
- Which factors regulate the flux.
- Lake Taihu acts as a source or sink of greenhouse gas (CO_2/CH_4/N_2O).

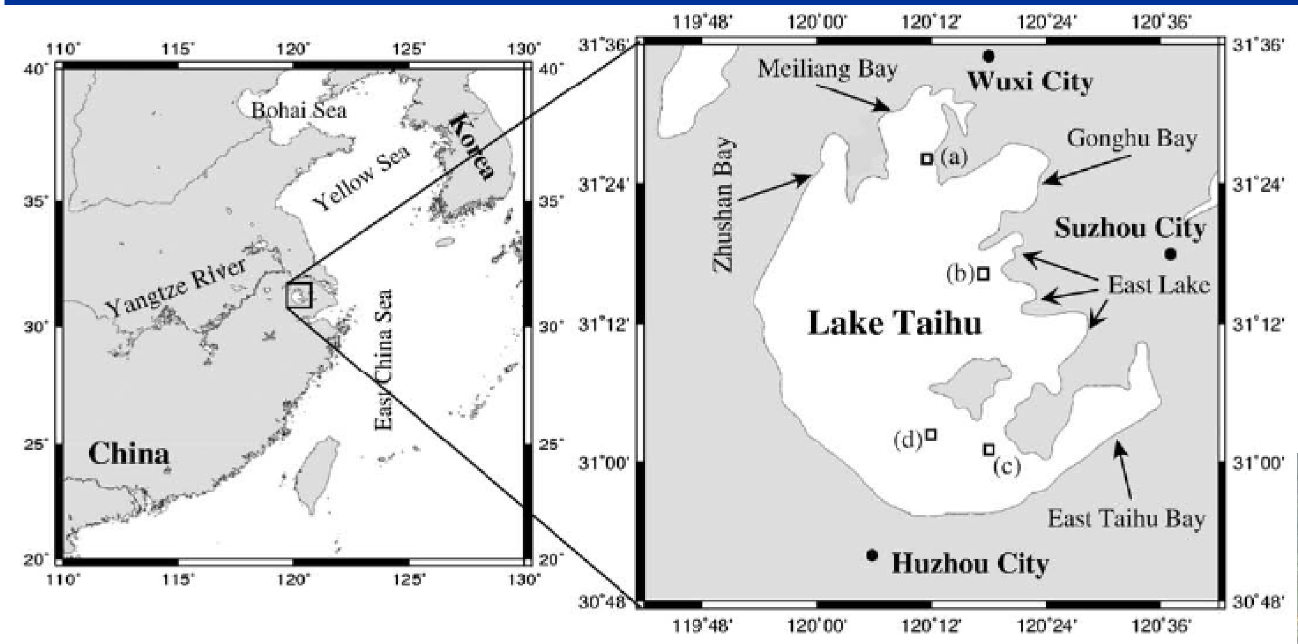
Objectives

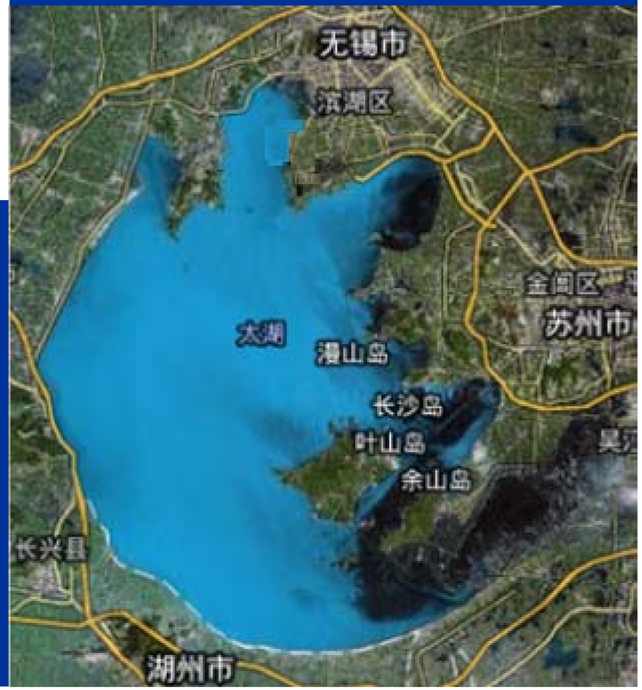
- To quantify CO_2, CH_4, and N_2O fluxes from Lake Taihu.
- To identify the factors that regulate the emissions of CO_2, CH_4, and N_2O from lake.

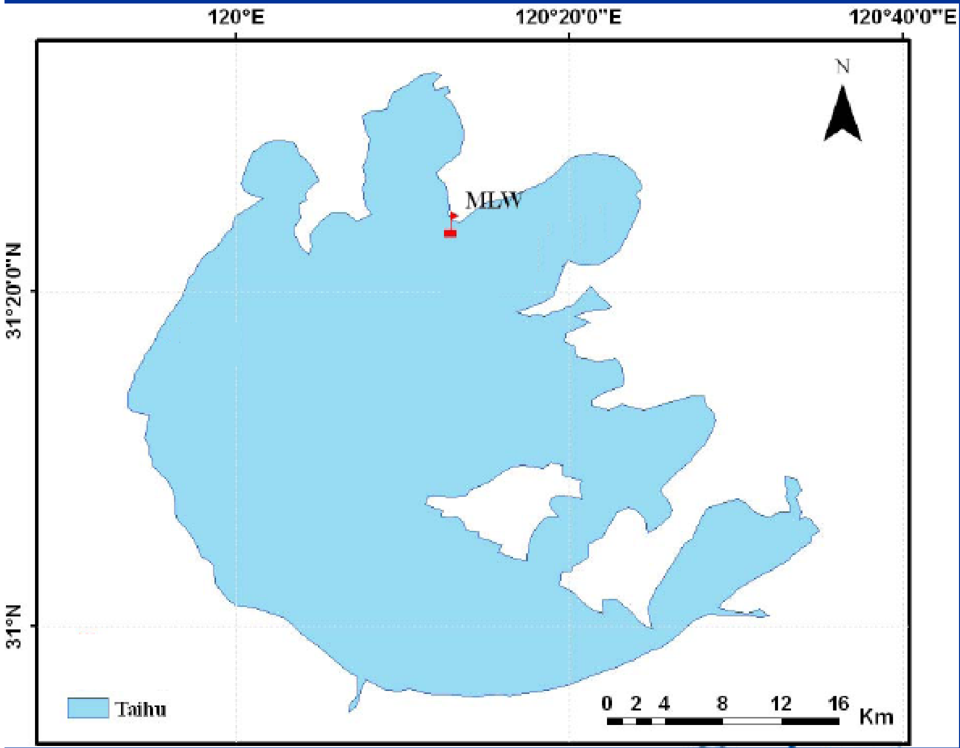
Significance: Data on lake-atmosphere greenhouse gas exchange would improve our understanding of the fundamentals of regional greenhouse gas budgets.

3 Methods

3.1 Study sites

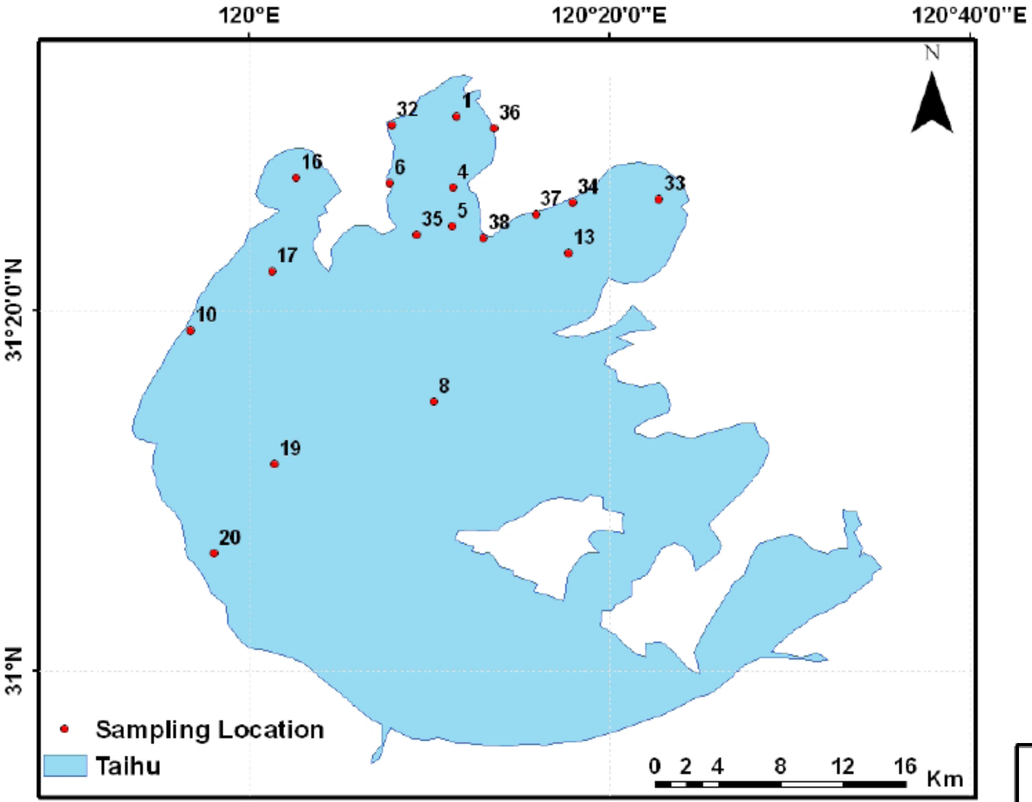


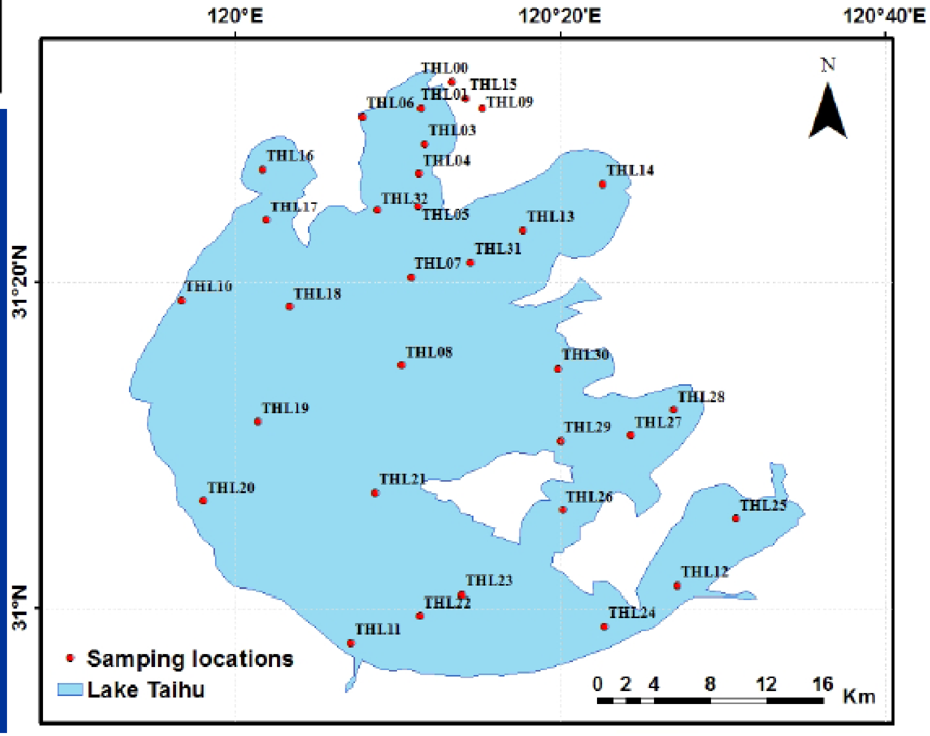




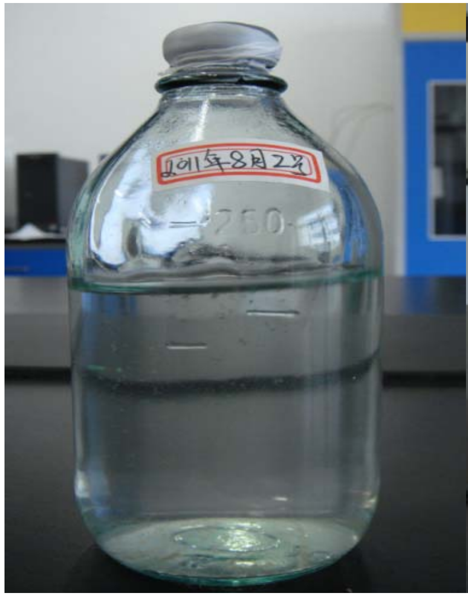
Sampling site

Sampling sites

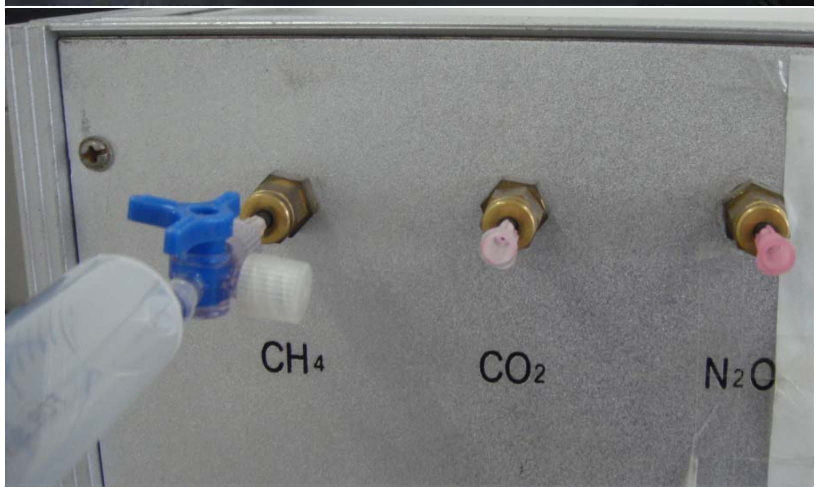




3.2 Measurements and calculation of GHG concentration



Pure nitrogen gas (99.999%)
2% $CuSO_4$



GHG concentration of gas in headspace

$$\frac{CH_4\,\text{标准气体浓度}}{CH_4\,\text{标准气体峰面积}} = \frac{\text{样品气体}\,CH_4\,\text{浓度}}{\text{样品气体}\,CH_4\,\text{峰面积}}$$

Calculation of GHG concentration in water of lake

$$[X]_L^0 = [X]_G \times (1/K + \beta)$$

$$K = [X]_G / [X]_L$$

$$\beta = \mathbf{V_G / V_L}$$

$[X]_G$ measured by GC

$[X]_L$ calculated by material equilibrium

3.3 Calculation of GHG fluxes

$$F = k \times (Cw - Ceq) \tag{1}$$

where k is the gas transfer coefficient (m d^{-1}), Cw the measured GHG concentration (mol m^{-3}) in the surface water (at the depth of 20 cm), Ceq the GHG concentration in water that is in equilibrium with the atmosphere at in situ temperature.

$$k/k_{600} = (\mathrm{Sc}/\mathrm{Sc}_{600})^{-n} \tag{2}$$

where Sc is the Schmidt number, Sc_{600} is the Schmidt number 600 at the temperature of 20 ^{0}C. The factor k_{600} is the corresponding value for Sc600.
n = 0.5, $U_{10} > 3.7$ m s^{-1}; n = 2/3, $U_{10} < 3.7$ m s^{-1}.

