Cryptic Methane Emissions from Upland Forest Ecosystems

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Executive Summary

This exploratory research on *Cryptic Methane Emissions from Upland Forest Ecosystems* was motivated by evidence that upland ecosystems emit 36% as much methane to the atmosphere as global wetlands, yet we knew almost nothing about this source. The long-term objective was to refine Earth system models by quantifying methane emissions from upland forests, and elucidate the biogeochemical processes that govern upland methane emissions. The immediate objectives of the grant were to: (i) test the emerging paradigm that upland trees unexpectedly transpire methane, (ii) test the basic biogeochemical assumptions of an existing global model of upland methane emissions, and (iii) develop the suite of biogeochemical approaches that will be needed to advance research on upland methane emissions. We instrumented a temperate forest system in order to explore the processes that govern upland methane emissions. We demonstrated that methane is emitted from the stems of dominant tree species in temperate upland forests. Tree emissions occurred throughout the growing season, while soils adjacent to the trees consumed methane simultaneously, challenging the concept that forests are uniform sinks of methane. High frequency measurements revealed diurnal cycling in the rate of methane emissions, pointing to soils as the methane source and transpiration as the most likely pathway for methane transport. We propose the forests are smaller methane sinks than previously estimated due to stem emissions. Stem emissions may be particularly important in upland tropical forests characterized by high rainfall and transpiration, resolving differences between models and measurements. The methods we used can be effectively implemented in order to determine if the phenomenon is widespread.

Report

I. Accomplishments

A. Objectives

My exploratory research on Cryptic Methane Emissions from Upland Forest Ecosystems was motivated by evidence that upland ecosystems emit 36% as much methane to the atmosphere as global wetlands, yet we know almost nothing about this source. The long-term objective is to help refine Earth system models by quantifying methane emissions from upland forests, and elucidate the biogeochemical processes that govern upland methane emissions. My immediate objectives were to: (i) test the emerging paradigm that upland trees transpire methane, (ii) test the basic biogeochemical assumptions of an existing global model of upland methane emissions, and (iii) develop the suite of biogeochemical approaches that will be needed to advance research on upland methane emissions. Although global emissions of methane from uplands appear to be highest in tropical forests and grasslands, I proposed to instrument a temperate forest system in order to explore the processes that govern upland methane emissions.

B. Accomplishments

Objective 1: Test the Paradigm That Upland Trees Transpire Methane

The research accomplished this goal. One component of the hypothesis is that upland trees emit methane, which was tested and accepted. As proposed, the study was designed to measure methane and carbon dioxide emissions from tree stems arrayed across a soil moisture gradient. At one end, the transect was adjacent to a forested wetland and soils were upland but wet, while on the other end the water stable was as deep as 10 meters. The first year of data demonstrated that methane was being emitted from tree stems as hypothesized. With additional support from DOE-TES in the form of a supplemental grant, a far more sensitive instrument was purchased and connected to an automated flux system designed by PhD candidate Scott Pitz. The result was more detailed observations that support that support the second part of the hypothesis, that methane is being emitted through the process of transpiration. The text of a manuscript that presents these data is presently in review and included as Appendix 1 in this report.

Objective 2: Test the assumptions of a model of upland methane emissions

The most rigorous effort to quantify methane emissions from uplands is provided by Spahni et al. (2011) who used a dynamic global vegetation model to simulate three ecosystems types, one of which was “wet mineral soils”. They defined wet mineral soil ecosystems as those that normally consume methane but can switch to emitting methane at a threshold of water-filled pore space. Based on very limited literature, they modeled thresholds ranging from 0.28 to 0.55 fractional water-filled pore space, varying with edaphic factors such as texture. Simultaneous measurement of tree stem methane emissions and soil moisture in this research effort indicated that methane can be emitted from upland tree stems at soil surface (10 cm) moisture levels as low as 16% (see Figure 1 of Appendix 1). This is consistent with the assumptions of Spahni et al. (2011), if one considers that methane emissions from tree stems do not necessarily drive net methane emissions from the full ecosystem (i.e. the sum of tree emissions and soil uptake). When scaled up, the soil and tree emission estimates suggest that the forest was a net source of methane during one month when soil moisture was 28%, which is consistent with the Spahni model.

Objective 3: Develop approaches to advance upland CH_4 emissions research

In order for upland trees to emit methane through a transpiration stream, there must be anaerobic zones imbedded in seemingly upland forest soils. It is well known that upland soils contain small areas that are anaerobic and produce methane, but these are difficult to characterize. One goal of the research was to investigate the potential of using a stable isotope dilution technique to detect areas of upland soil profiles where methane is being produced. The work showed that the soils in our transect do produce methane, and that this potential increases with soil moisture content.

Goals Not Met

Most of the goals set out in the proposal were met. One exception is that we did not make a set of preliminary measurements in Panama that were proposed. This decision was made to focus the financial resources of the grant on gaining additional insight into tree emissions from our focal study site. As a result, we developed an automated system for sampling tree emissions that was not proposed, which generated the data in Figures 2 and 3 of Appendix 1.

