Green-House-Gas budget of constructed wetlands: Understanding the sources to maximize benefits

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Abstract

Fixed nitrogen (N) is required for the growth for all biological organisms, and agriculture is dependent upon nitrogen for fertilizer. Ohio exports significant levels of nitrogen in its surface waters to Lake Erie and the Mississippi Basin due to its geology and agricultural land management techniques. Constructed wetlands can be used for nitrogen removal through the biologically-mediated process of denitrification, where nitrite is reduced to nitrogen gas and released to the atmosphere. Unfortunately, denitrification in wetlands comes with the tradeoff of increased Green House Gas (GHG) production. Wetlands sequester large amounts of carbon (C) from the atmosphere, removing the most common GHG – CO_2 but produce another and more potent GHG – methane (CH_4). In order to allow development of wetlands as a solution for N removal without concerns of GHG emissions, it is critical to understand how methane production in the wetland responds to different environmental conditions such as water and soil temperature, water chemistry. GHG emission rates and water and meteorological conditions can be measured simultaneously over wetlands using eddy-flux sensors that measure the combined emissions from a broad flux footprint area, and chamber measurements at specific points and provide spatially anecdotal and temporally sparse information. Highly variable rates of methane production and carbon sequestration at different sub-ecosystems within the wetland at a very small scale (meters) prohibits the generalization of measured environmental relationships from either eddy-flux or chamber measurements. The proposed work will use a combination of meteorological, water, and GHG flux and chamber measurements in a constructed wetland at the Olentagy River Wetland Research Center (ORWRP) over 2 years to parameterize a novel high-resolution flux footprint model. The model will be used to determine the atmospheric exchange rates of methane sources and carbon sinks at different sub-ecosystem components of the wetland. This will allow determining the strength of different environmental variables that control methane production, and will facilitate the parameterization of an empirical model to predict whole-wetland GHG budgets at ORWRP, and ultimately GHG budgets in other constructed and urban wetland ecosystems.

Methodology

We use continuous long-term eddy-covariance flux measurements to observe the rates of methane flux and the corresponding meteorological, water and soil conditions. We use a probabilistic footprint model to determine which of the tower-top observation has originated primarily from the wetland area and not from the surrounding grass, river or forest. We use an advanced neural-network model to gap-fill the flux data when an observation is missing or was filtered out. We look for empirical relationships between the meteorological, ecological and water variables in the wetland and the rates of methane flux emissions and use these observations to explain the drivers of methane flux.

Major Activity

General achievements for the whole project: We completed the eddy flux tower to for continuous methane and carbon flux measurements and the corresponding meteorological data. We have completed 3 years of continuous observations, and on-going. We installed a network of soil temperature sensors in various locations and depths across the wetland floor. We have completed the software for meteorological and flux data analysis from the wetland site. This includes the processing of the raw data, development of a new approach for despiking and data quality control, and an improved footprint model. We also completed the software and calibration of the post-processing of the data and specifically the gap-filling using an automated neural network (ANN) approach which was customized specifically for our site. We have registered the site with Ameriflux – a national open and free database of carbon and methane flux measurements and a component of a global FLUXNET database. We became the second site nationwide to report methane flux data to Ameriflux.

Specifically to the last reporting period: We conducted a detailed ground-based survey and airborne imaging of the vegetation in the wetland and developed high resolution detailed vegetation and patch type map of the wetland, and developed a procedure to repeat the survey and update the map every summer (Figure 1). We installed 5 pore-water peepers to conduct continuous measurements of methane and CO2 concentrations at the pore water in the sediments under the wetland. We completed a study of the diurnal and seasonal dynamics of flux from the wetlands (Morin et al 2014, *Ecological Engineering*, in press). We developed a neural-network based empirical multivariate model of the methane emissions from the wetland park (Figure 2) and conducted a sensitivity analysis to the effects of using model-gap-filled methane flux data as an input for the methane model. We developed a statistical approach to use intermittent chamber measurements of fluxes to correct eddy flux measurements for the effects of inter-patch variability of fluxes within the wetland and the spatial dynamics of the eddy-flux measurement footprint.

Figure 1. *The Olentangy River Wetland Research Park (ORWRP). Color shaded areas are included as components of the wetland park within the flux footprint. Yellow indicates the two experimental "kidney" wetlands, which are continuously flooded and are dominated by cattails (Typha spp.). Blue indicates permanently inundated areas which include the Olentangy River and a swale created from the southern outflows of the experimental wetlands. Green areas are forests which are periodically inundated. Blue-green indicates intermittently flooded fens where grass-like wetland vegetation dominates the plant growth. Brown areas are lawns which are never flooded but maintain a high water table. Grey shaded areas (including buildings and roads) were not counted as parts of the wetland park for the purposes of methane fluxes.*

