Geomorphic influence and hydrologic controls on greenhouse gas fluxes at the soil-atmosphere interface in northern forests.

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Introduction

- There is a knowledge gap between the predicted and actual rate of trace gas flux from forest soils, which are known to be both a source and sink of greenhouse gases (GHGs).
- Spatially representative direct measurements of soil-atmosphere gas fluxes is often an unrealistic method to assess the variability of gas flux across time and space. Therefore, the overarching objective of this research was to develop a method to estimate GHG flux at the soil-atmosphere interface throughout a northeastern forested watershed. The specific objectives included:

1. Quantify fluxes of CO_2, CH_4, and N_2O at the soil-atmosphere interface across time and space in a forested watershed.
2. Investigate the influence of landscape hydrogeomorphic characteristics on GHG dynamics to better constrain estimates of soil GHG fluxes at the watershed scale.
3. Relate GHG dynamics in forested soils to temporal indicators (i.e. temperature, precipitation, discharge).
4. Model GHG flux using topographic indexes.

Study Site and Methods

Archer Creek Watershed, Adirondacks, NY

Area: 135 ha ; **Average slope**: 11% ; **Total Relief**: 225 meters ; **Soil**: glacial till & greenwood mucky peats (wetlands) ; **Climate**: cool, moist, & continental ; **Mean Temperature:** 5°C ; **Mean Annual Precipitation:**1046 mm total; 303 cm snow

