Testing vertical influences on greenhouse gas fluxes (CO_2, CH_4 and N_2O) along tropical tree stems

Kabi Raj Khatiwada[1], Ivan A. Janssens[2], Andreas Richter[3], Benjamin Runkle[4], Clément Stahl[5], Laëtitia M. Bréchet[5]

[1]Environmental Dynamics Program, University of Arkansas, Fayetteville, AR 72701, USA

[2]Center of Excellence Global Change Ecology, Department of Biology University of Antwerp, Universiteitsplein 1, B-2610 Wilrijk, Belgium

[3]University of Vienna, Centre for Microbiology and Environmental Systems Science, Djerassiplatz 1, 1030 Wien, Austria

[4]Biological and Agricultural Engineering, University of Arkansas, Fayetteville, AR 72701, USA

[5]INRAE, UMR EcoFoG, CNRS, CIRAD, AgroParisTech, Université des Antilles, Université de Guyane, 97310 Kourou, France

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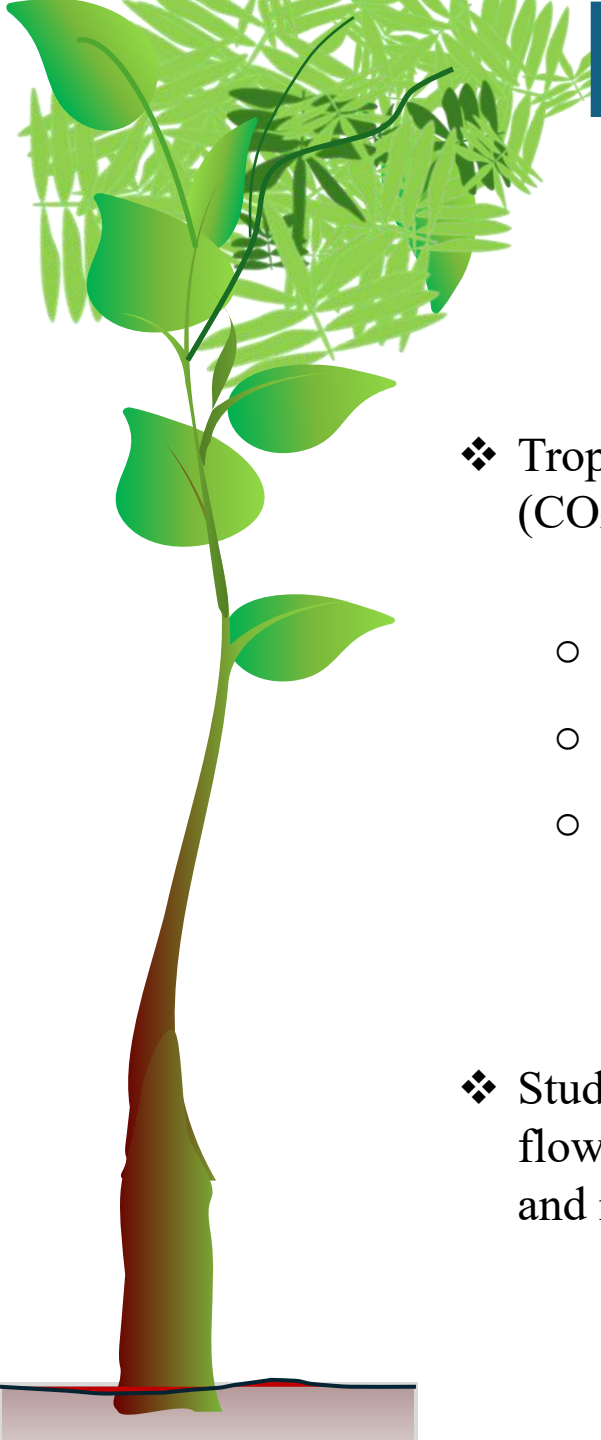




- ❑ Background
- ❑ Methods
- ❑ Results
- ❑ Take home message

Let’s imagine this as a tree from a tropical forest

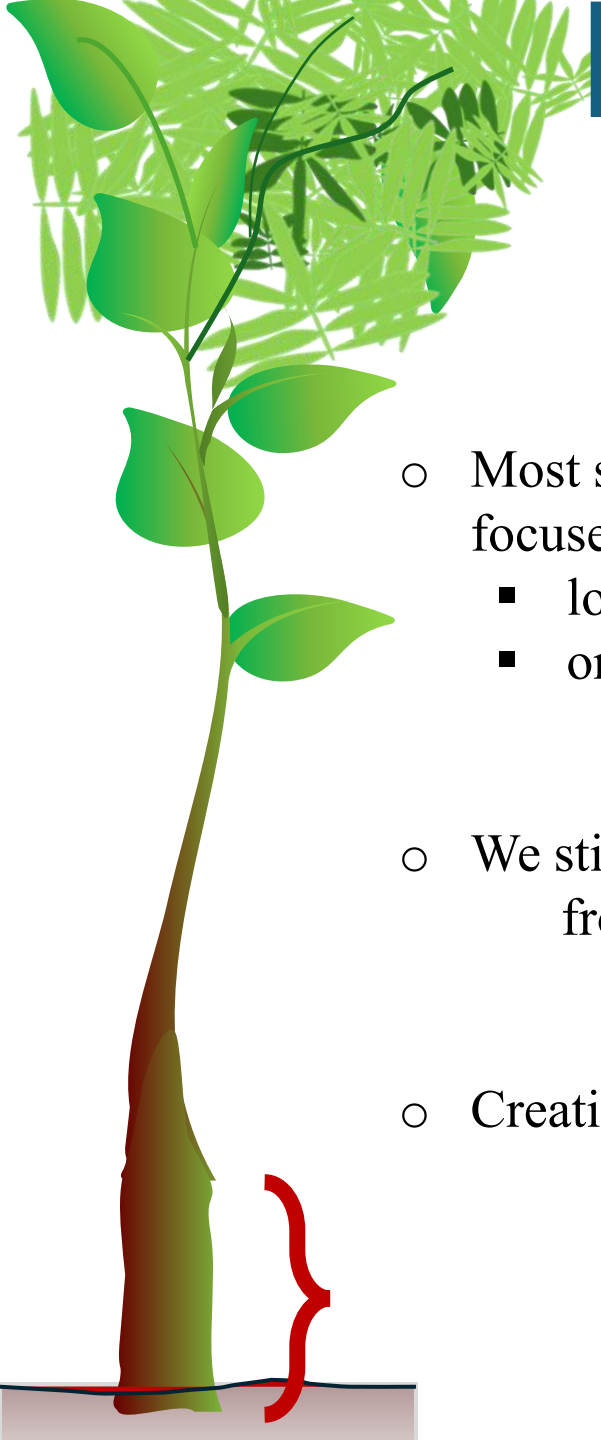
Background



- Tropical forests are now widely recognized as pathways for the flux of GHGs such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) through tree stems (Covey et al., 2012; Pangala et al., 2017).
  - Higher CO_2 fluxes in the upper canopy (Cavaleri et al., 2006) or at the stem base (Kunert, 2018).
  - Stem CH_4 fluxes generally decreased with height along the tree stem (Pangala et al., 2013).
  - Stem N_2O fluxes generally remain low, with no distinct vertical variation in tropical, temperate, or other forest biomes.

