Greenhouse gas fluxes from tree stems

Authors

Rodrigo Vargas[1*], Josep Barba[1]

Affiliation

[1]Department of Plant and Soil Sciences, University of Delaware, Newark, DE, 19711, USA

*Corresponding author

email: rvargas@udel.edu

Submitted to

Trends in Plant Science as a "Forum Article"

Abstract

Tree stems exchange carbon dioxide, methane and nitrous oxide with the atmosphere. The biophysical mechanisms controlling these fluxes are not properly understood and consequently not included in process-based models. We highlight advancements and opportunities that will allow to quantify the role of these plant structures for the local-to-global GHG balance.

Keywords

Greenhouse gases, woody plants, tree stems, automated measurements, wetland forests, upland forests

Terrestrial ecosystems play a key role in the global balance of greenhouse gases (GHGs), and with an estimated 3 trillion trees across the world [1], woody plants represent an important biophysical link between soils and the atmosphere. Consequently, unraveling soil-plant-atmosphere interactions is critical to understand the role of terrestrial ecosystems in the biogeochemical cycles of the Earth system. In this forum, we discuss current knowledge on GHG emissions from tree stems and propose general priorities for research.

Most studies from woody plants have focused on biophysical processes in leaves and fine roots, as these are considered to be the most active structures for mass and energy exchange. Arguably, the role of tree stems has mainly been considered for structural support or as conduits for transport of mass (e.g., water and carbohydrates), but their specific role in soil-plant-atmosphere interactions has been less studied or incorporated in process-based models. Recent discoveries are challenging this traditional view as these structures could represent important surfaces for plant-atmosphere interactions [2,3].

Plant respiration is a critical process that releases energy stored in the chemical bonds of carbohydrates produced during photosynthesis. Byproducts of this catabolic reaction include the release of carbon dioxide (CO_2) and water, which could be exchanged with the atmosphere across different plant structures including leaves, roots, or tree stems. Stem respiration (i.e., stem CO_2 efflux) has been studied for over 40 years [4]. Most of the CO_2 within a tree stem is originated from cell respiration within the tree stem or roots, but stem CO_2 efflux rates are dependent on internal CO_2 axial/radial transport and diffusion rates [4]. We postulate that the thermodynamic principles developed for transport and diffusion of CO_2 in tree stems [4] may be applicable to represent fluxes of other GHGs in process-based models [5].

Since the 1970s is known that trees can store CH_4 inside stems at high concentrations [6], but just recently it has been discovered that tree stems can emit CH_4 [2]. Most studies regarding stem CH_4 emissions have been done in forested wetlands or floodplains, where soils are usually net producers of CH_4 [2]. In these ecosystems, it is hypothesized that CH_4 can be transferred from soils to the atmosphere throughout tree stems with important implications for local-to-regional CH_4 budgets [7]. In upland forests, tree stems also emit CH_4, but the mechanisms of CH_4 production, oxidation and transport are a matter of debate [5]. There is evidence that CH_4 can be produced in the soil and transported to stems [8], or produced internally within the stem (by anaerobic bacteria) and emitted radially [9]. In upland forests, the magnitudes of CH_4 efflux from stems could counterbalance the uptake from soils (usually considered net CH_4 sinks), and may influence if a forest acts as a net CH_4 sink or source [9].

The largest knowledge gap exists in our understanding of N_2O fluxes from tree stems. Recent studies report contrasting results demonstrating that N_2O can be emitted or absorbed by tree stem surfaces [10]. It is possible that these fluxes could be associated to cryptogamic covers living on the surface of the bark [11], but is unclear if N_2O production or consumption could be associated in any way with microbial or fungal activity within the tree stem or with any plant biophysical process (e.g., photosynthesis, transpiration).

Automated measurements and functional relationships

Direct measurements of GHG fluxes have been traditionally done using manual measurements. These measurements provide valuable information regarding spatial variability (within a specific stem or across multiple stems), but have limitations to capture temporal variability as they require substantial personnel effort. With developments of cavity enhanced absorption and cavity ringdown spectroscopy coupled with mechanized close-system chambers, now is possible to perform automated and continuous measurements of a wide array of GHGs from stem surfaces [12]. These technological advancements have revealed the possibility of diurnal, synoptic and seasonal patterns of GHG fluxes from tree stems [12] (Figure 1).