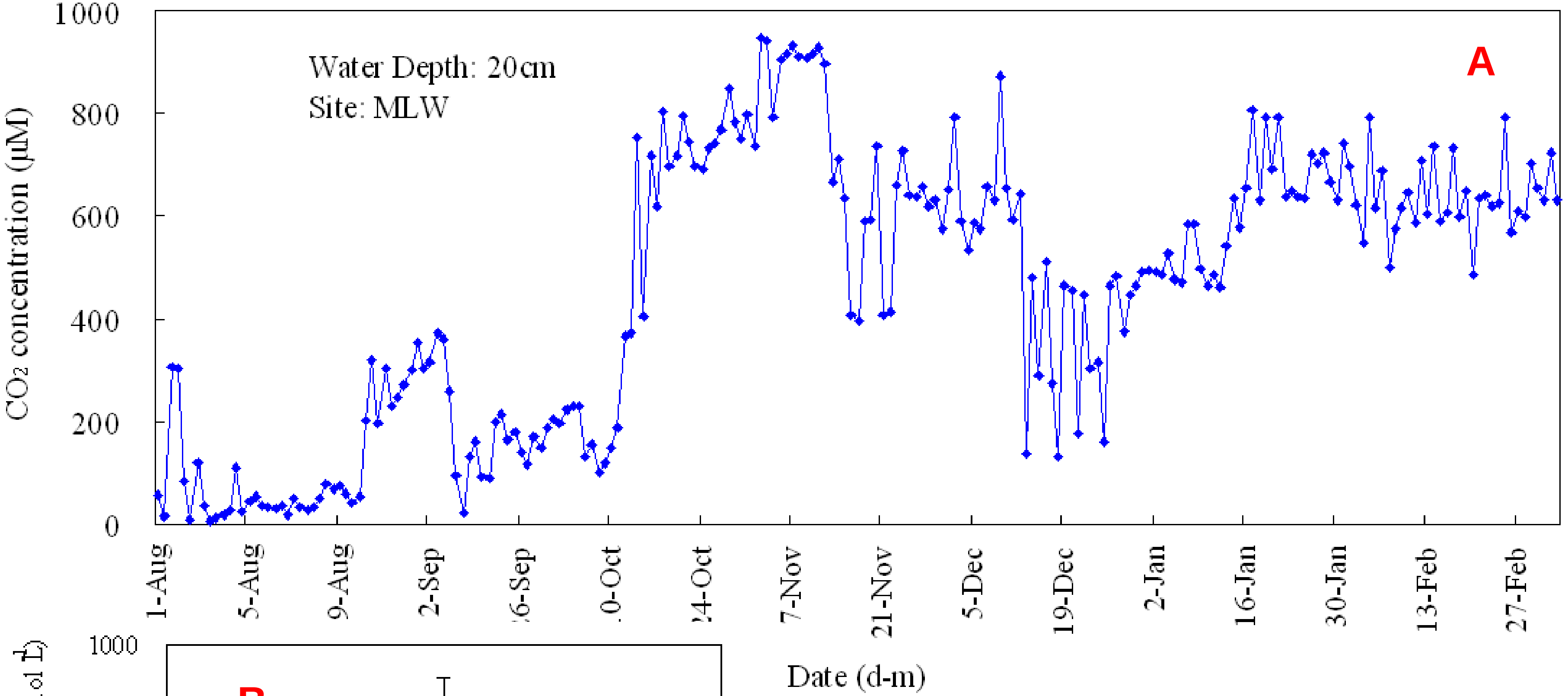
$$k_{600} = 2.07 + 0.215 \times U_{10}^{1.7} \tag{3}$$

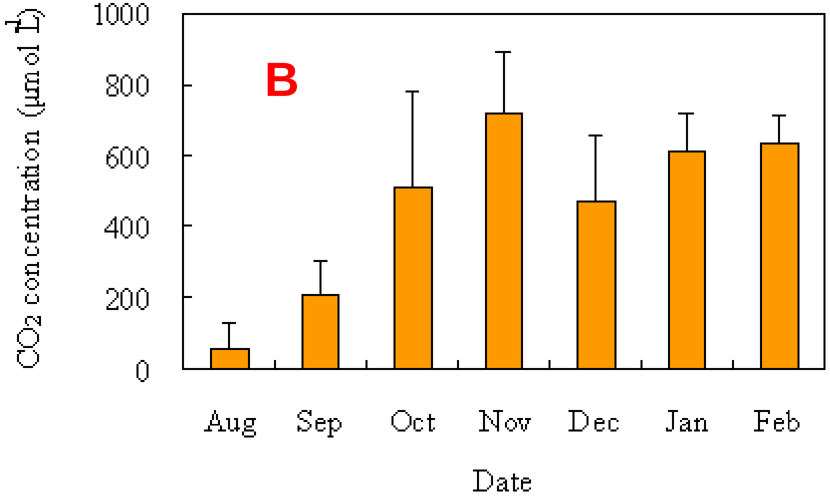
$$U_{10} / U = \ln(10/Z_0) / \ln(3.5/Z_0) \tag{4}$$

Z_0, roughness height, $Z_0 = 0.00035$ m; U, wind speed at 3.5 m height.

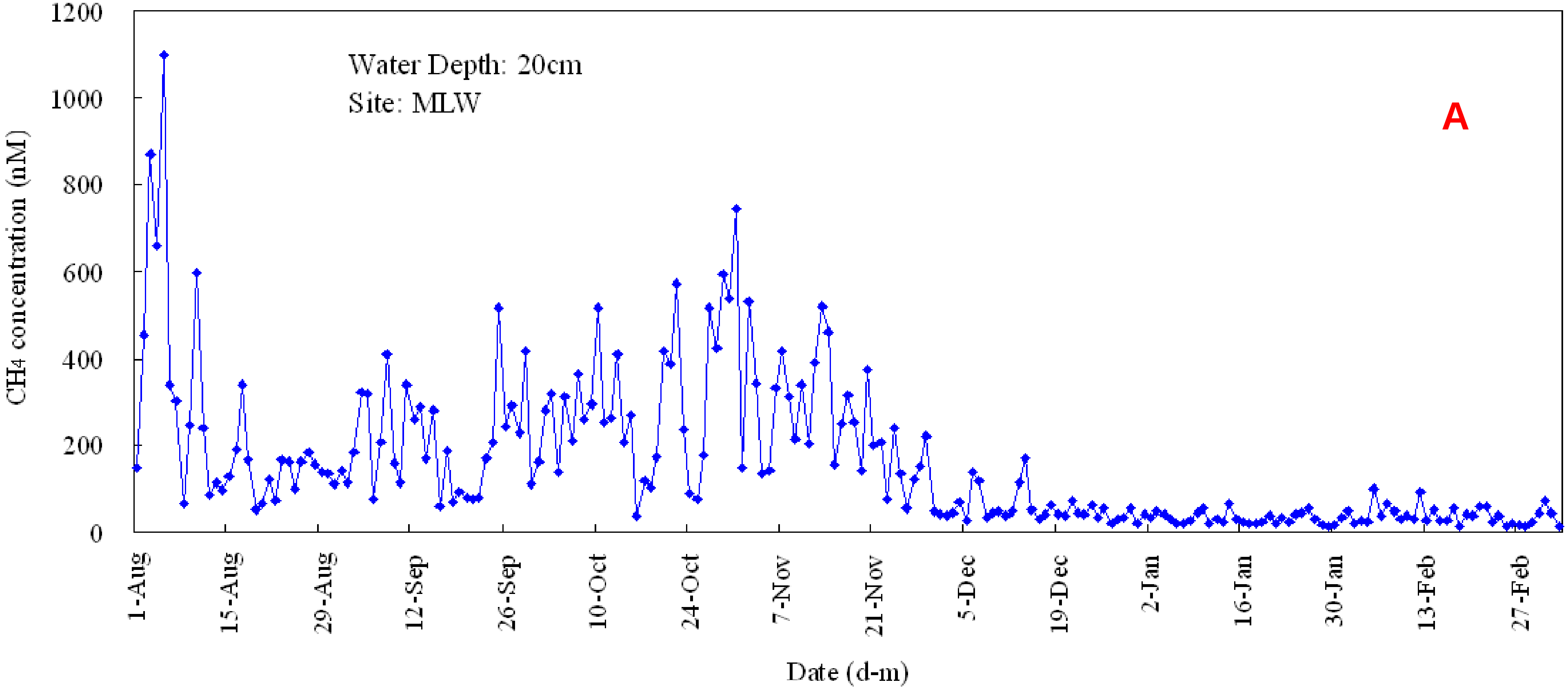
4 Results

4.1 Temporal variability of $CO_2/CH_4/N_2O$ concentration

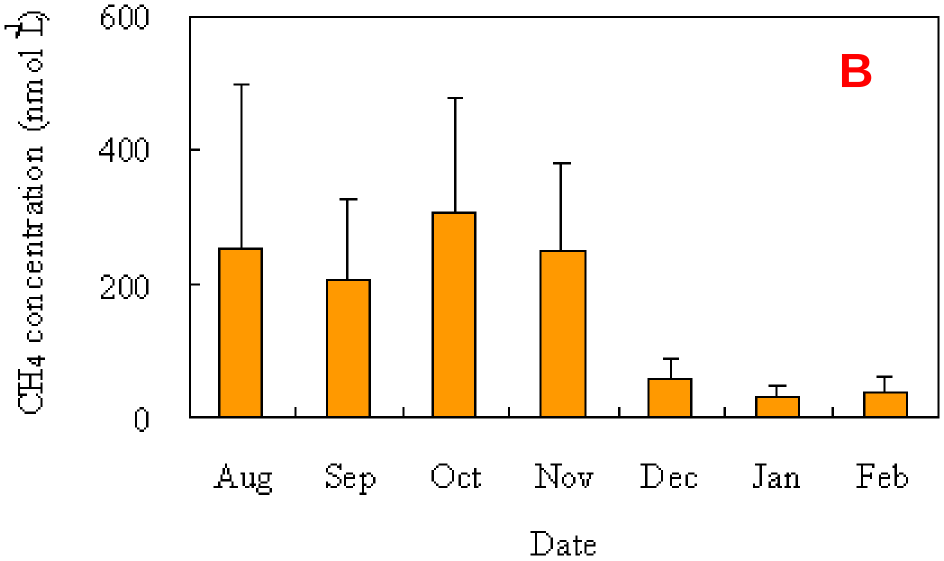




Site: MLW

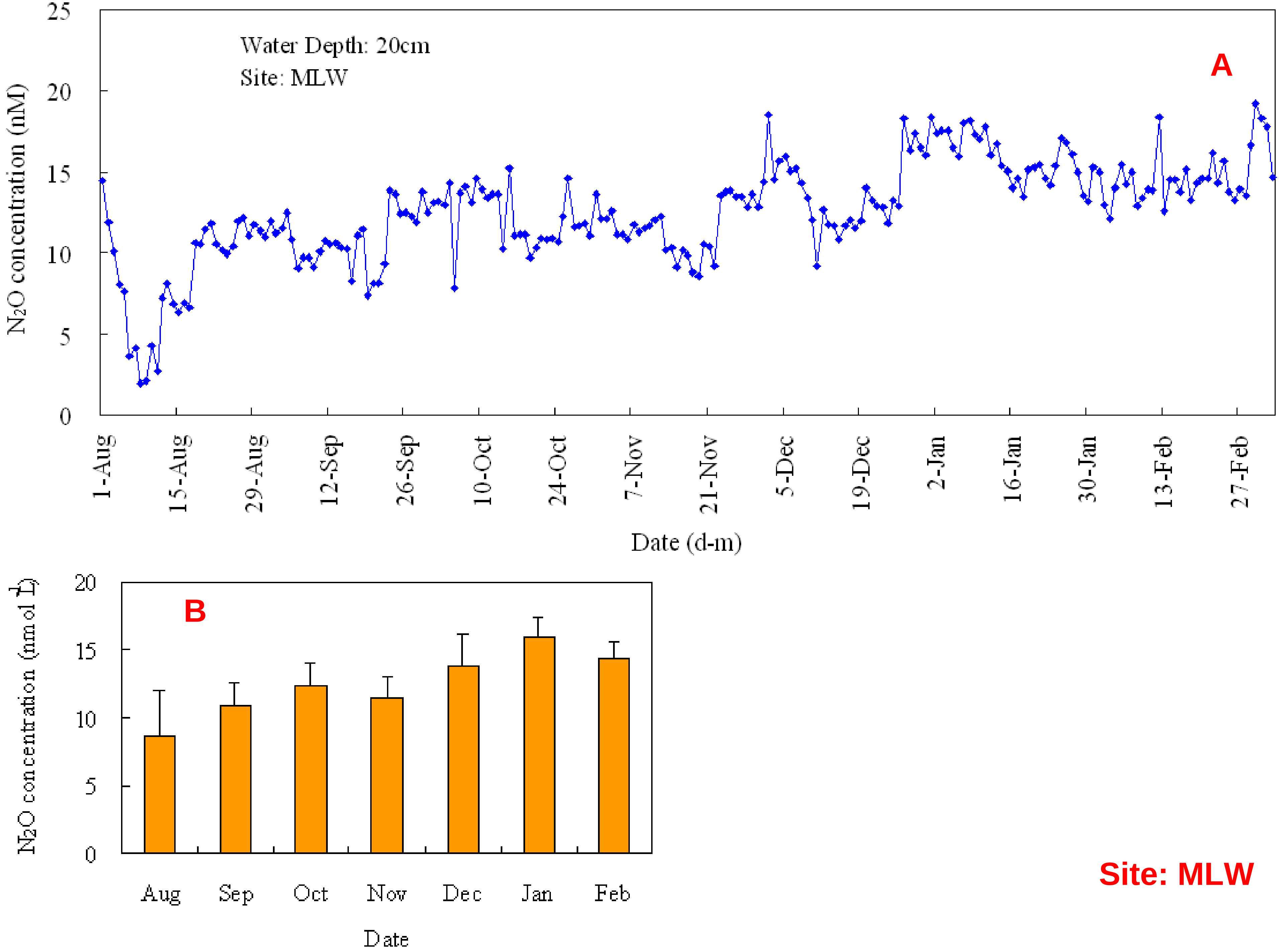


Water Depth: 20cm
Site: MLW
A
CH4 concentration (nM)
1200
1000
800
600
400
200
0
1-Aug
15-Aug
29-Aug
12-Sep
26-Sep
10-Oct
24-Oct
7-Nov
21-Nov
5-Dec
19-Dec
2-Jan
16-Jan
30-Jan
13-Feb
27-Feb
Date (d-m)



B
CH4 concentration (nmol L-1)
600
400
200
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