C. Opportunities for Training and Professional Development

Most of the resources in this grant were invested in support Scott Pitz, a PhD candidate at Johns Hopkins University. Scott is still engaged in the dissertation writing at this time. He attended the DOE-TES science meetings in 2014 and 2015, and gave several presentations at major meetings such as AGU and ESA. He received training from the lab of Dr. Joe von Fischer at the Colorado State University. A Post-Doctoral Fellow supported by the Smithsonian Institution also received training in the form of a collaborative project on methane emissions from a Bald Cypress swamp forest. She used the techniques developed for the upland forest project and will publish the study.

D. Dissemination of Results

The results were disseminated primarily through presentations at professional meetings and peer-reviewed publications.

III. Products

A. Presentations and Publications

i. Presentations

Megonigal, JP and S Pitz. 2012. Cryptic Methane Emissions from Upland Forest Ecosystems. Terrestrial Ecosystem Science Program Meeting.

Megonigal, JP and S Pitz. 2013. Cryptic Methane Emissions from Upland Forest Ecosystems. Terrestrial Ecosystem Science Program Meeting.

Pitz, S, JP Megonigal, L Schile, K Szlavecz. 2014. Methane emissions from upland trees. Department of Energy Carbon Science Meeting.

Pitz, S, JP Megonigal, L Schile, K Szlavecz. 2014. Methane emissions from upland trees. Ecological Society of America.

Pitz, S, JP Megonigal. 2015. Methane Emissions from Upland Trees. Department of Energy Terrestrial Carbon Science Meeting.

Pitz, S, JP Megonigal. 2015. Methane Emissions from Upland Trees. Ecological Society of America.

Megonigal, JP and S Pitz. 2015. Temperate Forest Methane Sink Diminished by Tree Emissions. American Geophysical Union.

Megonigal, JP and S Pitz. 2016. Temperate Forest Methane Sink Diminished by Tree Emissions. European Geophysical Union.

ii. Publications

Pitz, S and JP Megonigal. *In review*. Temperate Forest Methane Sink Diminished by Tree Emissions. Geophysical Research Letters.

Pitz, S and JP Megonigal. *In preparation*. Tree Stem and Soil Methane Fluxes Along an Upland-Wetland Gradient in a Temperate Forest.

Pitz, S and JP Megonigal. *In preparation*. Methane Production in Upland Forest Soils.

Schile, L, S Pitz and JP Megonigal. *In preparation*. Tree Stem and Soil Methane Emissions in a Bald Cypress Swamp.

B. Technologies

We developed a system that automates the measurement of methane emissions from tree stems.

IV. Participants and Other Collaborating Organizations

A. Individuals

1. J. Patrick Megonigal. Smithsonian Environmental Research Center (Principle Investigator). One month per year of effort for project period supported by the Smithsonian Institution. No collaborations with foreign countries.

2. Scott Pitz, Johns Hopkins University (Graduate Student)
Twelve months of effort per year for project period supported by this grant. No collaborations with foreign countries.

3. Kathy Szlavecz, Johns Hopkins University (Graduate Advisor)
One month per year of effort toward this project, supported by Johns Hopkins University. No collaborations with foreign countries.

4. Lisa Schile, Smithsonian Environmental Research Center (Collaborator).
One month per year of effort toward this project, supported by the Smithsonian Institution. No collaborations with foreign countries.

V. Impact

The project successfully demonstrated the upland forests can emit methane, a result that has help change the way upland forests are understood to interact with the global cycle of this greenhouse gas.

VI. Changes and Problems

The major change is that we did not make a set of preliminary measurements in Panama that were proposed. This decision was made to focus the financial resources of the grant on gaining additional insight into tree emissions from our focal study site. As a result, we developed an automated system for sampling tree emissions that was not proposed, which generated the data in Figures 2 and 3 of Appendix 1.

Appendix 1. The text of a publication supported by this grant that is currently being reviewed by Geophysical Research Letters.

Temperate Forest Methane Sink Diminished by Tree Emissions

Scott Pitz
Johns Hopkins University and the Smithsonian Environmental Research Center

J. Patrick Megonigal
Smithsonian Environmental Research Center

Global budgets ascribe 4-10% of atmospheric CH_4 sinks to upland soils[1-3] and assume that soils are the sole surface for CH_4 exchange between upland forests and the atmosphere. The prevailing dogma that upland forests are sinks of atmospheric CH_4 was challenged a decade ago by large discrepancies in bottom-up versus top-down models of CH_4 concentrations over upland forests that are still unexplained[4]. Evidence of a novel abiotic mechanism for CH_4 production from plant tissue[5] is too small to explain the discrepancy[6]. Alternative hypotheses for this observation have been proposed[3,8,9], but not tested. Here we demonstrate that CH_4 is emitted from the stems of dominant tree species in an upland forest. Tree emissions occur throughout the growing season while soils adjacent to the trees are consuming CH_4, challenging the concept that forests are uniform sinks of CH_4. Scaling by stem surface area showed the forest to be a net CH_4 source during a wet sample in June and a reduced CH_4 sink by 5% annually. High frequency measurements revealed diurnal cycling in the rate of CH_4 emissions, pointing to soils as the CH_4 source and transpiration as the most likely pathway for CH_4 transport. We propose the forests are smaller CH_4 sinks than previously estimated due to stem emissions. Stem emissions may be particularly important in upland tropical forests characterized by high rainfall and transpiration, resolving differences between models and measurements.