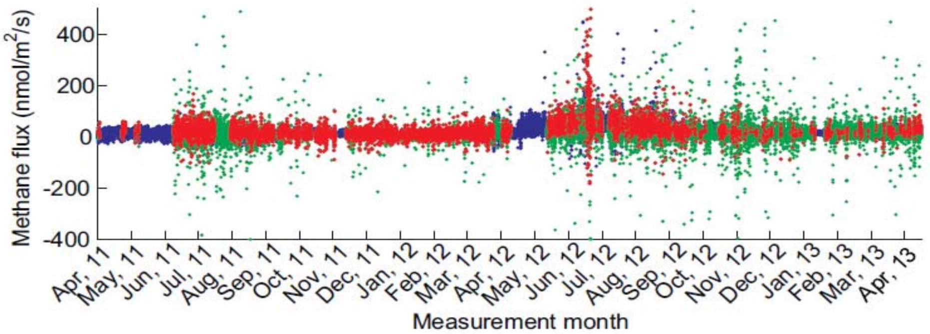

Figure 2. *Time series of methane flux from spring 2011 to spring 2013. Red points are half hourly processed flux data which gap filling was trained on. Green points were eliminated through the despike procedure, u* filter, or footprint filter and are not used for any data analysis or gap filling purposes. Blue points are gap filled by the neural network. Early data required heavy gap filling due to startup difficulties with the eddy-flux system. The large gap around April 2012 is when the tower height was adjusted.*

Findings

We determined the seasonal dynamics of methane fluxes at the wetland park as a whole (Figure 3). We found that fluxes in the winter are much lower, as expected, but sum up to about 30% of the annual emissions total. We determined the diurnal cycle of methane fluxes from the site at different seasons (Figure 4). We found that the diurnal cycle is strong in the summer than in the winter. However, even in the summer nighttime fluxes are a significant component of the diurnal total flux.

The mid-date peak flux rate during the summer may be explained at least in part by flux transport through plants, which provides an important mechanism for methane emission. The temporal patterns that are caused by transport through plants and seasonal and diurnal fluctuation in meteorological conditions must be accounted for when interpreting the results of limited-time campaigns.

We found that Peak covariences between methane and CO2 fluxes in the summer were at no lag (Figure 5), indicating that a large fraction of the relationship between methane and GPP is instantaneous and probably stomata driven. Nonetheless, the asymmetry of the covaiance structure indicates that at least some methane emission is lagged with respect to GPP and may be driven by the addition of labile carbon to the root zone. During the winters, when stomatal control of aerenchyma transport of methane is impossible, the maximum covariance is lagged about 0.5-2 hours indicating that methane production processes in the soil respond slower to light, temperature and other environmental forcing than GPP by algae in the water. The maximal covariance between methane flux and GPP is lower in the winter than in the summer which is consistent with the plant mediation hypothesis as *Typha* spp. dies off in cold weather and leaves only dead culms, which would not be expected to affect the temporal dynamic of CH_4 fluxes.

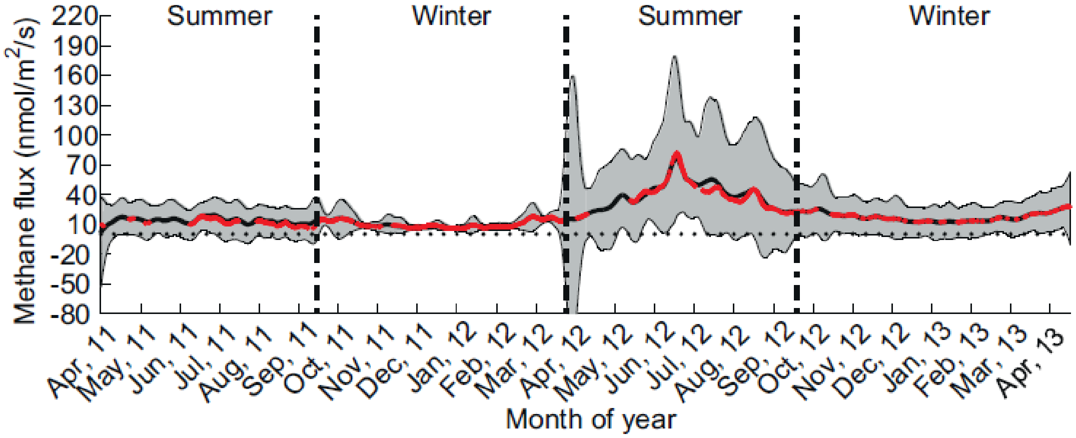

Figure 3. *2 week moving average of gapfilled methane flux data from spring 2011 through spring 2013. The light gray shading represents the 95% confidence interval given by the neural network runs. The red line with gaps shows observed methane flux data while the block continuous line shows the neural network model. When observed points were not available we used the neural network model for determining season dynamics. This shows a distinctive seasonal pattern with peaks occurring in summer months and dropping to low, but non zero, levels during the winter. Dotted line indicates the 0 nmol/m*^{2}*/s point.*

