Dear reviewer/editor:

We ssincerely appreciate your suggestions and help on this paper. We are pleased that the reviewers saw merit in our paper, and recognised the importance of this relatively new line of work. We read their comments with great interest, and we have managed to complete an extensive revision on time. We thank them for their efforts.

According to the two interactive comments, major revision of the manuscript is listed below:

Revision of introduction

1. The new introduction is more focused on the necessity of work on reservoirs, especially on the littoral zone. Limitations of previous work in the littoral zone were discussed as well as the unique contribution of this work. We have deleted some of the more general material about climate change (page 2, lines 10-32 and page 3, lines 1-16).
2. We have refined the hypothesis and objectives, spelling them out more clearly and accurately (page 3, lines 10-16).

Revision of methods

3. We have clarified several items in the 'methods' which the reviewers queried (page 3 lines 28-30; page 4 lines 3-4, lines 10-11, lines 17-25, line 32; page 5 lines 9-10, lines 19-25; page 6 lines 2-5, line 23, lines 28-30; page 7 lines 3-4).
4. We have revised the description of statistical methods including some new analysis (page 6 lines 28-31, page 7 lines 1-6).

Revision of results

5. We have carried out more statistical analysis, and in particular we have looked at the negative fluxes as well as the overall fluxes, and tried to relate them to environmental variables (page 7 lines 18-19, page 33 Fig. 6).
6. Diurnal variation of the flux was added. This demonstrates that the diurnal variation is small (page 7 lines 19-21, page 31 Fig. 4).
7. Fig1, 2, 3, 5 was kept as before but improved in some specific details.
8. Fig. 4 (page 31) was replace by a new figure which showed not just flux variation among water levels, but also variation among months and times of day. Furthermore, the new Fig. 4 also showed differences between ‘natural land’ and farmland (which could explain why emission of all sampling plot ‘C’ looks higher).
9. Fig. 6 (page 33) was improved by including negative fluxes. The relationship between flux and DO was plotted separately as a new Fig. 7 (page 34) which showed better correlations. Relationships between flux and wind was not included anymore as the correlation is very low.
10. Details of plant species found in the littoral zone during each month are listed as a table (page 24 Table 1).
11. Multi-ANOVA was done to show flux variations according to the factors: location, time of year and time of day. Location and time of year are strongly significant, time of day is not (page 25 Table 2).
12. The correlation at natural land and farmland between flux and environmental factors was added (page 26 Table 3).

Revision of discussion

13. The discussion was improved, both in logic and structure. New references were added. 50% of the text was rewritten according to the comments.

14. Discussion on flux from natural land and farmland of the present study was added (page 13 lines 23-30).
15. A brief conclusion paragraph was added at the end answering the objectives and addressing the important hypothesis raised in the introduction (page 14 lines 20-24).

For one-to-one response to each comment, see below please.

Anonymous Referee #1

General comments

This is a study of N2O emissions from a reservoir in China. Based on the area change upon a difference in low and high water level of 5 m the reservoir appears to be shallow over large areas. The sampling design seem rigorous by covering many water level regimes, being based on multiple sampling over the year to cover different seasons, diel sampling at each sampling day(?), flux chamber replication in space both taking nearby and more remote spatial variability within each water level zone. This extensive sampling gives the study a high potential for increased understanding of variability in space and time including spatial variaility by water level, spatial variability by vegetation types, diel variability, and seasonal or Monthly variability.

At the moment I do not think this potential is fully explored. There are many levels of variability studied that is not even mentioned in the paper. Further, the aims and unique contributions of the paper are not clearly expressed. The data is analyzed based on primarily single correlations and regressions without any outspoken strategy in terms of trying to explain different type of variability occurring at different levels in space and time with different environmental variables having synchronous variability. One way to approach this is to ask "What variability was greatest and need most attention in the future?". The "dimension" with greatest variability also dictates what environmental factors are likely to be important regulators. To just give an example (perhaps not relevant here): If the diel variability is greater than other types of variability, then it is not likely to find strong correlations with daily averages of environmental factors and variables having diel variability is needed to explain the observed diel flux patterns. It is not clear how such considerations are made when looking for correlations with environmental factors.

Several significant relationships are presented but the predictive power is very low and graphically it looks like the type of situation where statistical significance is reached because of a large number of data points, while the significant patterns do not help us gain new clear or improved understanding because of low predictive power. Some of these cases perhaps, and interestingly, point at a decoupling between N2O fluxes and environmental variables. Finally, the implications of the study are not explained clearly and with the amount of data available it would be nice to try to expand the results into more general implications in a clear way. I think this study has great potential if just these issues and the other comments below are considered carefully.

R: Diurnal sampling was done for each sampling day, seven times per day (including night).

Flux variations and correlations on different scales were analysed at different sampling positions, time of year and time of day. Flux variations at different spatial and time scales were shown in a new figure (page 31 Fig. 4). The correlations at different levels in space were showed in the revised manuscript (supplementary material: Table 1R), but not at different time scales because no appreciable difference or big improvement in r was observed. Discussion of the reasons for the low coefficients was improved or added including the presence of non-linear relationships which would lead to low coefficient in simple correlation analysis (page 8 lines 2-8, page 11 lines 23-26), and constraints of soil moisture and nutrients (page 11 lines 11-14, page 12 lines 25-32) which might inhibit the velocity of N_2O production and the apparent responses to other environmental parameters.

Detailed comments

Abstract Line 7: Unclear what control site means here as stable control conditions may be difficult to maintain under fluctuating water. Please clarify in what way these two sites served as control. (This is explained in the later text so this comment is about clarity for those only reading the abstract. However I think the word control site signals something else than what is the case here and what is called control site here does not stand out as very different from the other sites with stable water moisture, e.g. the NF site, so I wonder if it would not be good to omit using the word "control" to reduce the risk of confusion.)

R: This control area (SFC) was set as a control for the seasonal flooded area (SF). It had more or less the same vegetation and similar soil conditions as SF before SF was flooded. SFC was assumed as a substitute for SF to explore what the flux would be if there was no water level fluctuation. It is on slightly higher ground and so it was not flooded. More specific statement is now given in the abstract and elsewhere (page 1 lines20-22, page 4 lines15-17).

L17: Were N2O and CH4 measurements performed simultaneously or at different times? This is essential for the interpretation of the comparison.

R: Yes, N_2O and CH_4 measurements performed simultaneously.

L 18-20: The sentence "It showed that N2O flux and CH4 flux was influenced by distinct factors and in differing ways." is a bit vague. Would it be possible to briefly explain how N2O and CH4 fluxes and regulation differed instead?

R: The sentence has been rewritten. The differences between the driving variables of the two gases are too complex to be stated in the abstract, but we write about them in the discussion (page 13 lines 7-22).

L20-22: Instead of ending the abstract with emphasizing the complexity and challenges – please highlight the unique implications from this study and how it leads forward towards better understanding the complexity and reducing the future challenges.

R: The revised abstract ends with specific implications (page 2 lines 5-7) as "The littoral zone is a hot-spot for N_2O in the summer, especially when the shores of the lake are used for farming of maize. But in terms of the overall greenhouse gas budget, the fluxes of N_2O are not as important as those of CH_4."

1 Introduction After reading the introduction it was not clear to me what the unique contribution of this study will be. I am not contesting the uniqueness of the work but just note that this needs to be clarified. What specific knowledge gaps are addressed that has not been considered properly before? Are there any hypotheses to be tested? Even though I understand the need of descriptive studies tageting similar things at different locations to generate data for later synthesis work, it is beneficial if such studies could also test hypotheses or specifically address knowledge gaps. At the moment,the message I get from the Introduction is that similar work to in a few previous studies is now repeated in a new location, but I think this impression may not be true, and I would wish to learn from the introduction in what way this study is leading forward and providing a unique contribution (e.g. new hypotheses, better study design or measurements...etc; a now location may be fine too if there are very special reasons for believing that this location is important)

Below also a few references that I think could be important in the context of this study (both in the Introduction and Discussion parts) but do not seem to be considered at present:

Guerin, F., Abril, G., Tremblay, A., Delmas, R., 2008. Nitrous oxide emissions from tropical hydroelectric reservoirs. Geophysical Research Letters 35.

Huttunen, J.T., Vaisanen, T.S., Hellsten, S.K., Heikkinen, M., Nykanen, H., Jungner, H., Niskanen, A., Virtanen, M.O., Lindqvist, O.V., Nenonen, O.S., Martikainen, P.J., 2002. Fluxes of CH4,CO2, and N2O in hydroelectric reservoirs Lokka and Porttipahta in the northern boreal zone in Finland. Global Biogeochem. Cycles 16, 3-1 to 3-17.

Liengaard, L., Nielsen, L.P., Revsbech, N.P., Priemé, A., Elberling, B., Enrich-Prast, A., Kühl, M., 2013. Extreme emission of N2O from tropical wetland soil (Pantanal, South America). Front. Microbio. 3.

R: The introduction was revised. More statements focused on the specifics of the present work. We think the big improvement of this research is the sampling both in space and time which was expected to provide more representative data on N_2O emission for the littoral zone to match its diverse and dynamic emvironment. Another way in which the work is 'special' is the possibility of comparision with the CH_4 fluxes. Also the impact of the opportunitic agriculture (maize crops). The over-arching hypothesis in this work is: the littoral zone is a hot-spot of N_2O emissions that is influenced by seasonal changes in the water level. We have stressed these points in the revised introduction (page 2 lines 31-32, page 3 lines 1-16).

The reviewer's recommended references are cited in revised manuscript (page 2 line 20, line 25; page 3 line 3; page 9 line 19, line 23; page 10 line 30).

Methods and onwards (Page and Line numbers or section used from here).

P5337 L18. Is there any suitable reference for Level II Environmental Quality Standards?

R: Yes, it's a national standard (Environmental Quality Standards for Surface Water of People's Republic of China GB3838-2002), the number of the file and the access website was added in text (page 4 lines 3-5).

P5338 L7. It is unclear what the site NF is representative for. This is important for future attempts to upscale fluxes from different environments. Please clarify.

R: Site NF was 'seldom' flooded .The water level reaches here only in exceptionally wet years, and not in this year. Explanation was added (page 4 lines 17-19).

P5338 L24-28. Does opaque here mean that chambers were not transparent to PAR? If so, how could this have affected potential fluxes from plants?

R: The chambers were made of stainless steel. We think it was possible that the artificially induced dark changed the N_2O flux. But based on the previous researches, we cannot make sure how the fluxes had been changed since significant and insignificant differences both have been reported, e.g. Zhongjie Yu et al, 2012 and Dongqi Wang et al, 2009. In addition, the artificially increased temperature in any transparent chamber would make it more difficult to distingush any light effect from any temperature effects.

P5338 L25. What brand of gas sampling bags was used. Has these bags been tested for N2O?

R: The bags are produced by Guangming Research and Design Institute of Chemical Industry, China. This type of bag is designed and produced for gas sampling and analysis. We tested if storage period in the sample bag influences the concentration over one week, but no significant difference was observed.

P5339 L5. Please describe briefly how fluxes were calculated.

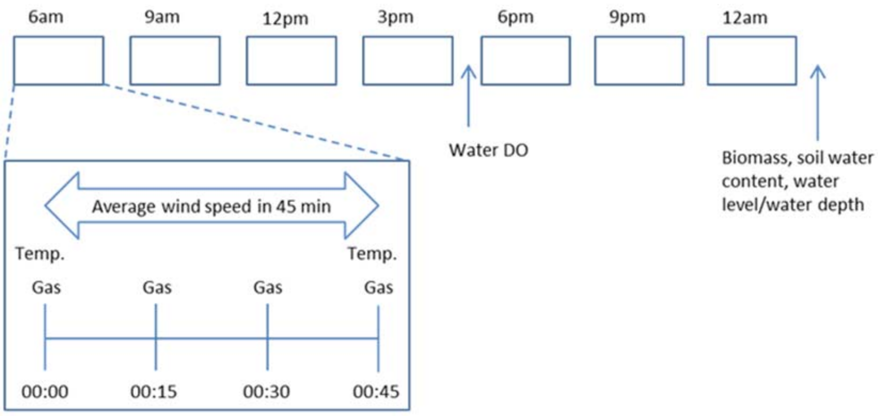
R: We added the formula and explanations for each parameters (page 5 lines 19-25).

P5339 L6. So, new positions each time. Could this have affected the results by introducing unknown variability? What is known about local variability?

R: Yes, in order to get a better understanding of the relationship between biomass and flux, the plant material inside chambers was harvested after every campaign, so that we could report biomass and see whether it was correlated with flux. Using new positions might introduce a biomass difference since the vegetation growth would not be exactly the same. In addition, there might be difference in terms of soil nutrients caused by invisible historical events in centimeters to meters scale, e.g. decomposition of necromass (plant or animal).

P5339 L10-16. So the time span of the different analyses varied? Please see comment to figure about drawing lines between sample points implying that data are valid for integration. This may not always be the case.

R: The precipitation was the weekly average which is the only parameter not measured by ourselves. As shown below, the diel wind speed and diel temperature were measured at the same time as the diel flux. Water DO, biomass, soil water content, soil water level/depth was just measured one time per sampling campaign at the location of each chamber.



P5340 L4. How was the soil extracted for pH measurements? There are several common protocols.

R: We used 1:5 soil-water extractions. This is now added in text (page 6 line 23).

P5340 L9-16. See comment to figure regarding the piecewise regression (which I am not convinced is a good idea).

R: We kept the piecewise regressions with temperature and soil nitrate but deleted the other two (we agree that no considerable piecewise regression exists in their cases). See below, please, for more explaination.

P5341 L2-9. Are the negative results considered? In one figure they were apparently not. I think an equally thorough analysis of the negative results could be interesting. ...I also think that the main fluxes should for at least one value be presented also in mmol m-2 h-1 units to give a reference point for those used to this unit.

R: Yes, the negative results have now been considered. To clarify that, this paragraph was rewritten to make it more clear (page 7 lines 17-30). And the negative flux was also added in scatter plots (page 33) so that in the revised manuscript all flux-related figures and tables show both positive and negative flux, i.e. all data. The main flux in units of μmol m^{-2} h^{-1} is now added in result (page 7 line 17).

P5341 Section 3.3. Figure 6, showing no visible correlation with log-transformed data, makes it very difficult to imagine any important relationships. It is a bit surprising that Table 1 indicates so many significant relationships. The highest r2 (correlation coefficient) is 0.35 vs DO which is very low given that the regression coefficient R2 is the square of r2 right? Further if the piecewise relationship for temp and nitrate is true this should substantially weaken any linear correlation. With enough data points almost all correlations become significant, but at low R2 they may not have any practical meaning. This is an important discussion I think and it is also important to show awareness of this when choosing what results are most important and should be highlighted from the study. I would consider emphasizing the low R2 and the absence if clear relationships rather than stressing that there were significant relationships.