Terrestrial soils are estimated to consume 20-45 Tg CH_4 per year[7], a sink comparable to the rate of methane accumulation in the atmosphere and, therefore, capable of influencing the radiative forcing caused by this potent greenhouse gas. Global methane budgets, climate models and carbon accounting polices generally assume that the rate of methane consumption by upland ecosystems can be determined by measuring the rate of methane consumption at the soil surface. This assumption is problematic in forests where soils, but not trees, can be enclosed in gas flux chambers, the most common technique for quantifying upland methane fluxes and the technique that unpins global budgets. Observations of higher than predicted air-column CH_4 pools over tropical forests[4], reports of novel sources of CH_4 emissions in nominally upland ecosystems[5,9-14], and eddy flux data[8,9] suggesting hot spots or hot moments of CH_4 emissions from upland forests have challenged this assumption. The global contributions of CH_4 from novel upland sources demonstrated to date are difficult to estimate, but they are expected to be too small to adequately explain the potential source-sink imbalance[3] of 8-46 Tg yr^{-1}. Despite significant advances in identifying novel sources of CH_4 in upland forests, there are no *in situ* observations of CH_4 being emitted from trees in demonstrably upland ecosystems, and therefore no estimates of how much of the soil sink could be offset by emissions across other surfaces. This lack of evidence limits representation of CH_4 emissions from upland ecosystems in global models. Here, we present the first direct measurements of methane emissions from both soils and the stems of upland trees and an estimate of the sink implications of the tree emissions. Our evidence is consistent with the hypothesis that CH_4 is produced in soils, then transported to the atmosphere by transpiration.

Seventeen trees in a temperate upland forest located in Maryland, USA were fitted with rectangular chambers[10] for measuring stem gas fluxes. Each tree was paired with a soil gas flux chamber placed within 1 m of the base (see Methods). A total of 68 paired CH_4 and CO_2 flux measurements were taken between May and September of 2014 with a portable cavity ring down spectrometer (CRDS), capable of measuring CH_4 concentration in a range of 0.01-100 ppm with a precision of 0.002 ppm at 0.5 Hertz. Each flux was calculated from ≥150 observations and considered to be significant if the R^2 was greater or equal to 0.80. The smallest significant consumption rate measured was -0.36 μmol m^{-2} hr^{-1} and the smallest significant production rate was 0.03 μmol m^{-2} hr^{-1}. The CRDS can also measure CO_2 in a range of 200-20,000 ppm with a precision of 0.3 ppm.

Sixty-six of the 68 (97%) soil methane fluxes showed significant net CH_4 consumption from the atmosphere, as expected in an upland forest (Fig. 1). One measurement that showed net consumption was deemed not significant (R^2=0.64). By comparison, 46 of the 68 (68%) stem measurements showed significant emissions of CH_4. The species emitting CH_4 were the common upland species *Fagus grandifolia*, *Liriodendron tulipifera*, *Carya tomentosa*, *Quercus velutina*, *Quercus michauxii*, *Acer rubrum*, and *Liquidambar styraciflua*. For all species other than three of the *Fagus grandifolia* trees, the depth to groundwater varied from 3-5 m below the soil surface; three of the *Fagus* trees grew near a forested wetland boundary where the water table ranged from 0.65 to 2.5 m (Supplemental Data). Soil CH_4 flux averaged over the growing season was -4.52 μmol m^{-2} soil hr^{-1}, while average stem flux was 1.59 μmol m^{-2} stem hr^{-1}. With one exception, every observation of a CH_4-emitting tree was paired with soil that was a net CH_4 sink. Emissions were particularly high during the June sample, when the average rate per unit area of tree stem was 9.53 μmol m^{-2} hr^{-1} compared to the average soil uptake was -0.9 μmol m^{-2} hr^{-1}. These are the first data to document *in situ* CH_4 emissions from demonstrably upland trees, and they establish that the global CH_4 sink ascribed to upland forests based on soil fluxes may be an overestimate.

Based on data from an adjacent 16 hectare forest plot, we estimate that the stem surface area of all trees from the soil surface to a height of three meters is 13.4% of the soil surface area (see Methods), and to the full height of the stem is 104% of the soil surface area. Three meters is a conservative estimate of the vertical extent of CH_4 emissions based on observations from an automated flux system (Figure 2) and the literature[11]. Scaling data from our June sample using these area estimates, our upland forest plot was a net source of CH_4, at a rate of 0.375 μmol m^{-2} soil hr^{-1}. This temporary net source was a result of a simultaneous increase in stem flux and a decrease in soil consumption caused by an increase in soil moisture from a precipitation event. Volumetric soil moisture content was highest, over 30%, during the June sample (Figure 1). At other times, the forest remained a net sink, albeit a smaller sink by 5%, than expected from soil surface CH_4 fluxes alone. Using the full height surface area, the annual reduction in the soil sink was 38%. This demonstrates that CH_4 cycling in upland forests needs to be reassessed in future greenhouse gas budgets and models.