Site: MLW

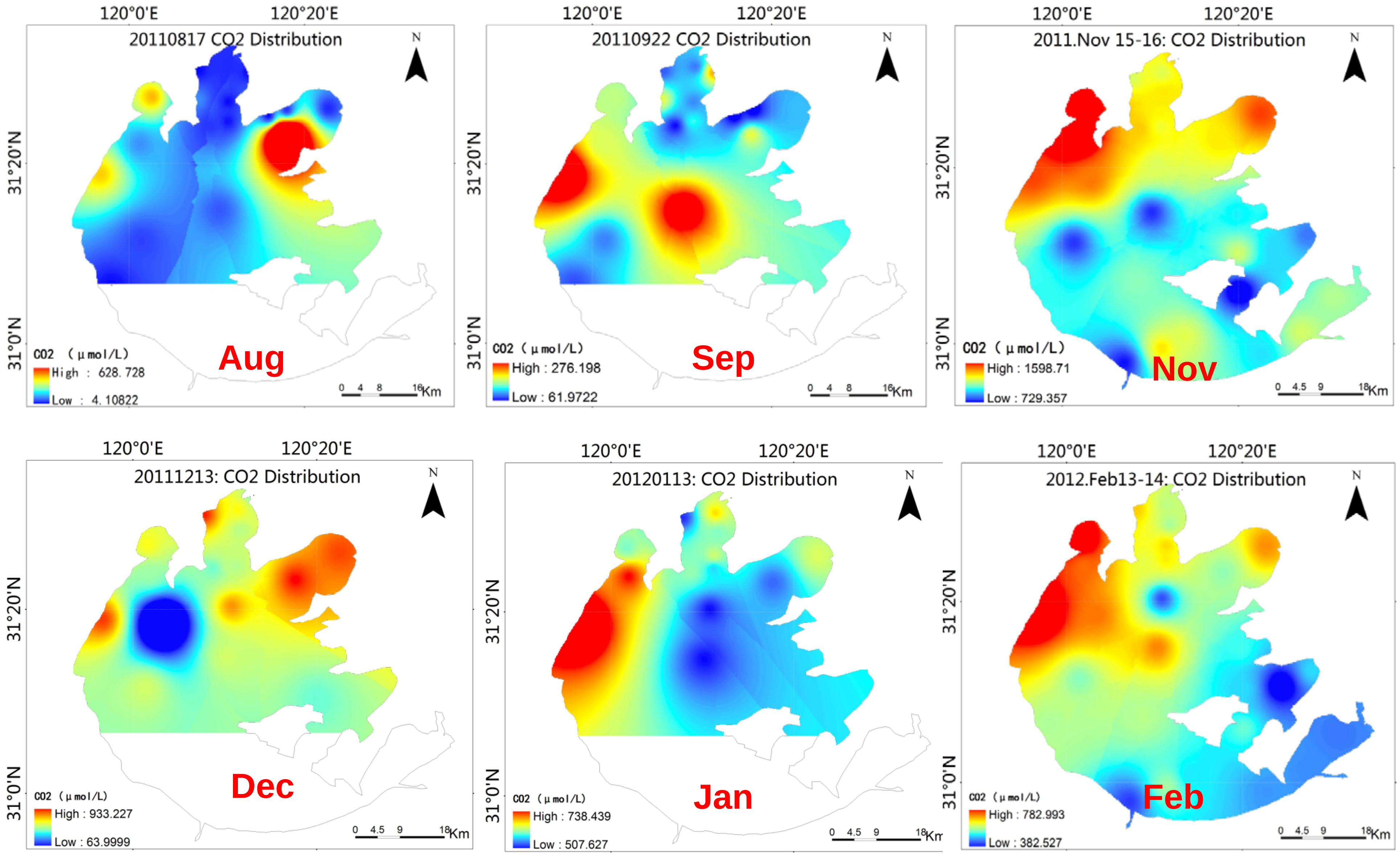


Water Depth: 20cm
Site: MLW
A
N2O concentration (nM)
25
20
15
10
5
0
1-Aug
15-Aug
29-Aug
12-Sep
26-Sep
10-Oct
24-Oct
7-Nov
21-Nov
5-Dec
19-Dec
2-Jan
16-Jan
30-Jan
13-Feb
27-Feb
Date (d-m)
B
N2O concentration (nmol L-1)
20
15
10
5
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