R: The coefficient in the table was r.

We agree with your opinion. Any non-linear response, including piecewise relationship, should weaken any attempted linear relationship and therefore a low r may not have practical meaning. We added discussion on the possible reasons for the low coefficients including weakening by non-linear relationships and constraints of soil water condition or nutrients (page 8 lines 2-8; page 11 lines 11-14, lines 23-26; page 12 lines 25-32).

The scatter plot of water DO and flux were re-plotted using average values of each spot (page 34 Fig. 7). The r increased to 0.8 (r^2=0.65).

P5342 L5. Why is the lowest flux noted in the text -2.29 when much lower fluxes are noted and visible in Figure 6 (as low as -27). If many negative fluxes are ignored very good reasons for this should be given. At present I do not understand how data were treated and how to interpret the results...and this undermines my confidence in the study. Please make necessary clarifications.

R: This was caused by taking an average at different time scales, i.e. the -2.29 was lowest montly average flux while the -27 was the lowest daily average flux. The conflict is now dealt with in the revised manuscript. To avoid confusion, clarifications on calculation methods were added when necessary in revised text (page 7 lines 3-4).

P5342 Section 4.1. Why not also refer to Table 2 for comparisons with other studies?

R: Added (page 9 line 14, line 23).

P5343 L1-16. CH4 fluxes and thereby the N2O to CH4 ratio cannot be properly evaluated without more information about the CH4 fluxes. Were they measured from the same hambers (if so good; if not comparability can be compromized by spatial or temporal variability)? Is ebulliton included or not in the CH4 fluxes?

R: Yes, N_2O and CH_4 was from the same chambers. All gas samples were analysed at the same time using gas chromatography for both N_2O and CH_4 concentrations. Unfortunatly, we did not collect ebullition gases using inverted funnel or similar equipment. Ebullition might have occurred occasionally, but it's hard to make sure.

P5344 L15-17. Does this mean that there may be a flooding pulse in N2O emissions for a few hours that is likely missed if there is not continuous sampling? If so, what does this mean for the interpretation of the presented results?

R: It might be. So the observed emission might be lower than the real and high frequency monitoring would certainly be better.. A few lines are added to acknowledge that fact (page 11 lines 18-21).

P 5345 and onwards - Section 4.3.2 - 4.3.4. I am not really convinced by this discussion because I am not sure there are any clear relationships between N2O fluxes and the environmental variables in this study. Significant regressions do not mean much if there are many data points and low R2. I would try to reanalyze the data and combine fluxes and variables acting at similar time scales. I would also try multiple regressions trying selected combinations of variables. If this does not reveal any stronger relationships the data may even indicate decoupling between flux and many environmental variables thought to be important, which is also interesting.

R: The correlation was analysed seperately according to different months, water levels and locations of the chamber. No improvement was obtained. The r of linear, and several non-linear multiple regressions including single or multiple factors also was low, just as in simple correlation analysis.

The discussion on wind speed was deleted because of the low r. The plot of flux with temperature, soil nitrate and water DO was re-plotted (page 33 Fig. 6, page 34 Fig. 7). It makes the relationship clearer. In addition, discussion on the likely reasons for low coefficients was added in this section (page 8 lines 2-8; page 11 lines 11-14, lines 23-26; page 12 lines 25-32).

Another question - why is not the diel variability shown and discussed more if the data exist?

R: Diurnal variation is now added (page 31 Fig. 4, page 7 lines 19-21, page 8 lines 25-31, page 9 lines 1-2).

P5347 L20-22. I do not understand the meaning of this sentence. Can it be clarified?

R: Soil moisture of the littoral zone is patchy and ranges from flooded to seasonally dry. Besides rice growing, crops do not tolerate flooding or drought. A more specific statement was added (page 14 lines 8-10).

Section 4.4. I miss a discussion of the implications of this study.

R: One paragraph was added at the end (page 14 lines 20-24), see below, to discuss the implications of this study, and we revisit the hypothesis as well.

"Finally, we return to our original hypothesis, which was: the littoral zone is a hot-spot of N_2O emissions that is influenced by seasonal changes in the water level. We find that the littoral zone is a hot-spot for N_2O in the summer, especially when the shores of the lake are used for opportunistic farming of maize. But in terms of the overall greenhouse gas budget, the fluxes of N_2O are not as important as those of CH_4."

Figure 1. I think then concept of this figure is nice. It seems that the figure includes some information that is not mentioned in the legend (e.g. difference between high WL and low WL and why SFC is referred to as a control and not just a different regime as any of the others). I do not understand the distances noted between sites A, B and C and would prefer to not have to find another paper to check this up. Can the legend be further clarified so that all its parts can be understood independently from the text?

R: More details are given in the legend, including but not limited to those you suggested (page 28 lines 3-5, lines 10-13).

The distances noted between sites A, B and C was in the horizontal. Species of A, B and C were listed in the revised manuscript as Table 1 (page 24).

Figure 2. Both wind speed and air temperature are highly variable over the day. What is really shown in the graphs? Is it snapshot measurements indicated with the points (if so I wonder if interpolation is valid as the time of the day for the sampling may be critical) or is it some kind of daily or weekly average?

R: The air temperature and wind speed shown in Figure 2 was the daily average value which was monitored when gas samples were taken, i.e. wind speed was the mean of seven 45-min averaged wind speeds in one day while air temperature was the mean of 14 snapshot measurement in one day, as shown below.

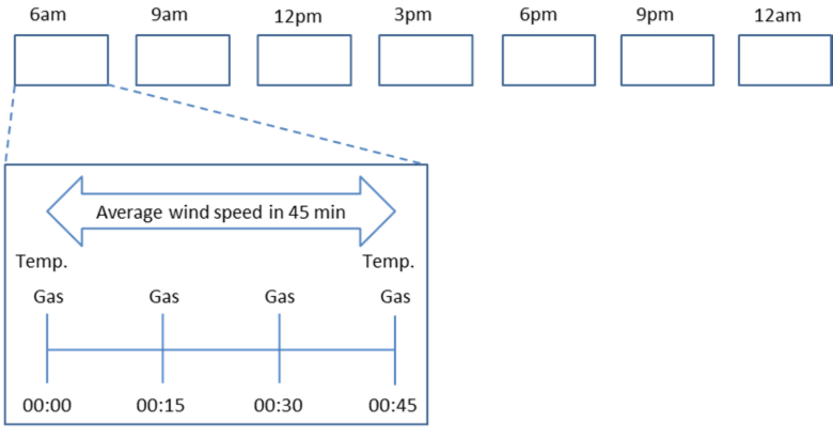


Figure 3. Interesting that the sum of NH4+ and NO3- is substantially lower at SFC than at the other sites. Why is that and could this be of importance when interpreting the data?

R: Besides maize, alfalfa (for cow feed) is another crop grown along water edge. One piece of land is not always maintained for growing maize or alfalfa, there is unregulated alternation depending on the farmer's view of what might be the most useful. Historical croping differences of land patches might be the reason for the patchy NH_4^+ and NO_3^- of soil. Compared to maize, farmers do not use N fertilizer (or not use as many as in maize cropping) for Fabaceae cropping, since Fabaceae can fix N themselves and grow well without extra N fertilization.

The highest N_2O emission was observed when highest NO_3^- occurred. Low NH_4^+ might inhibit nitrification.

Figure 4. What type of environment is NF representative for? All types of non-flooded soils? A narrow zone of moist soil near the water?

R: We think NF was typical of non-flooded soils. But it's hard to conclude that it represents all types of non-flooded soil since many other factors besides soil moisture also influence N_2O emission; pH for example.

Anonymous Referee #2

This manuscript discusses a detailed field study on N2O emissions in the littoral zone (which they define as from non-flooded to permanently inundated waters) of a large Chinese reservoir. They describe the sampling design well and included 7 campaigns throughout various seasons, including the flooding season which is most important to their study. They compare their results of N2O fluxes and its controls to a similar study on CH4 fluxes at the same reservoir. The detail of experimental/sampling setup makes this study relatively unique as does the comparison of N2O to CH4 fluxes in the same area of a reservoir. The focus on greenhouse gas emissions from seasonally inundated regions of a reservoir is an extremely important topic. While I do have some issues with data interpretation and the discussion (but include ways how to improve it), I believe after some major revision that this paper could be accepted for publication.

General comments:

1. My biggest concern with the manuscript is their definition of the littoral zone. From what I can gather, the authors included an area next to the lake that is never flooded (Site NF) in their analyses (in Table 1, for example). The littoral zone of a lake is the nearest to shore portion of a lake that is underwater. In the case of a reservoir, where water levels can change dramatically, I would think the definition of a littoral zone could be robust enough to include the drawdown region of the reservoir where changing water levels will leave a portion of the littoral zone seasonally dry. However, I find it hard to call a portion of the lake that is never inundated as part of the littoral zone. I thus find it strange to include measurements from such an area in regressions between flux from the littoral zone and the environmental parameters considered. The fact that Figure 5d (site NF) is a completely different scale to the other three panels containing the other three sites is enough of a reason to cause concern when including this site in your correlations. If by chance I misunderstood and site NF was not considered in the correlations, then I believe the authors should make that very explicit. However, if this site was included in the correlations then I strongly suggest that the authors re-do their analyses without these measurements. I also have an issue with the soil analyses and using site DW with the others. See comments below too.

R: Site NF is seldom flooded (one time per several years) and not flooded during our sampling campaigns. More explaination was added in 'method' (page 4 lines 17-19). The correlations at each water level is shown below (also as supplementary material Table 1R).

Spearman's Rank Correlation (r) between flux and environmental variables.

		Wind speed	Air temp	Water depth	SWC	Water DO	Biomass	Bulk density	Soil pH	Soil TC	Soil TN	Soil NH_4^+	Soil NO_3^-
Farmland and non-farmland	All site	0.07**	0.16**	-0.05*	-0.12**	0.23**	-0.04*	0.03	0.08**	-0.05*	0.01	-0.01	0.18**
	DW	0.21**	0.26**	0.24**	0	0.20**	-0.22**	-0.02	0.16**	-0.22**	-0.23**	-0.02	0.18**
	SW	0.06	0.20**	0.17**	0	0.10*	-0.07	0.04	0.05	0.08	0.10*	0.10*	-0.06
	SF	-0.04	0.07	-0.13**	-0.19**	0.14	-0.12**	0.01	-0.01	-0.02	0.13**	0.15**	0.04
	SFC	0.02	0.15*	0.23**	0.22**	No data	-0.27**	-0.06	0.09	0.17**	0.13*	-0.08	0.03
	NF	0.09	0.14**	0.25**	0.22**	No data	0	-0.31**	0.20**	0.21**	0.26**	0.18**	0.38**
Farmland	All farmlands	0.01	0.26**	-0.10*	-0.01	0.07	0.06	0.07	0.16**	-0.07	-0.05	0.05	0.23**
	SW-C	0.01	0.32**	0.40**	0	0.05	0.14	-0.02	0.04	0.02	0.02	0.04	0.05
	SF-C	-0.03	0.16*	0.1	0	-0.35**	0.16*	-0.04	-0.03	0.06	0.06	0.01	-0.01
	SFC-C	0.12	0.25*	0.50**	0.51**	No data	-0.49**	0.05	-0.05	-0.09	-0.09	0.09	-0.05
	NF-C	0.04	0.34**	-0.05	0.33**	No data	-0.05	0	0.01	0.04	0.04	-0.06	-0.06

	All non-farmlands	0.10**	0.12**	0.02	-0.13**	0.29**	-0.07**	-0.02	0.03	0.04	0.07**	-0.15**	0.13**
	SW-A, B	0.09	0.16**	0.13*	0	0.08	-0.06	0.05	0.06	0.06	0.03	0.07	0
Non-farmland	SF-A, B	-0.07	0.02	-0.27**	-0.35**	-0.11	-0.09	0.05	0	0.06	0.08	0.16**	0.05
	SFC-A, B	-0.01	0.09	0.08	0.06	No data	-0.07	-0.24**	0.01	0.24**	0.15	-0.43**	0.05
	NF-A, B	0.13*	0.06	0.24**	0.06	No data	0.03	-0.04	0.19**	-0.14**	-0.15**	-0.11*	0.22**

2. There were many times in the discussion that I felt the authors skipped details crucial to understanding their line of thinking. Please take special note of those when implementing my comments below.

R: The discussion has been rewritten. We think the revised text is better in logic, as well as in its information content.

3. There is an incredible amount of data in this study and I believe the authors have not drawn as much out of the data as they could and should. Their 24-hr measurements are impressive as not many researchers spend the time to perform flux measurements every 3 or so hours. I highly encourage the authors to go into more detail regarding temporal variability in their data, while taking care about the spatial variability and not to compare apples to oranges.

R: A graph of diurnal variation is now added. The variation at different times of day was not significant even when the analysis was done seperately at each water level. No good correlation was found between diurnal flux and environmental factors (temperature and wind speed was measured at the same time and frequency as diel flux). So, to summarise the pattern of variation, just one line plot (page 31 Fig. 4) and the ANOVA (page 25 Table 2) is shown in the revised manuscript.

4. I believe the paper could benefit from some type of summary/conclusion paragraph. This will also help the authors find their focus in regards to the main findings/results of this study.

R: One paragraph was added at the end summarising the objectives and hypothesis raised in introduction (page 14 lines 20-24).

Specific comments:

Abstract:

1. Line 7-9: Don't use the word 'area' so much when describing the five sampling locations.

R: Deleted (page 1 lines 18-19).

2. Line 19 – were N2O and CH4 measurements made at the exact same time?

R: Yes, the N_2O and CH_4 measurements were made at the exact same time. It was specified in abstract (page 2 lines 1-4).

Why only comparable methods? I would be clear in the abstract but not give too much detail. For example, ': : :compared with a previously published study of CH4 emissions from the same sites as those in this study which was carried out simultaneously.'

R: Thank you! Revised accordingly (page 2 lines 3-4).

Introduction:

1. P5335, L4 – list some of the man-made sources of N2O

2. L9 – where have the variations in N2O flux been noted? List some refs

3. L9-13 – make this one long sentence into 2

4. P5336, L8 – 'microbial activity' instead of 'activity of microbes'

R: The introduction was revised. The new introduction focused on the necessity of a study on the reservoir, especially on the littoral zone. Limitation of the previous work by others in the littoral zone were discussed as well as the contribution of this work. Considering focus and length, some rather general matters were deleted.