The observation that CH_4 is emitted from tree stems adjacent to soils that consume CH_4 indicates that trees are integrating the balance of opposing microbial respiration processes over a much deeper soil profile than is apparent from soil surface flux measurements. Consumption of atmospheric CH_4 at the soil surface occurs because oxidation exceeds production as integrated through the full soil profile. Depth profiles of soil CH_4 in upland ecosystems can have subsurface peaks near the water table, indicating that CH_4 from multiple sources is quantitatively consumed in these dominantly aerobic systems[12]. Methane transport from anaerobic microsites through the root system and stem vascular tissue bypasses oxic soil horizons where it would be subjected to oxidation by methanotrophs. In most ecosystems, 5% of the roots are deeper than 1 m[13], maximum root depths can exceed 4 m[14], and deep roots can contribute disproportionate amounts of water to canopy transpiration[15,16]. Correlations between CH_4 concentration in the groundwater and CH_4 emissions from stems have been reported from wetland trees[5,7].

We constructed an automated system for high frequency tree CH_4 flux measurements to gain insights on the source and mechanism of CH_4 emitted from upland trees (see Methods). During a three-day period in July 2014, CH_4 and CO_2 fluxes were measured from the bole of a tulip poplar (*Liriodendron tulipifera*) at three heights above the soil surface (75, 165 and 245 cm) and an American beech (*Fagus grandifolia*) at one height (75 cm), with measurements repeated at 45 min intervals. Emissions ranged from 0.625 to over 19 μmol m^{-2} stem hr^{-1} and varied systematically with stem height and tree species. Methane emissions declined with increasing height from the base of the stem (Fig. 2). The same pattern has been observed in wetland tree stems[11,17,18] and is expected when soils are the CH_4 source. CH_4 and CO_2 emission rates followed a clear diurnal pattern (Fig. 3), with peak emissions in the early afternoon and minimum emissions at night. For both gases, the magnitude of diurnal variation was greater in the tulip poplar than the beech tree.

An anaerobic, microbial soil source is the most likely explanation for the patterns of CH_4 emissions we observed in this upland forest. There was no evidence of heart rot in wood cores extracted from each of the trees at a height of 1.3 m. Anaerobic sites within the tree (i.e. heart-rot) have been shown to produce peak *in situ* concentrations at ~1.3 m above the soil surface and lower concentrations at the base[19], which was not pattern of stem emissions observed in this study (Figure 2) or wetland tree studies[11,17,18] were soils are clearly a CH_4 source. UV-driven emissions are eliminated by the opaque chambers used in this study. Fungi on tree stems may be emitting CH_4, but reported rates are far less than observed here.. The most likely source of CH_4

to support tree emissions is soils. Methane is produced in upland soils by a variety of microorganisms, including archaebacteria in anaerobic microsites[20] and fungi[21]. In addition, methane can be present in deep soil horizons saturated by groundwater.

Gas transport via transpiration can explain patterns in the CH_4 emissions data. Mid-day peaks in CH_4 and CO_2 emissions correspond to peak transpiration[22]. The decline in CH_4 emissions with height suggests release of CH_4 from a rising transpiration stream. Soil CO_2 has been shown to be entrained in the transpiration stream of trees, with emissions that vary with transpiration and xylem flow[23]. Diurnal cycling of CH_4 emissions from cypress seedlings in a microcosm experiment[24], varied with light and therefore transpiration. A second potential mechanism of gas transport through stems is diffusion[25]; nighttime CH_4 emissions are evidence that diffusion transport occurs in upland trees.

Tree stem CH_4 emissions may be large enough to explain observations of unexpectedly high pools of atmospheric CH_4 over tropical forests[1]. Our conservative estimates indicate that tree stem CH_4 emissions are large enough to change a demonstrably upland temperate forest from a net sink to a source during a period of high precipitation. High precipitation in tropical forests favors high soil moisture, low soil O_2, and large volumes of persistent hypoxic or anaerobic microsites, conditions that simultaneously favor CH_4 production and inhibit CH_4 oxidation[26]. We expect that tropical forests may support higher tree stem CH_4 emissions that temperate forests, particularly if transpiration proves to be an important mechanism controlling stem emission rates. About 70% of evapotranspiration from tropical forests bypasses a portion of the aerobic soil surface through plant vascular tissue as transpiration, a volume of water at least twice as high as temperate forests[27]. There are satellite products and global models that measure and predict transpiration (MOD16); incorporating stem CH_4 emissions and transpiration into bottom-up models may bring these estimates into agreement.