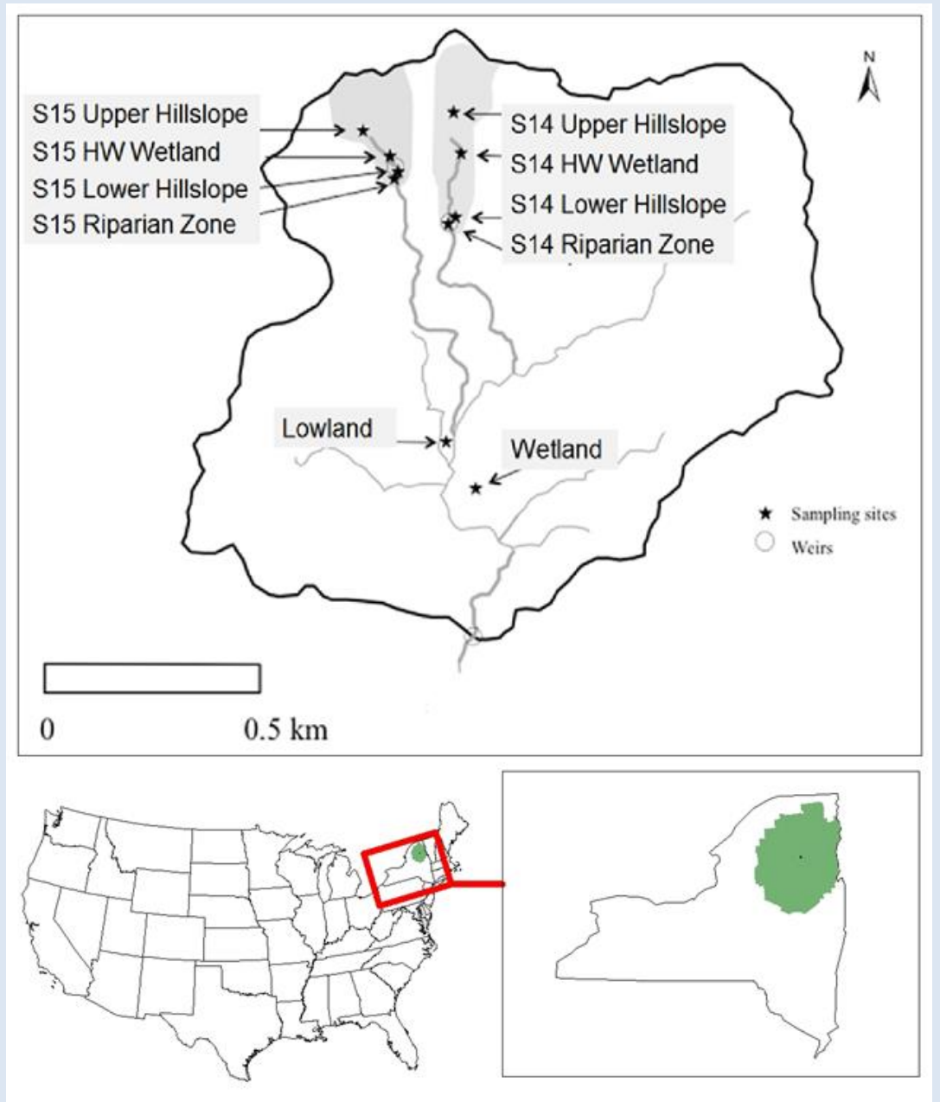
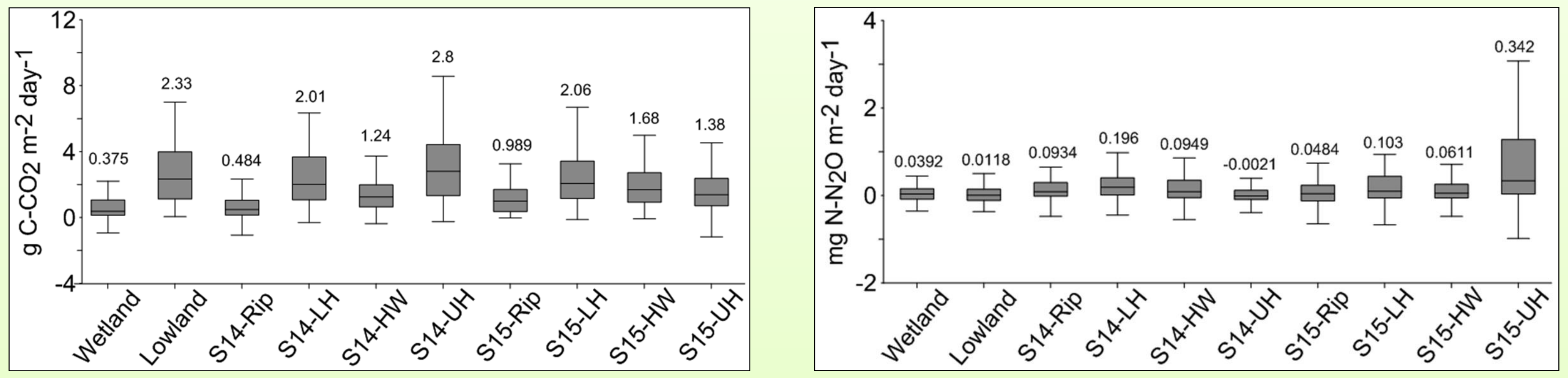