Methods/Results/Discussion

1. P5337, L23-25 – there should be more explanation as to how this unusual flooding impacted your sampling design or results. If this is not an every year occurrence then this will have implications for your results.

R: This provided us with a seasonal flooded area which made possible an exploration of the effects of summer flooding on greenhouse gas emissions. The water level increase in summer does not happen every year, in some years the level is stable; it may even decreased. The sentence was rewritten to clarify (page 4 lines 7-11).

2. Figure 1 – The figure is nice but I'm confused about how many plots within a site there were. This needs to be made explicit in the figure caption and text. I believe there are the 5 major sites relative to water level, then at each site you had 3 sampling locations and at each of those you made 4 replicates – these last two numbers would explain the many ovals in the figure, correct? And then you performed this sampling 7 times each day you sampled (so over almost a 24 hr period) and you did this 6 times in the year to cover different seasons and covering the transition in and out of the flooding season well. Is this correct? Please present a more organized way to say all of this in the methods section and again in the figure caption.

R: Yes, exactly. Both figure caption and text was improved carefully (page 28 lines10-13, page 3 lines 4-6, page 4 lines 27-32).

3. P5341, L2 – you say that significant differences were found between the 5 sample areas, but it looks like from Figure 4 that only NF is different from the other sites and that the other sites are all similar. Is this true? This also lends to my concern that NF does not belong in the analyses. And now that I look closer, I see that C in every panel (at every site) is different than the rest. What makes C so special? I see that A, B, and C represent different vegetation but you don't describe this anywhere in the text. Please sort this out and explain the vegetation types and why C would be so different.

R: Yes. The only different flux was in NF. C in SFC and NF grew maize in the year of study while C in SF and SW was maize during last summer. Details of plant species at each plot are now listed in a table in revised manuscript (page 24 Table 1). Flux of 'natural' and 'farmland' are shown seperately and discussed (page 31, Fig. 4, page 32 Fig. 5, page 4 lines 19-24, page 13 lines 23-30).

4. Table 1 – define 'SWC' in a footnote or somewhere.

R: Added (page 26 line 4).

5. P5342, L6 – is this Austrian lake study the only other temperate lake that had emissions measured in the littoral zone? Make that clear if it's the case.

R: No, the report on littoral zone in temperate zone is limited, but this is not the only one. We changed the sentence in manuscript, pointing out that the Austrian lake was an example (page 9 lines 8-10).

6. P5342, L9-12 – this is not a fair comparison -> while both of these systems are located in temperate regions like yours, the Diem paper looks at only high elevation lakes and presumably the Jacinthe study was done on a low elevation reservoir. I think this paragraph needs a bit more reworking to make sense logically. Also, you state later on line 20-21 that your emissions are much lower than those from boreal and Antarctic lakes. Then mention something important about water quality that comes up again later (P5347,L5-6). The comparisons with other lakes and reservoirs have to be done in a logical way considering major factors, such as latitude and climate zone but also elevation and general characteristics. There is potential here for a nice literature comparison but it needs work.

R: The text has been re-organised (page 9 lines 8-31), and we hope that it is now more logical. Of course, there are many variables when one compares sites to put together the global picture, and the data available are still quite sparse. Therefore, it is hard to generalise.

7. L12 – where is this Jacinthe reservoir located? Put it in the text.

R: Information was added. It's near Indianapolis, USA (page 9 line 28).

8. L13 – why do all the 'ffi' look funny throughout the paper?

R: Evidently, this font makes 'ffi' look funny. We submitted in Times New Roman where 'ffi' looked normal.

9. L22 – 'might be because'

R: Revised (page 9 line 20).

10. P5343, L7 – You should definitely give some more details about why your earlier report was more biased because of the flooding.

R: In our previous study, N_2O variation was investigated with a water recession process. Significant increases (nearly up to 1000 times) of N_2O flux were observed after sediment exposure of 5 months which were believed to be mainly caused by soil water content declining to 60-90%. In this research, the soil water content never was in this range and that may have biased the comparison. This information is now added in manuscript (page 10 lines 8-13).

11. P5344, L6 – it 'could' or it 'should' inhibit? Is this is a proper debate? Or there is just no consensus?

R: Gas transport by diffusion in unstirred water is about 10000 times slower than transport in air. We were merely indicating that standing water will tend to cause anoxia. We think that isn't controversial, so we don't see a reason to change the statement.

12. L8 – I believe what you meant to say here was 'While our results did not reject this possibility, they did not completely support that hypothesis either.'

R: Yes, revised (page 10 lines 30-31, page 11 line 1).

13. L11 – this 'extraordinary' observation at SF-C is interesting and I noted it earlier as well. This C vegetation needs to be explained.

R: C in SF and SW used to be maize, at least during the last summer, while C in SFC and NF had maize during sampling. Details of plant species at each plot are listed in table of the revised manuscript (page 24 Table 1). To explain the uniqueness of C, the flux of natural and farmland are shown seperately and discussed (page 31, Fig. 4, page 32 Fig. 5, page 4 lines 19-24, page 13 lines 23-30).

14. P5345, L4 – 'emission even more challenging'

R: This sentence was deleted in order to make the discussion more specific.

15. L5-7 – the English here needs to be improved

R: This sentence was replaced by more clear statement of implication (page 11 lines 18-21).

16. L8 – the subtitle is 'other soil conditions' – are you using the word 'soil' here to also represent 'sediment'? For the most part, the bottom of a lake would be considered sediment and not soil. This is perhaps not the case when you are in the littoral zone and have seasonally flooded soils. However, you site DW seems to have very different 'soil' than the other sites based on Figure 3. Was DW also used in the correlations? Again, this may be a situation where you are comparing apples and oranges. I would take a look at the correlations with and without DW.

R: The 'soil' in text was changed into 'soil/sediment' when refered to both flooded and non-flooded soils (page 4 line 24; page 5 line 1; page 6 line 19, line 21; page 13 line 17; page 30 line 3).

Yes, DW was used in the correlations. Below the correlation was shown seperately of each water level (also as supplementary material Table 1R). Discussion on the reasons for a low coefficients is now added in text section (page 8 lines 2-8; page 11 lines 11-14, lines 23-26; page 12 lines 25-32).

		Wind speed	Air temp	Water depth	SWC	Water DO	Biomass	Bulk density	Soil pH	Soil TC	Soil TN	Soil NH_4^+	Soil NO_3^-
Farmland and non-farmland	All site	0.07**	0.16**	-0.05*	-0.12**	0.23**	-0.04*	0.03	0.08**	-0.05*	0.01	-0.01	0.18**
	DW	0.21**	0.26**	0.24**	0	0.20**	-0.22**	-0.02	0.16**	-0.22**	-0.23**	-0.02	0.18**
	SW	0.06	0.20**	0.17**	0	0.10*	-0.07	0.04	0.05	0.08	0.10*	0.10*	-0.06
	SF	-0.04	0.07	-0.13**	-0.19**	0.14	-0.12**	0.01	-0.01	-0.02	0.13**	0.15**	0.04
	SFC	0.02	0.15*	0.23**	0.22**	No data	-0.27**	-0.06	0.09	0.17**	0.13*	-0.08	0.03
	NF	0.09	0.14**	0.25**	0.22**	No data	0	-0.31**	0.20**	0.21**	0.26**	0.18**	0.38**
Farmland	All farmlands	0.01	0.26**	-0.10*	-0.01	0.07	0.06	0.07	0.16**	-0.07	-0.05	0.05	0.23**
	SW-C	0.01	0.32**	0.40**	0	0.05	0.14	-0.02	0.04	0.02	0.02	0.04	0.05
	SF-C	-0.03	0.16*	0.1	0	-0.35**	0.16*	-0.04	-0.03	0.06	0.06	0.01	-0.01
	SFC-C	0.12	0.25*	0.50**	0.51**	No data	-0.49**	0.05	-0.05	-0.09	-0.09	0.09	-0.05
	NF-C	0.04	0.34**	-0.05	0.33**	No data	-0.05	0	0.01	0.04	0.04	-0.06	-0.06
Non-farmland	All non-farmlands	0.10**	0.12**	0.02	-0.13**	0.29**	-0.07**	-0.02	0.03	0.04	0.07**	-0.15**	0.13**
	SW-A, B	0.09	0.16**	0.13*	0	0.08	-0.06	0.05	0.06	0.06	0.03	0.07	0
	SF-A, B	-0.07	0.02	-0.27**	-0.35**	-0.11	-0.09	0.05	0	0.06	0.08	0.16**	0.05
	SFC-A, B	-0.01	0.09	0.08	0.06	No data	-0.07	-0.24**	0.01	0.24**	0.15	-0.43**	0.05
	NF-A, B	0.13*	0.06	0.24**	0.06	No data	0.03	-0.04	0.19**	-0.14**	-0.15**	-0.11*	0.22**

17. L13 – what were the other five soil variables that correlated with CH4 flux and not N2O flux? This entire paragraph should be comparing these relationships but it is not clear to me what the correlations with CH4 flux were and thus I cannot tell how they were different from those with N2O. You seem to be just listing possibilities for soil-N2O correlations from previous findings. Either make more reference to CH4 in this paragraph or not at all. This point of this paragraph needs to be better focused.

R: The other five soil variables were soil bulk density, pH, TC, TN and NH4+. This paragraph is reorgnised (page 13 lines 7-22).

18. P5346, L7 – there are more relevant papers than the Schilder one to describe gas exchange processes in water. Use a more commonly cited paper.

R: Discussion on wind effects was deleted, considering such weak indications of correlations in our data.

19. L10 – why do you assume that wind influences gas exchange over soil more than over water? I wouldn't necessarily assume that and you shouldn't in this case. If this is known, then present a reference. This needs further discussion. And in general, this paragraph needs to focus more on how YOUR wind data impacted fluxes at each of your sites. You have saturated and unsaturated sites. Use that to draw more conclusions.

R: The correlation between flux and wind speed was analysed in each water level. Considering the low correlation coefficients and the pattern of the scatter plot, disscussion of the wind effects has been abandoned.

20. L21-23 – Improve these sentences: 'For N2O, negative relationships between N2O flux and oxygen are reported in both laboratory experiments and field studies (xxx). This is explained by the fact that denitrification, which is activated in anoxic environments, is likely controlling N2O emissions ().'

R: Thank you! Done (page 12 lines 9-12).

21. Line 24-25 – ': : :those previous conclusions because a significantly positive correlation: : :'

R: Thank you! Done (page 12 lines 12-13).

22. Line 25-26 – 'This implies that in some environments different processes may control N2O emission rates.'

R: This sentence was deleted. More references were cited to make the discussion on the effects of water DO clearer (page 12 lines 16-19).

23. P5347, L1 – 'in the water column has been shown to depend not only: : :'

R: Thank you! Done (page 12 line 14).

24. L3 – 'might provide an explanation for our finding.': : : please explain this more. How does this explain??

R: One new reference was cited to help explain our positive correlation (page 12 lines 16-22). This study showed that denitrifying activity decreased with a decline of DO concentration, but the N_2O producing activity increased because of less N_2O reduction to N_2 (Senga et al., 2002). Furthermore, this study also pointed out that N_2O produced by nitrification could also be reduced to N_2 via denitrification. That might have happend in our study, i.e. along with increasing of water DO, a decrease in N_2O reduction to N_2 allowed more N_2O to be released at the water-air interface, no matter which processes produced the N_2O.

25. L5-8 – are you saying that your reservoir is clean and that is why you didn't find a negative relationship with DO? Please explain more clearly your point with this last statement.

R: We were trying to relate to practical activity. Beacause of the lack of consistency, this statement is now replaced by something more specific (page 12 lines 14-24).

26. Line 24 – 'Reservoir construction does provide an: : :'

R: This paragraph now ends with a more specific way (page 14 lines 10-17).

Responses of N_2O flux to water level fluctuation and other environmental factors at littoral zone of Miyun Reservoir: a comparison with CH_4 fluxes

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Abstract

There have been only a few studies that allow us to estimate the contribution of ~~newly created~~ reservoirs to greenhouse gas budgets. In particular, information is limited for understanding the spatiotemporal variation of N_2O flux and the underlying mechanisms in the littoral zone where complex biochemical processes are induced by water level fluctuations. A study was carried out at five different water levels (deep water~~ area~~, shallow water~~ area~~, seasonally flooded~~ area~~, control ~~site ~~for seasonally flooded~~ area,~~ and non-flooded~~ area) at~~) all within the littoral zone of a temperate reservoir using the static chamber technique. The ‘control for seasonal flooded’ had similar vegetation to the ‘seasonally flooded’ but was not actually flooded as it was on a higher piece of land. Seasonal, diurnal and spatial variations of N_2O flux and environmental factors were monitored throughout the growing season including a flood event during summer rains. The N_2O flux ranged from ~~–2.29 to 182.47 μg m^{-2} h^{-1}.~~136.6 to 381.8 μg m^{-2} h^{-1} averaging 6.8 μg m^{-2} h^{-1}. Seasonal and spatial variation was significant but diurnal variation was not. Non-flooded dry land emitted more N_2O than flooded land, no matter whether it was permanently or seasonally flooded. ~~However, no significant difference~~Piecewise correlation was ~~observed~~found between ~~seasonally flooded sites and their~~

control sites. Wind speedN_2O flux, air temperature, soil water content, and soil nitrate. Positive correlation was shown between N_2O flux and dissolved oxygen in water and soil nitrate influenced N_2O flux significantly. Besides deep water area, contrasting sampling between natural land and farmland (maize) was carried out showing significant higher emission in farmland. In order to know the contrasting characteristics of N_2O and CH_4 fluxes in the littoral zone of the reservoir, results were compared with a previouspreviously published study onof CH_4 emissionemissions, carried out simultaneously at the same sites and time with comparable methods. It showed that N_2O flux and CH_4 flux was influenced by distinct factors andsite as those in differing ways. This work highlights the complexity of N_2O flux atpresent study. Completely different patterns between the two gases are demonstrated. In conclusion, the littoral zone. The different response ways is a hot-spot for N_2O in the summer, especially when the shores of N_2O and CH_4 to environments implies the big challengethe lake are used for farming of maize. But in terms of the overall greenhouse gas emission control through ecosystem managementbudget, the fluxes of N_2O are not as important as those of CH_4.