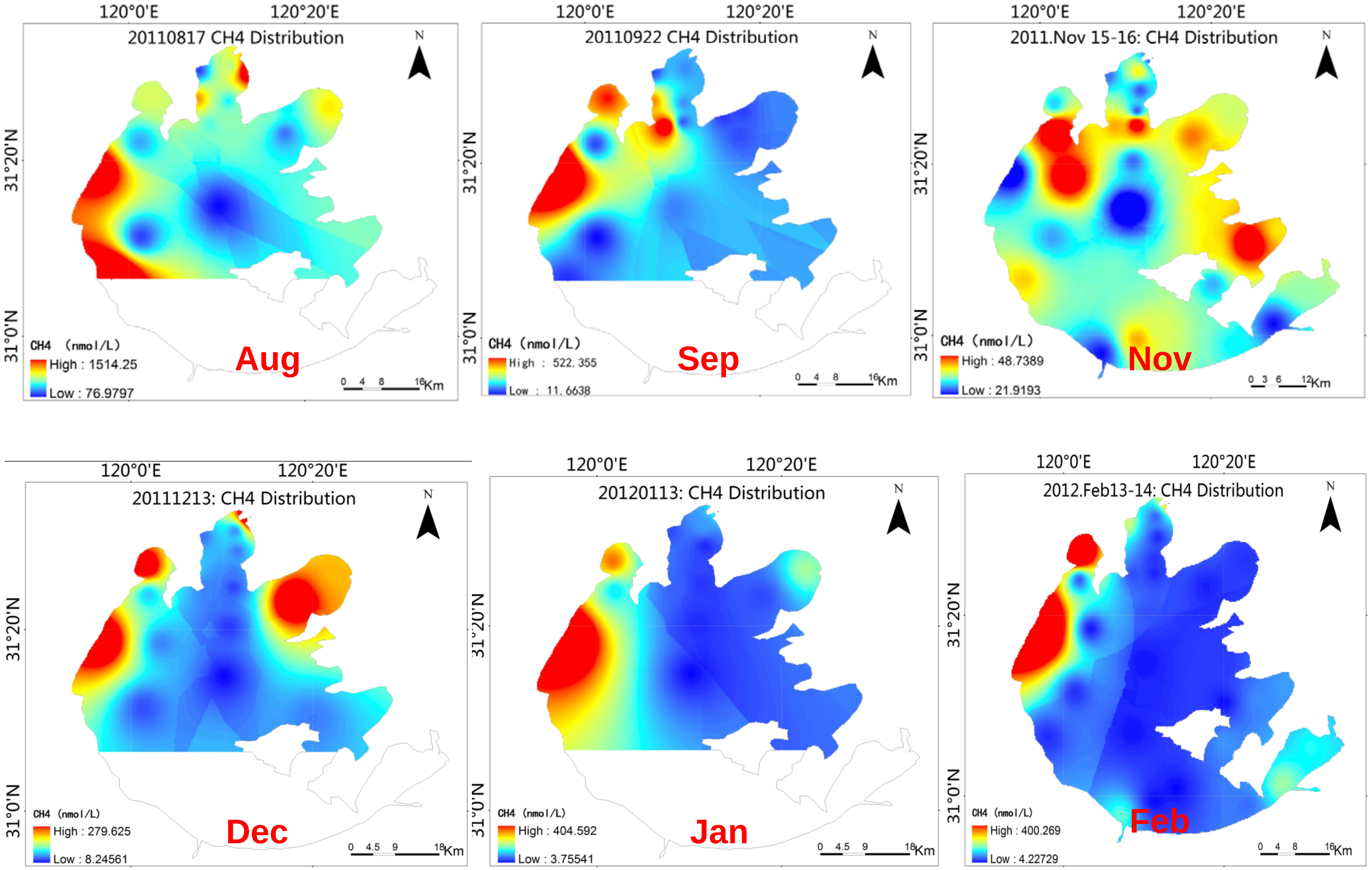
Site: MLW

4.2 Spatial variability of $CO_2/CH_4/N_2O$ concentration

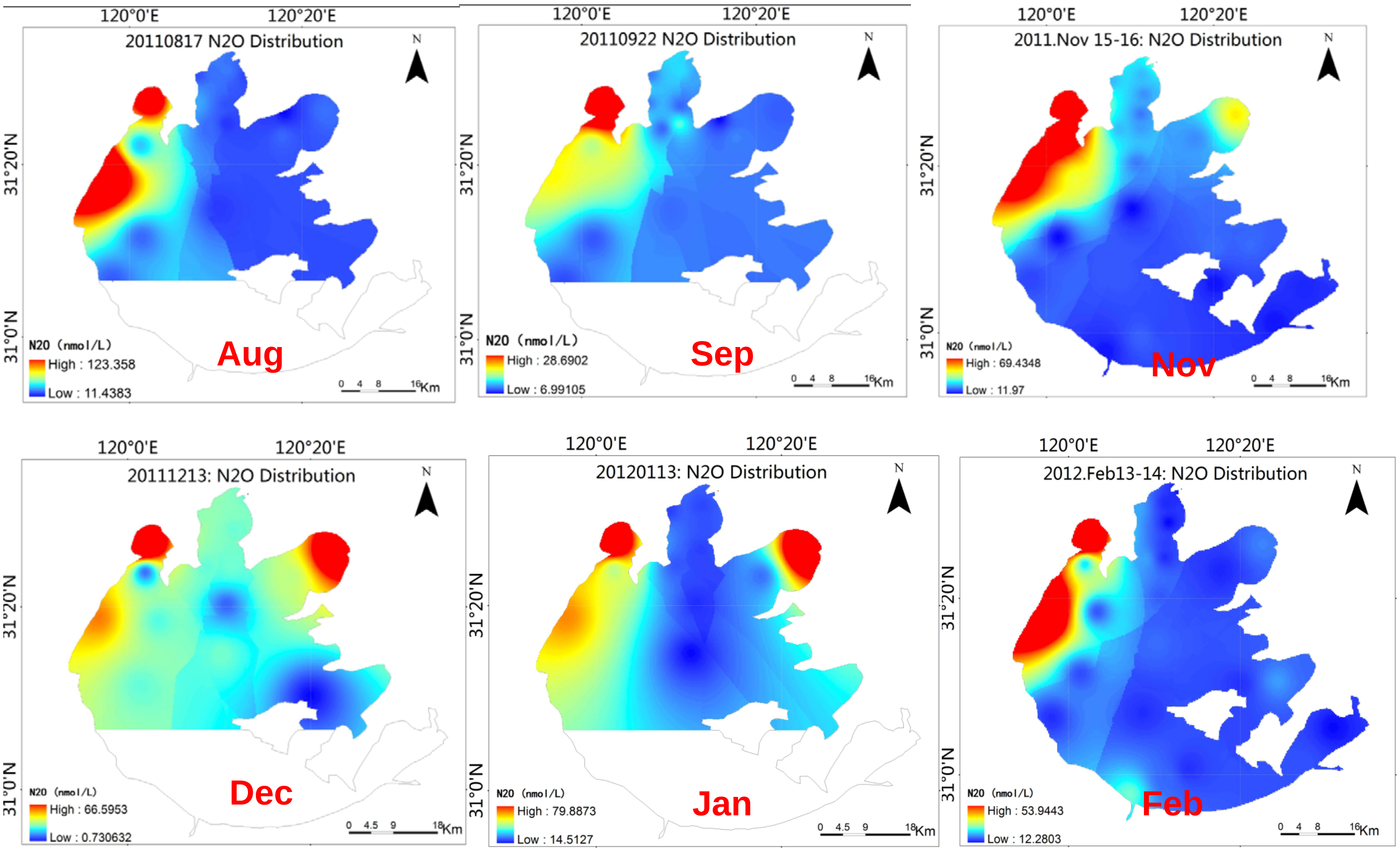
CO_2 concentration



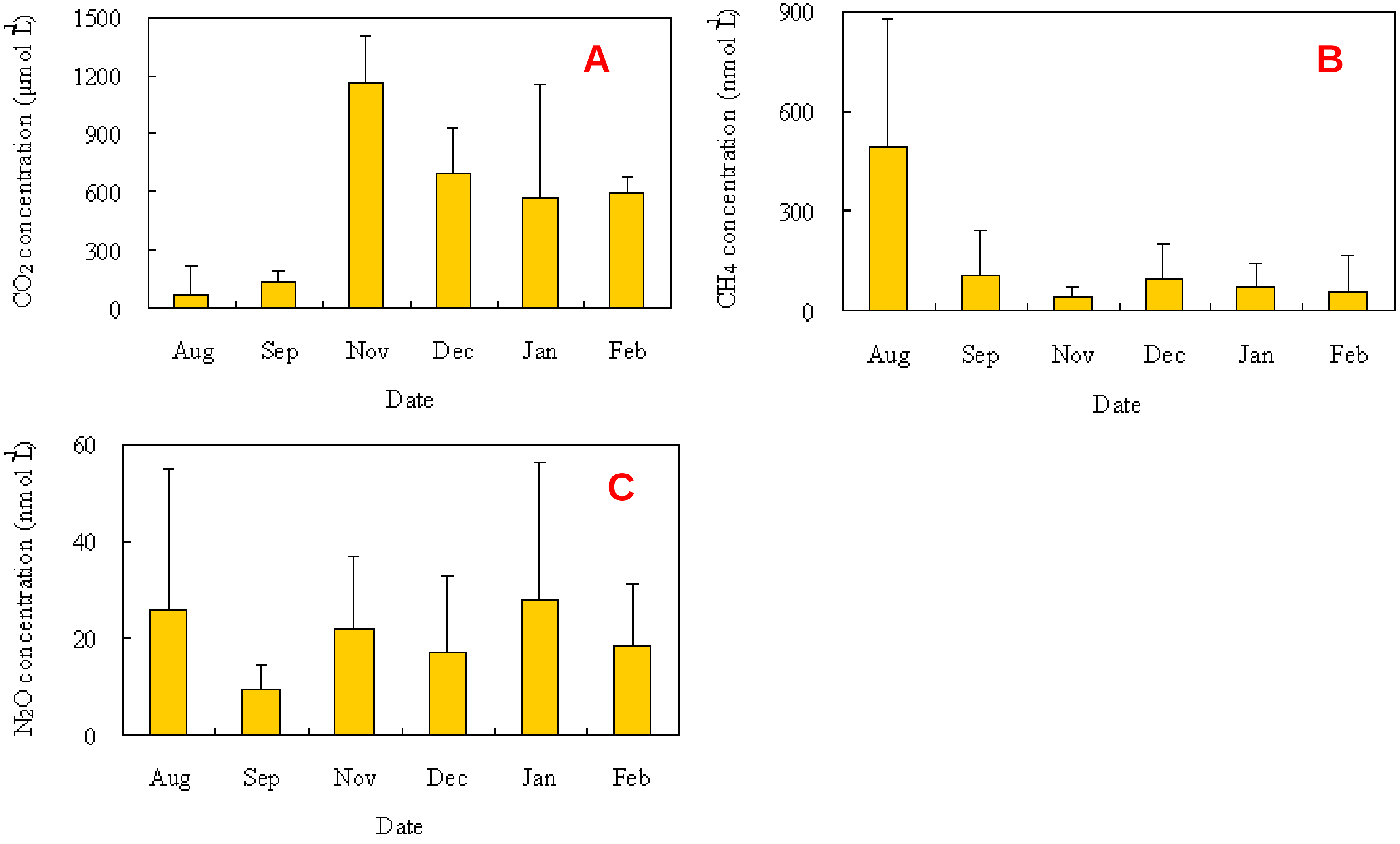
CH_4 concentration



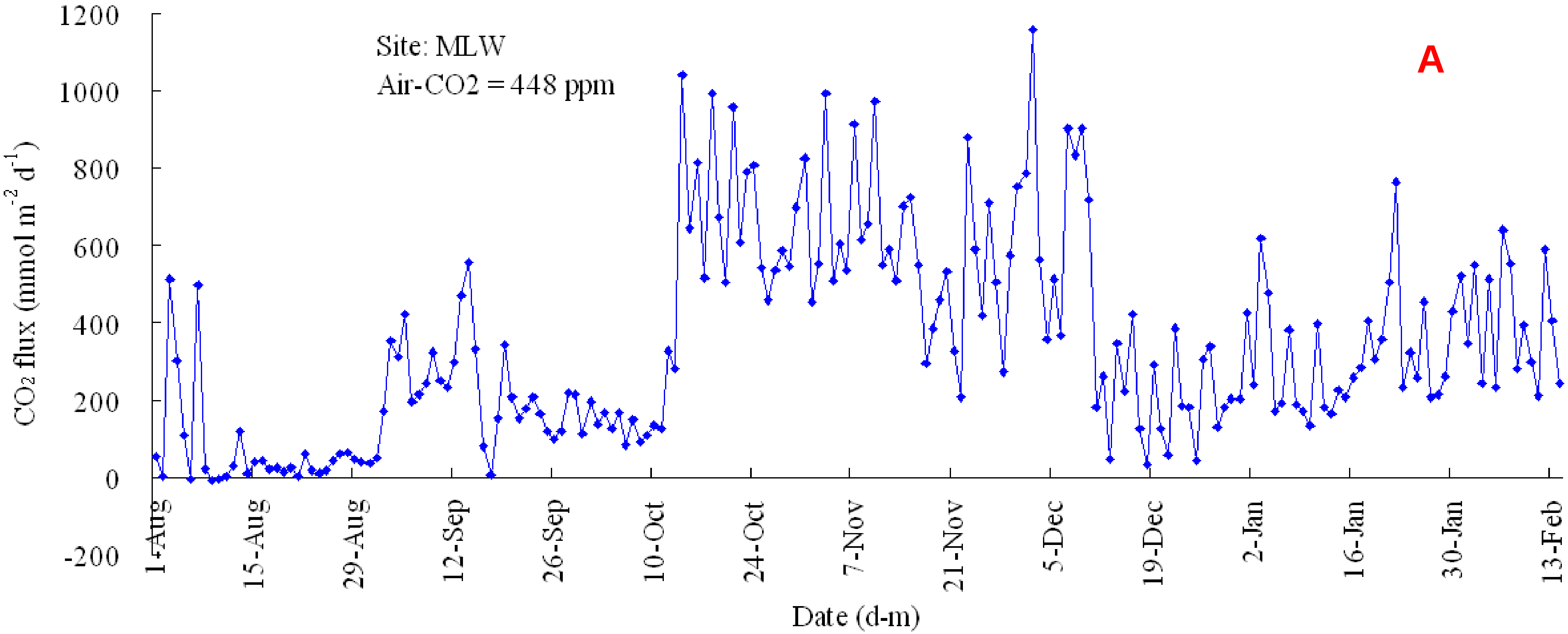
N_2O concentration

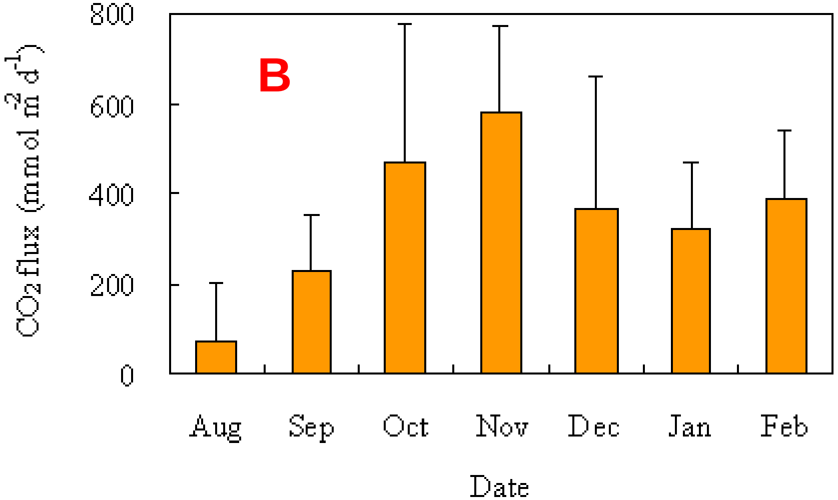


Mean GHG concentration of half lake

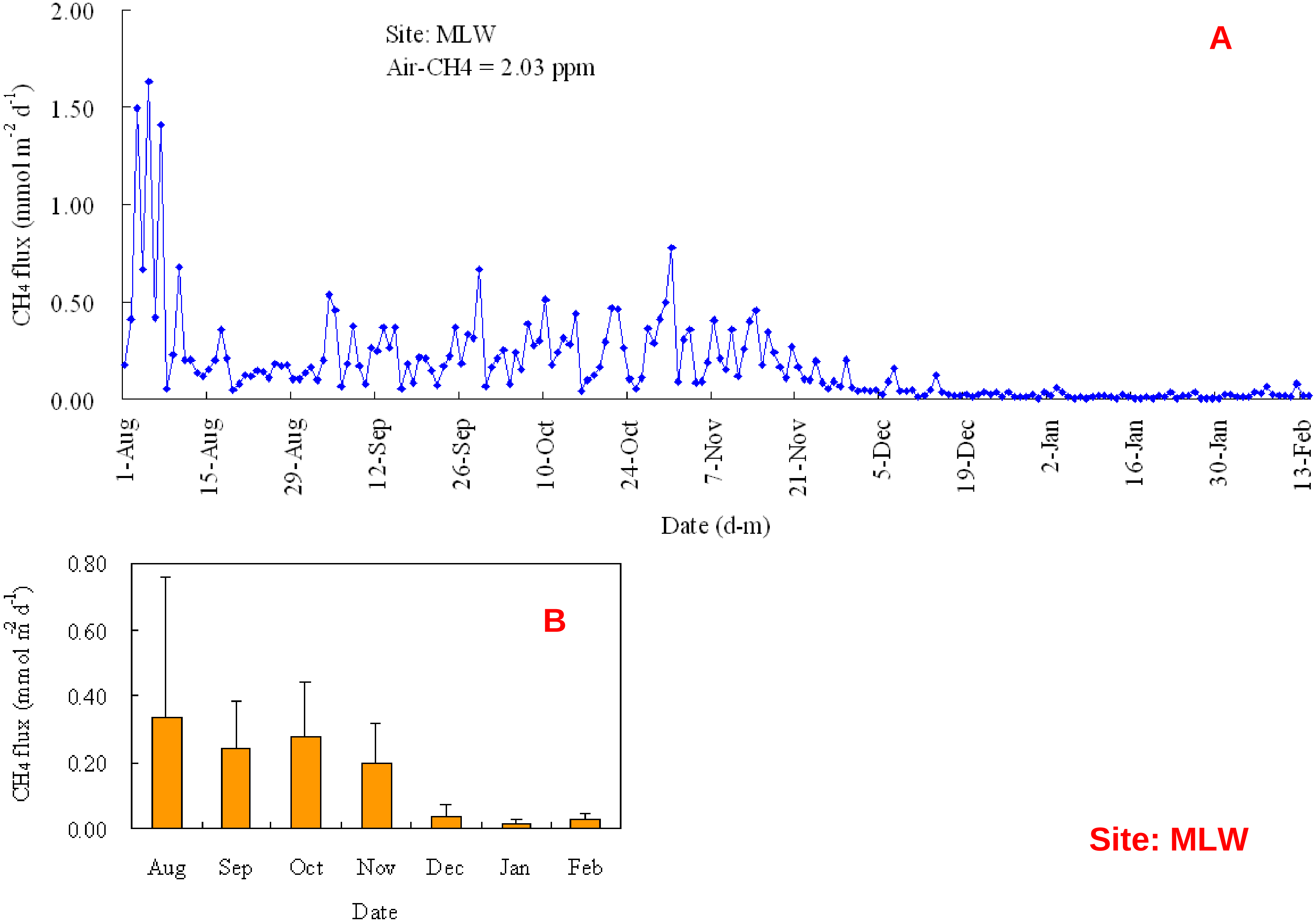


4.3 Temporal variability of CO_2/CH_4/N_2O fluxes



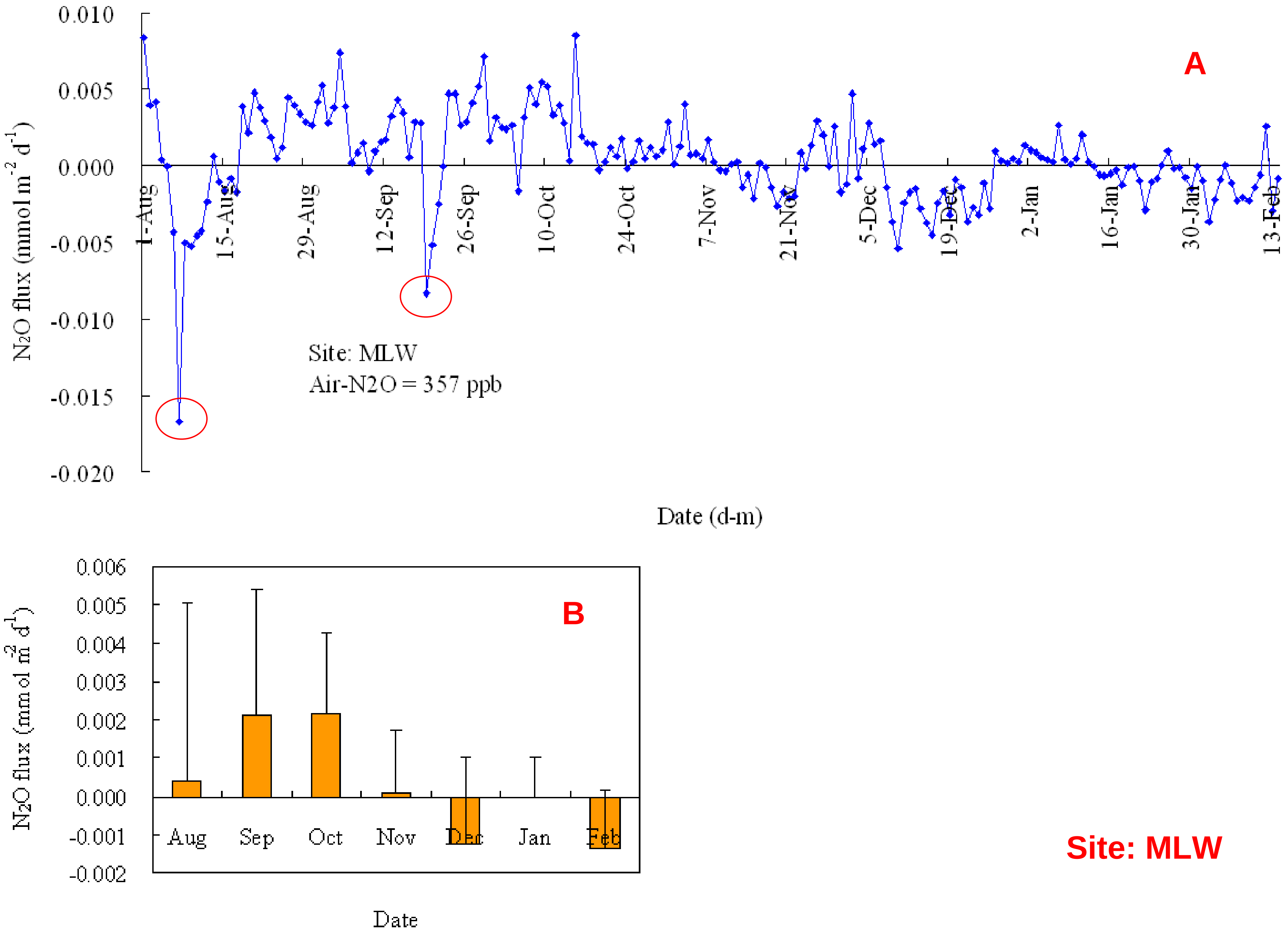


Site: MLW



Site: MLW
Air-CH4 = 2.03 ppm
A
2.00
1.50
1.00
0.50
0.00
CH4 flux (mmol m-2 d-1)
1-Aug
15-Aug
29-Aug
12-Sep
26-Sep
10-Oct
24-Oct
7-Nov
21-Nov
5-Dec
19-Dec
2-Jan
16-Jan
30-Jan
13-Feb
Date (d-m)
B
0.80
0.60
0.40
0.20
0.00
CH4 flux (mmol m-2 d-1)
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date