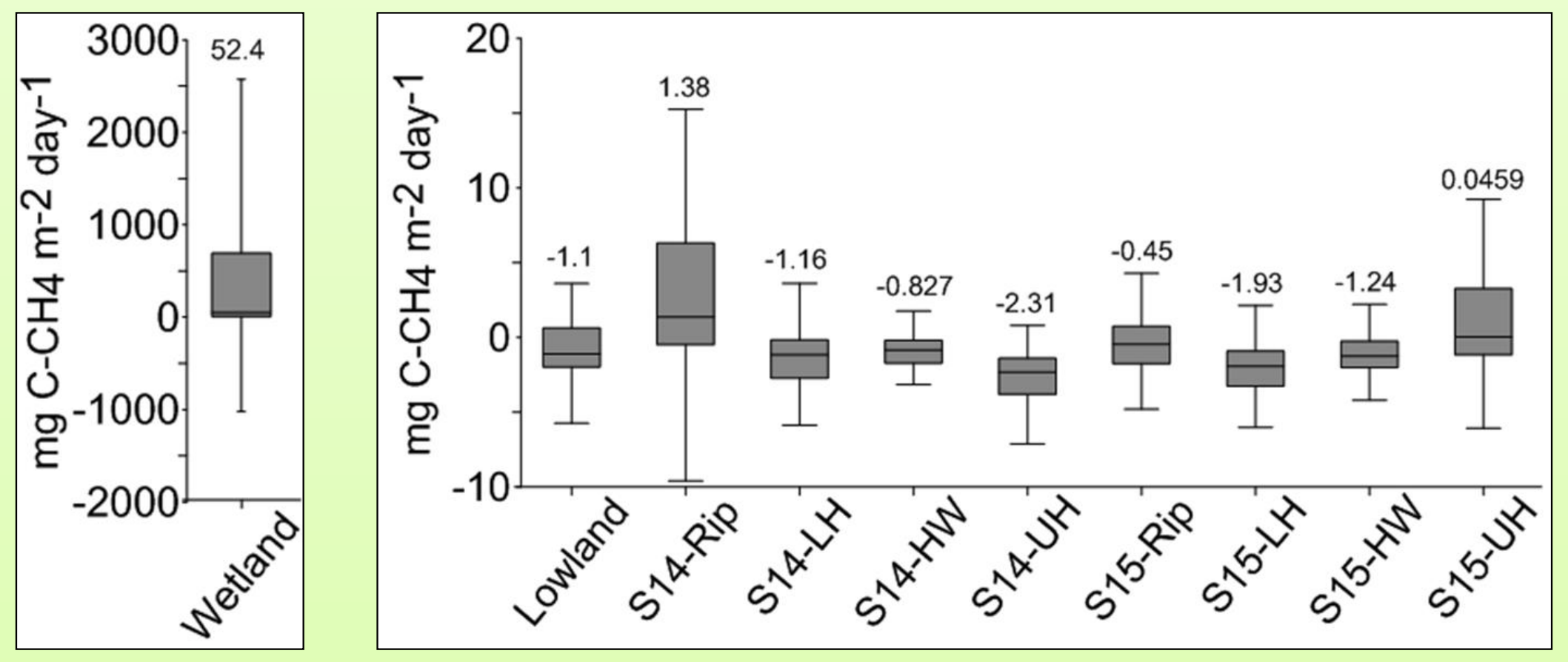
Figure 1: Location of the Archer Creek Watershed in the context of the United States and New York State.

- 60 static chambers were used at 10 geomorphically distinct sites. Gas chromatography was used to measure CO_2, CH_4, and N_2O concentration change over time.
- Sampling occurred biweekly in the summer of 2011, and at least monthly between June 2012 and July 2013. Four high frequency diel sampling periods complemented the data set.
- GHG flux dynamics were evaluated in relation to commonly measured environmental variables (i.e. soil temperature, antecedent moisture conditions)
- Topographic features of the watershed were evaluated in Geographic Information Systems using 1m resolution Lidar data.

Spatial Variability

Figure 2: Box plots depicting descriptive statistics for the 10 study sites across the study period for CH_4, CO_2,and N_2O fluxes. Median values are displayed above the upper whisker for each site.





- The Hillslopes had the highest median CO_2 flux (Figure 2), most likely associated with soils that have steeper slopes (Figure 3) and a low propensity to be saturated.
- N_2O fluxes were variable in space. The S14 Upper Hillslope is a N_2O sink, which is consistent with findings from other studies (Chapuis-Lardy et al., 2007; Goldeberg and Gerbauger, 2009).
- The Wetland had the largest median CH_4 flux of 52.4 mg C-CH_4 m^{-2} day^{-1}. This was expected due to moist, anoxic, and carbon rich soils. The S14 Riparian Zone was the next largest contributor at 1.38 mg C-CH_4 m^{-2} day^{-1}. All other sites were net methane sinks, or very close to zero net flux (Figure 2).