1 Introduction

Nitrous oxide is an important greenhouse gas, with a Global Warming Potential 298 times that of carbon dioxide. It accounts for 0.17 W m^{-2} of the current radiative forcing according to recent reports (Stocker et al., 2013). Moreover, N_2O also plays an important role in ozone depletion in the stratosphere (Revell et al., 2012; Kroeze, 1994). Concentrations of N_2O have increased by 20% compared to the pre-industrial level, reaching 324 ppb and exceeding the highest concentration recorded in ice cores during the past 0.8 million years. Man-made sources of N_2O are estimated to be 11 Tg N yr^{-1}, accounting for nearly 40% of the total amount of natural and anthropogenic sources of this gas (Stocker et al., 2013). N_2O emissions have often been measured in terrestrial systems including farmlands, forests and grasslands (e.g. van Kessel et al., 2013; Wu et al., 2013; Cheng et al., 2014), but much less often in aquatic systems. Great spatial and temporal variations of N_2O flux have been noted, although the data are in some cases quite limited, especially for wetlands (Nicolini et al., 2013), and there have been very few studies dealing with the special case of reserviors, where conditions

~~are often quite different from those of natural lakes, especially in regard to the extent of inundation of the littoral vegetation.~~

Currently the greenhouse gas emissions from reservoirs are attracting the attention of researchers because these water bodies are increasing rapidly in number and area, growing with the continuing demand for water and hydropower. In rapidly developing countries like China, India and Brazil this growth is likely to continue for many years (Yang and Lu, 2014; Kumar et al., 2011). ~~Of all the greenhouse gases, methane has received the most attention, but nitrous oxide may also be important.~~ It is speculated that the construction of impoundments causes sediment accumulation and vegetation change, and when agricultural lands are inundated during creation of reservoirs, and for many years afterwards, there may be a strong enhancement of greenhouse gas emissions (Tranvik et al., 2009). It is noteworthy that this speculation is usually based on the expectation of an altered carbon cycle whilst data on aspects of the nitrogen cycle are lacking (L. Yang et al., 2014).

The ~~littoral~~pelagic zone of reservoirs have more often been studied (Beaulieu et al., 2014; Guérin et al., 2008; Huttunen et al., 2002; X. L. Liu et al., ~~plays an important role for both nature and humans, including providing habitats for many kinds of creatures, acting as a filter between the terrestrial ecosystems and the aquatic body, and providing possibilities of recreational activities (Capon et al., 2013; Likens, 2010). Comprehensive and accurate understanding of the littoral zone of reservoirs is the basis for ecosystem evaluation, management and wise use. As an active material exchange area, the littoral zone is reported to~~2011) but there are limited studies in the littoral zone which may be a hotspot of N_2O emissions (Wang et al., 2006). ~~This zone is usually smaller than the pelagic zone, but in the~~ In the few cases where it has been studied, ~~its~~ N_2O emissions ~~(~~of the littoral zone in natural lakes~~),~~ have been observed to be higher than the pelagic zone even though the area differences had been taken into account (Huttunen et al., 2003).

Because of the strong gradients in water level and water level fluctuations, compared to the more or less stable pelagic zone and some other ecosystems (e.g. grassland and farmland), the environment of the littoral zone is more diverse and dynamic in terms of soil moisture, plant taxa and soil nutrients across scales of both space and time (Peng et al., 2011; Ahn et al., 2014; Trost et al., 2013). Those factors would in turn influence N_2O production (Lu and Xu, 2014). Limited previous studies on N_2O emissions of the littoral zone suggested significant spatio-temporal variations. But most of the studies just focus on a single water level (with different communities sometimes) which might miss the spatial variations between different water levels (Chen et al., 2011b; Y. Liu et al., Soil water status is a critical factor for the N cycle and for N_2O emissions (Peng et al., 2011). It influences soil oxygen concentration, input of nutrients, vegetation distribution and activity of microbes (Ahn et al., 2011). Temporally, reports always showed seasonal variation but not diurnal variation (Chen et al., 2010; Huttunen et al., 2003). To match the diverse and dynamic environment of the littoral zone, we combined five water levels on a transect from water to dry land, three plant communities for each water level including both natural and cropped land, six times during the year and seven times of day. The improved sampling both in space and time was expected to provide more representative data on N_2O emission of the littoral zone, and to provide further insights into the nature of the underlying processes.

To be more specific2014; Trost et al., 2013), which in turn influence N_2O production (Lu and Xu, 2014). Periodic wet/dry changes in the soil could provide both aerobic and anaerobic environments for nitrification and denitrification which are the most important two processes producing N_2O as a middle or end product (Mander et al., 2005). Laboratory assessed denitrification activity is reported to be approximately 4 times higher in flood-affected than in flood-protected areas (Jacinthe et al., 2012a). The direct control of groundwater table over the rates of soil N cycle is assumed to override other key factors such as climatic condition, vegetation cover and soil type (Hefting et al., 2004). However, counter observations have been published in which flooding did not always change the N_2O flux (Hernandez and Mitsch, 2006), suggesting large uncertainly in our level of understanding.

Although the influence of water levels on fluctuations of N_2O emissions have been reported at periodically flooded environments, e.g. marshes, estuaries or rice paddies (Sun et al., 2014; Hou et al., 2012; Kudo et al., 2014), there is no direct information about emissions, following flooding, from the littoral zone of reservoirs or even the analogous natural ecosystem, i.e. lake. Considering the differences in ecological characteristics, including vegetation species and distribution, hydrological regime and sediment deposition (Kumar et al., 2011) there is an urgent need to characterize the emissions from the littoral zone of reservoirs. To address this information gap, the objectives of this present study was carried out with objectives of included (i) capturing the spatial and temporal variation of the N_2O flux at the littoral zone of the Miyun Reservoir and; (ii) finding the relationship between the observed flux and environmental factors~~. It is hoped also to be able to evaluate the~~; and (iii) evaluating the relative importance of ~~the~~ N_2O ~~flux~~and CH_4 fluxes by comparing ~~it to~~with our earlier report ~~on~~of the CH_4 fluxes ~~of~~made simultaneously from the same site (M. Yang et al., 2014). The over-arching hypothesis in this work is: the littoral zone is a hot-spot of N_2O emissions that is influenced by seasonal changes in the water level.

2 Methods

2.1 Study area

The research was carried out at Miyun Reservoir (40° 29′ N, 116° 50′ E), which is located in the northern mountainous area of Beijing, China. It was built in 1960 with a maximum water area of 188 km^2. Its catchment is characterized by warm temperate semi-humid monsoonal climate with an annual average air temperature of 10.5°C, maximum air temperature of 38°C, and a minimum of −18°C. The reservoir is normally covered by ice from the middle of November to the end of March. The growing season is from April to November. The annual average precipitation is close to 600 mm, of which 80% is concentrated from July to August (Gao, 1989). Over 93% of the soils around the reservoir are classed as cinnamon soils (*korichnezems*) with typical soil pH from 7.0 to 8.2 (Anonymous, 2008). Alongside the reservoir, higher land (sometimes just slightly higher) is always ~~reclaimed as farmland~~used by local people for growing maize~~,~~. This opportunistic agriculture is typically from May to September. Nitrogenous fertilizer is applied during sowing, and sometimes with further application in the middle of the growing season. This reservoir is mainly used as the domestic water supply for Beijing. The water quality is controlled to level II according to Environmental Quality Standards for Surface Water of People's Republic of China GB3838-2002 (levels are rated on a scale I to V, where level I is the cleanest, available at: http://kjs.mep.gov.cn/hjbhbz/index.htm). The annual change in the water level is 1–5 m, reflecting the balance between rainfall, evaporation and usage. The area between the highest and lowest water level from 1984 to 2005 was 84 km^2 (Cao et al., 2008). In the summer of 2012, when the work was carried out, unusual and continuous heavy rain in July caused a sudden water level increase of ~~one meter~~0.8 m in 15 days, and part of the littoral vegetation was inundated. ~~Such severe inundation does not occur in every year.~~This provided us with a seasonal flooded area which made possible an exploration of the effects of summer flooding on greenhouse gas emissions.

We divided the littoral zone into five areas based on water level (Fig. 1). Sites were selected ranging from locations in open water to the dry area on higher ground, to provide five contrasting environments: (i) deep water area (DW); (ii) shallow water area (SW); (iii) seasonal (August and September) flooded area (SF); (iv) 'seasonally flooded control' (SFC) area, which was 500 m away from SF, had the same plant species ~~and similar soil carbon/nitrogen content~~ as SF, but escaped the flood in August and September because of its ~~1~~ slightly (about 1 m~~-~~) higher elevation; and (v) ~~permanent~~an area which is seldom flooded (the last flooding was several years ago) which hereafter we call the non-flooded area (NF). ~~Details of the water levels~~Three typical plant communities in each water level were selected. At SW, SF, SFC and NF, land cropped with maize (*zea mays*) was included as it is a typical practice, and allows some assessment of the impact of farming. Maize land in SW and SF was abandoned by the local farmer after our first sampling campaign because of flooding. So these ~~areas~~lands were colonised by wild plants since the second campaign. Dominant species of each month are shown in Table 1. Details of climate, biomass and soil/sediment parameters are shown in Fig. 2~~(d). For more details on biomass and soil, see Fig. 2(f)~~ and Fig. 3.

2.2 N_2O flux measurements

Nitrous oxide flux was measured in November 2011, then May, July, August, September and October 2012. The experiment~~ with three plots~~ at site SFC was carried out just after the flooding and during the time when the water level dropped from August to October 2012. In order to reduce uncertainty in the average daily flux, a sampling protocol designed to capture any diurnal variation was performed at three-hourly intervals (local time: 6, 9, 12, 15, 18, 21 and 24 h). Each plot had four ~~replicates~~replicate chambers located within three meters from each other. To eliminate disturbance to the soil/sediment during sampling~~,~~ wooden access platforms were built.

The static opaque chamber technique was used to determine the N_2O flux. The chambers were made of stainless steel (volume: 125 litres; surface area: 0.25 m^2) and ~~covered~~coated with polyethylene foam to minimize any warming effect inside the chamber. An extension chamber (volume: 200 litres; surface area: 0.25 m^2) was added if plants were tall. Two fans were built into the chamber for air mixing. Four gas samples (200 ml each) were taken using

100-ml polypropylene syringes at 15-min intervals over a 45-min period after enclosure, and stored in 500-ml plastic and aluminum membrane gas sampling bags~~.~~ (Guangming Research and Design Institute of Chemical Industry, China). The concentration of N_2O was analyzed within one week by gas chromatography (7890A, Agilent, USA) equipped with a micro-electron capture detector (μ-ECD). Gases were separated with a column (3 m, 3.2 mm) packed with Porpak Q (80/100 mesh). The temperatures of the oven, injector, and detector were 70°C, 20°C, and 330°C, respectively. The flow rate of the carrier gas (N_2) was 25 ml min^{-1}. Standard N_2O gas (310 ppb in air, China National Research Center for Certified Reference Materials, China) was used for precision verification for N_2O concentrations. The coefficient of variation was below 1.5%. The flux of N_2O was calculated following ~~Li~~Chen et al. (~~2014).~~ 2011b):

$$F = \frac{M}{V_0} \times \frac{P}{P_0} \times \frac{T_0}{T} \times \frac{dC_t}{dt} \times H \quad (1)$$

where F is the flux of N_2O (mg m^{-2} h^{-1}); M is the molar mass of N_2O (g mol^{-1}); P (kPa) is the atmospheric pressure of the sampling site; T (K) is the absolute temperature of the sampling time; V_0 (22.4 L), P_0 (101.325 kPa) and T_0 (273.15 K) is the molar volume, atmosphere pressure and absolute temperature, respectively, under standard conditions; dC_t/dt (ppm h^{-1}) is the rate of concentration change; and H (m) is the chamber height over the water or soil surface.

Chambers were reset into new positions near the old positions each sampling month. All positions at each site were within an area of 20 m^2, but not so close to each other to cause artifacts in the data through (for example) changes in the local hydrology.

2.3 Environmental factors

Weekly precipitation was accessed through the China Meteorological Data Sharing Service System (http://~~cdc. cma~~www.escience.gov.cn/~~home.do~~metdata/page/index.html). Average wind speed was recorded during the sampling period with a hand-held vane anemometer (4101, Testo, Germany~~). Diurnal air~~), taking an average over the 45 minute period during which gas was sampled. Air temperature was measured by a digital thermometer (JM624, Jinming, China) at the start and end of each gas sampling at every plot. Dissolved Oxygen (DO) in water was measured during the gas sampling by a handheld multi-parameter meter

(Professional Plus, YSI, USA)~~, after flooding.~~). The aboveground biomass of every replicate in the chamber was weighed after drying at 80°C to constant mass.

Water level was measured after gas sampling at DW, SW and SF (when SF had standing water in August and September 2012). At site SF (when there was no standing water in November 2011, May, July and October 2012) and SFC, a 1-m PVC tube was inserted vertically into the soil under the chamber after all monthly gas sampling was complete, allowing two hours for the water level to equilibrate before measuring the level. The water table of site NF was calculated according to the elevation measured by a Global Navigation Satellite System receiver (BLH-L90, Daheng International, China).

Soil water content (SWC) was measured every month after all gas sampling with a Soil Water Sensor (UNI1000, Shunlong, China). Soil/sediment samples (0–30 cm) at site DW, SW, SF and NF were collected ~~from three different layers (0–10 cm, 10–20 cm, and 20–30 cm below ground)~~ at each replicate location in November 2011, except site SFC in October 2012. Fresh soil/sediment samples were used for NH_4^+ and NO_3^- ~~analysing~~analysis using a discrete analyser (Smartchem 300, AMS, Italy). After air-drying and grinding (passing through a 100 mesh sieve), pH of 1:5 soil-water extractions were measured using a pH meter (IQ160, Hach, USA) while soil total carbon (TC) and nitrogen (TN) ~~were~~was analyzed using an elemental analyzer (vario MACRO cube, Elementar, Germany). Soil bulk density was measured following Chinese national standards NY/T 1121.4-2006 ~~-~~(MAPRC, 2007).

2.4 Statistical analysis

Flux differences were ~~analyzed with one~~tested using a three-way ANOVA, and then using LSD for multiple comparisons~~.~~ (Table 2 and Fig. 4). One-sample T test was used for testing if the negative fluxes were different from zero. A log10 transformation was used to ~~show~~explore the correlation between ~~positive~~ N_2O flux and ~~wind speed,~~ environmental variables (air temperature~~, water DO~~ and soil NO_3^-~~. Where~~$^-$); where appropriate, a piecewise function (two segment liner) was calculated ~~using~~ (SigmaPlot ~~(version~~ 11.0, SYSTAT, USA). Spearman's Rank Correlation was used to test for correlations between flux and environmental factors. Figure 5, 6, 7 and Table 3 was made using daily average fluxes to eliminate the influence of not independence of fluxes at different times of day. All the analyses above were performed using IBM SPSS Statistics (version 19.0, IBM, USA). Charts were made using SigmaPlot (version 11.0, SYSTAT, USA).