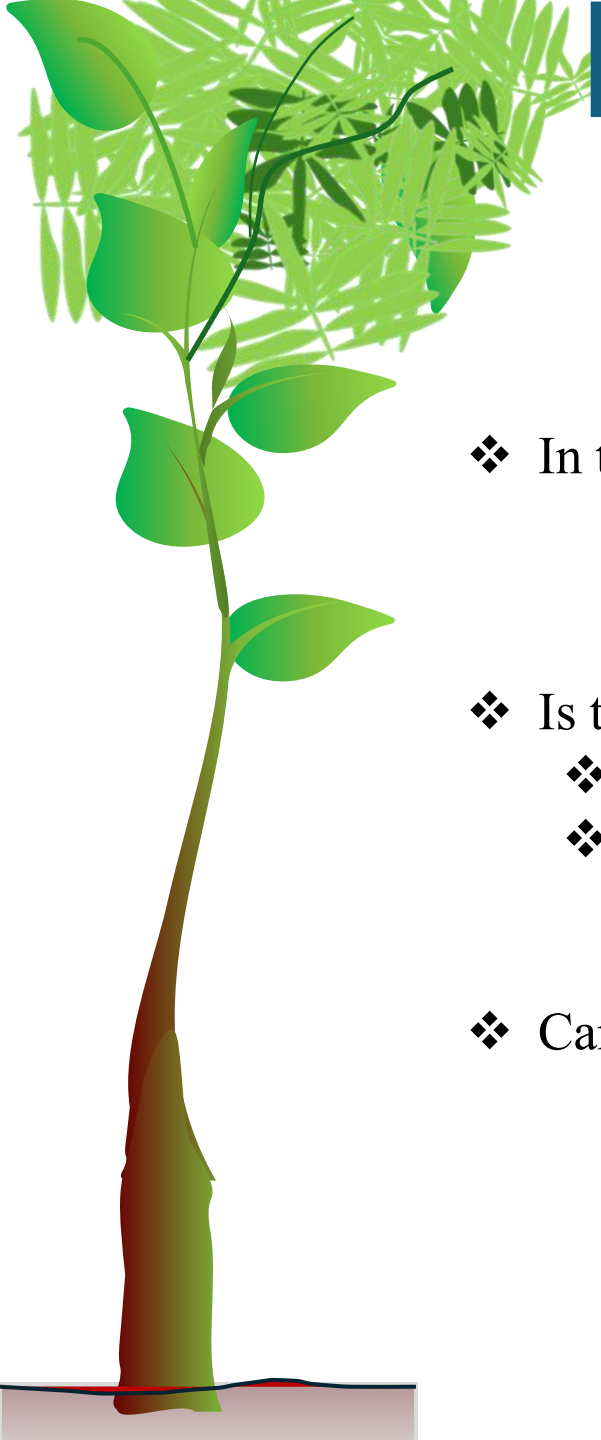
- Studies have shown high temporal variation in stem GHG fluxes that were closely linked with sap flow (Barba et al., 2024), humidity and pH (Moisan et al., 2025), soil moisture (Covey et al., 2012), internal decay and microbial processes (Covey & Megonigal, 2019; Kirschke et al., 2013).

Background



- Most studies on vertical variation in GHG fluxes have focused predominantly on:
  - lower stem sections,
  - only on one of the GHGs.
- We still lack clear picture of how major GHGs change, from the forest floor to the canopy height.
- Creating uncertainties in contributions from trees?

Study	GHG measured	Measurements heights (m)
Epron et al. (2025)	CH_4	up to 12 m above ground
Klaus et al. (2024)	CO_2, CH_4, N_2O	0.35, 0.75, 1.55
Jeffrey et al. (2023)	CH_4	0.3,0.55,0.9, 1.2
van Haren et al. (2021)	CO_2, CH_4	0.07 to 4.91 m
Katayama et al. (2019)	CO_2	1, 22, 32
Barba et al. (2019)	CO_2, CH_4, N_2O	0.75, 1.5
.....		



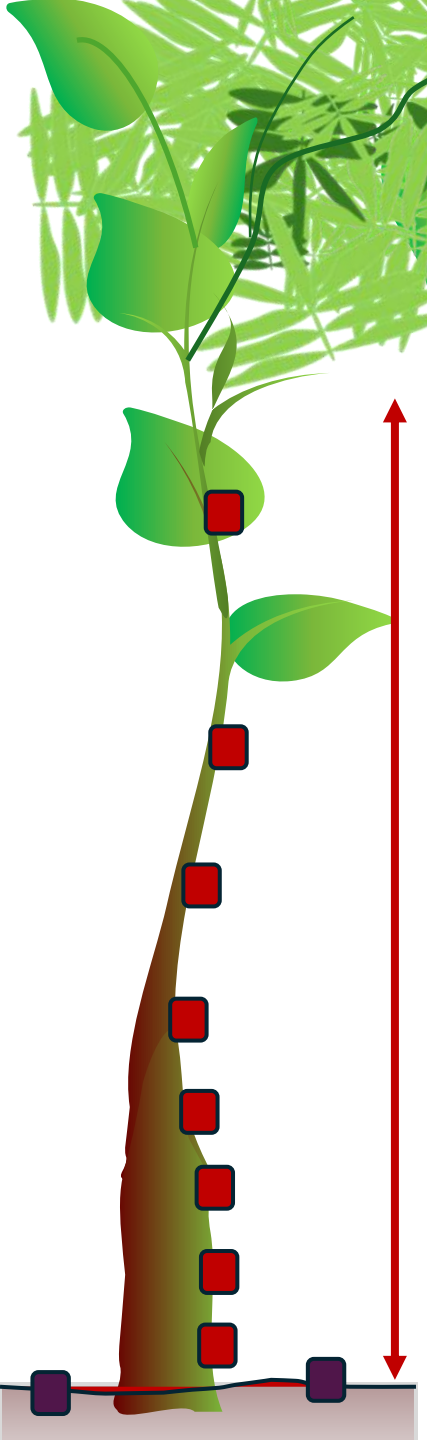
Questions we are trying to answer

- In tropical forests on upland soils,
  how does stem CO_2, CH_4 and N_2O fluxes change with an increase with height?

- Is there a **consistent pattern** of GHG fluxes along the tree height continuum?
  - Emissions decrease from the stem base to the canopy ?
  - A fixed height from where a tree shifts from net source to net sink or vice versa?

- Can we expect **tree traits to explain the variability** in the vertical net GHG fluxes?