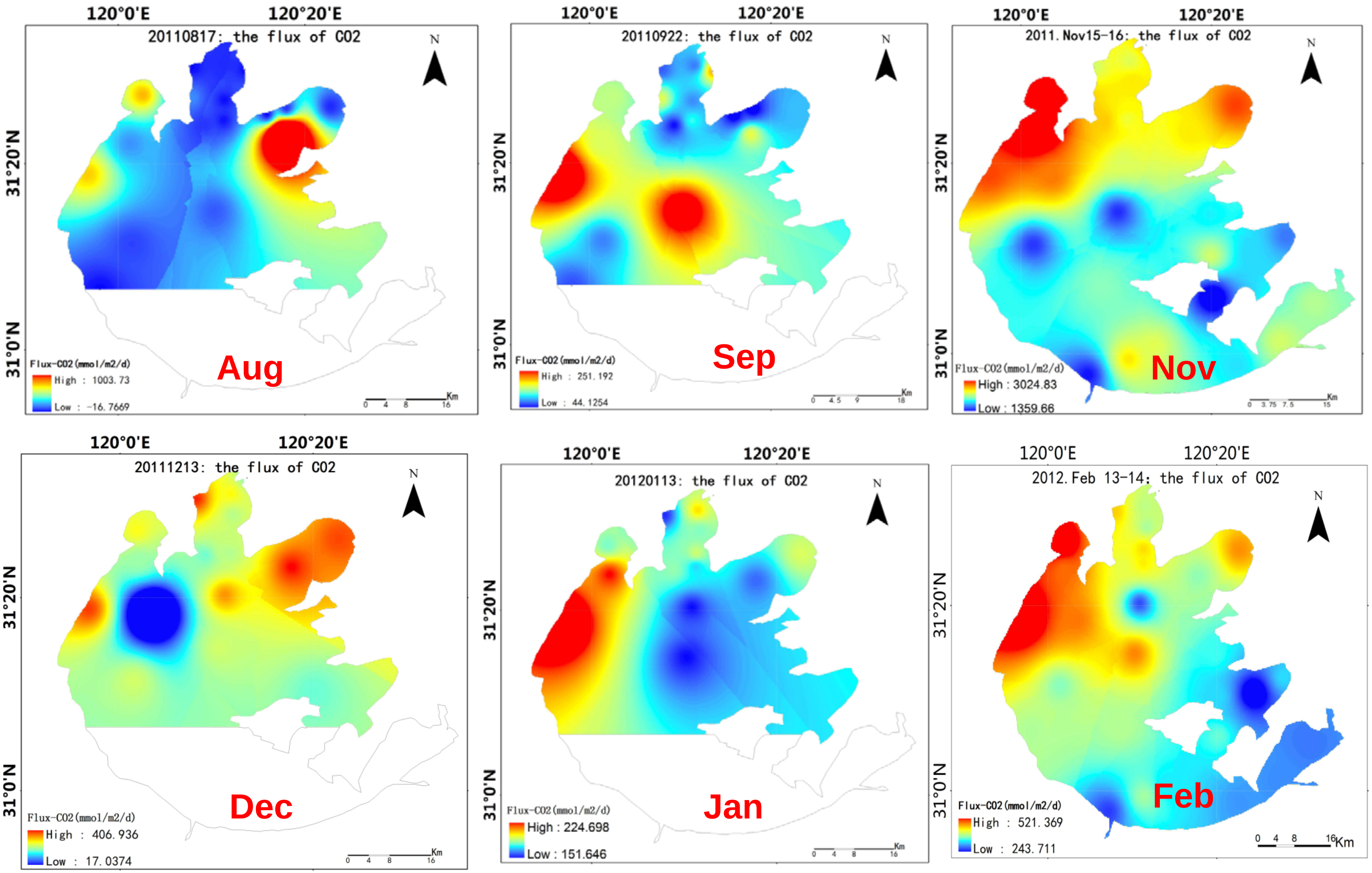
Site: MLW



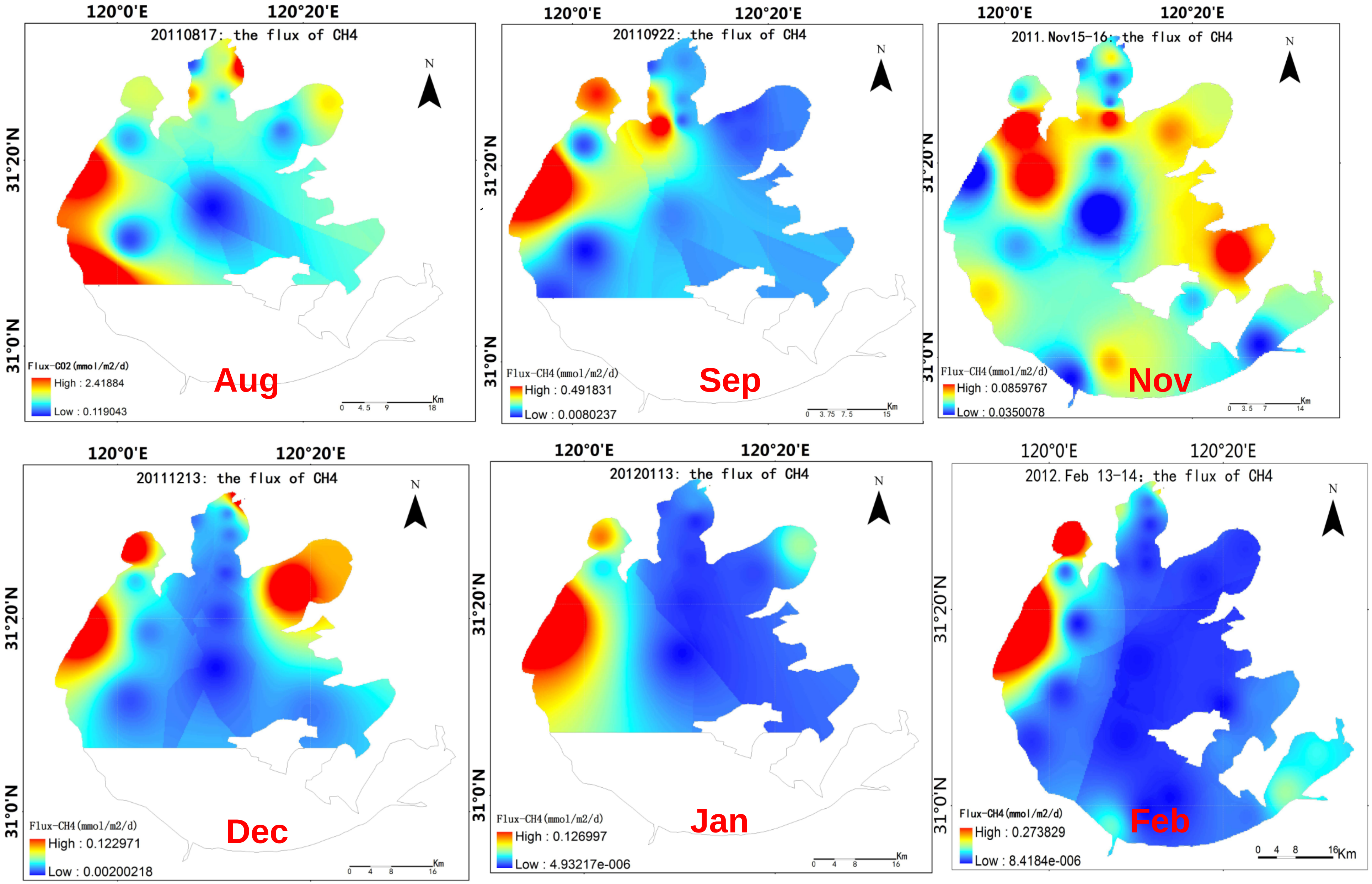
A
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
N2O flux (mmol m-2 d-1)
1-Aug
15-Aug
29-Aug
12-Sep
26-Sep
10-Oct
24-Oct
7-Nov
21-Nov
5-Dec
19-Dec
2-Jan
16-Jan
30-Jan
13-Feb
Site: MLW
Air-N2O = 357 ppb
Date (d-m)
B
0.006
0.005
0.004
0.003
0.002
0.001
0.000
-0.001
-0.002
N2O flux (mmol m-2 d-1)
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Date
Site: MLW

4.4 Spatial variability of CO_2/CH_4/N_2O fluxes

CO_2 fluxes

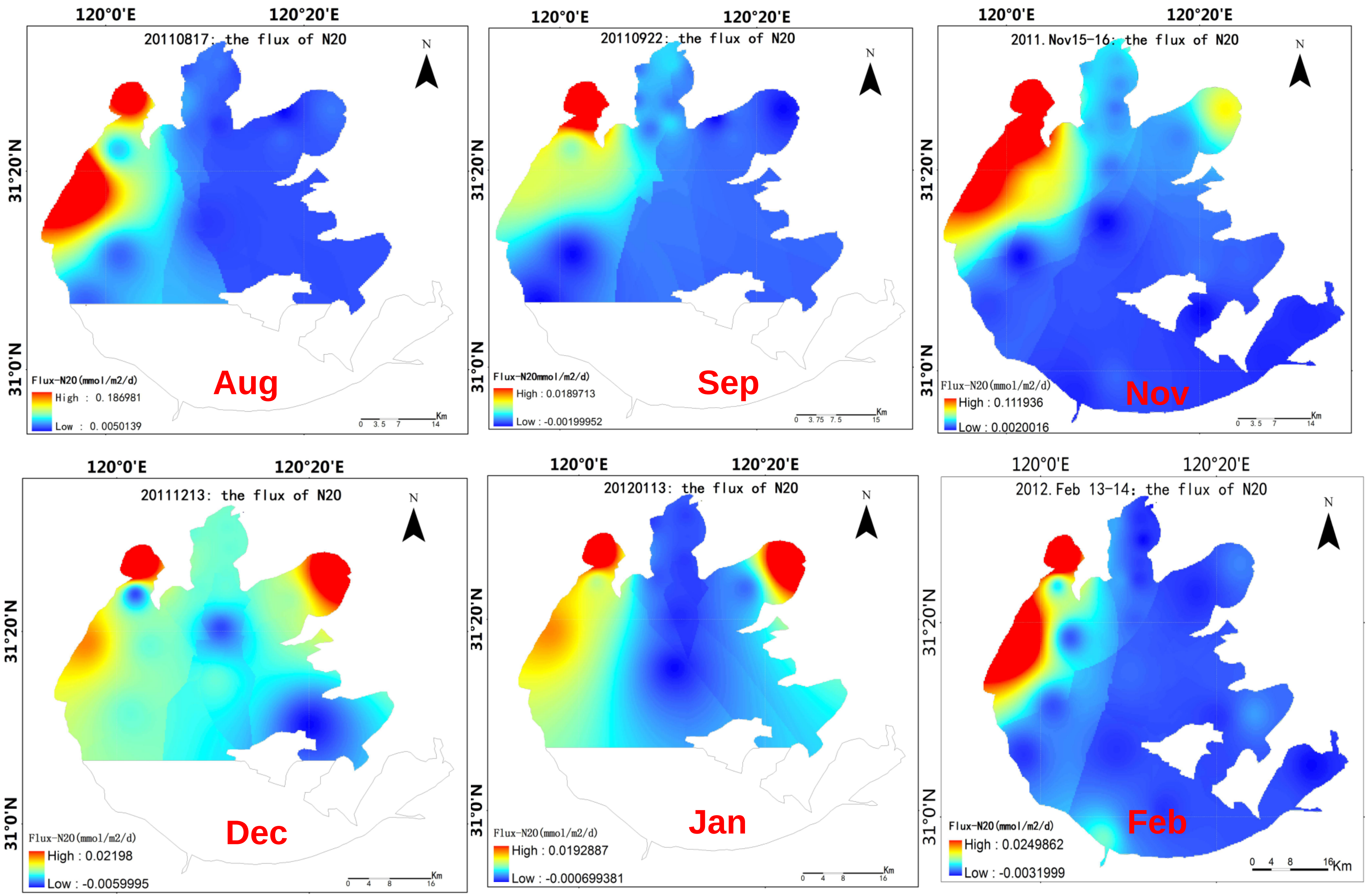


CH_4 fluxes

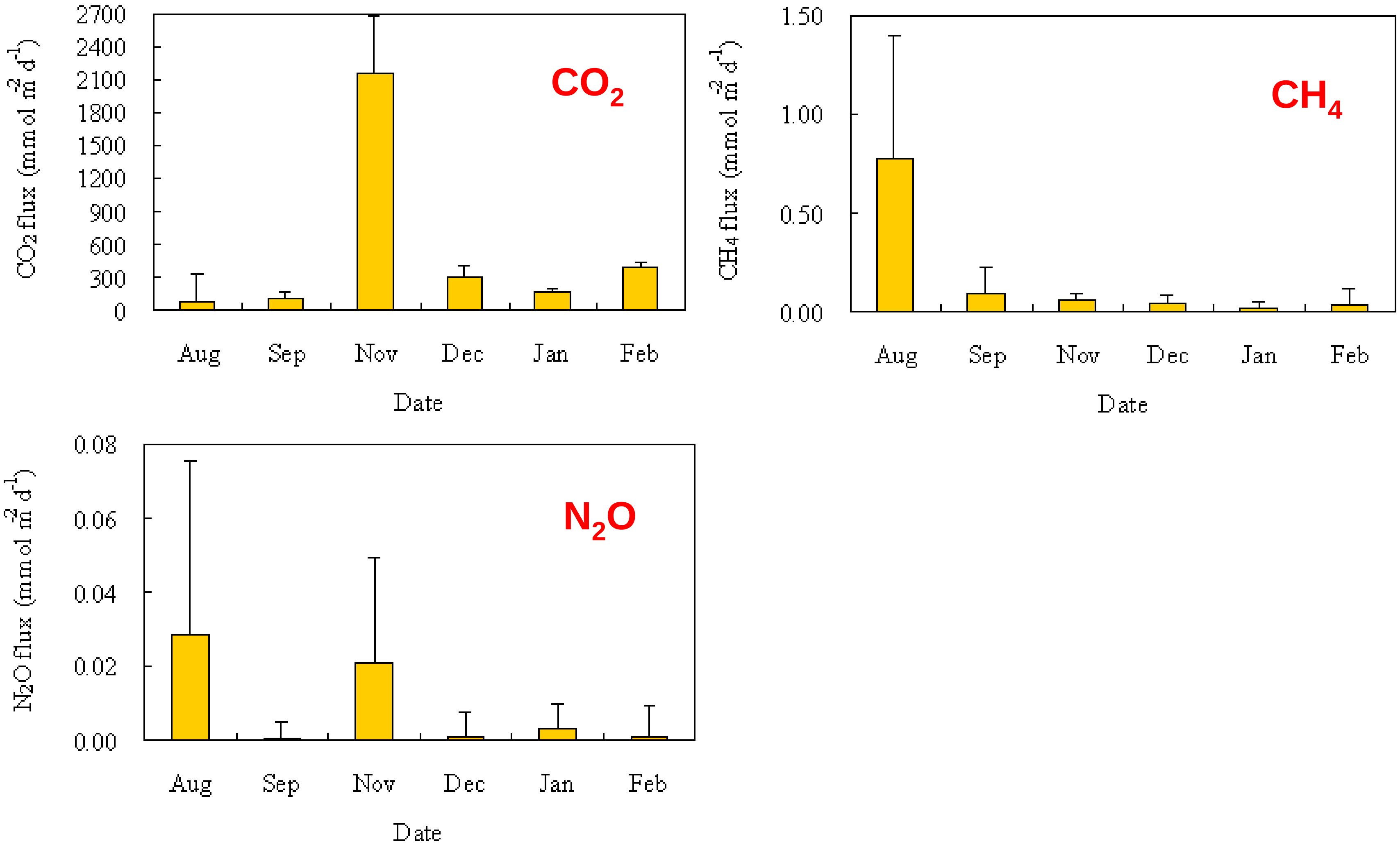


120°0'E
120°20'E
20110817: the flux of CH4
31°20'N
31°0'N
Flux-CO2 (mmol/m2/d)
High : 2.41884
Low : 0.119043
Aug
0 4.5 9 18 Km
20110922: the flux of CH4
Flux-CH4 (mmol/m2/d)
High : 0.491831
Low : 0.0080237
Sep
0 3.75 7.5 15 Km
2011.Nov15-16: the flux of CH4
Flux-CH4 (mmol/m2/d)
High : 0.0859767
Low : 0.0350078
Nov
0 3.5 7 14 Km
20111213: the flux of CH4
Flux-CH4 (mmol/m2/d)
High : 0.122971
Low : 0.00200218
Dec
0 4 8 16 Km
20120113: the flux of CH4
Flux-CH4 (mmol/m2/d)
High : 0.126997
Low : 4.93217e-006
Jan
2012.Feb 13-14: the flux of CH4
Flux-CH4 (mmol/m2/d)
High : 0.273829
Low : 8.4184e-006
Feb
N

N_2O fluxes

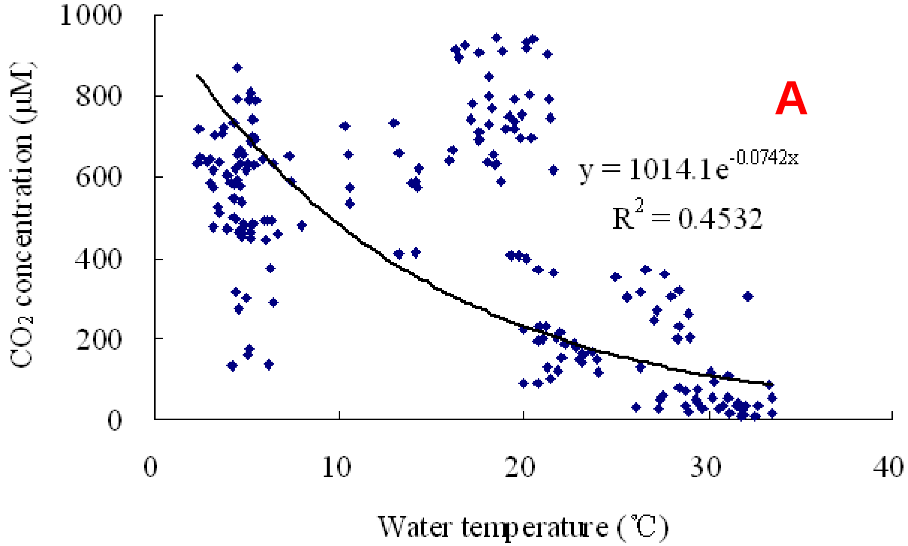

120°0'E
120°20'E
31°20'N
31°0'N
20110817: the flux of N2O
N
Flux-N2O(mmol/m2/d)
High : 0.186981
Low : 0.0050139
Aug
Km
0 3.5 7 14
20110922: the flux of N2O
Flux-N2Ommol/m2/d)
High : 0.0189713
Low : -0.00199952
Sep
0 3.75 7.5 15
2011.Nov15-16: the flux of N2O
Flux-N2O(mmol/m2/d)
High : 0.111936
Low : 0.0020016
Nov
20111213: the flux of N2O
Flux-N2O(mmol/m2/d)
High : 0.02198
Low : -0.0059995
Dec
0 4 8 16
20120113: the flux of N2O
Flux-N2O(mmol/m2/d)
High : 0.0192887
Low : -0.000699381
Jan
2012.Feb 13-14: the flux of N2O
Flux-N2O(mmol/m2/d)
High : 0.0249862
Low : -0.0031999
Feb