3 Results

3.1 Environmental characteristics

Precipitation occurred from March to November. The highest rainfall was in July which accounted for one fourth of the total (Fig. 2(a)). Water levels rose rapidly after the summer monsoon rainfall, and then declined after August (Fig. 2(d)). Temperature peaked at ~~summer time~~summertime (Fig. 2(c)). Diurnal range in temperature was about 10 °C. The non-flooded site was very dry before the rains began (Fig. 2(e)), increasing from a dry condition (only 10% water content) to a moist condition after rain (but never exceeding 35%).

3.2 N_2O fluxes

The mean flux from the littoral zone of the Miyun reservoir was 6.~~61~~8 μg m^{-2} h^{-1}~~. Significant differences were observed between the 5 sample areas ($p<0.05$; Fig. 4).~~ (0.15 μmol m^{-2} h^{-1}), ranging from –136.6 μg m^{-2} h^{-1} to 381.8 μg m^{-2} h^{-1}. Negative flux was observed at all sampling plots in about one-third of the cases ($n=739$, $p<0.001$). In ANOVA (Table 2), both time of year and position on the transect were statistically significant (both $p<0.001$), but time of day was not significant ($p=0.97$). N_2O emission from the non-flooded area (NF) was ~~16.96±5.45~~17.0±2.3 μg m^{-2} h^{-1}, which was significantly higher ($p<0.001$) than the other 4 areas. There was no statistical difference ($p=0.91$) between emissions from the seasonal flooded area (SF) and its control site (SFC~~), which was~~): fluxes were 4.~~39±1.10~~4±0.7 μg m^{-2} h^{-1} and 4.~~17~~2±0.~~89~~7 μg m^{-2} h^{-1} respectively. ~~Highest~~For SW, SF, SFC and NF, the average emission of non-farmland plots was 2.6 μg m^{-2} h^{-1} but the land cropping maize the sampling summer or the last summer reached 24.0 and 8.4 μg m^{-2} h^{-1} respectively (Fig. 4). Especially high emissions (43.7 μg m^{-2} h^{-1}) were observed on farmland of NF (Fig. 4). Besides SF, where the highest emission occurred in late autumn, other high emissions were observed in the warm season, July and August in particular (Fig. ~~5). The highest emission was 182.47±45.11 μg m^{-2} h^{-1} occurring in July at site NF-C.~~5).

3.3 Relationships between flux and environmental parameters

~~Significant positive correlations ($p<0.05$) were obtained between flux and wind speed, air temperature, water DO and soil NO_3^-, while negative~~ Rank correlation analysis was

~~observed~~carried out between N_2O flux and ~~SWC (Table 1). There was~~ environmental parameters, but the coefficients were no ~~significant~~ higher than 0.38 (Table 3). For more information, correlation analysis was also done separately at each water level. The correlations were different among water levels and higher coefficients were shown between flux and ~~water depth, biomass, soil density, pH, TN, TC and NH_4^+.~~air temperature in several cases (Table 1R). Linear correlations can hide important non-linear features and so scatterplots are also shown, where log10 flux was plotted against ~~wind speed,~~ air temperature~~,~~ ~~water DO and soil NO_3^- (Fig. 6).~~ and soil NO_3^- (Fig. 6). As fluxes were often negative (and significantly less than zero, implying a sink for N_2O), we carried out a separate analysis of negative fluxes. Piecewise correlations were found between log10 flux and air temperature~~,~~ ~~also log10 flux and soil NO_3^- (p<~~ (Fig. 6). For positive fluxes, there~~0.05). There~~ was a negative correlation (p=0.03, n=65) when the air temperature was from 5.2 °C to 18.7 °C ~~and~~but a positive correlation (p<0.01, n=175) when air temperature was from 18.7 °C to 31~~°C. The~~.1 °C. For negative fluxes, there was a positive correlation (p<0.01, n=43) when the air temperature was from 5.2 °C to 17.6 °C and a insignificant negative correlation (p=0.12, n=41) when air temperature was from 17.6 °C to 31.1 °C

We present the relationship between nitrate and N_2O emission. For positive flux, the soil NO_3^- seemed to accelerate N_2O emission when its concentration was higher than 7.1 mg kg^{-1}~~,~~ (p<0.01, n=122), but it did not influence emission rate when lower than this ‘knot ~~point.~~point’ (p=0.30, n=118). Piecewise analysis was not done between negative flux and nitrate considering the narrow nitrate concentration (almost no data when soil NO_3^- higher than 10 mg kg^{-1}).

~~4 Discussions~~

4 Discussion

4.1 N_2O flux

Variations of N_2O fluxes were compared at different spatial and temporal scales (Fig. 4 and Table 2). Significant differences were observed among water levels and sampling months, but not among times of day. Diurnal variation in N_2O flux over lakes and reservoirs has seldom been discussed. However diurnal variation in other aquatic system also seems to be insignificant (Xia et al., 2013). Further research is required on the infrequently-studied diurnal variation in N_2O flux. We may expect soil microbes to respond to temperature, and given a diurnal range in temperature of about 10 ℃ we would have expected a diurnal pattern in the N_2O flux. We assume that the reason for a lack of response is that the microbial population is mostly deep in the soil/sediment/water system, where temperature variations are much smaller.

The mean flux from the littoral zone of the Miyun reservoir was 6.61 μg m^{-2} h^{-1}. Besides one observation which was as high as 182.47±45.11 μg m^{-2} h^{-1}, the mean fluxes ranged from -2.29±1.81 μg m^{-2} h^{-1} to 31.61±8.87 μg m^{-2} h^{-1} (Fig. 5), which is8 μg m^{-2} h^{-1}, from –136.6 μg m^{-2} h^{-1} to 381.8 μg m^{-2} h^{-1}. Negative fluxes were observed in about one-third of the cases, demonstrating a process of N_2O consumption to be occurring. It is generally acknowledged that under certain conditions the capacity of soil to be a sink for N_2O can, through denitrification, exceed its capacity to emit N_2O (Baggs and Pilippot, 2010). .

How do these fluxes compare to those reported from elsewhere? Our fluxes are comparable to those from the littoral zone of temperate-zone lakes, for example, a shallow lake in Eastern Austria, also in the temperate region (Soja et al., 2014). However, in most of the cases, our fluxes were lower, as shown by the following comparisons. One similar-latitude lake, Lake Baiyangdian, had nearly 10 times higher N_2O emissions, averaging 58 μg m^{-2} h^{-1} (Yang et al., 2012). Higher emission also been reported in the littoral zone of lower-latitude sites, for example the Three Gorges Reservoir (Table 4). The seriously eutrophic Taihu Lake (latitude: 30°N) had a broader extent ranging from –278 to 2101 μg m^{-2} h^{-1} in the littoral zone (Wang et al., 2007). Greenhouse gas emissions from low latitude ecosystems are found to be higher than the corresponding ecosystems at high latitude because of the temperature effects (Zhu et al., 2013). The average N_2O emission found in the present research was lower than that reported for boreal and Antarctic lakes (Huttunen et al., 2003; Y. Liu et al., 2011). The low N_2O emission of Miyun Reservoir might be the consequence of relatively good water quality or high soil pH (Van den Heuvel et al., 2011).

As for the case of CH_4, N_2O emissions from the littoral zone has been reported to be greater than for the pelagic zone (e.g. Huttunen et al., 2003 and see Table 4).We did not examine N_2O fluxes from the pelagic zone in this research, but we can compare our fluxes with pelagic data from elsewhere, as follows. The N_2O emission in this study is slightly higher than those from five perialpine and alpine reservoirs (1.56 μg m^{-2} h^{-1}) in Switzerland (Diem et al., 2012), while it is much lower than a same-latitude fluvial reservoir (84 μg m^{-2} h^{-1}) located in an agricultural landscape (Jacinthe et al., 2012b).near Indianapolis, USA (Jacinthe et al., 2012b). It should be noted that the comparison between littoral zone and pelagic zone of different reservoirs includes uncertainties, for example differences of elevation, nutrients input and influence of topography on microclimate.

Nutrient loading is considered to be an efficient accelerator for N_2O production (Trost et al., 2013; Pilegaard, 2013). Indeed, hyper-eutrophic lakes in China do show very high fluxes: the same-latitude lake Baiyangdian averaged 58 μg m^{-2} h^{-1} (Yang et al., 2012) and the seriously eutrophic Taihu Lake ranged from −278 to 2101 μg m^{-2} h^{-1} in the littoral zone (Wang et al., 2007).

Greenhouse gas emissions from low latitude ecosystems are found to be higher than the corresponding ecosystems at high latitude because of the temperature effects (Zhu et al., 2013). The average N_2O emission found in this research is lower than that reported for boreal and Antarctic lakes (Huttunen et al., 2003; Liu et al., 2011b). The low N_2O emission of Miyun Reservoir might because of relatively good water quality or high soil pH (Van den Heuvel et al., 2011).

4.44.2 Relative greenhouse gas effect: comparison with CH_4

Elsewhere, we presented data on methane emissions from this reservoir (M. Yang et al., 2014b2014). The Global Warming Potential (GWP) of N_2O over a 100-year time-span is 298 while CH_4 is 34 (Stocker et al., 2013). We can use the GWPs to calculate the emissions as CO_2-equivalent emissions, and thus compare the warming effect of the two gases. The mean N_2O emission in this study was 2.0 mg CO_2-equivalent m^{-2} h^{-1}. The CH_4 emission was 44.2 mg CO_2-equivalent m^{-2} h^{-1} (M. Yang et al., 2014b2014), which is 22.1 times that of N_2O. This contrasts with our previous findings, where the warming ratio of CH_4:N_2O was 1.5 (Li et al., 2014). But in our earlier report there, N_2O variation was investigated with a water recession process. Significant increases (nearly up to 1000 times) were more observationsobserved after floodingsediment exposure of 5 months. The high emissions may be the result of soil water content declining to 60–90% (Ciarlo et al., 2007). In this research, the soil water content was not in this range at all, and thisthat may have biased the comparison. In general, the flux ratio of CH_4 to N_2O in aquatic environments varies considerably. For example, the CH_4:N_2O ratio of permanent flooded areas at Poyang Lake was 1.1 (Liu et al., 2013) while the ratio was 0.6

for the pelagic zone of a fluvial reservoir in central Indiana (Jacinthe et al., 2012b). In a study which monitored the flux of both littoral and pelagic zone of a temperate lake, the average CH_4:N_2O ratio is 7.2 (Soja et al., 2014). For a freshwater marsh at northeast of China, it was found to be as high as 66.5 (Yang et al., 2013). Although the ratio varies greatly, there is nevertheless a considerable contribution of N_2O emission from aquatic ~~ecosystem~~ecosystems to global warming, whose importance may have been somewhat understated in relation to the large CH_4 emission.

~~4.5~~4.3 Environmental controls~~: comparison with CH_4~~

~~N_2O and CH_4 are both important greenhouse gases, but we found N_2O and CH_4 emissions are influenced by different factors and in different ways, depending on soil conditions, meteorology and vegetation. In relation to global change, we expect temperatures to increase, patterns of inundation to alter with rainfall, and the supply of nitrogenous fertilizers to increase in countries like China, Brazil and India, as agriculture becomes more intensive. Here we examine how the factors of global change may determine emissions.~~

~~4.5.2~~4.3.1 Flooding

Unlike the specific influence of flooding on CH_4 emission (M. Yang et al., ~~2014b~~2014), flooding effects on N_2O emission was not very clear in this study. The N_2O flux of seasonal flooded area SF was as high as its control area SFC which escaped flooding because of higher elevation (Fig. 4). Inundation nearly always causes a drop of N_2O emissions (Yang et al., 2013). Standing water could inhibit N_2O emission through slowing down the diffusive transportation of gas~~ and enhancing ~~, causing anoxia, activating a different component of the microbiota, leading to the reduction of N_2O to N_2 (~~Hernandez and Mitsch, 2006~~Liengaard et al., 2013; Pilegaard, 2013). Our result did not reject those possibilities when looking into the seasonal variation of N_2O flux of seasonal flooded sites~~ (Fig.~~, they did not completely support that hypothesis either (Fig. 5(c)). After flooding, the fluxes of two sites (SF-A and SF-B) were no higher than before flooding and no higher than their control sites. However, a single extraordinary observation showed the highest emission during flooding (Fig. 5(c), SF-C). A somewhat similar result was also observed at an artificial wetland (Hernandez and Mitsch, 2006). ~~In riparian zones, floods may influence N_2O production both in the long-term and short term (Jacinthe et al., 2012a). One~~An incubation study ~~carried out at a coastal marsh~~

showed a quick response of N_2O flux after flooding, i.e. both increasing N_2O emission decreased in 2.5–5 hours after flooding and then increased to the original level after flooding for 7.5 hours (Sun et al., 2014).

Such observations are hard to explain solely by denitrification, at least based on present understanding of this process, although it is considered to be the most common and major way of N_2O production in natural environments (Senbayram et al., 2009). Our extraordinary observation and stable emission during flooding at site SF-C might be a result of nitrification or nitrate ammonification, or a combined result of denitrification, nitrification and nitrate ammonification. Nitrificationdifferent treatments, i.e. N_2O emission of residue-incorporated soils, increased remarkably from the 6th to 30th days of flooding and decreased to lower level than before flooding afterward. However, the N_2O emission of the soils with residues on the surface was found to be the predominant N_2O-producing process in a laboratory study on the effect of soil and fertilizer types using the ^{15}N tracer technique, accounting for more than 80% of the total N_2O emission (Uchida et al., 2012). Denitrification and nitrate ammonification is found occur simultaneously in soil (Fazzolari et al., 1990).stable before and during flooding (Zschornack et al., 2011). It suggested that other factors would influence N_2O emission responses to flooding. Even thought there are uncertainties about the mechanisms, this study suggestedimplied that flooding introduces a complex set of processes that influence N_2O flux, when compared to non-flooded areas whose fluxes were all coordinated with temperature variation (Fig. 5(a), (b) and (d)). The increasing possibility of changes in worldwide rainfall patterns (Stocker et al., 2013) would make prediction of the N_2O emission more challenging. Thus we propose that more studies should focus on the N cycle in the flooding affected zone of aquatic ecosystem considering of the mechanism's complexity and the significant contribution of inundation to N_2O emission (more or less coordinated with temperature variation (Fig. 5(a), (b) and (d)).Wang et al., 2006).