Methods





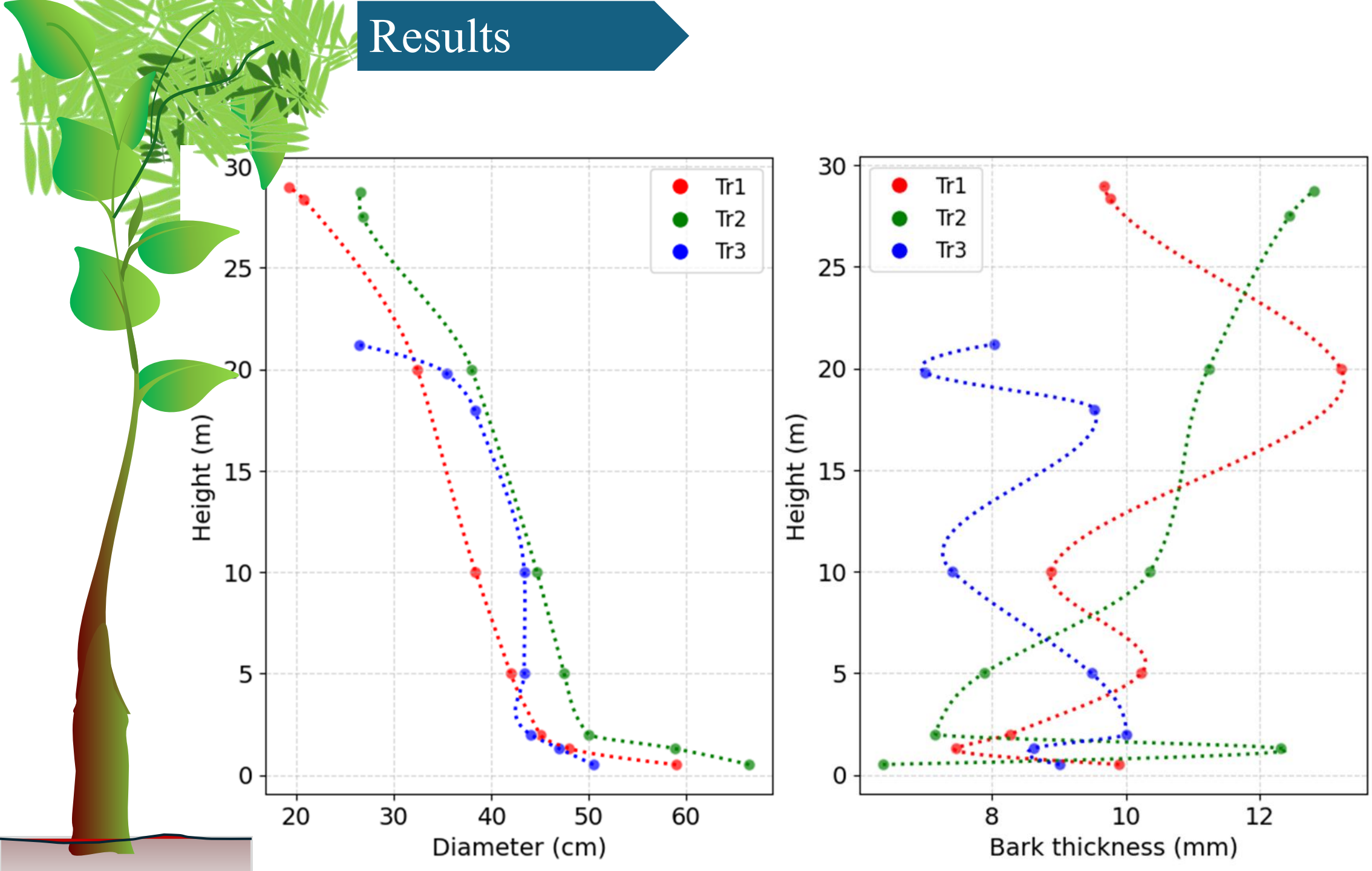
Paracou research station (5°50'N, 52°55'W),
located in the coastal region of **French Guiana, South America.**
(March 2020)

Eight measurements were taken along the tree stems
from the base to the canopy,
at 0.5 m, 1.3 m, 2 m, 5 m, 10 m, 20 m, 28 m, and 29 m
(For one tree canopy height measurements were at 20 m, 21 m).

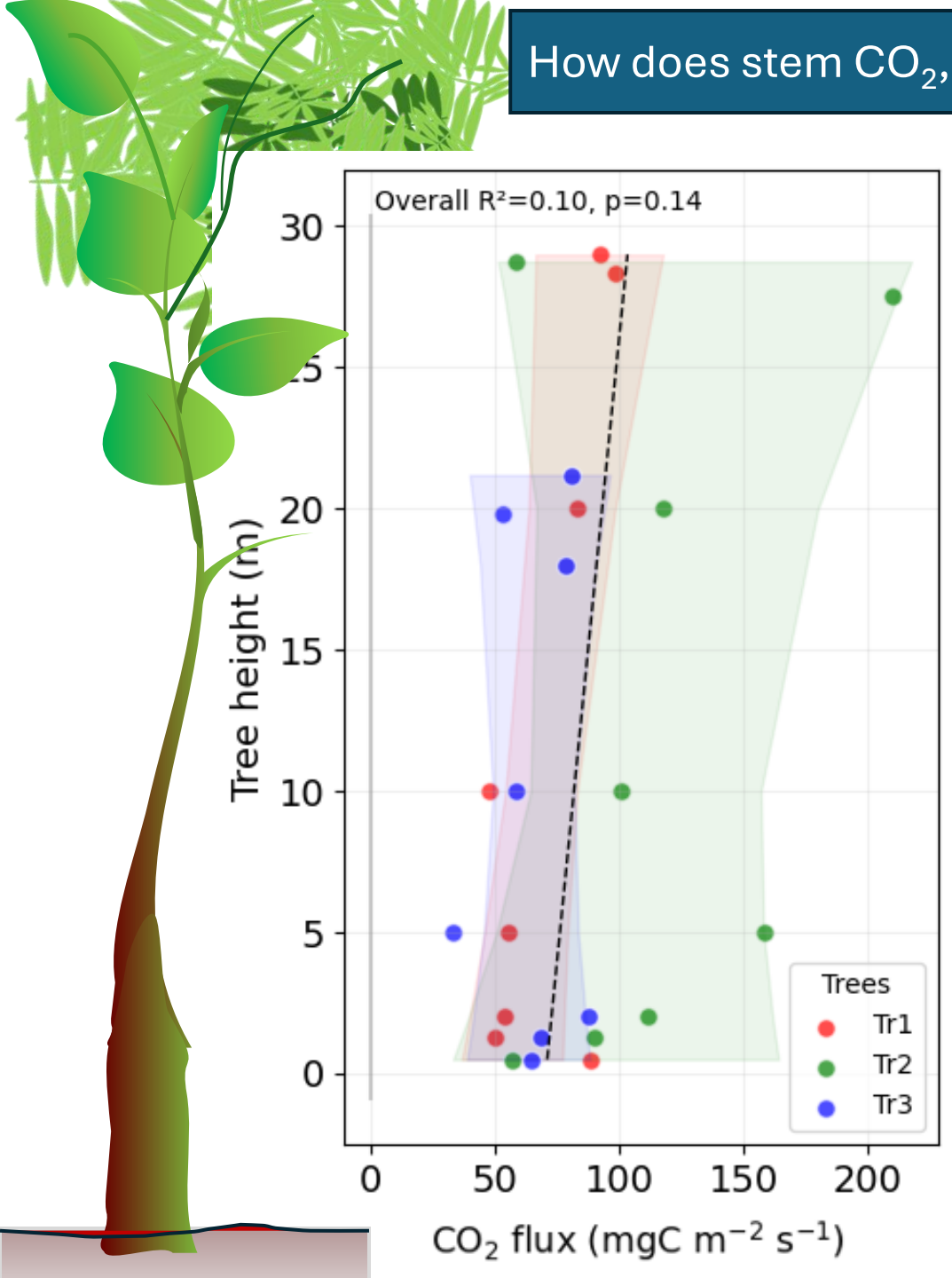
Three trees were measured as individual entities,
trees Tr1 and Tr2 (Fabaceae) and tree Tr3 (Lecythidaceae),
both of which belong to dominant families at the study site.