For example, stem CO_2 efflux usually has diel, synoptic and seasonal patterns during the growing season (Figure 1A, B). These patterns may be associated with temperature variation, water availability and plant physiology (e.g., phenology, photosynthesis, transpiration). Stem CH_4 fluxes seem to be influenced by synoptic events (e.g., rainfall, potential changes in soil moisture, or heat fluctuations), as diel patterns may be present in a few days but are unlikely the norm (Figure 1C, D). Stem N_2O fluxes reveal the most complex temporal patterns where uptake and efflux can occur within hours of each other. Consequently, there are no diel patterns and synoptic events may drive the temporal variability of N_2O fluxes (Figure 1 E, F). Longer and diverse time series are needed to: a) clearly define the temporal patterns of GHG emissions; b) identify temporal correlations with biophysical factors; and c) identify differences among tree stems within and among species across different environmental conditions.

Functional relationships among stem GHG fluxes could be explored with increasing data availability across the world. As discussed earlier, it may be possible to model stem GHG fluxes using similar physical principles [5], but also functional relationships could be explored by semi-empirical models. It is theoretically feasible to predict stem CO_2 efflux [4], so it may be possible to predict stem CH_4 or N_2O fluxes if there is a relationship with stem CO_2 efflux. Across a growing season there was a strong relationship between stem CO_2 and CH_4 fluxes (Figure 2a), but there were no relationships among other combinations of stem GHG fluxes (Figure 2a, b). The strength and consistency of this relationship needs to be tested, but opens possibilities for identifying shared functional drivers with the ultimate goal of incorporating these plant fluxes into process-based models. Finally, we recognize that multiple tools including laboratory incubations, microbial DNA and RNA analyses, amplicon based and metagenomics approaches, and isotope experiments will be needed to fully understand the mechanisms regulating GHG fluxes from tree stems [5].

Concluding remarks

This emerging field of research will require a trans-disciplinary approach, where plant physiologists, molecular biologists, microbiologists, atmospheric scientists, ecosystem ecologists, and modelers should join efforts. This will open new opportunities to identify biophysical mechanisms and functional relationships to explain the temporal and spatial variability of stem GHG fluxes, and could reconcile bottom-up and top-down estimations of the land-atmosphere GHG balance. We conclude by suggesting four general priorities for research:

(i) Quantifying temporal and spatial patterns of stem GHG fluxes across tree species and ecosystems.

(ii) Identifying sources and biophysical pathways for GHG production, consumption and transport that regulate the net exchange between tree stems and the atmosphere.

(iii) Incorporation of production/consumption rates and passive/active mechanisms for GHG emissions from tree stems into process-based models with prognostic capabilities.

(iv) Quantifying the role of tree stem GHG fluxes for the local-to-global GHG balance under changing climatic conditions.

References

1 Crowther, T.W. *et al.* (2015) Mapping tree density at a global scale. *Nature* 525, 201–205

2 Covey, K.R. and Megonigal, J.P. (2018) Methane Production and Emissions in Trees and Forests. *New Phytol. in press*.

3 Machacova, K. *et al.* (2016) Pinus sylvestris as a missing source of nitrous oxide and methane in boreal forest. *Sci. Rep.* 6, 23410

4 Teskey, R.O. *et al.* (2008) Origin, fate and significance of CO2 in tree stems. *New Phytol.* 177, 17–32

5 Barba, J. *et al.* (2018) Methane emissions from tree stems: a new frontier in the global carbon cycle. *New Phytol. in press.* DOI: 10.1111/nph.15582

6 Zeikus, J.G. and Ward, J.C. (1974) Methane formation in living trees: a microbial origin. *Science* 184, 1181–1183

7 Pangala, S.R. *et al.* (2017) Large emissions from floodplain trees close the Amazon methane budget. *Nature* 552, 230

8 Maier, M. *et al.* (2018) Combining soil and tree-stem flux measurements and soil gas profiles to understand CH 4 pathways in Fagus sylvatica forests. *J. Plant Nutr. Soil Sci.* 181, 31–35

9 Wang, Z.-P. *et al.* (2016) Methane emissions from the trunks of living trees on upland soils. *New Phytol.* 211, 429–439