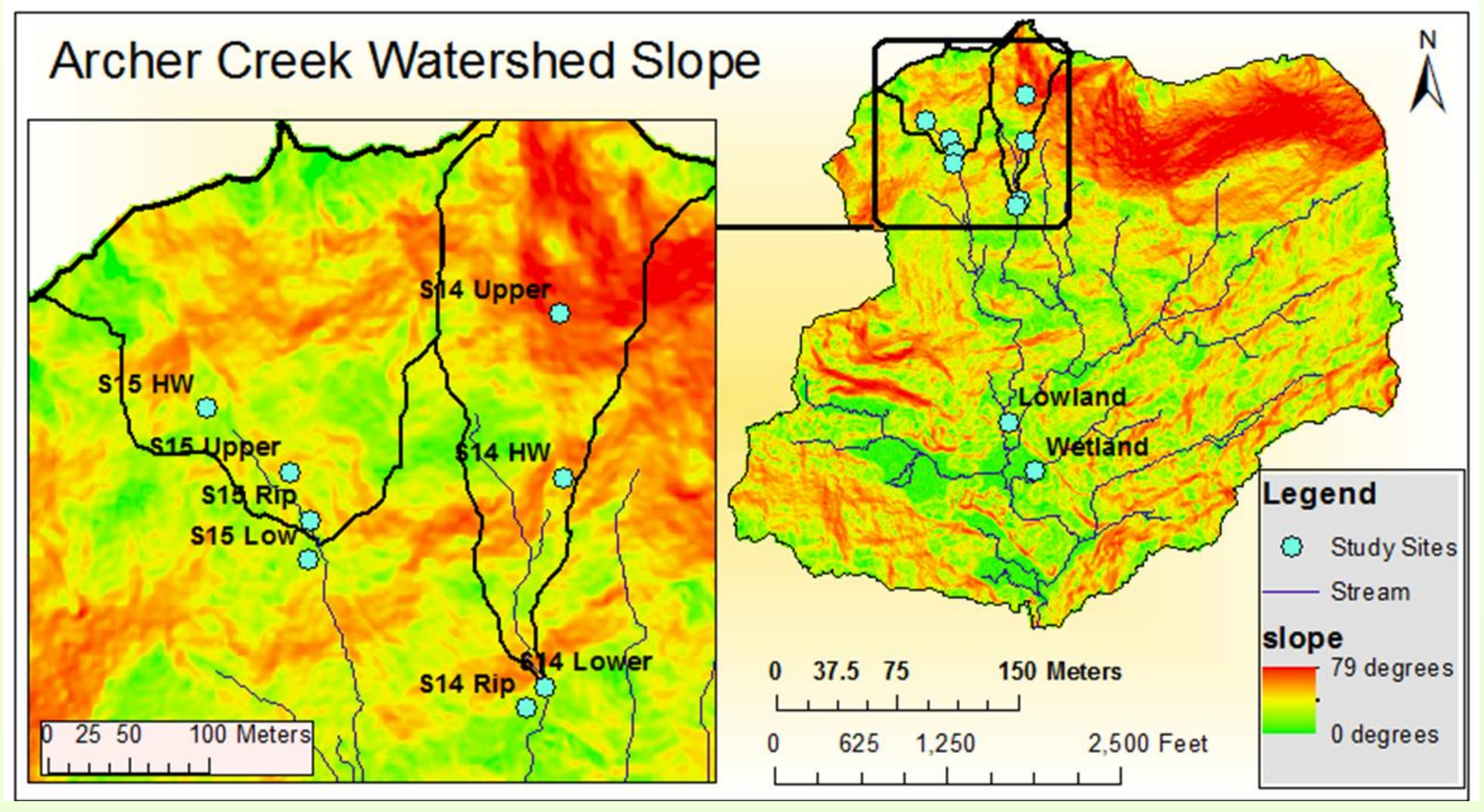


Figure 3: Slope gradient of the Archer Creek Watershed.