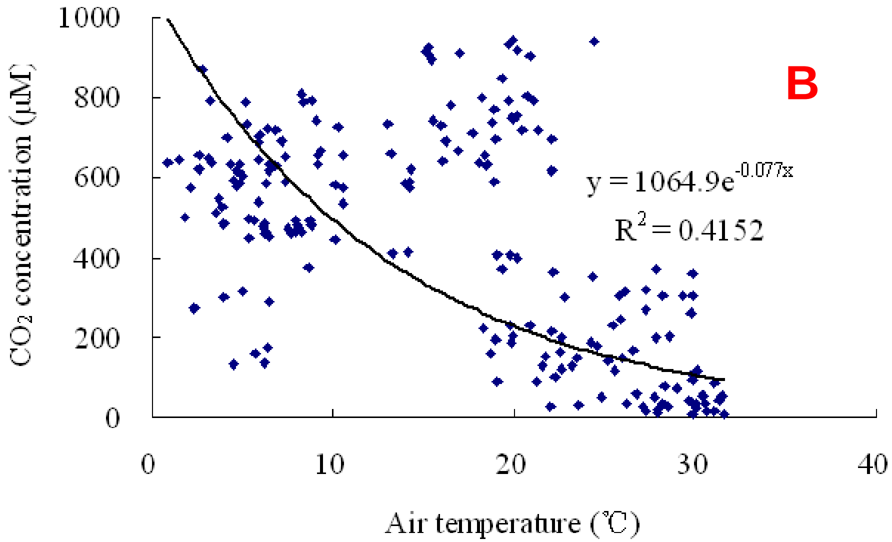
Mean GHG fluxes of half lake

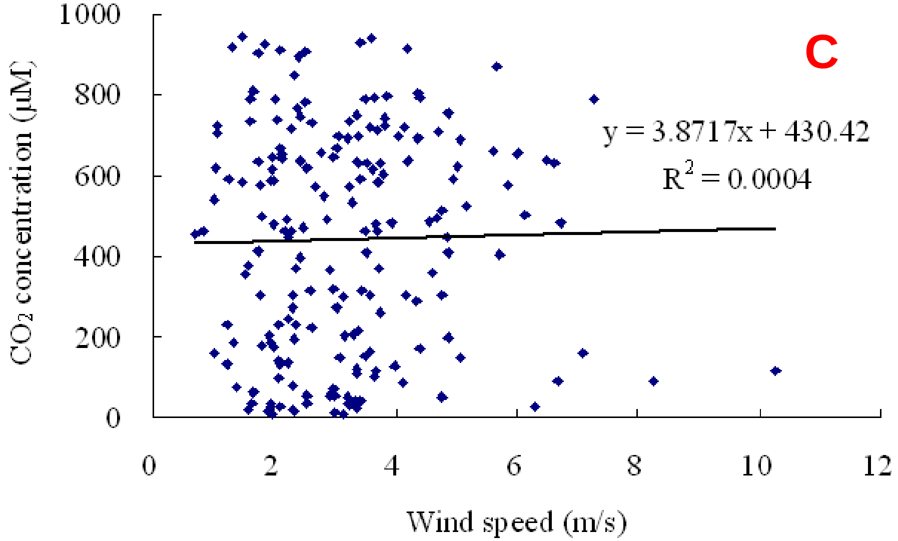


4.5 Relationship between micromet and GHG concentration/fluxes

- CO_2 concentration-

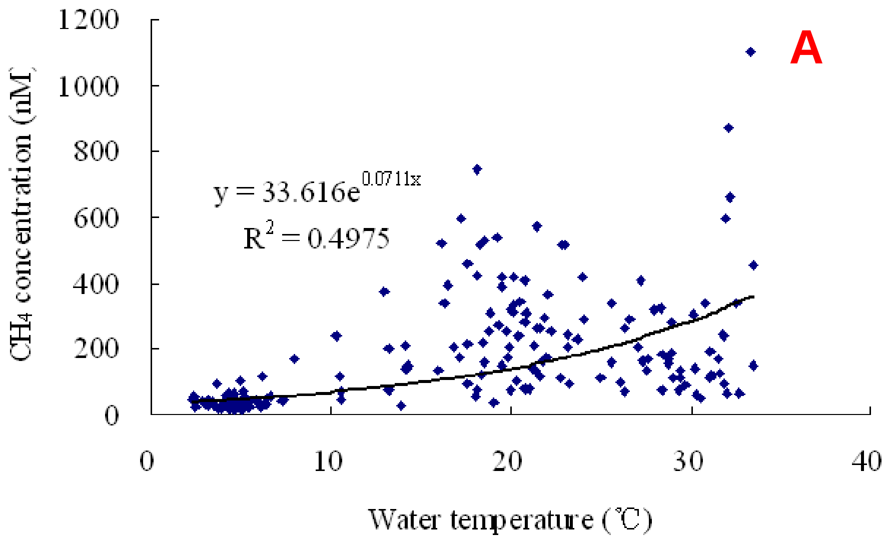


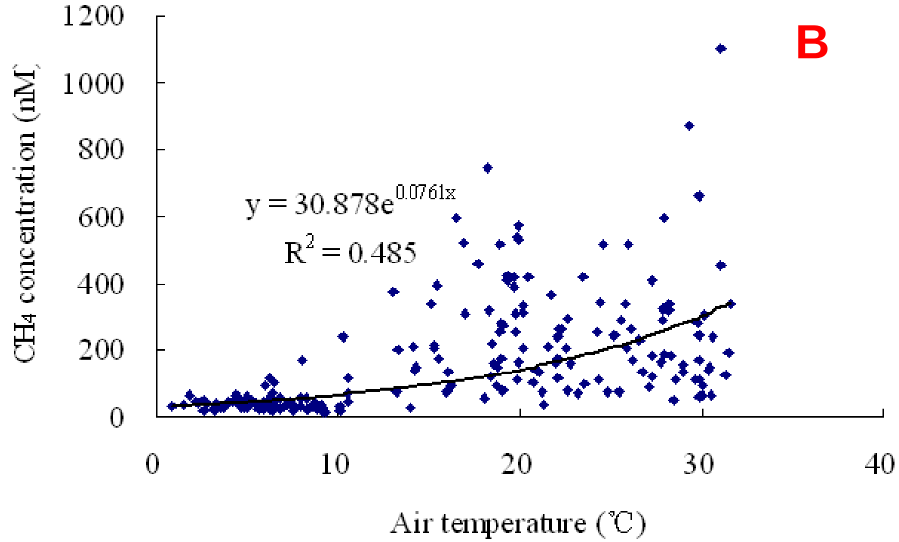


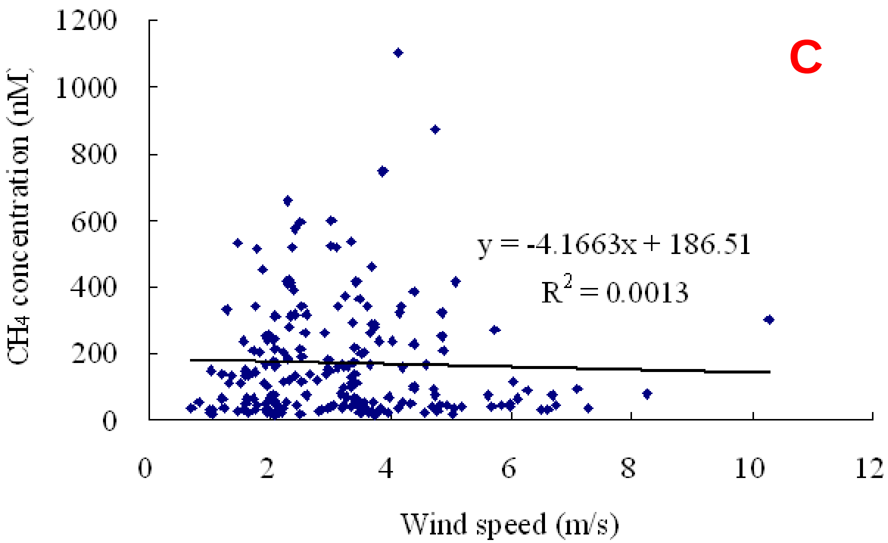


Site: MLW

- CH_4 concentration-

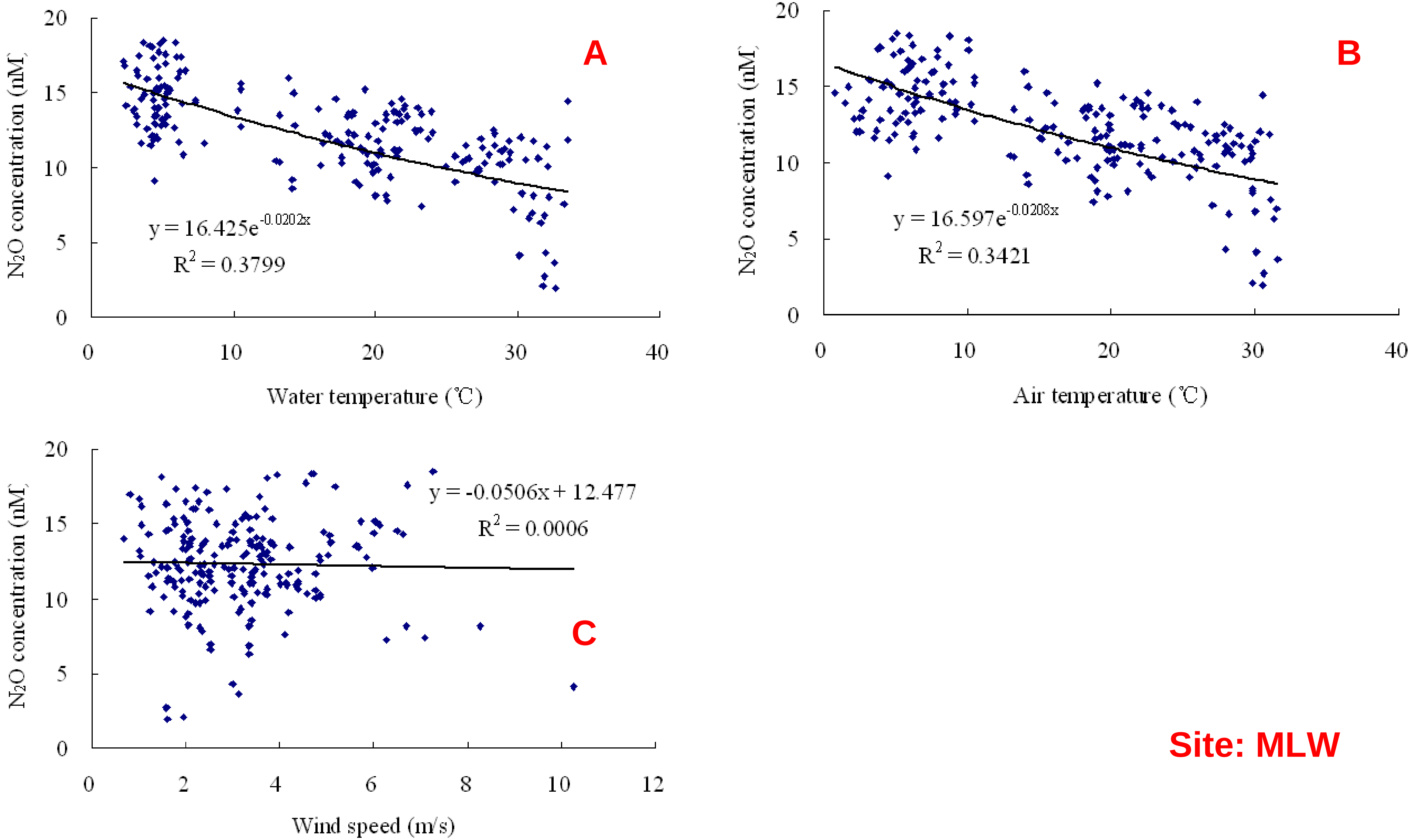






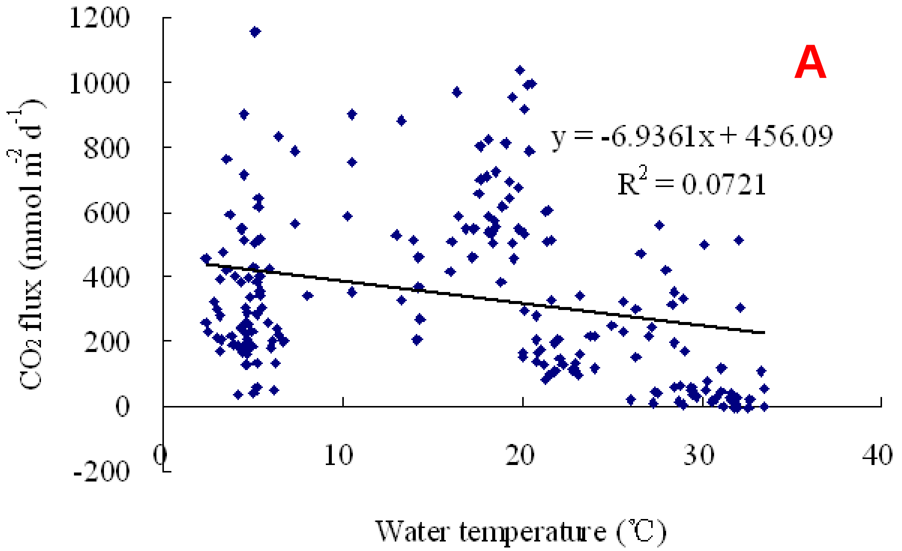
Site: MLW

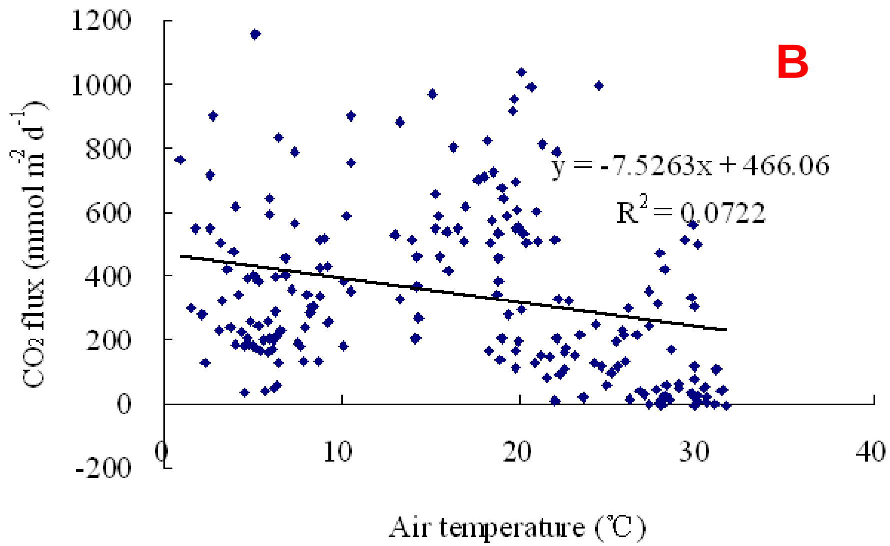
- N_2O concentration-

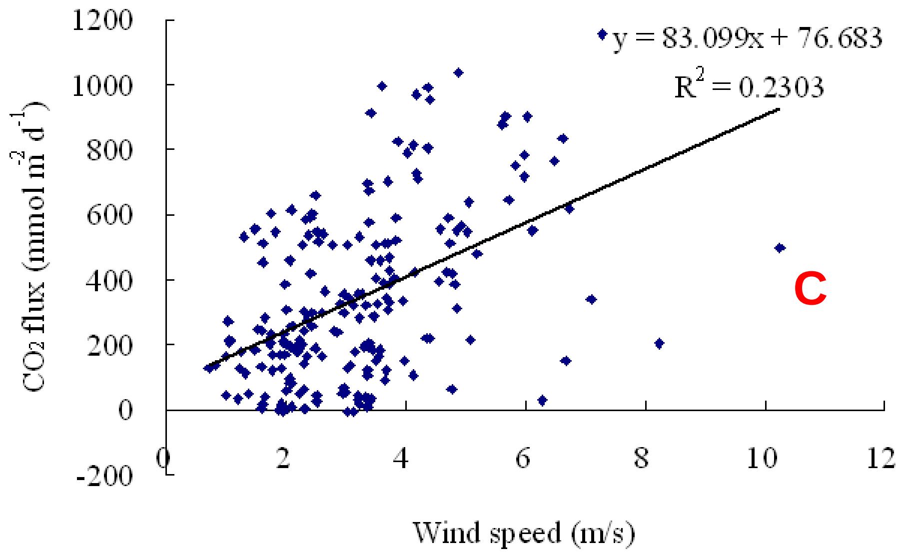