Methods Summary

This study was conducted in a mature, temperate, deciduous, forest at the Smithsonian Environmental Research Center near Annapolis, Maryland, USA. Stem and soil gas fluxes were collected in closed chambers designed for measuring stem CO_2 respiration. Chamber were constructed of acrylic and permanently fixed to stems 30-60 cm above the soil. Chambers were attached to the stem using elastic shock cord. To create an airtight seal, closed-cell neoprene foam was placed between the chamber edge and the stem, and sealed with dental amalgam to create a non-VOC seal (Examix^{TM}, GC America, City, State, USA). Soil rings or constructed out of 30.5 cm-diameter schedule 80 PVC pipe and placed 5 cm into the soil surface. Gas concentrations were measured using a portable cavity-ring down spectrometer (CRDS) (Los Gatos Research, Los Gatos, CA, USA). This instrument is capable of measuring CH_4 in a range of 0.01-100 ppm with a precision of 0.002 ppm. The CRDS can also measure CO_2 in a range of 200-20000 ppm with a precision of 0.3 ppm. Readings were taken at 2 s intervals. The CRDS is a closed system and a non-destructive measurement technique; sample air is returned to the chamber from the measurement cell.

Automated measurements were made using the same chamber design, modified with a lid that was opened and closed by a pneumatic cylinder controlled by an Arduino Mega microcontroller. A solenoid manifold sequentially sampled air from one chamber at a time for a period of eight minutes, flowing it through the CRDS, with a three minute flushing after each measurement. Slopes of the measurements were calculated using linear regression, after removing the first 20% of the observations to remove any potential artifacts related to closing of the lid. Gas flux was calculated using the following equation:

$$F = \frac{M\,V}{S}$$

Where F is the flux in μL m^{-2} hr^{-1}, M is the slope in μL gas L^{-1} hr^{-1}, V is the volume of the chamber in L, and S is the surface area that the chamber encloses. The flux units were then converted to μmol m^{-2} hr^{-1}. Fluxes were only considered to be significant if the $R^2 > 0.80$. Pearson's R was used to calculate the correlation coefficient between CH_4 and CO_2 emissions from the automated system. Only paired, significant fluxes (R^2>0.80) were used to calculate the correlation coefficient.

Stem surface area estimates were made using data from the Forest-GEO plot located at the Smithsonian Environmental Research Center. Data from over 30,000 stem diameter measurements was used to calculate the mean circumference. An allometric equation was used to derive height from diameter based on data from a subset of trees, whose diameter and height were measured. The surface area was then calculated using the formula for the surface area of the curved surface of a cylinder. The surface area of the base ends was not included. When calculating mean flux values or scaling fluxes to the plot level, all fluxes were used, regardless of R^2 value. Fluxes that are too low to measure are still important on a per unit area basis when scaling to a plot or ecosystem level. To remove non-significant fluxes from soil methane consumption or stem emission scaling, would be to bias them low or high, respectively.

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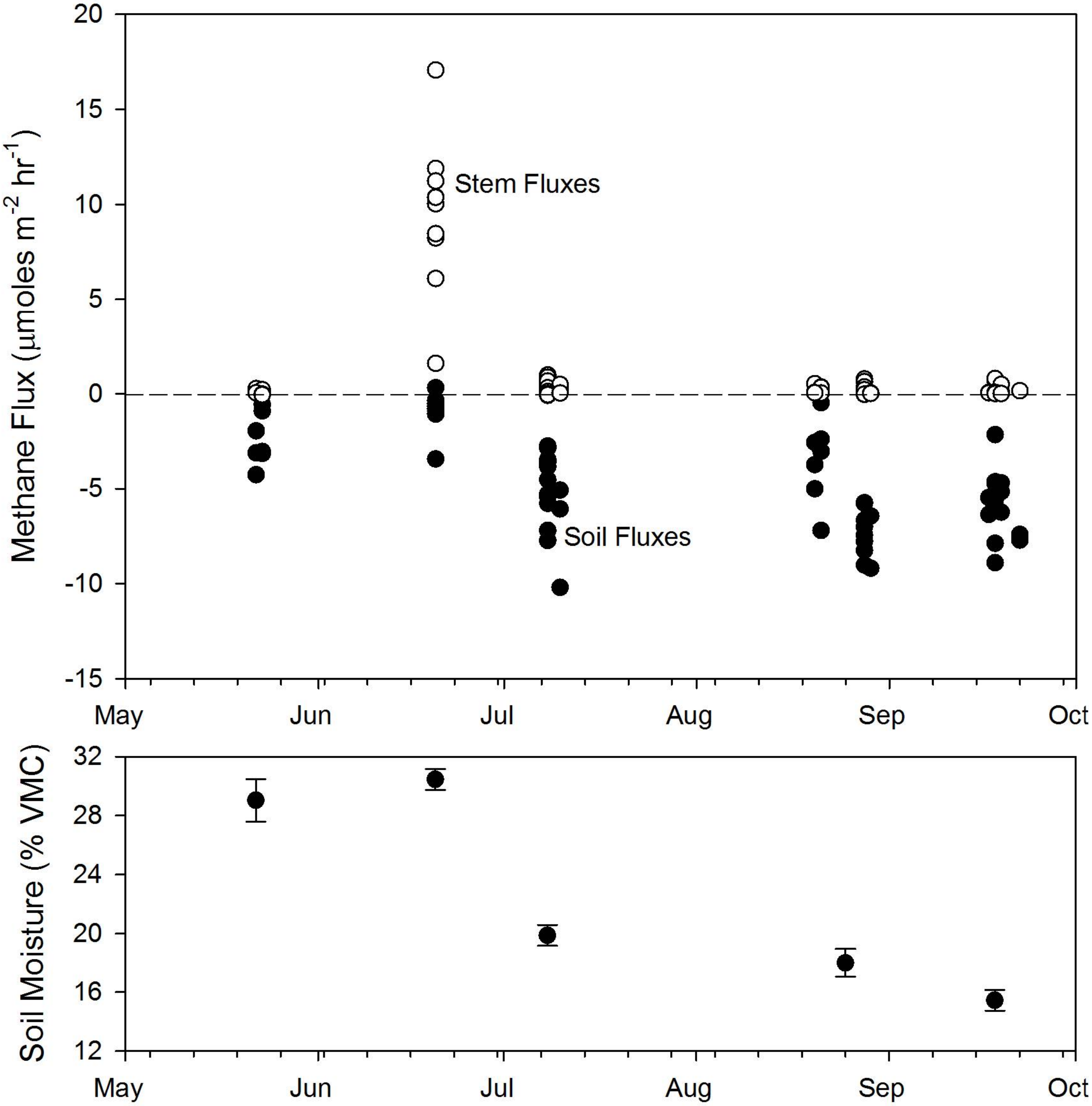