Besides, floods may influence N_2O production both in the long-term and short-term (Jacinthe et al., 2012a). Quick response of N_2O flux after flooding was showed at a coastal marsh, i.e. N_2O emission decreased in 2.5–5 hours after flooding but then increased to the original level after flooding for 7.5 hours (Sun et al., 2014). The possibility of emissions occurring in discrete pulses, especially by ebullition, should be kept in mind when interpreting results from flux chambers. It also emphasizes the importance of continuous high frequency monitoring to reveal flooding effects with lower uncertainties.

4.5.34.3.2 Other soilenvironmental conditions

Positive correlations between N_2O emission and temperature were reported in previous studies (e.g. Wang et al., Beside soil moisture, other soil conditions are also important for the processes involved in the carbon and nitrogen cycles (Butterbach-Bahl et al., 2013; Serrano-Silva et al., 2014). But not surprisingly, we found that the soil factors correlated with CH_4 and N_2O fluxes were totally different from each other (2014). But in this study we found both positive and negative fluxes, and decided to fit a piecewise regression to the log-transformation data (Fig. 6). This complex and non-linear picture might explain the low coefficients in the correlation analysis (Table 3).

N_2O production is generally caused by several processes, for example denitrification, nitrification, nitrate ammonification and nitrifier denitrification. N_2O consumption has been much less studied (Baggs and Pilippot, 2010). Some studies have found denitrification to be the main contributor in N_2O emission while some others pointed out that several processes occurred simultaneously with a shifting dominance of processes caused by environmental limitations, for instance soil moisture and O_2 availability (Kool et al., 2011; Zhu et al., 2013). Controlled studies showed that N_2O production via a single process always changes according to temperature, if not exceeded by biotic tolerance (Sierra, 2002; Veraart et al., 2011). Our complex N_2O response to temperature supported the latter notion, i.e. multi-processes occurring and competing during our sampling campaigns. Furthermore, it demonstrated that the response of N_2O production and consumption to temperature was at different rates (Xie et al., 2003). As some chambers within a treatment showed efflux whilst others showed influx, we may presume that the substrate is patchy, over scales of a few metres, reflecting an underlying heterogeneity possibly raised by decaying vegetation.

Negative relationships between N_2O flux and O_2 Yang et al., 2014b). N_2O flux was only influenced by soil NO_3^-, while CH_4 flux was affected by another five variables. Soil NO_3^- is the substrate for denitrification (Pilegaard, 2013), and positive correlations with nitrate are reported broadly (Soja et al., 2014; Liu et al., 2011b; Liu et al., 2011a). It is therefore not surprising to find a significant correlation between the N_2O flux and the NO_3^- in the soil. A global analysis based on 233 studies pointed out that the N_2O response to N inputs usually grow significantly faster than expected from the linear model (Shcherbak et al., 2014). N additions to soil in a temperate forest in China were followed by N_2O emission pulses and the emissions were only significantly correlated with soil NO_3^- and temperature, but not soil NH_4^+, pH, clay and moisture (Bai et al., 2014). Another study at a tropical forest in the Andes pointed out the role of soil NO_3^- more specifically (Teh et al., 2014). A nitrogen input experiment provided an explanation for such correlation: the N_2O to N_2 ratios increased from 0.18±0.03 to 0.68±0.16 with the addition of NO_3^- (Zhao et al., 2014). Higher NO_3^- concentrations are suggested to suppress the reduction of N_2O to N_2 via enzymic processes involving, for example nitrous oxide reductase (*nos*) (Silvennoinen et al., 2008; Beaulieu et al., 2011). Those findings suggested that intensive agriculture increased greenhouse gas emission while the difference responses of CH_4 and N_2O to soil conditions indicated a further challenge for climate change adaptation.

4.5.4 Wind speed

Wind speed influenced N_2O flux significantly but was not correlated with CH_4 flux. We believe this contrast to be caused by the different responses of soil and water to wind disturbance. Wind influences gas exchange through increasing turbulence in the surface water, thus increasing the diffusion velocity (Schilder et al., 2013). But it also causes pressure fluctuations on the soil environment and produces the so-called 'bellows effect' which squeezes and pumps out gas from the soil pore space (Reicosky et al., 2008). We also assume that wind might influence gas exchange more at the air-soil interface than at the air-water interface. The effect of wind is presumably short term, as it merely speeds up the flux of gas stored in pockets with the soil and sediment, but does not influence the fundamental production rate. To understand wind effects thoroughly, any future study should focus on long-term responses of gas exchange to wind, using continuous measurement systems such as eddy covariance (Merbold et al., 2013).

4.5.5 Water DO

In this study the dissolved oxygen concentration of water also influenced CH_4 and N_2O in different ways. When CH_4 is produced in sediments, a large proportion of it may be oxidized into CO_2 (Guerin and Abril, 2007). For N_2O, negative relationships are reported in both laboratory experiments and field researches (Sarma and Rao, 2013; studies (Rosamond et al., 2012; Rubol et al., 2012; Zhao et al., 2014). TheThis is explained by the fact that denitrification process (, which is activated in the anaerobic environment) is assumed to be anoxic environments, is likely controlling the N_2O emissionemissions (Xia et al., 2013).

~~However our~~Our present result contradicted those previous conclusions~~. Significantly~~ because a significantly positive correlation was observed between N_2O flux and ~~DO. This might imply that in some environments different process control the emission rate.~~water DO (Fig. 7). N_2O accumulation in the water column ~~is reported depending~~has been shown to depend not only on production rate, but also on the extent of N_2O reduction to N_2 by reductase enzymes (Zhao et al., ~~2014). That might provide an explanation for our finding. However, it was difficult to exclude the possibility of~~2014). An incubation study showed that denitrifying activity decreased along with decline of DO concentration, but the N_2O producing activity increased because of less N_2O reduction to N_2 (Senga et al., 2002). Furthermore, Senga's study also pointed out that N_2O produced by nitrification could also be reduced to N_2 via denitrification. That might have happened in our sampling field, i.e. along with increasing of water DO, decreasing of N_2O reduction to N_2 allowing more N_2O to be released at water-air interface, no matter which processes the N_2O was produced. Further study should focus on responses of both N_2O production and reduction to water DO and factors determining which process is the dominance.

Soil NO_3^- is an important substance in N cycle (Butterbach-Bahl et al., 2013). Positive correlations between N_2O flux and nitrate are reported broadly (Soja et al., 2014; Y. Liu et al., 2011; X. L. ~~the positive correlation was an apparent~~Liu et al., 2011). It is therefore not surprising to find the highest emission where highest soil NO_3^- occurred. However, in this research when soil NO_3^- was less than the threshold value of 7.1 mg kg^{-1} there was no relationship ~~masking by other stronger~~with NO_3^-. In agricultural studies the NO_3^- concentration are generally much higher, but even then a threshold phenomenon has been reported (Bao et al., 2012). It implied that substrate constrain might be a reason for the weak correlations between N_2O flux and other environmental factors. ~~A decrease in DO is commonly seen in a polluted water body, and any future study of the relationship between emissions and water quality might be~~ In the present study, no significant correlation was showed between N_2O flux and NH_4^+, although NH_4^+ is also important in the N cycle. An N fertilizer experiment in a temperate forest found that the N_2O emissions were only significantly correlated with soil NO_3^- and temperature, but not soil NH_4^+ (Bai et al., 2014). An global review study found that among the five chemical forms of N fertilizer assessed (including NH_4^+), NO_3^- showed the strongest stimulation of N_2O emission, approximately 2 to 3 times higher than the others (Liu and Greaver, 2009).

Based on the above discussion and discussion in a previous paper (M. Yang et al., for future reservoirs where global warming mitigation may be required as a design criterion.

4.6 Comparison with farmland

The responses of N_2O and CH_4 emissions to soil water condition are quite different. But the littoral zone provides a seasonally variable water level, providing conditions for both N_2O and CH_4 production in different stages of inundation, from dry to extremely wet. This explains the rather high N_2O and CH_4 emission rates in the littoral zone. 2014), the influence of environmental factors on N_2O and CH_4 emission was summarized as follow. The emissions of these two gases are influenced by different factors and in different ways (Table 3), depending on soil conditions, meteorology and vegetation. Methane shows relatively strong correlation with environmental variables while the correlations are always rather weak in N_2O, reflecting the number and complexity of the microbial processes governing the flux of N_2O. The variables likely to be associated with anoxia (soil water depth, soil water content, water DO) were important for both N_2O (see above discussion) and CH_4 (Serrano-Silva et al., 2014) but acted in converse ways. Soil nutrients also influence both of the two gases, but, it seems, through different parameters (Table 3). Different forms of C or N tend to be consistency in soil/sediment, so consistency emission of N_2O and CH_4 along nutrients is expect, but sometimes could be covered by effects of soil water content. Soil water condition in natural environment controls anoxia and influence soil temperature and soil nutrients, implies the fundamental role of soil water level playing in N_2O and CH_4 emission. Therefore, we conclude that water level is the most important factor determining N_2O and CH_4 emission in littoral zone.

4.4 Comparison with farmland

Reclamation of the shore by local farmers, to supplement their income, is not rare. In this research we compared the N_2O emission of natural and farm-related area in the littoral zone. Significant higher emissions were observed at sites cropped with maize in the sampling season or the last growing season. The emission was 24.0 μg m^{-2} h^{-1} and 8.4 μg m^{-2} h^{-1} respectively, while the emission of natural sites was 2.6 μg m^{-2} h^{-1}. As discussed in the above section, soil NO_3^- might partly explain the flux difference between farm related land and natural land. Besides, tillage might also influencing N_2O emission through soil aeration (Buchkina et al., 2013).

Reservoirs are being developed, in part, for ‘clean energy’, and reports of high greenhouse gas emissions from reservoirs have already led some authors to question the ‘clean’ concept, especially in relation to the mitigation of climate change (Gunkel, 2009).

To evaluate the role that reservoirs play in climate change, their greenhouse gas emissions ought to be compared with those of the prior ecosystem (Tremblay et al., 2005). Farmland is one of the several ecosystems which are lost by flooding during reservoir construction in China. The range of soil water content of most farmland soils in this part of China is relatively narrow, and may not provide conditions that are particularly conducive for either N_2O or CH_4 emissions. However, because of the applied fertilizer, the greenhouse gas emission of farmland is often higher than that of the littoral zone, especially in terms of N_2O (Table 2). Reservoir construction does bring an appropriate environment for greenhouse gas production, especially methane, but agricultural soils emit more nitrous oxide, perhaps because fertilizer application rates are often excessiveIn this two compare cases (Table 4), total emission of N_2O and CH_4 in littoral zone was higher than farmland, respectively. The range of soil water content of most farmland soils is relatively narrow and even. Besides rice growing, crops do not tolerate flooding or drought. But soil moisture of the littoral zone is patchy and ranges from flooded to seasonally dry. The littoral zone is therefore precarious in terms of N_2O or CH_4 emissions than farming (Groffman et al., 2009). Even thought the emission of littoral zone was higher, considering its small area and the low emission of pelagic zone, N_2O and CH_4 emission of reservoir is high likely lower than farmland. It’s worth noting that N_2O and CH_4 emission of different types of crop might vary the comparison, especially when refers to rice paddy whose CH_4 emission might high enough to result in opposite conclusion. Besides, N_2O emission of farmland was higher than both of littoral zone and pelagic zone, perhaps because of fertilizer application.

5 Conclusions

Finally, we return to our original hypothesis, which was: the littoral zone is a hot-spot of N_2O emissions that is influenced by seasonal changes in the water level. We find that the littoral zone is indeed a hot-spot for N_2O in the summer, especially when the shores of the lake are used for opportunistic farming of maize. But in terms of the overall greenhouse gas budget, the fluxes of N_2O from the littoral zone are not as important as those of CH_4.

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Table 1. Dominant plant species at each plot in different months. DW: deep water site, SW: shallow water site, SF: seasonally flooded site, SFC: 'control site' for seasonally flooded site, NF: non-flooded site. A, B, C indicates sample plot with different vegetation. Species with aerenchyma are denoted ^{A}, species that are emergent are denoted ^{E}.

<table>
<tr><th colspan="2">Site</th><th>Nov 2011</th><th>May 2012</th><th>Jul 2012</th><th>Aug 2012</th><th>Sep 2012</th><th>Oct 2012</th></tr>
<tr><td rowspan="3">DW</td><td>A</td><td>Echinochloa olonum^{AE}</td><td colspan="2">Myriophyllum sp.</td><td colspan="3">Trapa^{AE} sp.</td></tr>
<tr><td>B</td><td colspan="6">no vegetation</td></tr>
<tr><td>C</td><td colspan="6">Typha angustifolia^{AE}</td></tr>
<tr><td rowspan="3">SW</td><td>A</td><td>Xanthium sibiricum^{E}</td><td colspan="2">Scirpus planiculmis^{AE}</td><td colspan="3">Echinochloa colonum^{AE}</td></tr>
<tr><td>B</td><td>Setaria viridis^{E}</td><td colspan="2">Bidens pilosa^{E}</td><td colspan="3">Echinochloa colonum^{AE}</td></tr>
<tr><td>C</td><td>Zea mays^{E}</td><td colspan="4">Polygonum lapathifolium^{E}</td><td>Typha angustifolia^{AE}</td></tr>
<tr><td rowspan="3">SF</td><td>A</td><td>Xanthium sibiricum</td><td colspan="2">Cirsium setosum</td><td colspan="2">Cirsium setosum^{E}</td><td>Cirsium setosum</td></tr>
<tr><td>B</td><td>Setaria viridis</td><td colspan="2">Hemarthria altissima</td><td colspan="2">Hemarthria altissima^{E}</td><td>Hemarthria altissima</td></tr>
<tr><td>C</td><td>Zea mays</td><td colspan="2">Polygonum lapathifolium</td><td colspan="2">Polygonum lapathifolium^{E}</td><td>Polygonum lapathifolium</td></tr>
<tr><td rowspan="3">SFC</td><td>A</td><td colspan="3">no data</td><td colspan="3">Cirsium setosum</td></tr>
<tr><td>B</td><td colspan="3">no data</td><td colspan="3">Hemarthria altissima</td></tr>
<tr><td>C</td><td colspan="3">no data</td><td colspan="3">Zea mays</td></tr>
<tr><td rowspan="3">NF</td><td>A</td><td colspan="6">Xanthium sibiricum</td></tr>
<tr><td>B</td><td>Setaria viridis</td><td colspan="5">Artemisia argyi</td></tr>
<tr><td>C</td><td colspan="6">Zea mays</td></tr>
</table>

Table 2. ANOVA table to test the effects of water level, sampling month and time of day on N_2O flux. The category of farmland included 4 plots, i.e. SW-C, SF-C, SFC-C and NF-C, which grown maize in the sampling growing season or the last growing season. The category of non-farmland included other 11 spots (see Table 1 for details of vegetation).