10 Welch, B. *et al.* (2018) Tree stem bases are sources of CH4 and N2O in a tropical forest on upland soil during the dry to wet season transition. *Glob. Chang. Biol. in press.* DOI: 10.1111/gcb.14498

11 Lenhart, K. *et al.* (2015) Nitrous oxide and methane emissions from cryptogamic covers.

Glob. Chang. Biol. 21, 3889–3900

12 Barba, J. *et al.* Automated measurements of greenhouse gases fluxes from tree stems and soils: magnitudes, patterns and drivers. *Sci. Rep. (under review)*

Figures

Figure 1. Time series and Power Spectra of tree stem greenhouse gas (GHG) fluxes. Stem fluxes of carbon dioxide (CO_2; A), methane (CH_4; C) and nitrous oxide (N_2O; E) during the growing season (April - July 2017) in an upland temperate forest [12]. Continuous measurements of GHGs were performed using a Picarro G2508 (Picarro, Santa Clara, CA, USA) and automated chambers LI-8100 (Licor, Lincoln, NE, USA) as previously described [12]. Normalized power spectra for each GHG time series using the continuous wavelet transform (B, D, F for CO_2, CH_4 and N_2O, respectively). Relevant periodicities for each GHG are marked within each panel. DOY = day of the year.

Figure 2. Relationships between tree stem greenhouse gas (GHG) fluxes. (A) Linear relationship between methane (CH_4) and carbon dioxide (CO_2). There are no significant relationships between nitrous oxide (N_2O) and CO_2 (B) or CH_4 (C). Measurements correspond to daily means of tree stem GHG fluxes during the growing season (April - July 2017) in an upland temperate forest [12].