Results


Tr1
Tr2
Tr3
Height (m)
Diameter (cm)
Bark thickness (mm)
0
5
10
15
20
25
30
20
30
40
50
60
8
10
12

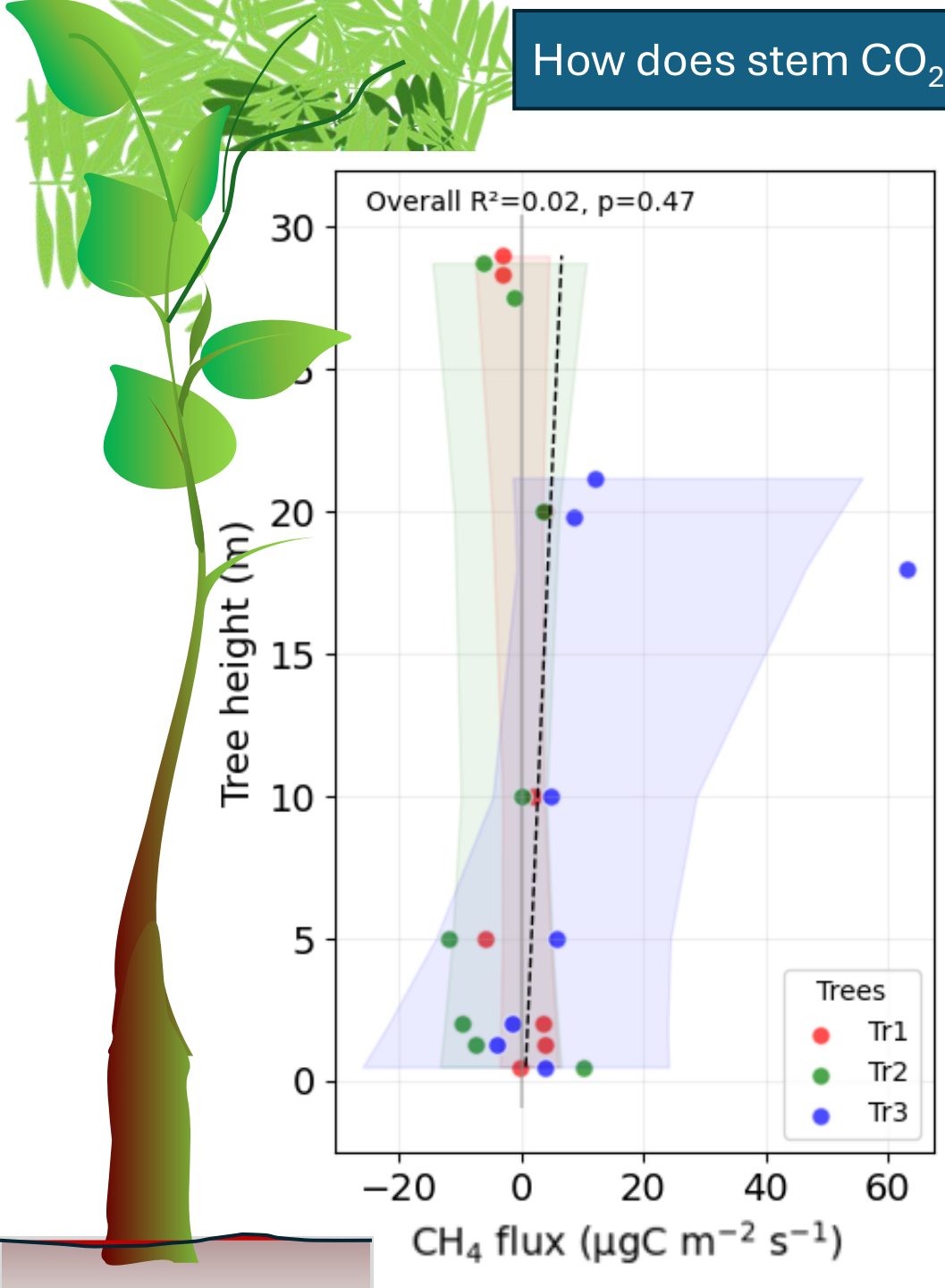
How does stem CO_2, CH_4 and N_2O fluxes change with an increase with height ?



- All three trees had similar CO_2 fluxes (50 -100 mg C m^{-2} s^{-1}) up to ~3 m along the tree stem, and beyond that, each tree **showed distinct patterns** up to a canopy height.

- The mean fluxes of Tr1 and Tr3 were **comparable**, i.e., 90 (± 50) mg C m^{-2} s^{-1}, **however**, the mean of Tr2 was much higher 130 (± 60) mg C m^{-2} s^{-1}.

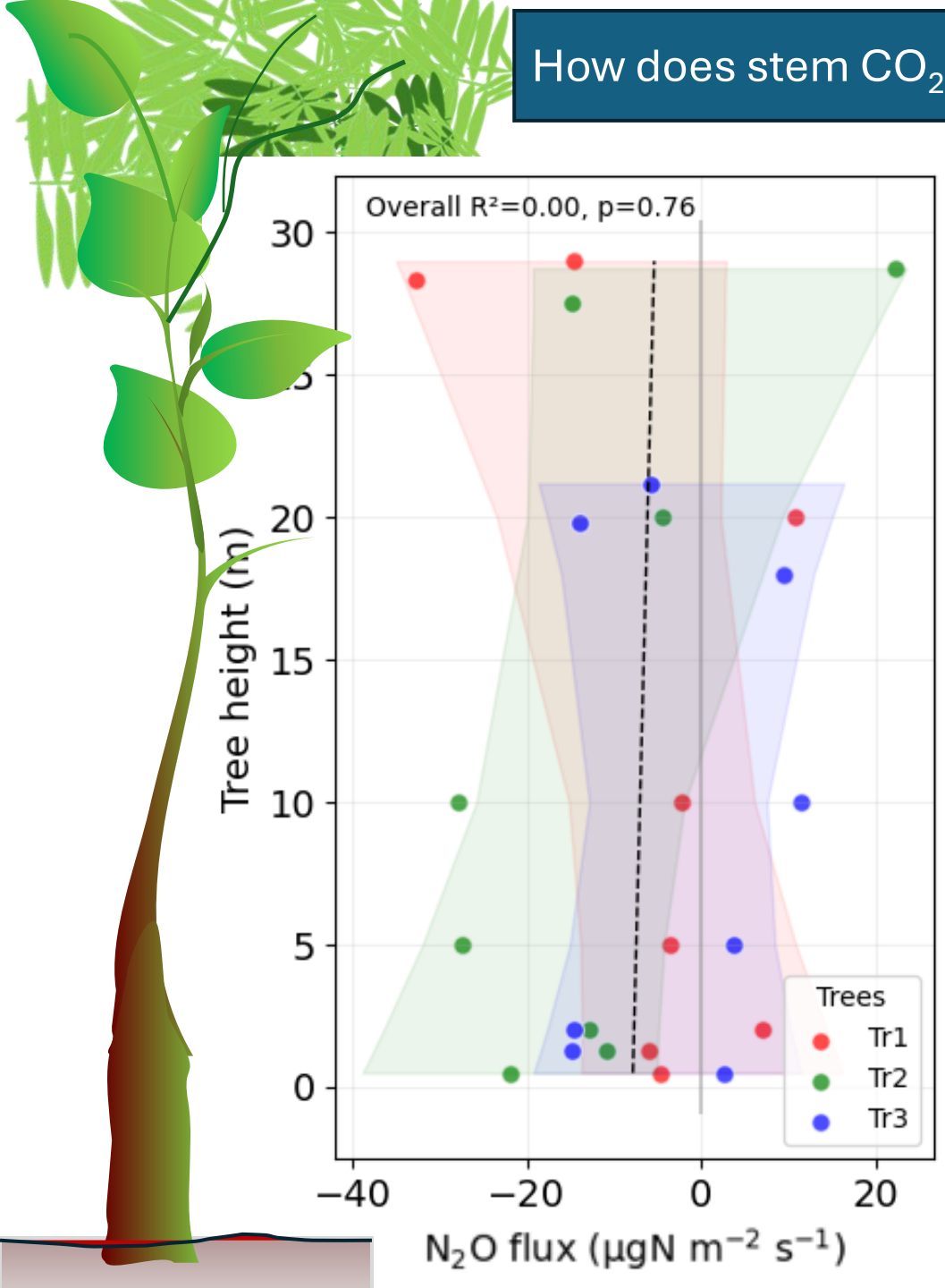
How does stem CO_2, CH_4 and N_2O fluxes change with an increase with height ?