	Effect	Type III SS	df	MS	F	p
All	Water level	65,808	4	16,452	25.3	<0.001
	Month	65,546	5	13,109	20.2	<0.001
	Time	918	6	153	0.2	0.965
	Water level * Month	176,351	17	10,374	16.0	<0.001
	Water level * Time	4,901	24	204	0.3	0.999
	Month * Time	7,277	30	243	0.4	0.999
	Waterlevel * Month * Time	31,728	102	311	0.5	1.000
	Error	1,347,885	2073	650	-	-
Non-farmland	Water level	2,982	4	745	5.9	<0.001
	Month	3,525	5	705	5.6	<0.001
	Time	668	6	111	0.9	0.505
	Water level * Month	11,830	17	696	5.5	<0.001
	Water level * Time	3,087	24	129	1.0	0.431
	Month * Time	4,657	30	155	1.2	0.179
	Waterlevel * Month * Time	14,385	102	141	1.1	0.198
	Error	186,701	1485	126	-	-
Farmland (or use to be)	Water level	145,935	3	48,645	48.8	<0.001
	Month	214,645	5	42,929	43.1	<0.001
	Time	1,286	6	214	0.2	0.972
	Water level * Month	490,401	12	40,867	41.0	<0.001
	Water level * Time	6,406	18	356	0.4	0.994
	Month * Time	16,766	30	559	0.6	0.972
	Waterlevel * Month * Time	46,388	72	644	0.6	0.988
	Error	439,735	441	997	-	-

Table 3. Spearman's Rank Correlation (r) between flux and environmental variables, included in the table are data from M. Yang et al. (~~2014b~~2014) on the flux of CH_4, collected at the same time as the N_2O. ** indicates significant correlation (p <0.01), * indicates significant correlation ($p < 0.05$). SWC: soil water content, DO: dissolved oxygen, TC: total carbon, TN: total nitrogen. Daily average fluxes were used in the correlation analysis, n is from 84 to 324. #: Data of DW was not included in the analysis since there was no contract sampling of farmland and non-farmland.

	N_2O flux	N_2O flux non-farmland#	N_2O flux farmland#	CH_4 flux	Wind speed	Air temp	Water depth	SWC	Water DO	Biomass	Bulk density	Soil pH	Soil TC	Soil TN	Soil NH_4^+	Soil NO_3^-
N_2O flux	1															
CH_4 flux	-0.10			1												
Wind speed	0.14*	0.06	-0.01	0.03	1											
Air temp	0.19**	0.05	0.38**	0.25**	0.30**	1										
Water depth	-0.02	-0.21**	-0.11	0.75**	0.06	0.16**	1									
SWC	-0.12*	-0.33**	-0.04	0.70**	0.03	0.29**	0.87**	1								
Water DO	0.35**	0.04	0.14	-0.28**	0.43**	-0.15	0.24**	0.00	1							
Biomass	-0.08	0.11	0.11	-0.26**	-0.15**	-0.34**	-0.38**	-0.52**	-0.48**	1						
Bulk density	0.00	0.17*	0.13	-0.53**	-0.01	-0.05	-0.78**	-0.67**	-0.26**	0.35**	1					
Soil pH	0.08	0.21**	0.19	-0.17**	-0.02	-0.03	-0.25**	-0.18**	-0.14	0.06	0.35**	1				
Soil TC	-0.04	-0.06	-0.08	0.62**	0.01	0.05	0.81**	0.74**	0.13	-0.35**	-0.77**	-0.26**	1			
Soil TN	0.03	-0.01	-0.06	0.56**	0.03	0.05	0.76**	0.67**	0.15	-0.33**	-0.73**	-0.21**	0.96**	1		
Soil NH_4^+	0.01	-0.13	0.03	0.18**	-0.14*	0.02	0.06	0.23**	-0.21**	-0.16**	-0.12*	-0.02	0.08	0.06	1	
Soil NO_3^-	0.25**	0.09	0.25*	-0.02	0.04	-0.01	0.09	0.10	0.28**	-0.07	-0.20**	0.27**	0.17**	0.19**	-0.11*	1

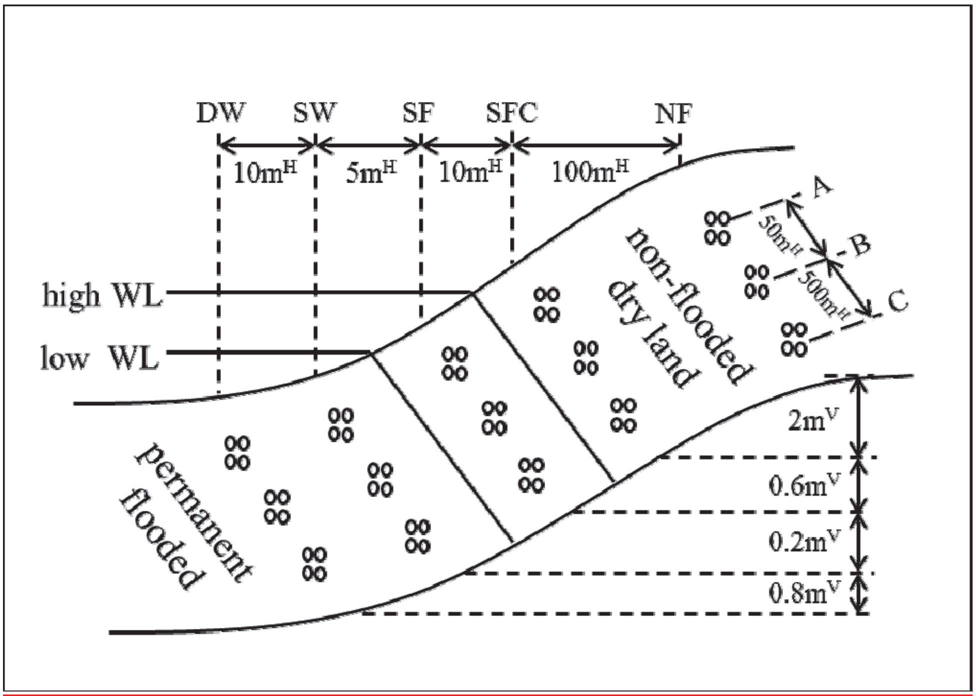
Table 4. Comparison of N_2O and CH_4 emission from reservoir and farmland (both expressed as CO_2 equivalent, see text). Flux was transformed into CO_2 equivalent according to the Global Warming Potential (Stocker et al., 2013), i.e. 1 N_2O=298 CO_2, 1 CH_4=34 CO_2. *: The N_2O flux equalled 0.87 mg CO_2 m^{-2} h^{-1} while CH_4 flux equalled 60.2 mg CO_2 m^{-2} h^{-1} when excluded farmlands, i.e. SW-C, SF-C, SFC-C and NF-C, which grown maize in the sampling growing season or the last growing season (flat land along water edge of Miyun reservoir always be used for opportunistic cropping by local farmer, more information see section of study area). #: Just SFC-C and NF-C was used for calculation, where grew maize the whole sampling time. §: Unpublished data. Hubei is the province where part of the Three Gorges Reservoir is situated. Beijing is the city which includes the Miyun Reservoir.n is from 168 to 324.

Table 2. Comparison of N_2O and CH_4 emission from reservoir and farmland (both expressed as CO_2 equivalent, see text).

Maize, rice and wheat are the first three crops in terms of area in China.

-	Study area	-	N_2O (mg CO_2 m^{-2} h^{-1})	CH_4 (mg CO_2 m^{-2} h^{-1})	Sum (mg CO_2 m^{-2} h^{-1})	Data source
Reservoir	Three Gorges Reservoir	littoral zone	9.2	227.8	237	(Chen et al., 2010; Chen et al., 2009)
		pelagic zone	4.2	8.8	13	(Zhu et al., 2013; Chen et al., 20112011a)
	Miyun Reservoir	littoral zone	2.0*	44.2*	46.2	This study; (M. Yang et al., 2014b2014)
		pelagic zone	NDNo data	10.2	10.2	(Yang et al., 2011)
Farmland	China-IPCC		2.5–16.7	ND	2.5–16.7	(Xu et al., 2014; Smith et al., 2002)
	Hubei-DNDC		26.8	85	111.8	(Li et al., 2003)
	Typical farmland near Three Gorges Reservoir-observed	rice	24.1	100.6	124.7	(Zhang et al., 2012)
		rice and rape	33.7	47.6	81.3	(Zhang et al., 2012)
	Beijing-DNDC		17.9	6.8	24.7	(Li et al., 2003)
	Typical farmland near Miyun Reservoir-observed	wheat	4.8	0.4	5.2	(Hu et al., 2013)
		maize	24.1	0.5	24.6	(Hu et al., 2013)
		maize	9.1#	-0.3#§	8.8	This study

ND indicates no data.



~~Flux was transformed into CO_2 equivalent according to the Global Warming Potential (Stocker et al., 2013), i.e. 1 N_2O=298 CO_2, 1 CH_4=34 CO_2. Hubei is the province where part of the Three Gorges Reservoir is situated. Beijing is the city which includes the Miyun Reservoir.~~

Figure 1. Experimental design. WL: water level. The difference between high WL and low WL was caused by summer flooding. m^H indicates meters in horizontal; m^V indicates meters in vertical. The sites are grouped at different heights. DW: deep water site; SW: shallow water site; SF: seasonally flooded site; SFC: 'control site' for the seasonally flooded site, which had similar vegetation and soil moisture as site SF before it was flooded; NF: non-flooded site, which flooded one time per several years and not flooded in the sampling year. A, B and C denote samples from different vegetation types within each height band, species details see (Yang et al., 2014b).Table 1. There were 15 plots in total, four replicates in each caseplot, repeatedly sampled six times (alsoin the year to cover different seasons and covering the transition in and out of the flooding season. Also to capture diurnal variation, plots were repeatedly sampled seven times in aper day) in the year. . For more details on water depth and other environmental parameters, see Fig. 2 and Fig. 3.

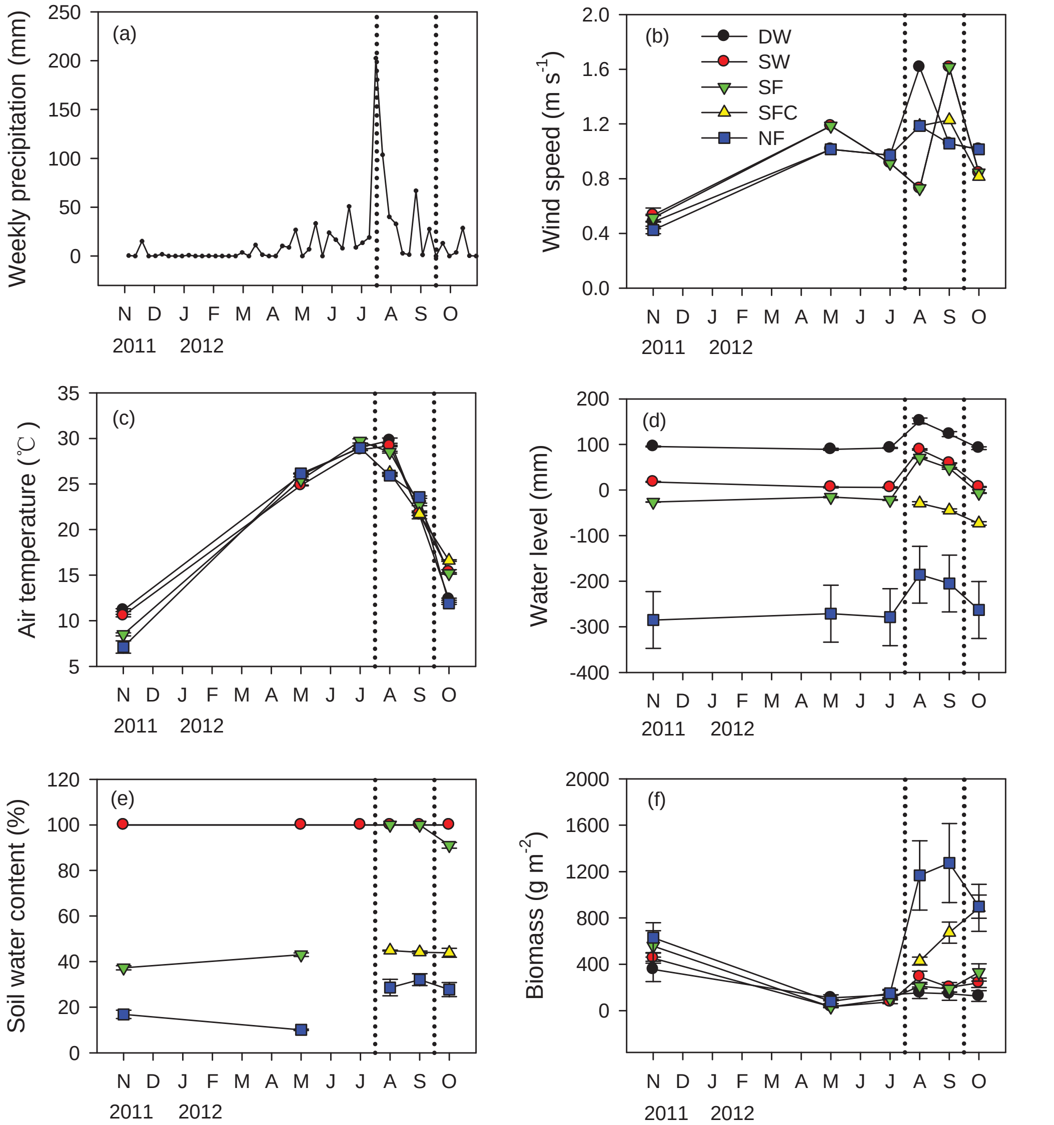


Figure 2. Environmental characters (Mean±SE) of each sampling area. Some SE bars are not visible. Days between dotted lines ~~was~~were the high water level period and thus the seasonal flooded site (SF) was under water. DW: deep water site; SW: shallow water site; SF: seasonally flooded site; SFC: 'control site' for the seasonally flooded site; NF: non-flooded site. There was no soil water content data for July because of instrument malfunction.