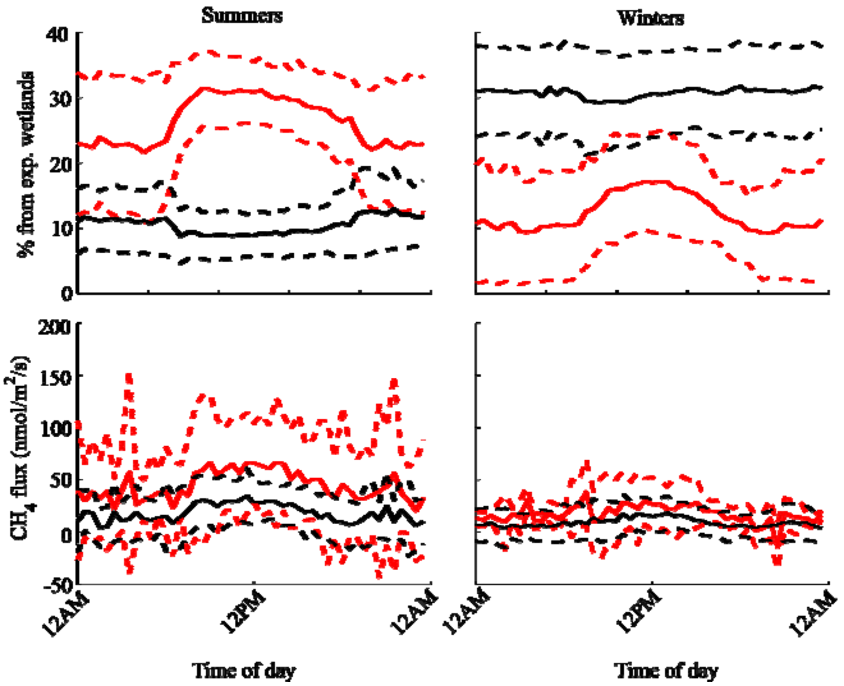

Figure 4. *Diurnal patterns of observed methane emissions from the experimental wetlands (lower panels) and the corresponding diurnal patterns of the fraction (in %) of the experimental "kidney" wetlands of the total flux source footprint (upper panels). The red lines show data for 2012, after the tower was raised while the black lines indicate the 2011 observations. Dashed lines show the standard deviation of the observations. The diurnal pattern in all seasons shows a stronger flux during the daytime and lower fluxes at night with a maximum shortly after midday.*

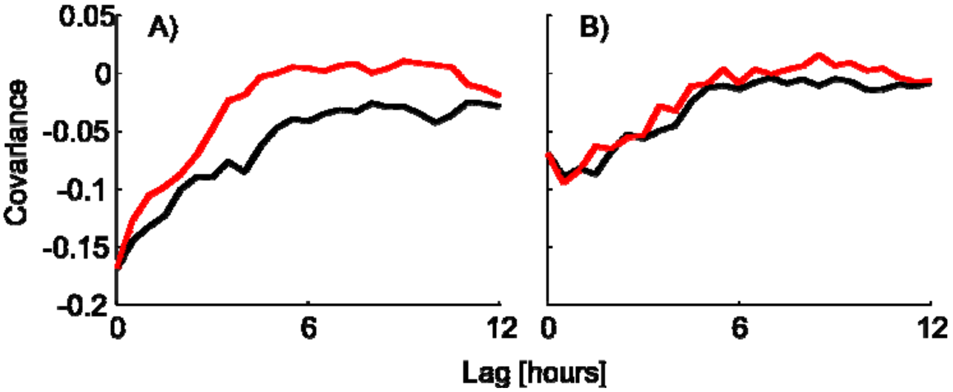

Figure 5. *The covariance between GPP and CH$_4$ fluxes as a function of lag time between the fluxes time series for (A) summer and (B) winter. The black line indicates the covariance as methane is lagged with respect to GPP (positive lag time, GPP happen earlier relative to methane flux) while the red line indicates the covariance as GPP is lagged with respect to methane (negative lag time, GPP happens later relative to methane). As GPP is measured as a negative flux of CO$_2$, a lower (more negative covariance) black curve relative to the red indicates a non-symmetric relationship with stronger lagged response of methane after GPP.*

Significance

The implications of these findings are that chamber-based and other intermittent methods of methane flux measurements must include a broad sample of all times of day and seasons in order to measure a correct annual budget of methane flux.

The plant-related influences indicate that knowledge of a wetland’s plant community at high temporal resolution and their growth dynamics throughout the year, as well as the effects of these plants on methane emission mechanisms are essential for accurate quantification of its methane fluxes. Our observations provide further support for the hypothesis that plant mediated transport is responsible for a significant component of the ecosystem-level methane flux from wetlands. Further effort should target measurements that could be used to parameterize such models at an appropriately small spatial scales and high temporal resolutions.