- There were **no clear vertical patterns** of CH_4 flux along the tree stems:
  - At 1.3 m, only Tr1 emitted CH_4, while
  - at the heights of 5 m, only Tr3 emitted.

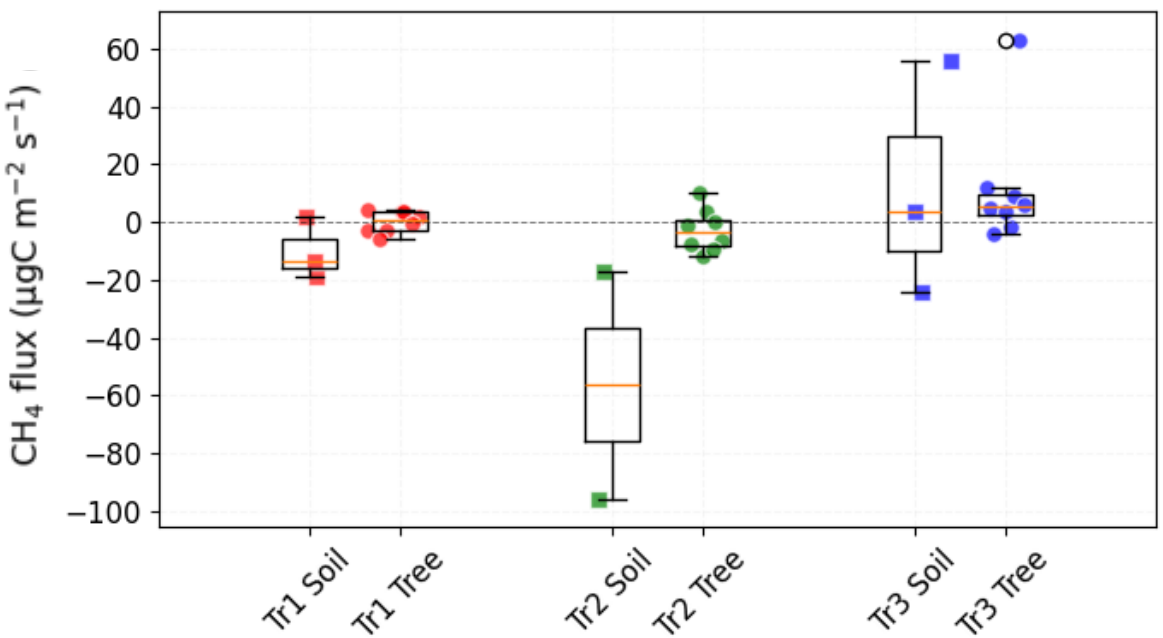
- No clear pivotal point for the change in the flux behavior

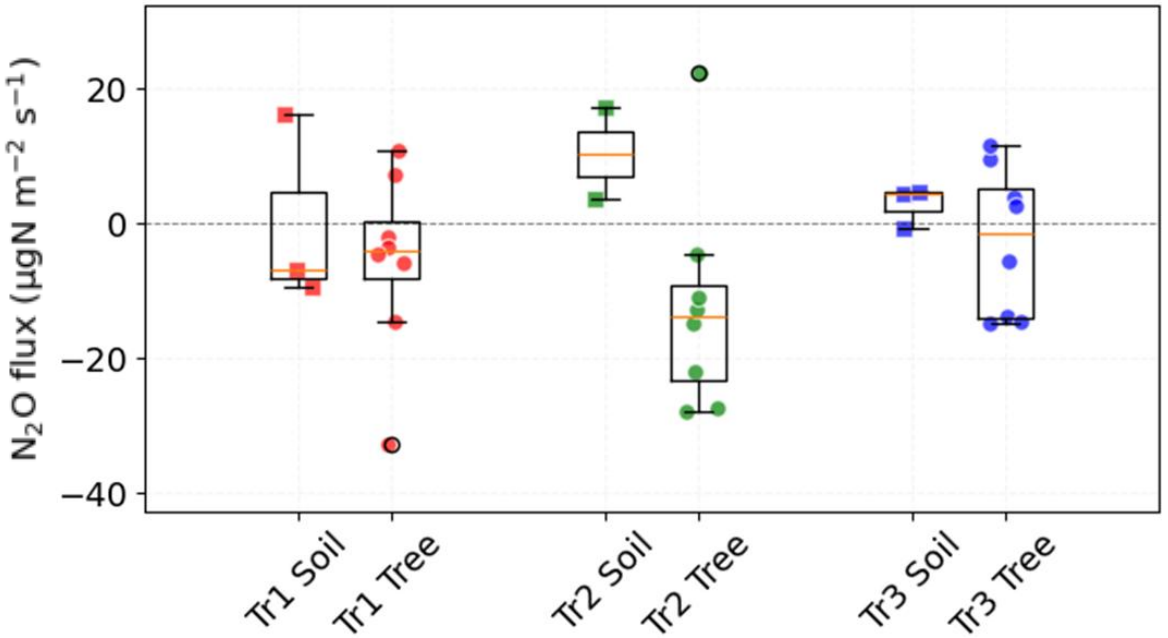
How does stem CO_2, CH_4 and N_2O fluxes change with an increase with height ?



- Stem N_2O fluxes were **either emissions or uptake** depending on the height and the tree.
- It is **difficult to generalize** and mean of fluxes of the trees were near to zero.

Soil as source of forest fluxes ?





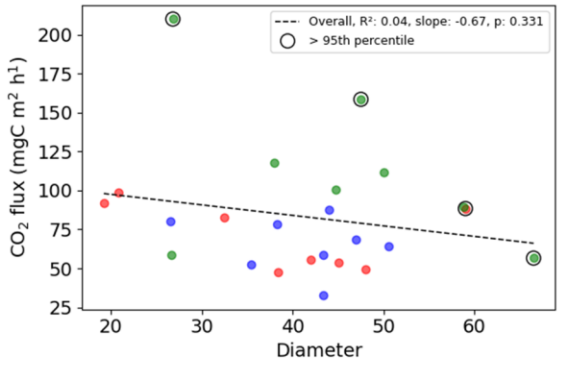
For CH_4 flux:
Forest floor around the trees showed both uptake (~100 µg C m^{-2} s^{-1}) and emission (~60 µg C m^{-2} s^{-1}).

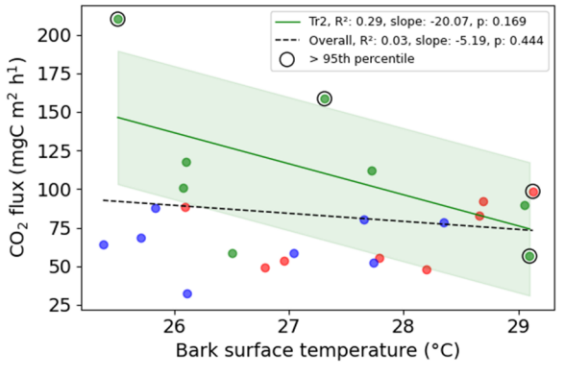
For N_2O flux:
Forest floor showed variability of 10 (± 10) µg N m^{-2} s^{-1} for Tr2, and 3 (± 3) µg N m^{-2} s^{-1} for Tr3.

Stem traits as determinants of stem GHG fluxes ?