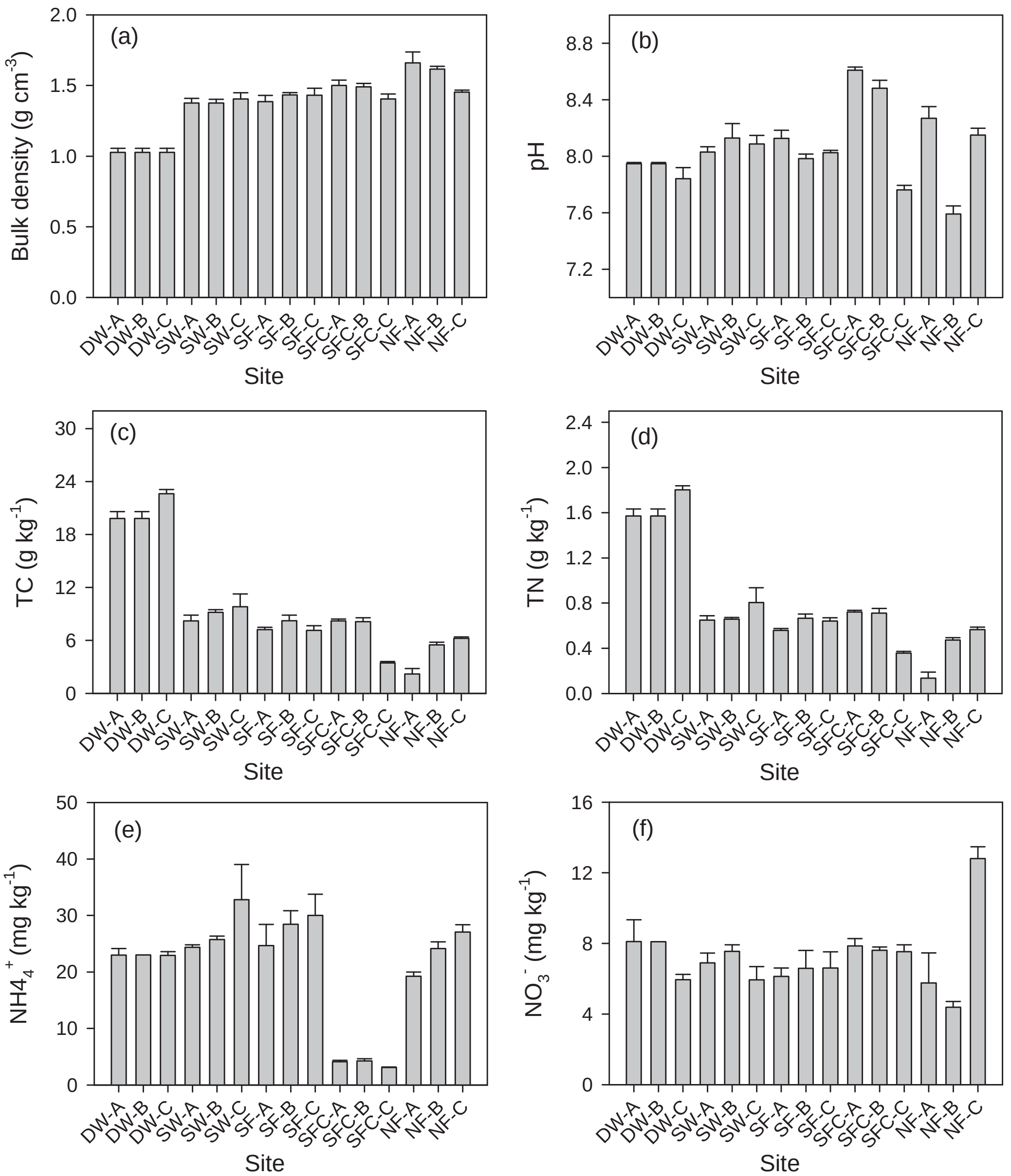


Figure 3. Physicochemical properties (Mean±SE) of soil/sediment of each site. Some SE bars are not visible because they are too small. DW: deep water site; SW: shallow water site; SF: seasonally flooded site; SFC: 'control site' for the seasonally flooded site; NF: non-flooded site. A, B and C denote samples from different vegetation types within each height band. ~~There was no soil water content data at July because of instrument malfunction.~~

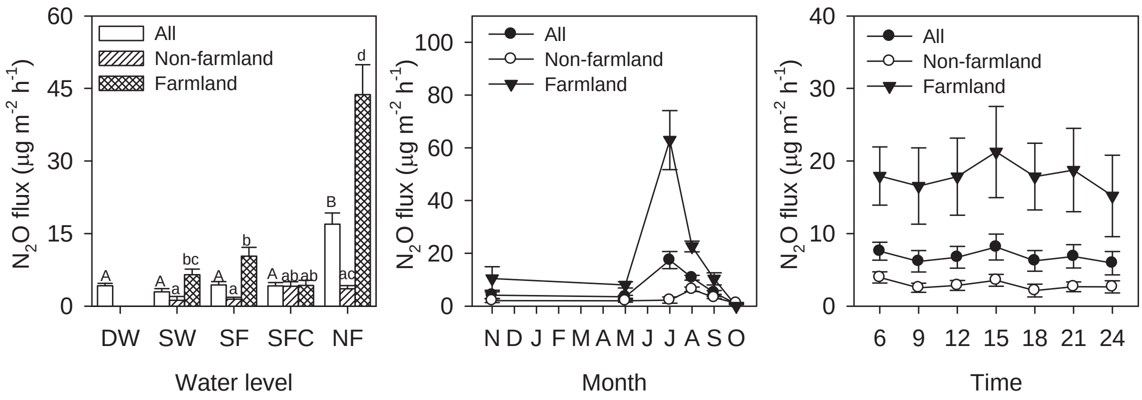
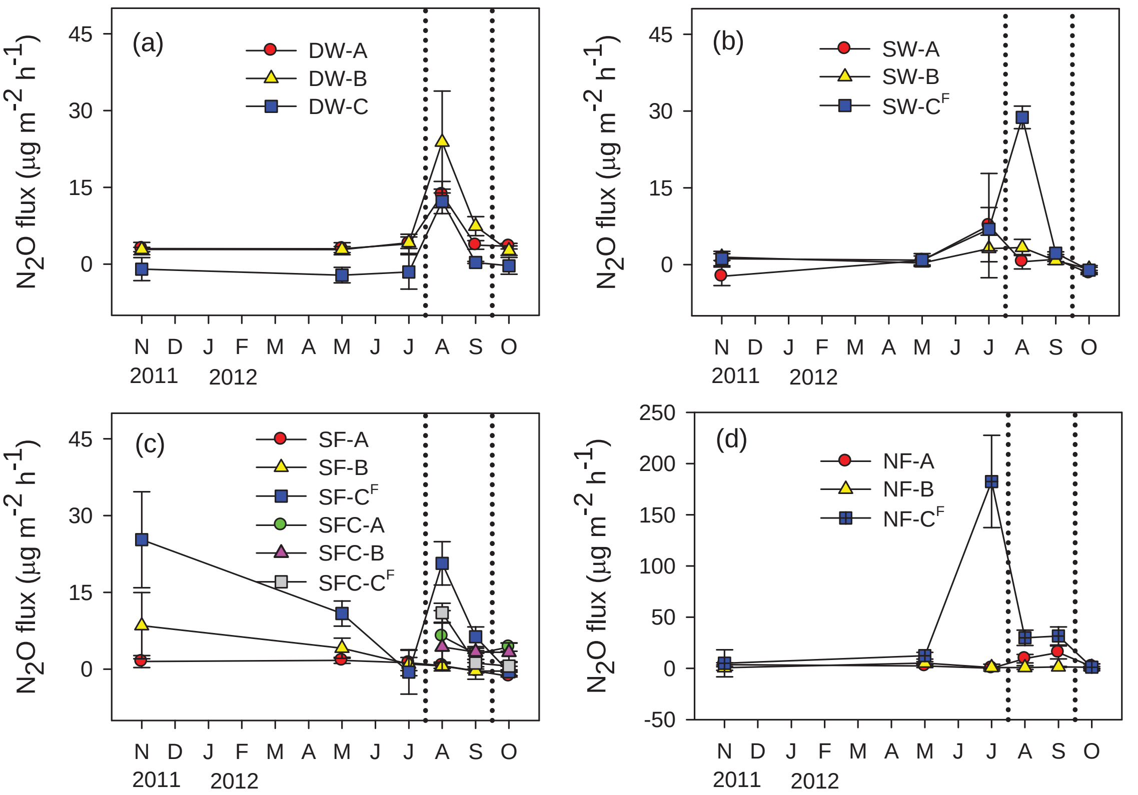


Figure 4. N_2O flux (Mean±SE) at different water levels, months and times of day. Farmland included 4 plots, i.e. SW-C, SF-C, SFC-C and NF-C, which grew maize in the sampling growing season or the last growing season. Non-farmland included other 11 spots (see Table 1 for details of vegetation).~~**Figure 3.** Physicochemical properties (Mean±SE) of soil/sediment of each site. Some SE bars are not visible.~~ DW: deep water site; SW: shallow water site; SF: seasonally flooded site; SFC: ‘control site’ for the seasonally flooded site; NF: non-flooded site. Bars with different letters indicate a significant difference at $p<0.05$. Difference analysis of bars with capital letters and small letters was done separately.~~A, B and C denote samples from different vegetation types within each height band.~~

~~**Figure 4.** N_2O flux (mean±SE) of each area.~~



~~Bars with different letters indicate a significant difference at p<0.05. DW: deep water site; SW: shallow water site; SF: seasonally flooded site; SFC: 'control site' for the seasonally flooded site; NF: non-flooded site.~~

Figure 5. Monthly N_2O flux (~~mean~~Mean±SE) of each site. Days between dotted lines ~~was~~were the high water level period and thus the seasonal flooded site (SF) was under water. DW: deep water site; SW: shallow water site; SF: seasonally flooded site; SFC: 'control site' for the seasonally flooded site; NF: non-flooded site. A, B and C denote samples from different vegetation types within each height band. Superscript F indicates farmland during the whole/part sampling time.

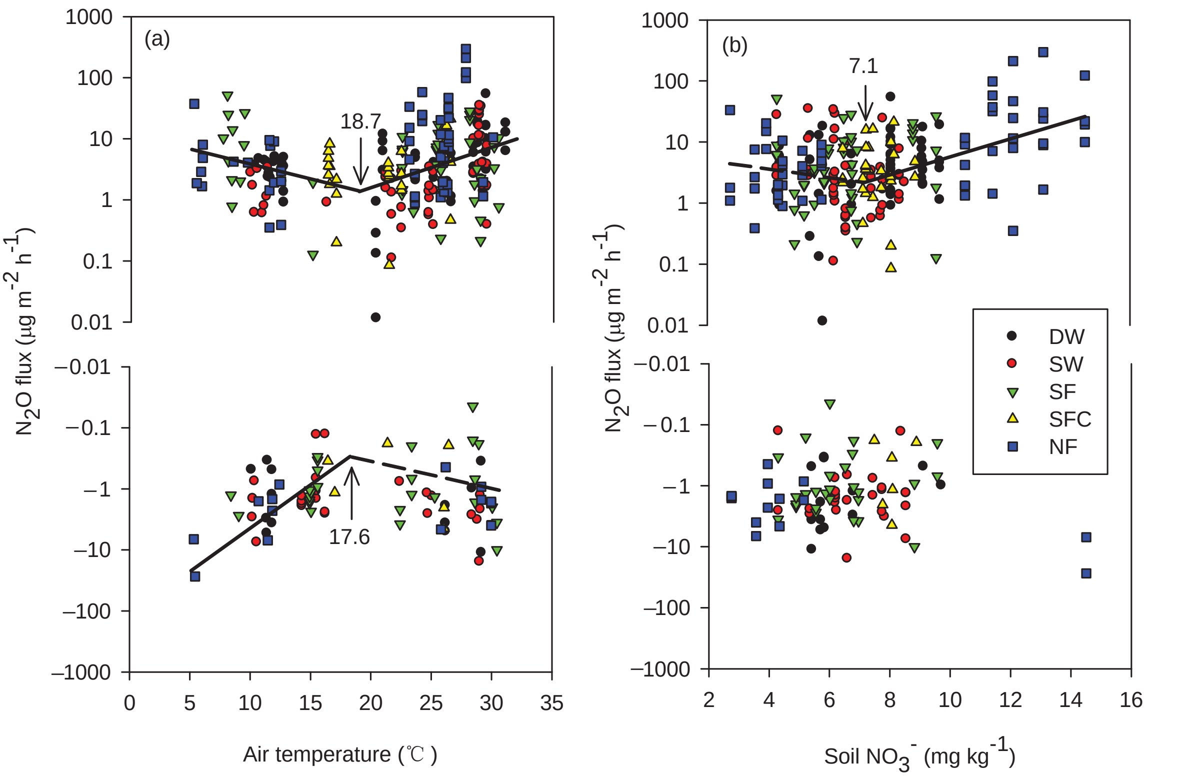


Figure 6. Relationship between flux and wind speed, air temperature, water DO and soil NO_3^-. DW: deep water site; SW: shallow water site; SF: seasonally flooded site; SFC: 'control site' for the seasonally flooded site; NF: non-flooded site. ThereThe result of piecewise correlation was no standingplotted using flux data after log10 transformation. Dashed lines indicate insignificant correlations while solid lines indicate significant correlations. See text for details.

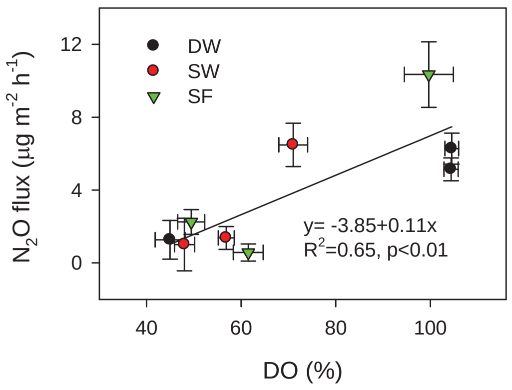


Figure 7. Relationship between flux and water DO (Mean±SE). DW: deep water at site SFC and NF thus no data of ; SW: shallow water DO. Negative fluxes (which ranged from 0 to 27.3 µg m^{-2} h^{-1}) were excluded from the analysis.site; SF: seasonally flooded site.