Site: MLW

- CO_2 fluxes-

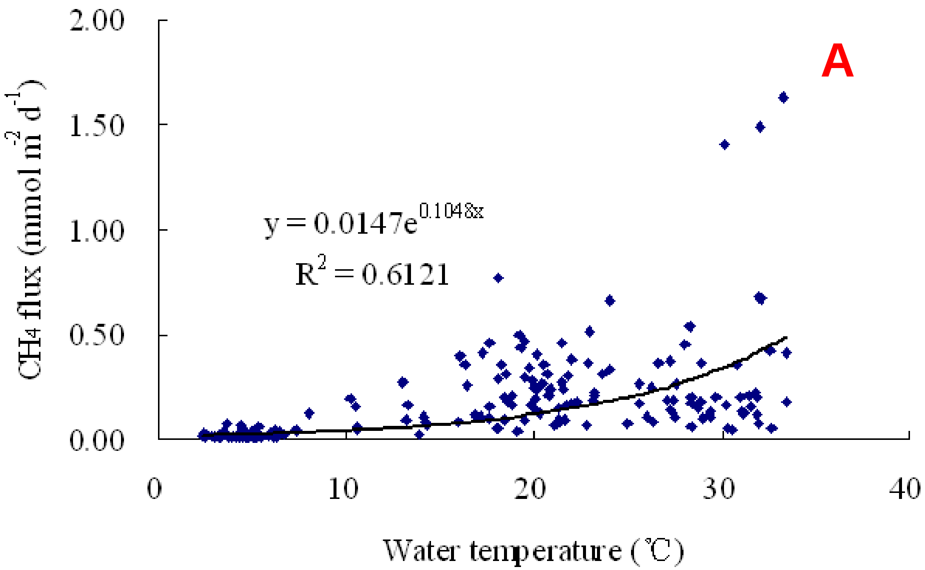


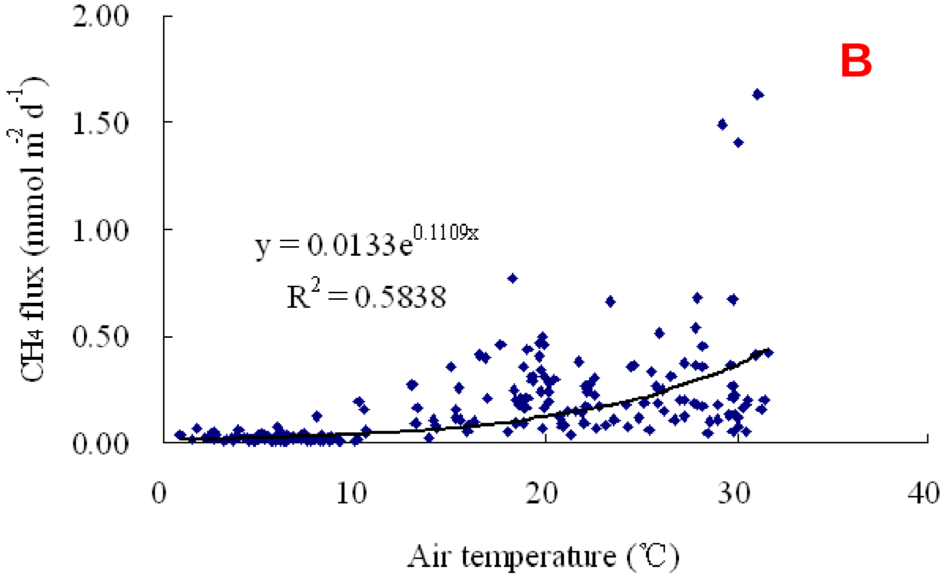


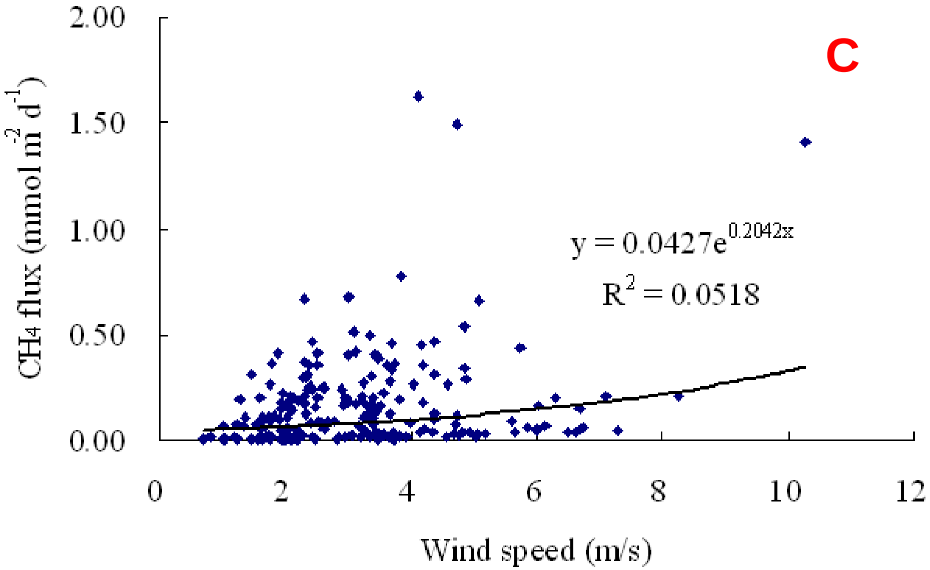


Site: MLW

- CH_4 fluxes-

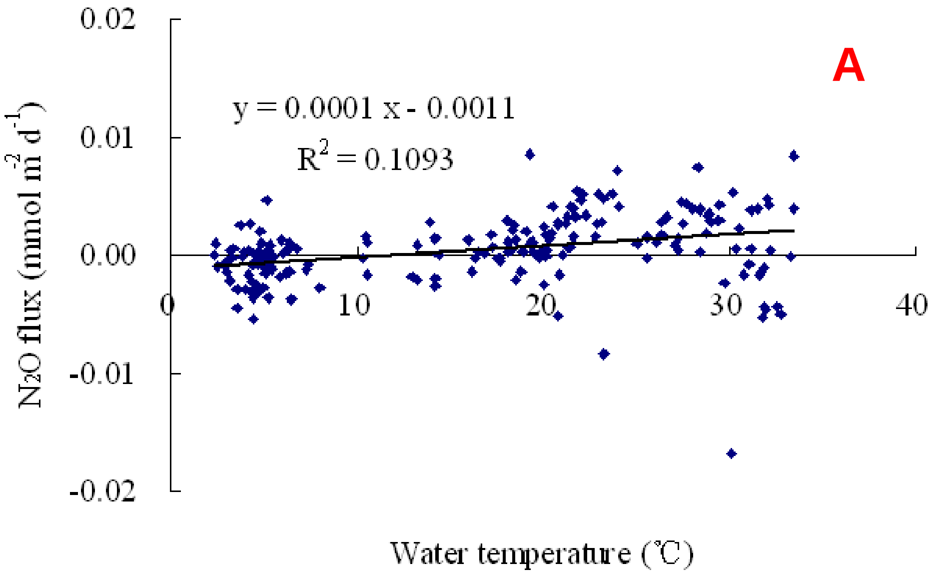


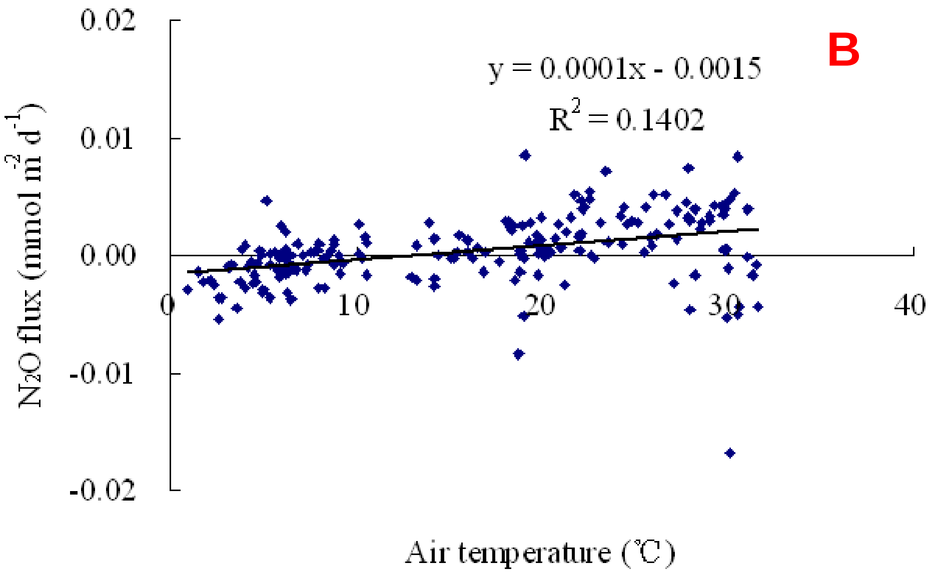


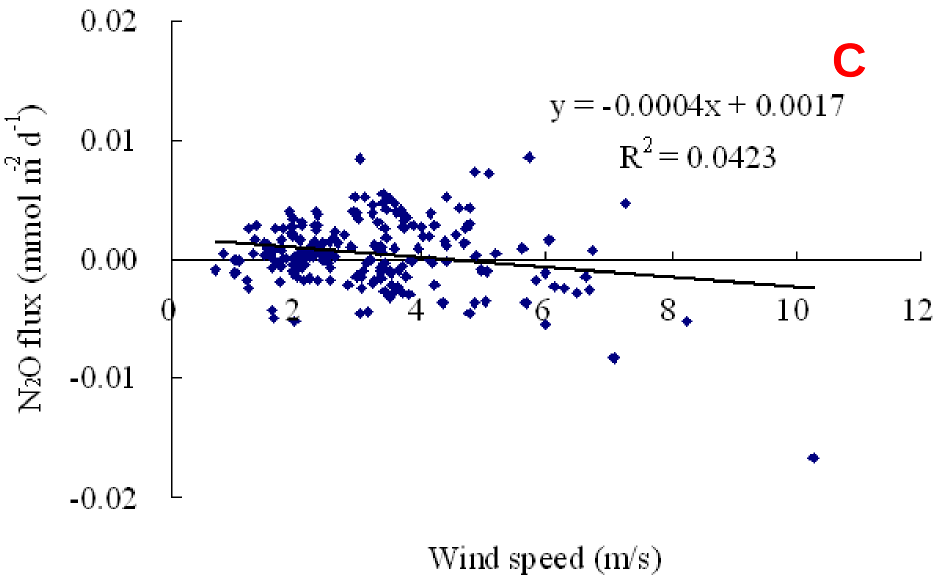


Site: MLW

- N_2O fluxes-

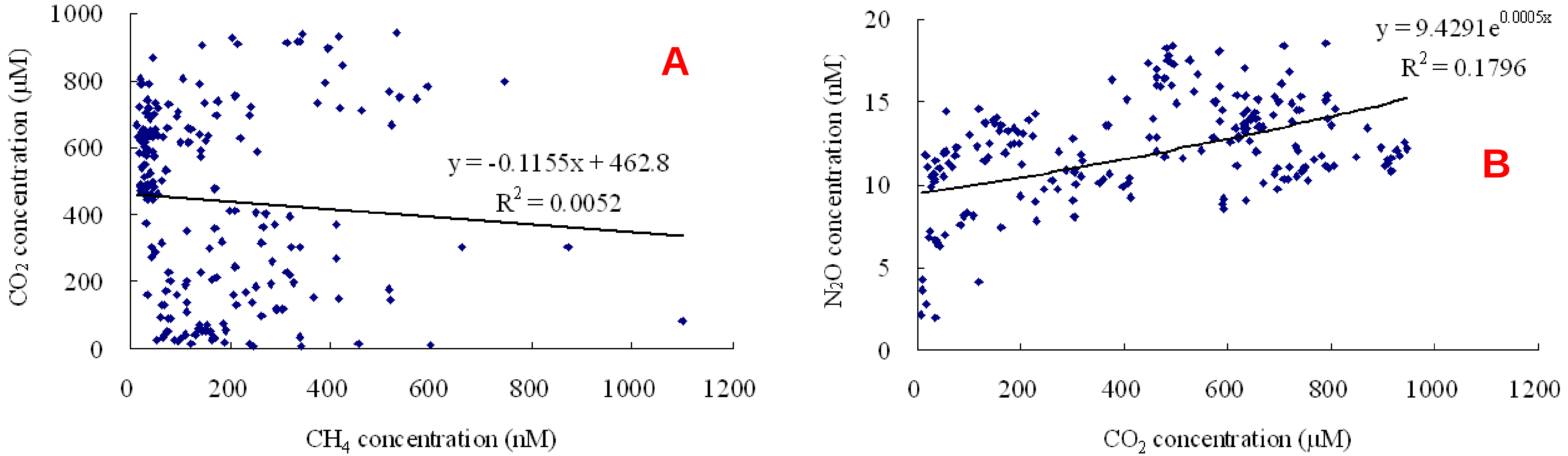


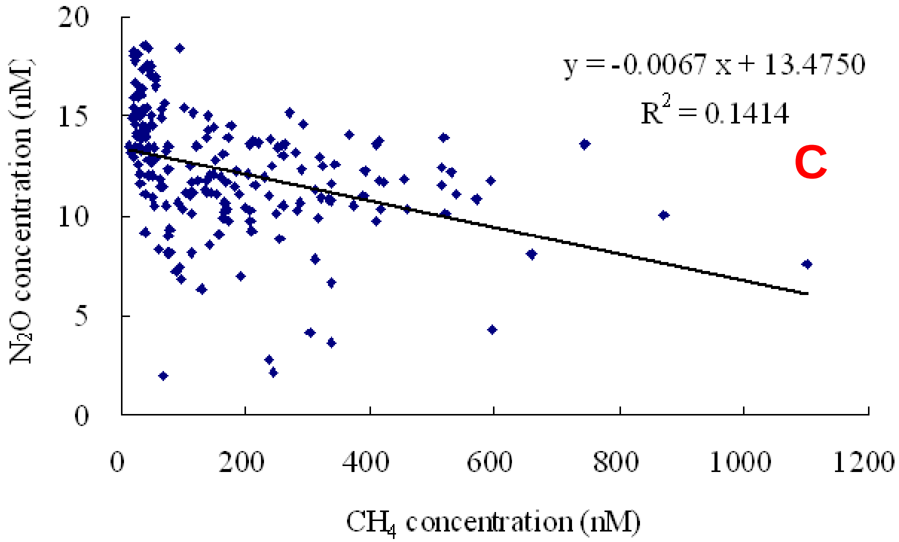




Site: MLW

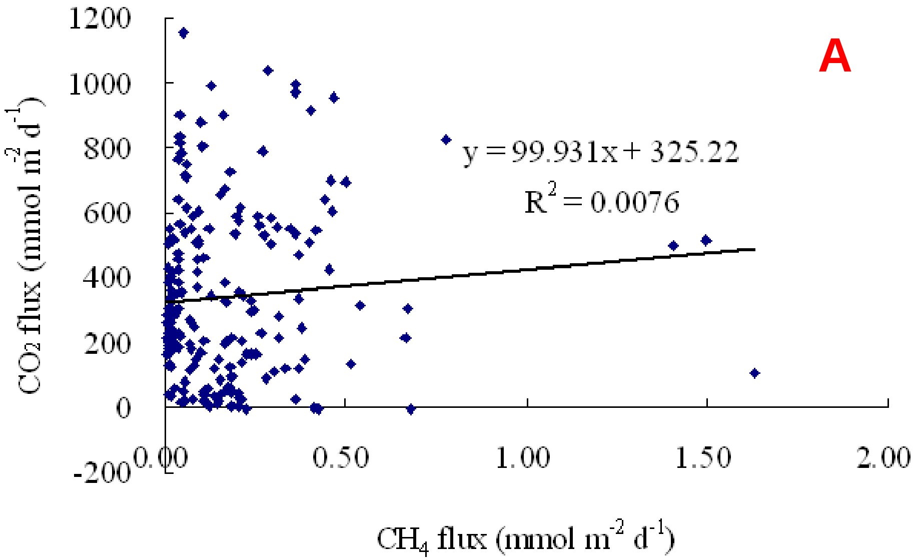
4.6 Relationship among CO_2,CH_4,and N_2O concentration