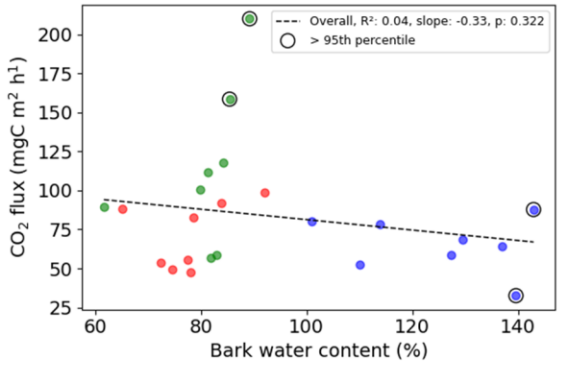
A.

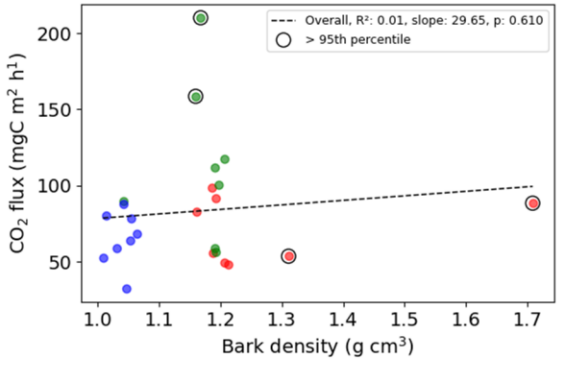
Tree traits (related to surface of tree)



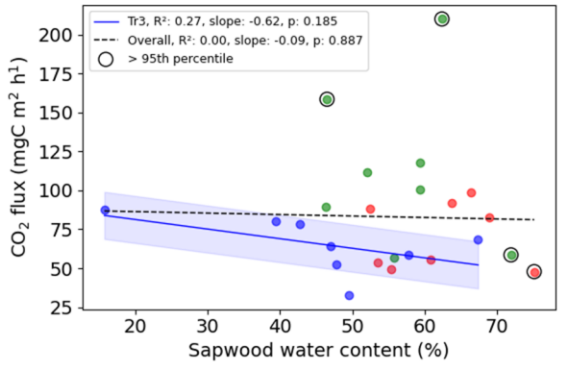


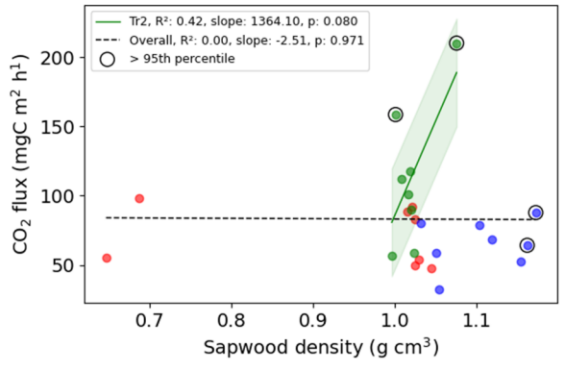
Tree traits (related to bark of tree)





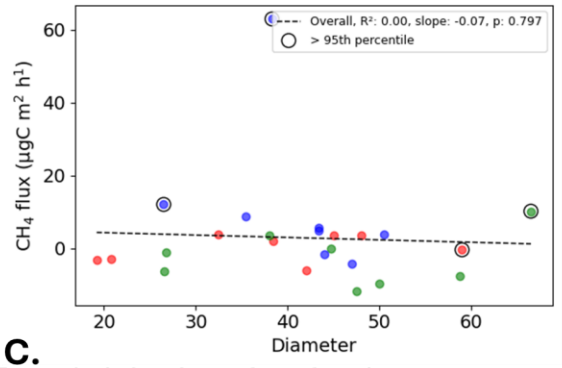
Tree traits (related to sapwood)

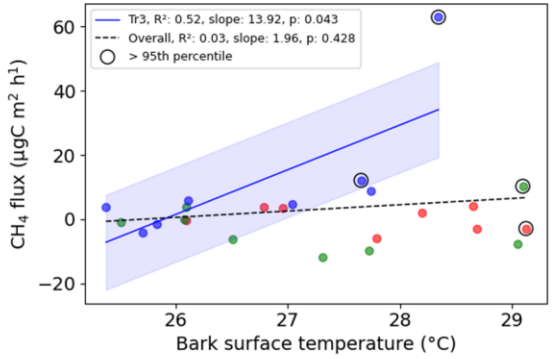


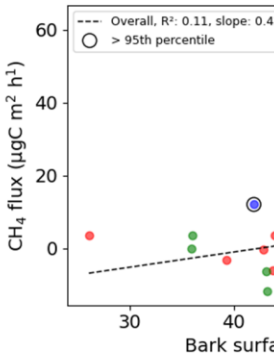


B.

Tree traits (related to surface of tree)

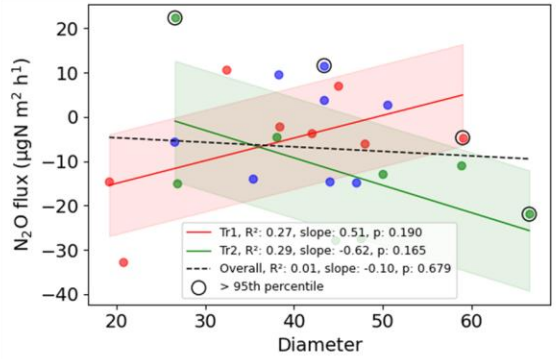


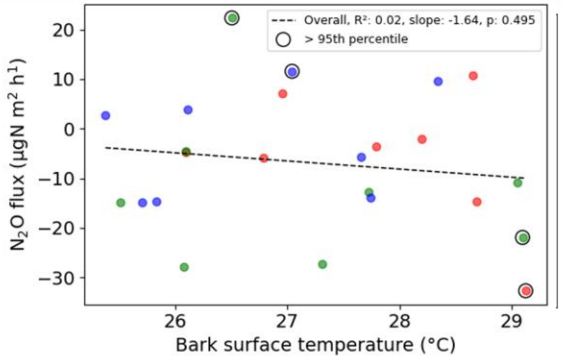


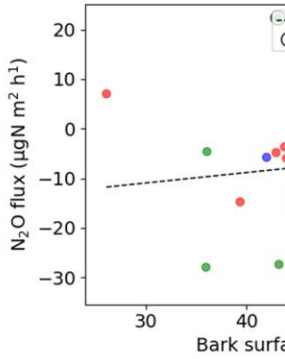


C.

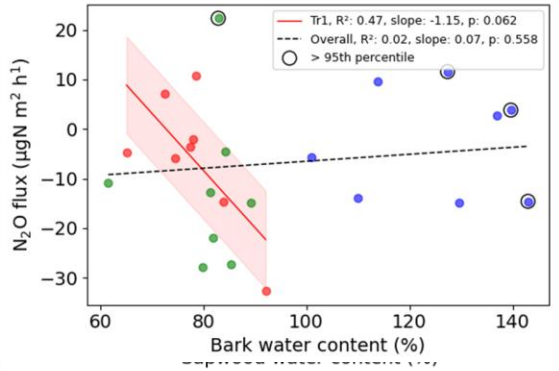
Tree traits (related to surface of tree)