Steps to Developing an Estimated Watershed GHG Budget

1. Implement the topographic wetness index.TWI= ln (*a*/tanβ), where *a* is accumulated contributing area and tanβ is the local slope angle (Beven and Kirkby, 1979).
2. Designate geomorphic classes using specific ranges of the TWI (Figure 4).

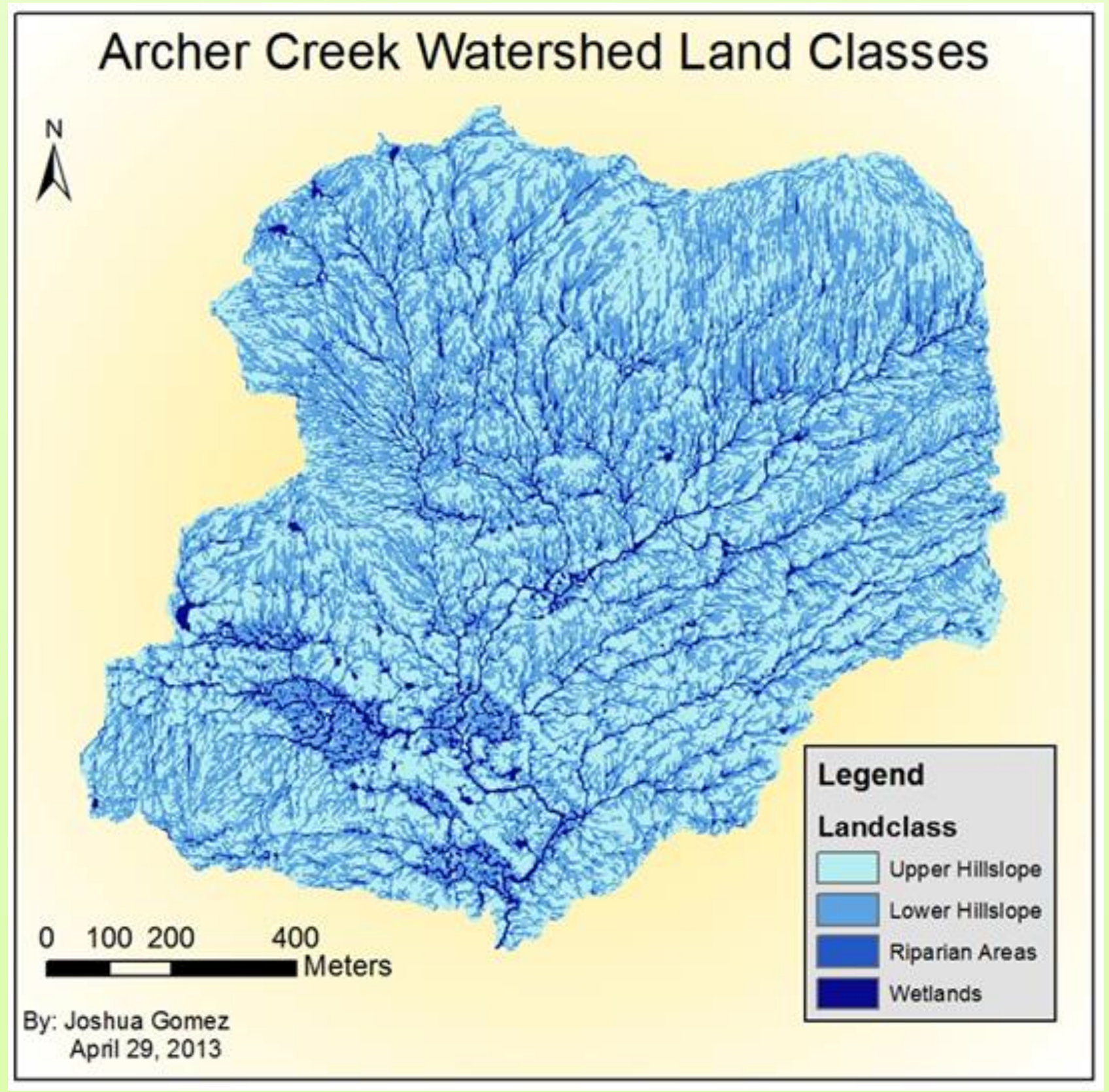


Figure 4: Geomorphic classifications based on the TWI developed in a GIS framework. Riparian areas include headwater wetland sites, and the lowland site is included in the lower hill slope land class.

3. Relate median trace gas fluxes to the TWI.
4. Develop watershed budget using area weighted gas efflux.

- Implementing the topographic wetness index resulted in a TWI value of 0-24 for the Archer Creek Watershed. Neighborhood statistics were used to generalize the landscape into 4 categories which were related to median GHG fluxes (Figure 4).
- The Hillslopes accounted for 89% of the Archer Creek Catchment area. Riparian and headwater areas comprise 7%, and the wetlands account for 3%, respectively.
- Methane contributed the highest CO_2 equivalent flux at the wetlands.
- CO_2 contributed the most significant portion of CO_2 equivalent flux across all other geomorphic classes.

Challenges of using the topographic wetness index in a GIS framework:

1. Flow routing algorithms (single and multiple direction) failed to accurately assess the true location of flow accumulation & stream locations, especially in the low order stream sections.
2. Wetland areas tend to result in an unrealistic braided flow accumulation.