Figure 1. Top graph shows methane fluxes across tree stem and soil surfaces in an upland forest. Each point represents a significant flux (R^2>0.8). The bottom graph shows the corresponding soil moisture (% VMC) for each sampling event.

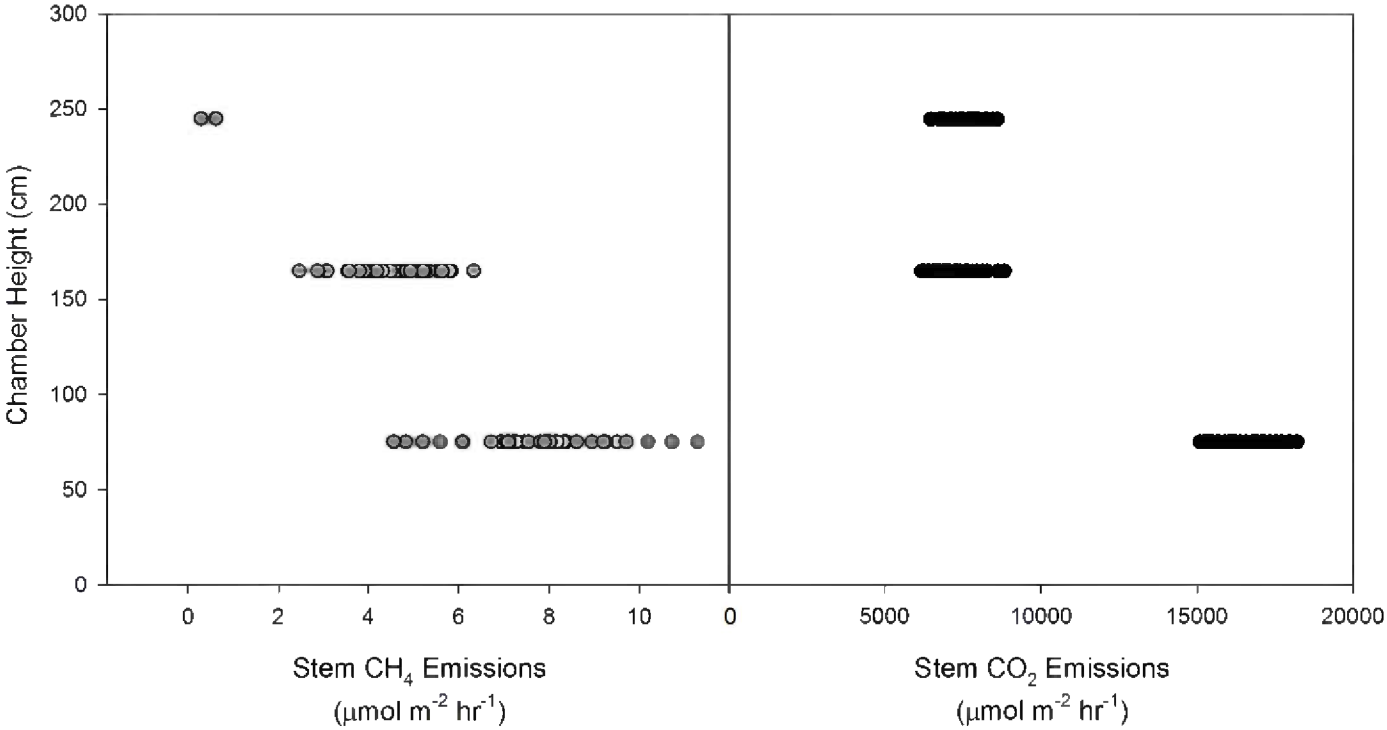


Figure 2: Vertical profiles of CH_4 and CO_2 (stem respiration) emissions from a *L. tulipifera* stem on Julian day 210. Each point represents a significant flux ($R^2 > 0.8$).