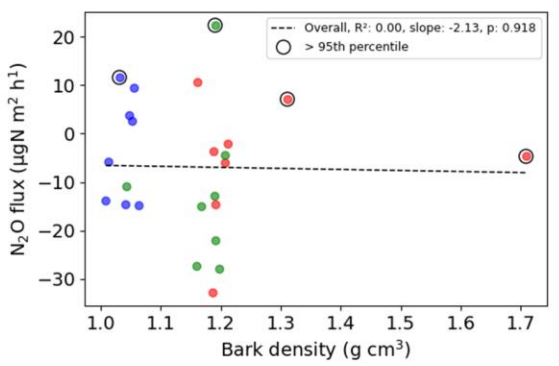


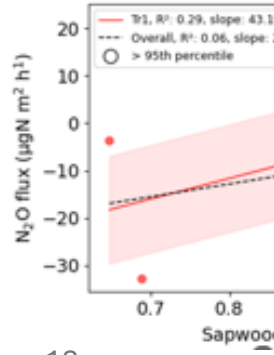




Tree traits (related to bark of tree)

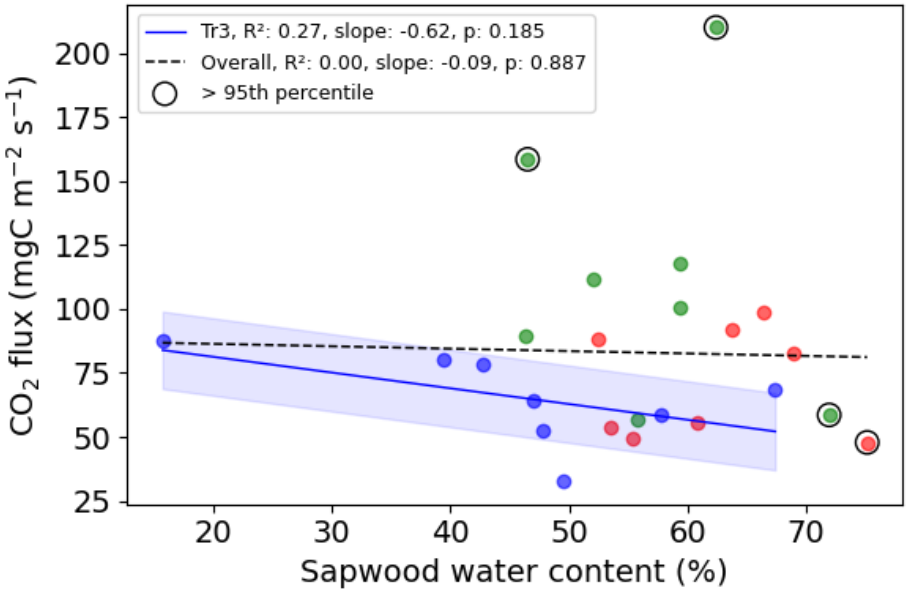


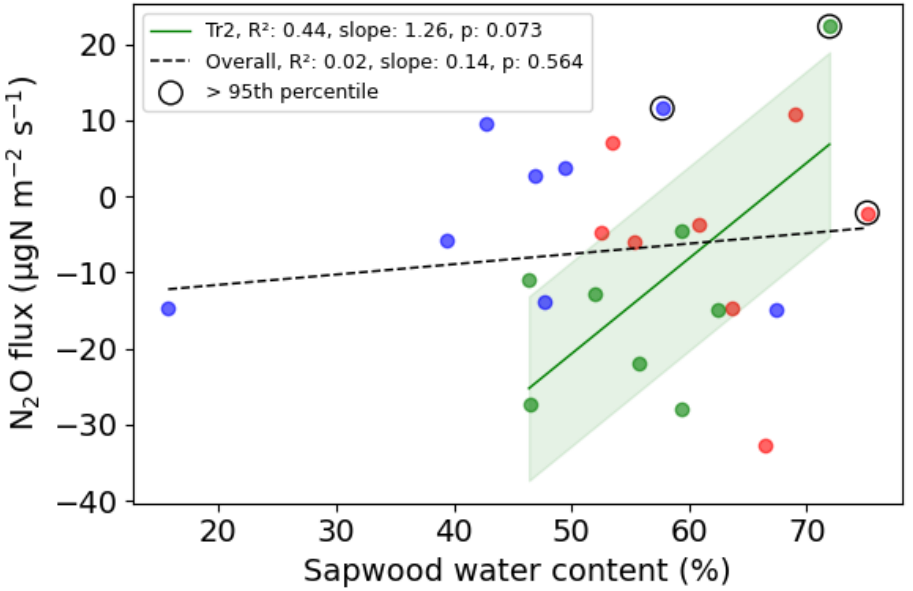




Stem traits as determinants of stem GHG fluxes ?

- Some tree traits seem linear to the fluxes ($R^2 > 0.25$), they failed to reach statistical significance of 5%.





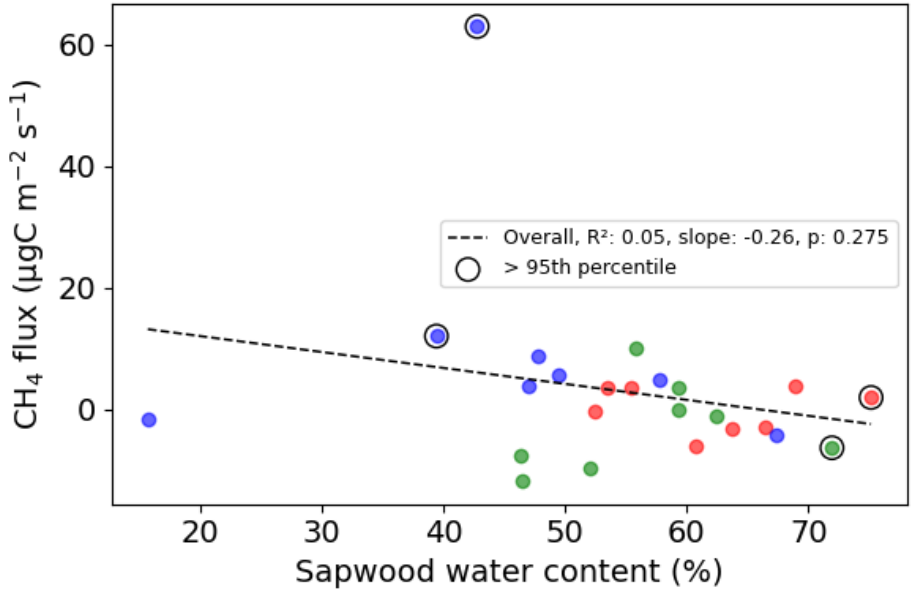


Figure: *Linear relationships between flux and tree traits.*

Each tree is represented by a unique circular color: Tree 1 in red, Tree 2 in green, and Tree 3 in blue.

Data points exceeding the 95th percentile in overall flux or tree traits value are circled in black.

The overall linear fit considering all data (black dashed line) is shown for all the plots, while individual tree regression lines and shading of ±1 residual standard deviation are shown only when R2 > 0.25 or p-value < 0.05.

Multiple linear regression models

Two model selection criteria:

Akaike information criterion (AIC)

$$AIC = 2k - 2ln\,(L)$$

where,

K is the number of parameters,

L is the maximum likelihood estimate.

Adjusted R^2

$$\text{adj_}R^2 = 1 - \left(\frac{(1 - R^2)(n - 1)}{n - p - 1}\right)$$

where,

R^2 is the regular R-squared,

n is the number of observations,

p is the number of predictors in the model.

Why these criteria?

- Penalizes model with more parameters or sample size
- Balance goodness-of-fit, avoid overfitting by discouraging unnecessary complexity

Selected three best models from each selection criteria

Stem traits as determinants of stem GHG fluxes ?