Figure 1

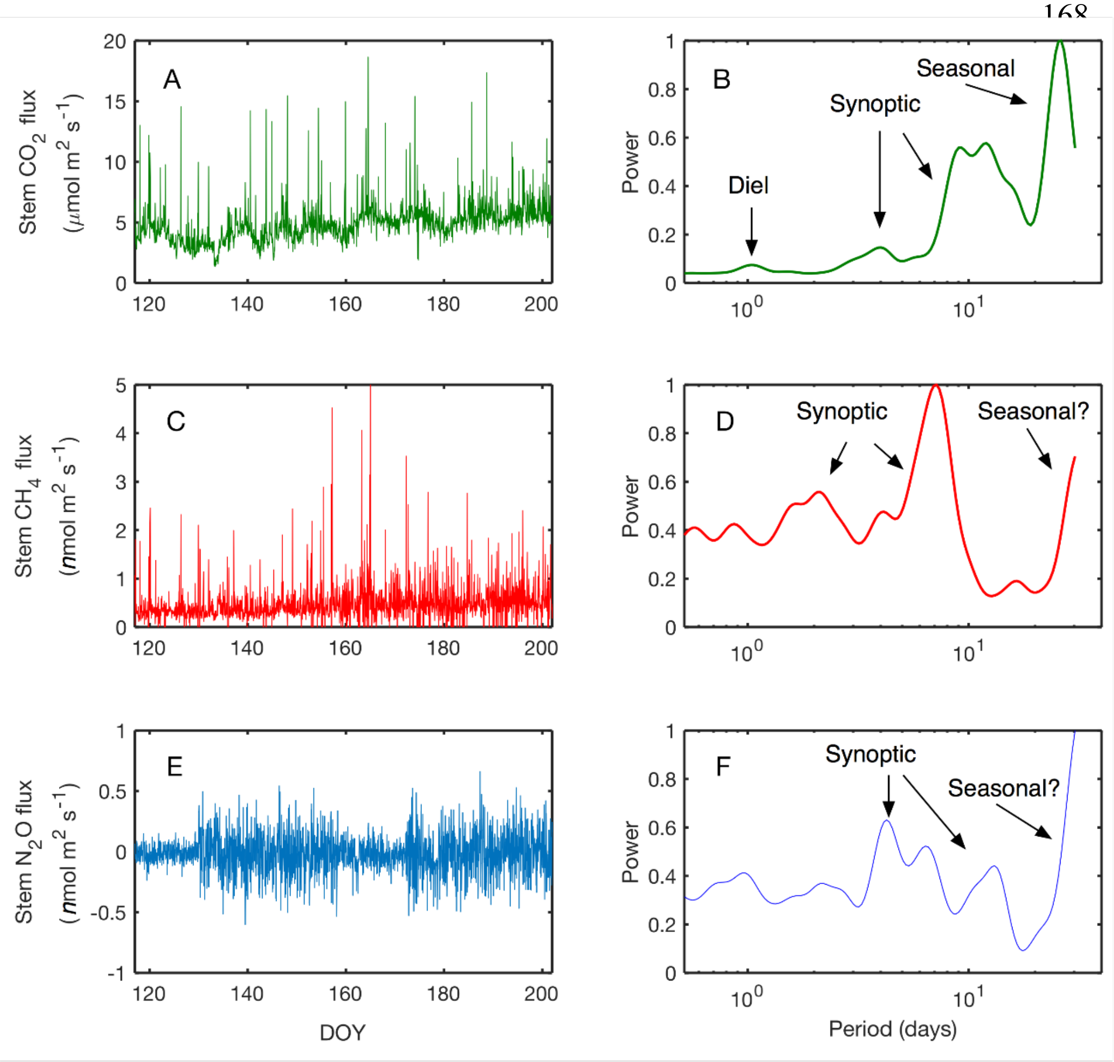
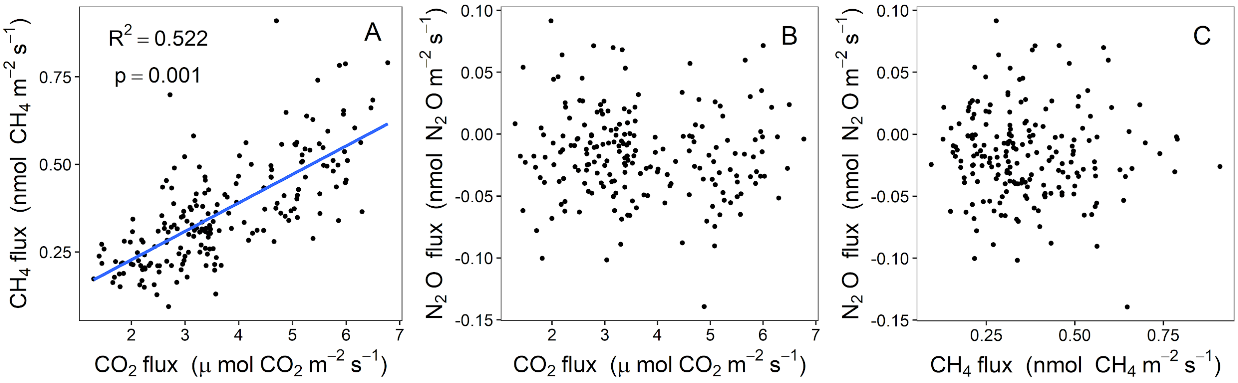

A
Stem CO_2 flux (μmol m^2 s^{-1})
20
15
10
5
0
120
140
160
180
200
B
Power
1
0.8
0.6
0.4
0.2
0
Diel
Synoptic
Seasonal
10^0
10^1
C
Stem CH_4 flux (nmol m^2 s^{-1})
5
4
3
2
1
0
120
140
160
180
200
D
Power
Synoptic
Seasonal?
10^0
10^1
E
Stem N_2O flux (nmol m^2 s^{-1})
1
0.5
0
-0.5
-1
120
140
160
180
200
DOY
F
Power
Synoptic
Seasonal?
10^0
10^1
Period (days)

Figure 2


A
$R^2 = 0.522$
$p = 0.001$
CH_4 flux (nmol CH_4 m^{-2} s^{-1})
0.75
0.50
0.25
2
3
4
5
6
7
CO_2 flux (μ mol CO_2 m^{-2} s^{-1})
B
N_2O flux (nmol N_2O m^{-2} s^{-1})
0.10
0.05
0.00
-0.05
-0.10
-0.15
2
3
4
5
6
7
CO_2 flux (μ mol CO_2 m^{-2} s^{-1})
C
N_2O flux (nmol N_2O m^{-2} s^{-1})
0.10
0.05
0.00
-0.05
-0.10
-0.15
0.25
0.50
0.75
CH_4 flux (nmol CH_4 m^{-2} s^{-1})