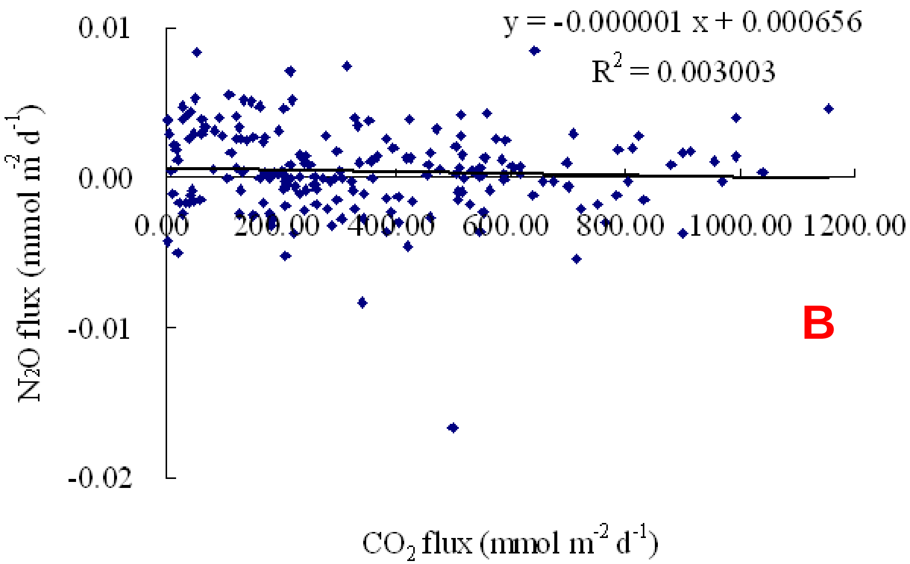


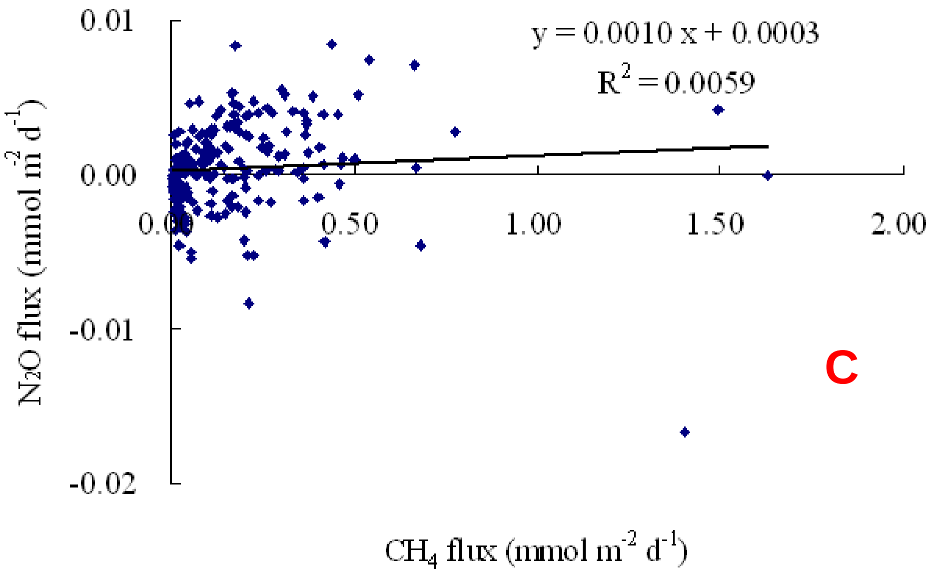


Site: MLW

4.7 Relationship among CO_2, CH_4, and N_2O fluxes







Site: MLW

4.8 Net annual global warming potential (GWP)

- We adopted the IPCC factors to calculate the combined GWPs for 100 years.

GWP = 25 $\times CH_4$ + 298 $\times N_2O$ + CO_2 (kg CO_2-equivalents ha^{-1} yr^{-1})

Ecosystems	Site	GWP (kg CO_2-equivalents ha^{-1} yr^{-1})
Lake	Lake Taihu	55 268
Cropland*	Taoyuan, Hunan Province	12 587

*, Shang et al. 2011. Global Change Biology

5 Discussion

5.1 N, P, and OM input in catchment

- Due to the close linkage between Lake Taihu and its catchment, it is obvious that catchment disturbances can disturb the lake greenhouse gas emissions.
- Lake Taihu CO_2 saturation can additionally be enhanced by inputs of DOC from catchment.
- Increased nutrient input into Lake Taihu causes eutrophication. Anoxic conditions can increase CH_4 emissions from lake by enhancing the CH_4 production and/or decreasing the CH_4 oxidation.
- Low oxygen availability can also promote N_2O production.

5.2 Water quality characteristics

- CO_2 and CH_4 production and emission are regulated by variable such as sediment and water temperature, oxygen availability, organic matter, sediment and water chemistry, pH, EC (Schrier-Uijl et al. 2011; Juutinen et al. 2009).
- CH_4 production depends on the availability of alternative electron acceptors: O_2, NO_3^-, Fe^{3+}, and SO_4^{2-} (van Bodegom and Scholten 2001).

5.3 CH_4 ebullition

- Ebullition can also contribute to the emission of CH_4 from lakes (Walter et al. 2006,2007).
- Ebullition was observed in two lakes and accounted for 19-37% and 11-40% of the total CH_4 emissions in a summer study (Repo et al. 2007).
- In our study, only diffusive fluxes of CH_4 were measured.

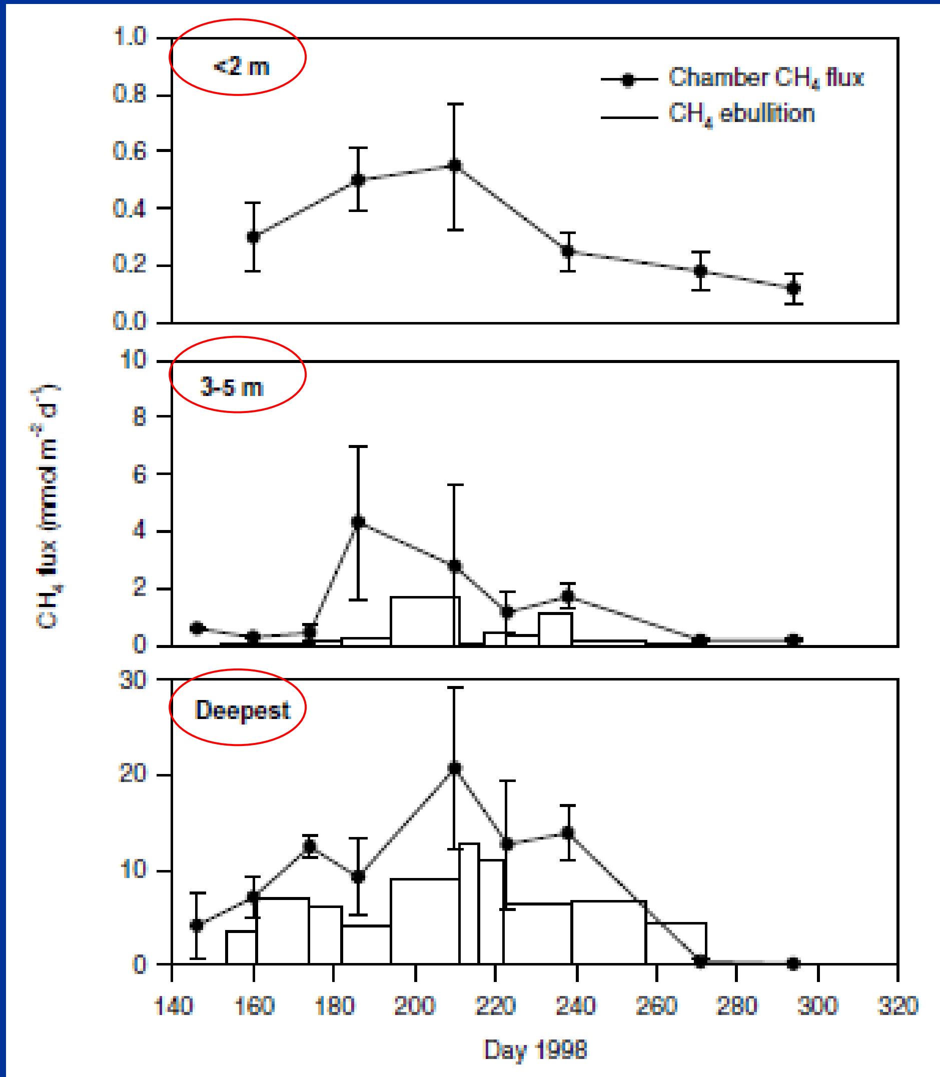
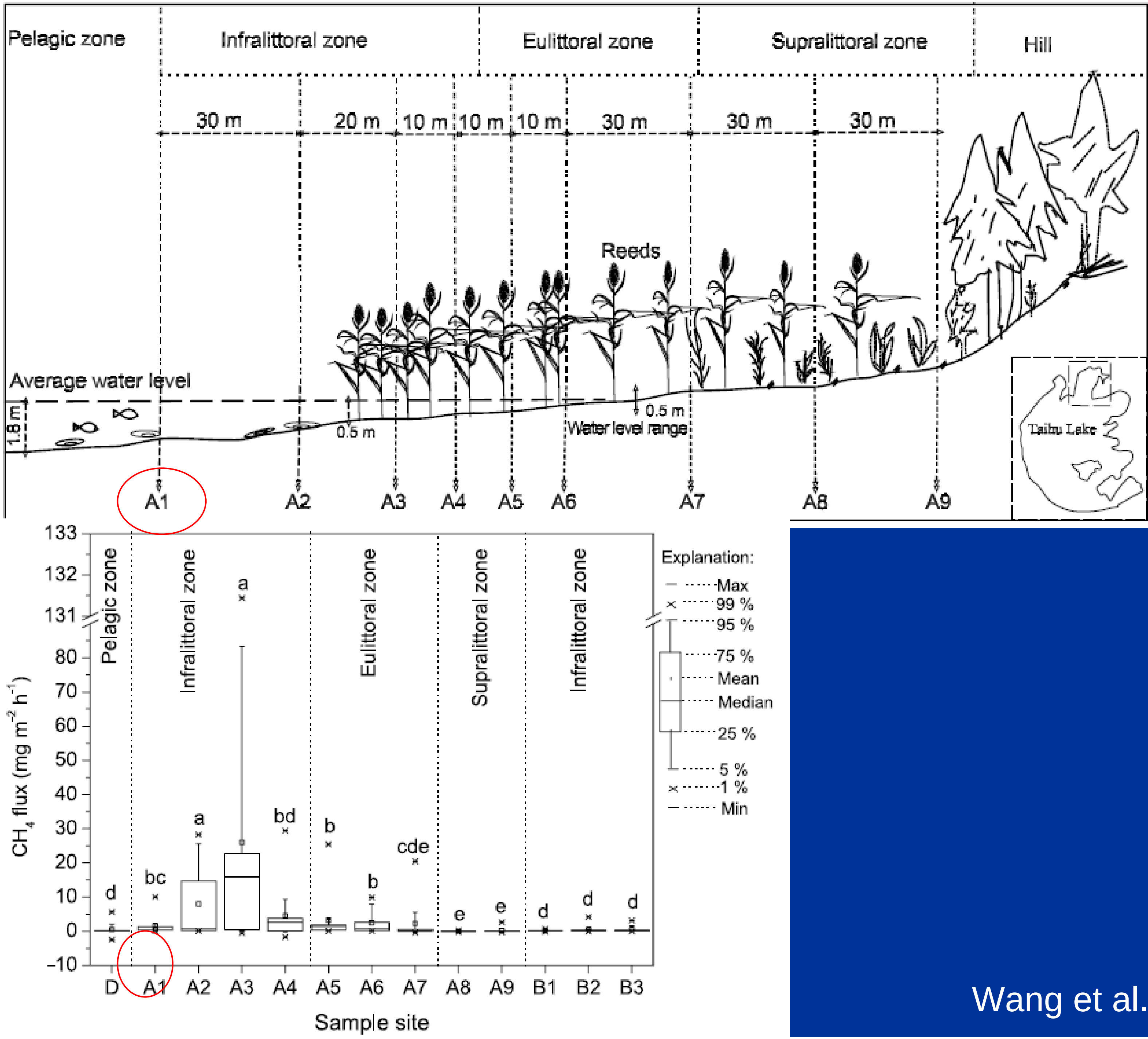


Fig. 3. The CH_4 emissions measured by the chambers and the CH_4 ebullition monitored by the funnel gas collectors at the stations at different depths in the highly eutrophic Lake Kevätön in 1998. Note different scales in each part. Error bars represent standard deviation.

Huttunen et al. 2003

5.4 GHG fluxes from different ecosystems

Ecosystem	Flux (mg m^{-2} d^{-1})			References
	CO_2	CH_4	N_2O	
Bireak/temperate forest	-2100	-1.0		Crill 1991, Savage et al.1997
Tropical forests	-710	-0.2		Keller et al.1986, Phillips et al.1998
Northern peatlands	-230	51		Gorham 1991
Temperate reservoirs	1500	20		Vincent et al.2000
Tropical reservoirs	3500	100		Vincent et al.2000
Lakes (worldwide)	700	9		Cole et al.1994, Schlesinger 1997
Finnish lakes			0.05	Huttunen et al. 2003
Lake Taihu			0.52	Wang et al. 2009
Lake Taihu		3.4		Wang et al. 2006
Lake Taihu	15067	2.76	0.02	Our study



Wang et al. 2006

6 Conclusion

- Lake Taihu is a source of CO_2 and CH_4 emissions to the atmosphere.
- Lake Taihu is a moderate source of N_2O emissions to the atmosphere.
- Lake Taihu had a higher GWP.
- GHG Concentration and flux had significant relationship to meteorological factor, such as water temperature, air temperature, and wind speed。

Thank you