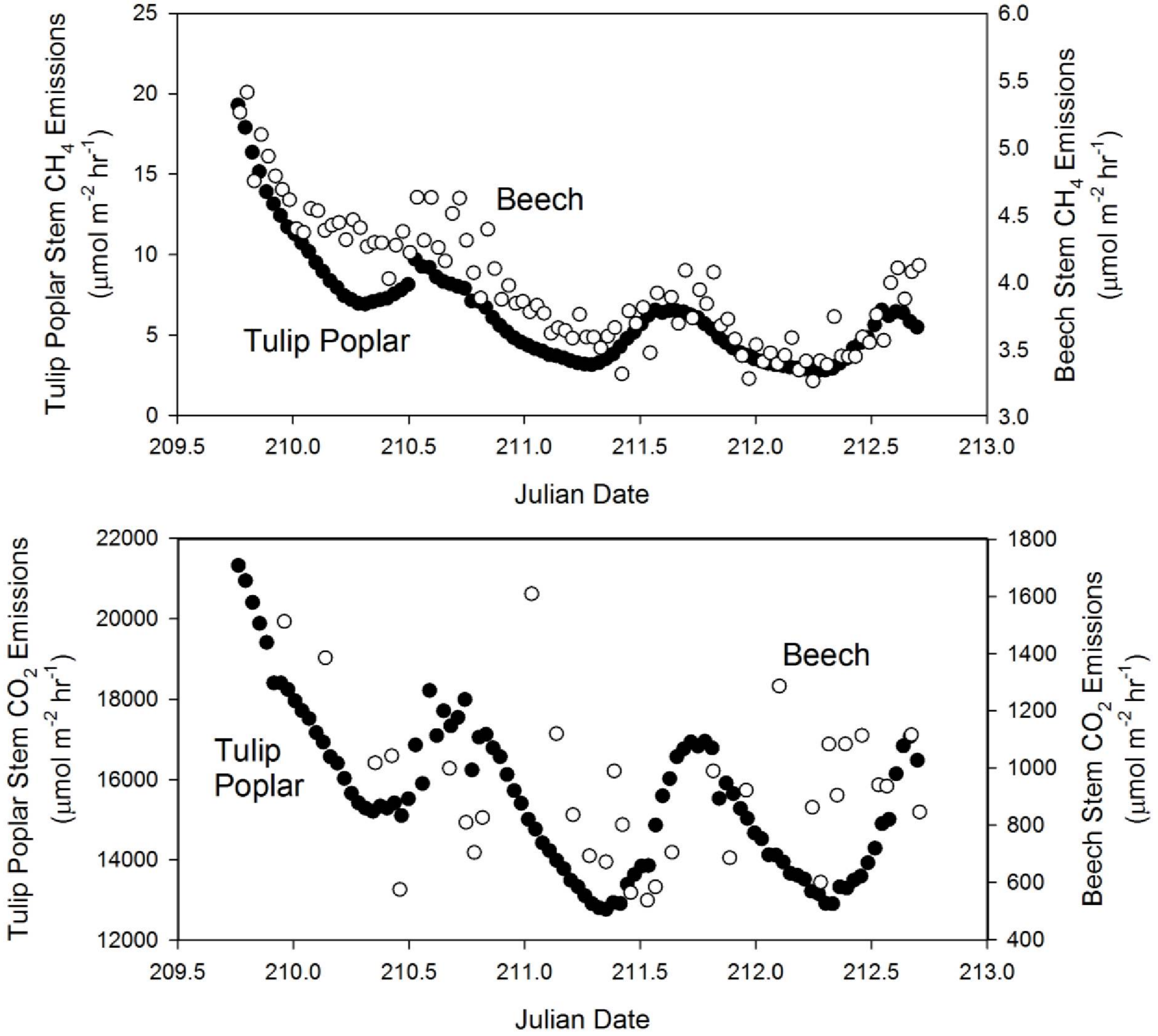
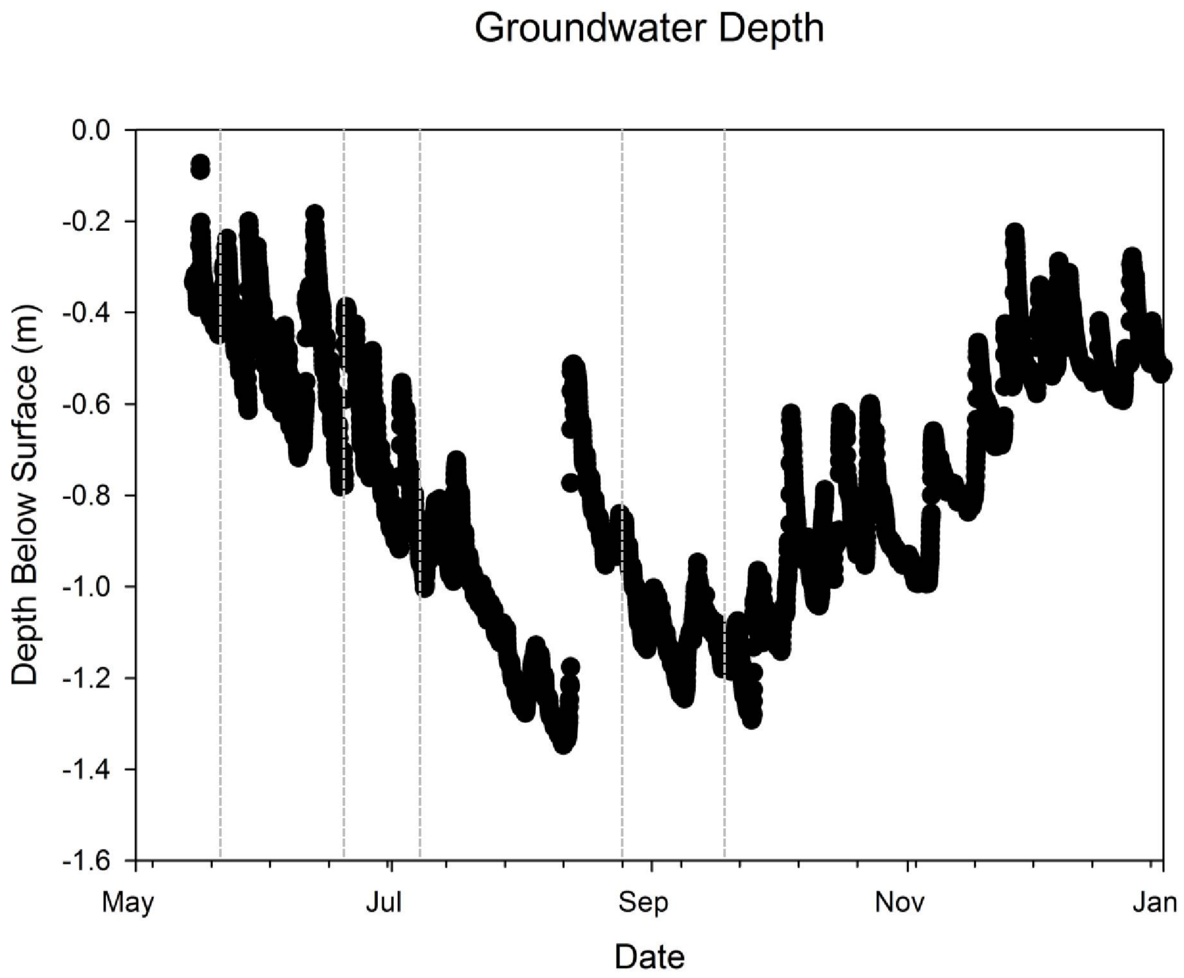