3. Implementing the topographic wetness index required methods to reduce "noise".

Archer Creek GHG Budget: A Comparison of Two Methods

Table 1: Daily CO_2 equivalent flux forCH$_4$, CO_2, and N_2O for contrasting geomorphic classes .

Area-Weighted CO_2 Equivalent Flux									
Method 1: Topographic Index Based Geomorphic Class Area Calculation						Method 2: Manually Calculated Geomorphic Class Area			
Geomorphic Class	Mean TWI Range	CO_2 Equivalent			Area (m^2)	Area (m^2)	CO_2 Equivalent		
		CH_4	CO_2	N_2O			CH_4	CO_2	N_2O
Upper Hillslope	(0.0 - 2.249)	-1.82×10^4	4.42×10^6	4.78×10^4	5.77×10^5	4.19×10^5	-1.32×10^4	3.21×10^6	3.46×10^4
Lower Hillslope	(2.5 - 3.99)	-2.46×10^4	4.94×10^6	3.20×10^5	6.32×10^5	7.43×10^5	-2.89×10^4	5.80×10^6	3.76×10^5
Riparian	(4.0 - 5.99)	-3.52×10^3	3.66×10^5	3.32×10^3	9.17×10^4	8.10×10^4	-3.11×10^3	3.24×10^5	2.94×10^3
Wetland	(> 6.0)	6.73×10^4	4.62×10^4	8.71×10^2	4.59×10^4	1.08×10^5	1.58×10^5	1.09×10^5	2.05×10^3
Total		$\mathbf{2.09 \times 10^4}$	$\mathbf{9.77 \times 10^6}$	$\mathbf{3.72 \times 10^5}$			$\mathbf{1.13 \times 10^5}$	$\mathbf{9.44 \times 10^6}$	$\mathbf{4.16 \times 10^5}$

1.02×10^7 **Total Watershed CO_2 Equivalent Flux Per Day** **9.97×10^6**

- Total Watershed CO_2 equivalent flux results are similar for both methods, indicating that there is potential for using a TWI based method for larger watersheds.
- Wetland area calculations are dissimilar, which can be attributed to limitations in apportioning flow accumulation using the TWI method.