Output flux	Tree traits	AIC	adj_R2	p-value	Both criteria
CO_2 flux (mg C m^{-2} h^{-1})	Bark surface humidity	244.90	0.03	0.21	False
	Bark thickness	244.00	0.06	0.12	False
	Bark surface humidity, Bark thickness	244.83	0.07	0.19	False
	Diameter, Bark surface temperature, Bark water content, Sapwood water content	245.49	0.10	0.20	False
	Diameter, Bark surface temperature, Bark surface humidity, Bark water content, Sapwood water content	246.19	0.10	0.23	False
	Diameter, Bark surface temperature, Bark water content, Bark thickness, Sapwood water content	246.94	0.07	0.28	False
CH_4 flux (µg C m^{-2} h^{-1})	Bark surface humidity	195.46	0.07	0.11	False
	Bark surface temperature, Bark surface humidity	196.06	0.08	0.15	False
	Bark surface temperature, Bark surface humidity, Sapwood density	196.20	0.11	0.16	False
	Bark surface temperature, Bark water content, Sapwood density	196.03	0.12	0.15	True
	Bark surface temperature, Bark water content, Bark density, Sapwood density	197.37	0.09	0.22	False
N_2O flux (µg N m^{-2} h^{-1})	Bark thickness	195.07	0.03	0.22	False
	Sapwood density	195.36	0.01	0.27	False
	Bark surface humidity, Bark thickness	195.68	0.04	0.26	False
	Bark thickness, Sapwood density	195.17	0.06	0.21	True
	Bark thickness, Sapwood density, Sapwood water content	196.39	0.04	0.29	False

Dominant traits: bark surface humidity, sapwood density, bark surface temperature, bark water content……

Take home message

There was **no significant pattern** in CO_2, CH_4 and N_2O fluxes with height for three tropical trees.

If you rely on flux assumptions,

recognize their limits before drawing broad conclusions.

There was **no clear pivotal point** at a given height for the change in the flux behavior.

If someone claims flux shifts from 2 or 3 or *X* m,

accept it with interest but not as general proof.

Multiple tree traits, related to the surface of the tree, bark and sapwood, **co-define** the magnitude of the fluxes.

If total tree flux is extrapolated from base height measurements,

encourage reconsideration of linear flux assumptions.

Thank you ☺









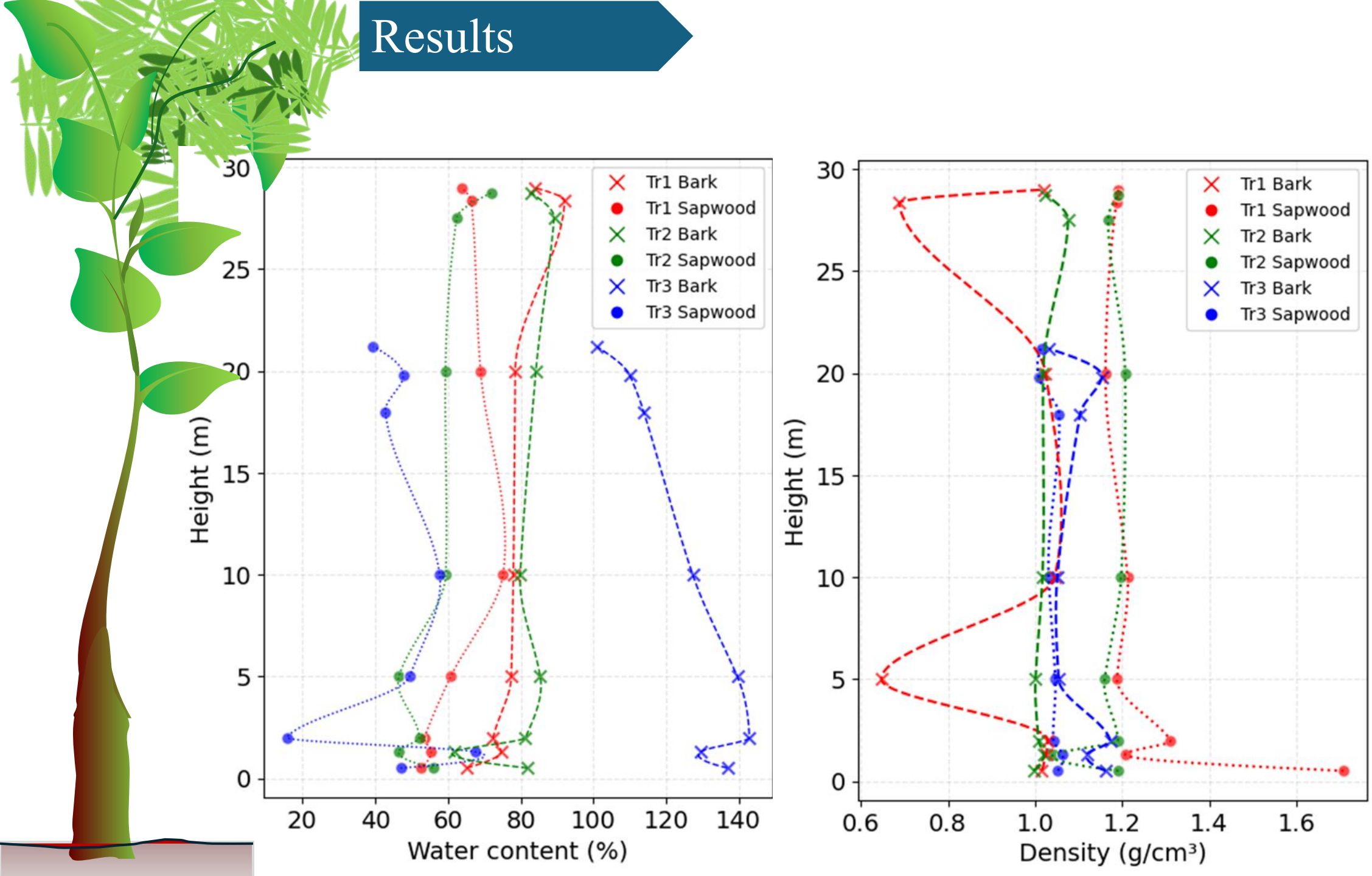


https://meetingorganizer.copernicus.org/EGU26/EGU26-6055.html

Abstract:

- Our knowledge of how greenhouse gas (GHG) fluxes vary from the soil to the tree canopy is limited, particularly in upland tropical rainforests. In this case study, we show changes in the fluxes of the primary GHGs (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)) along the soil - stem continuum, and their relationships with corresponding stem traits at different heights. To do this, we used static chambers to measure the GHG fluxes from three stems, both on the surrounding forest floor and at eight heights ranging from 0.5 m to 30 m, while also assessing tree traits at these heights. We selected representative emergent trees from a tropical forest in French Guiana, South America. We found no clear pattern in the GHG fluxes along the stems, with highly variable CO_2 emissions and alternating CH_4 and N_2O emissions and uptake.
- Regression analysis showed that stem traits related to the tree's surface area, bark, and sapwood partly explain the measured fluxes along the stem height.
- For CO_2 fluxes, the best explanatory variables are identified as bark surface temperature, bark water content, and sapwood density; for CH_4 fluxes, the key drivers are tree diameter, bark water content, and bark surface temperature; and for N_2O fluxes, the more influential variables are sapwood density, and sapwood water content. We concluded that the variability in GHG fluxes along the stems was not only specific to tree traits, but also to individual trees. These findings pose a challenge for scaling efforts - it will not be trivial to create bottom-up estimates of tree-impacted fluxes, and a convergence of approaches will be needed to generate a complete GHG balance for these ecosystems.

Results


Tr1 Bark
Tr1 Sapwood
Tr2 Bark
Tr2 Sapwood
Tr3 Bark
Tr3 Sapwood
Height (m)
Water content (%)
Density (g/cm³)