Figure 3: Methane and CO_2 emissions from two upland tree species (*F. grandifolia* and *L. tulipfera*) at 75 cm above the soil surface. Closed circles are L. tulipfera and open circles are F. grandfolia. Note that each species has independently scaled Y axes. Emissions from *L. tulipfera* were also measured at 165 cm and 245 cm (Figure2). All points represent significant fluxes ($R^2 > 0.8$).



Supplemental Figure 1: Graph of data from automated groundwater logger from 2014. The water level is relative to the ground surface at Well 2. Well 2 is at the lowest relative elevation of the plot and closest to the forested wetland boundary. All trees are higher than this well. The dashed lines represent sampling events.

Supplemental Table 1: Species data and relative elevation of trees and groundwater wells in the plot. DBH is in centimeters.

Type	**ID**	**Tree Species**	**DBH (cm)**	**Wetland Type†**	**Elevation Above Well 2 (m)**
Tree	12001	*Fagus grandifolia*	56.1	FACU	5.132
Tree	12002	*Fagus grandifolia*	56.2	FACU	0.419
Tree	12003	*Fagus grandifolia*	53.0	FACU	2.270
Tree	12006	*Fagus grandifolia*	44.9	FACU	0.936
Tree	12008	*Fagus grandifolia*	31.4	FACU	5.113
Tree	12010	*Liriodendron tulipifera*	31.8	FACU	6.009
Tree	12011	*Carya tomentosa*	22.8	NaN	5.360
Tree	12012	*Fagus grandifolia*	55.9	FACU	6.907
Tree	12013	*Quercus velutina*	65.8	NaN	7.445
Tree	12014	*Quercus michauxii*	65.9	FACW	6.887
Tree	12015	*Acer rubrum*	17.0	FAC	6.271
Tree	12016	*Liriodendron tulipifera*	71.1	FACU	6.256
Tree	12017	*Fagus grandifolia*	47.1	FACU	7.658
Tree	12018	*Liquidambar styraciflua*	34.8	FAC	8.123
Tree	12019	*Liquidambar styraciflua*	27.2	FAC	6.000
Tree	12020	*Liquidambar styraciflua*	21.9	FAC	8.962
Tree	12021	*Liriodendron tulipifera*	92.6	FACU	7.473
Well	Well 2				0.000
Well	Well 3				4.749
Well	Well 4				6.928

† Wetland type is from the USDA classification database. Abbreviations are Facultative Upland (FACU, usually occur in non-wetlands), Facultative Wetland (FACW, usually occurs in wetlands), Facultative (FAC, occurs in wetlands and non-wetlands), and NaN means no observations.