Temporal Variability

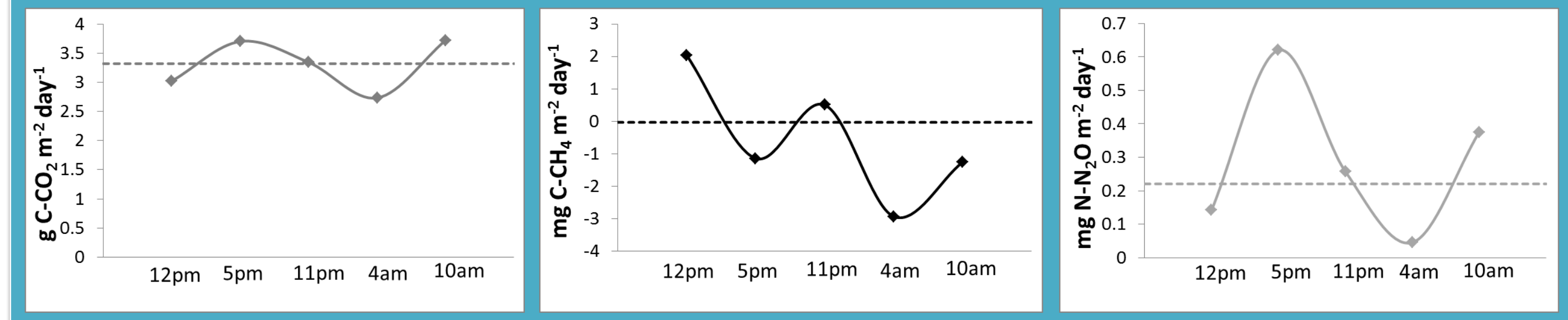
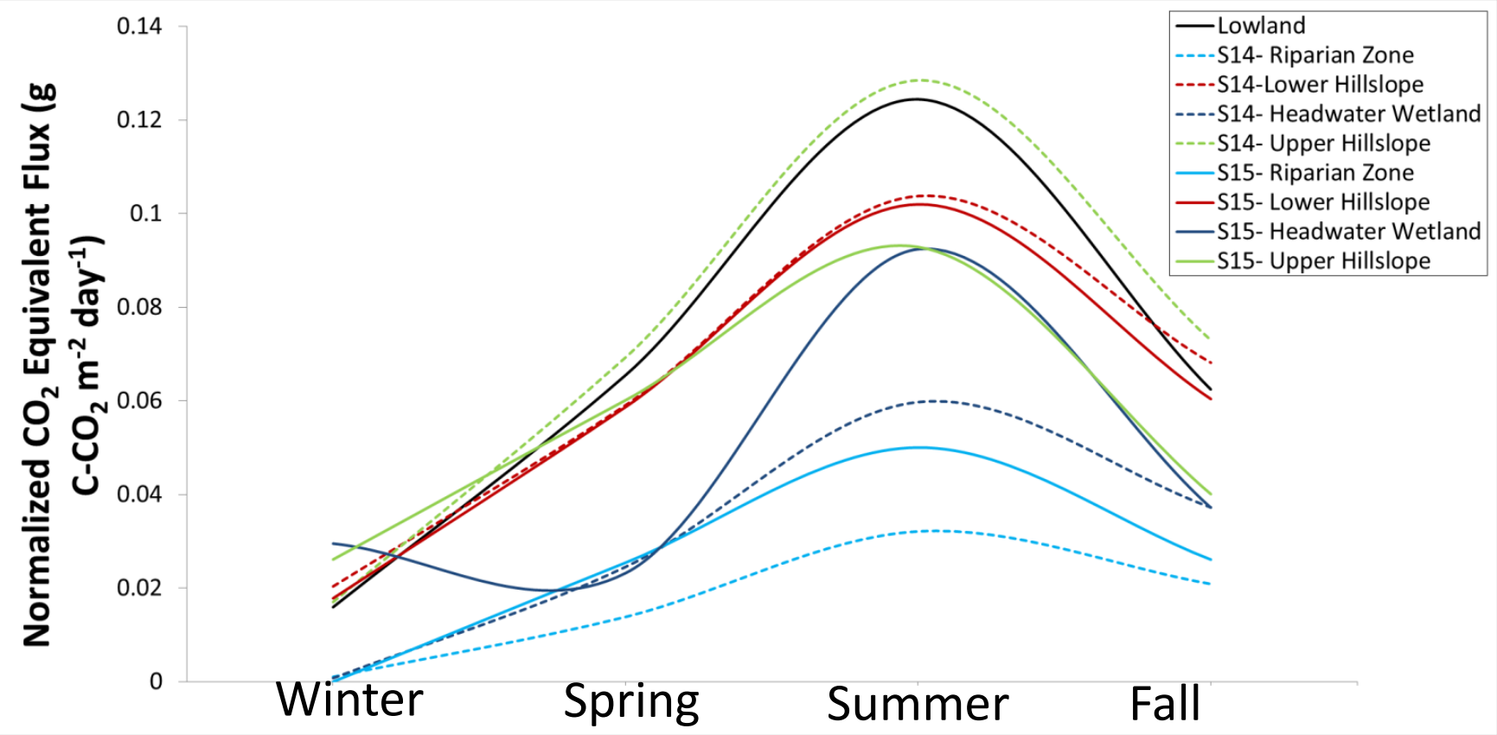


Figure 5: Diel variation for CO_2, CH_4, and N_2O (solid lines) plotted about the flux measurements taken during daytime only sampling protocol (dashed lines).

Figure 6: Seasonal variation for CO_2 equivalent flux (sum of CO_2 equivalent flux for each gas) of each site.



- Diurnal variation was not statistically different than the daytime flux.
- The summer season had the greatest CO_2 flux and *total CO_2 equivalent flux* of soils to the atmosphere. The winter had the lowest *CO_2 equivalent flux* (Figure 6).
- Most sites were a net CH_4 sink. The Wetland and S14 Riparian Areas were CH_4 sources throughout the seasons (data not shown).
- N_2O fluxes were increased in magnitude during the spring season at the S15 Hillslopes (data not shown).

Conclusions/Significance

- Methane, carbon dioxide, and nitrous oxide fluxes varied by season, with the summer season possessing the most global warming potential. In light of predicted longer and hotter summer seasons (Hayhoe et al., 2006), northern forests may become a larger source of CO_2 equivalent emissions.
- Spatial distribution of gas fluxes is apparent across the hillslope slope gradient. Uplands have a high global warming potential due to CO_2 efflux, while wetlands and moist riparian soils emit higher methane fluxes.
- Modeling spatial trends in GHG flux by relating GHG flux to a topographic indices is difficult due to limitations of flow routing algorithms, DEM attributes within the GIS framework, and the spatial and temporal heterogeneity of GHG fluxes.

References: [1]Chapuis-Lardy, Lydie, Nicole Wrage, Aurelie Metay, Jean-Luc Chottes, Martial Bernoux. 2007. Soils, a sink for N2O? A review. *Global Change Biology* 13: 1-17, doi: 10.1111/j.1365-2486.2006.01280.x [2]Goldeberg, S.D., G. Gerbauer. 2009. Drought turns a central European Norway spruce forest soil from an N_2O source to a transient N_2O sink. *Global Change Biology* 15: 850-860, doi: 10.1111/j.1365-2486.2008.01752.x [3] Beven, K. J. and Kirkby, M. J.: A physically based, variable contributing area model of basin hydrology, Hydrol. Sci. Bull., 24, 43–69, 1979 [4] Hayhoe, K., C.P. Wake, T.G. Huntington, L. Luo, M.D. Schwartz, J. Sheffield, E.F. Wood, B. Anderson, J. Bradbury, A. DeGaetano, T. Troy, and D. Wolfe.2006. Past and future changes in climate and hydrological indicators in the U.S. Northeast. Climate Dynamics. DOI 10.1007/s00382-006-0187-8