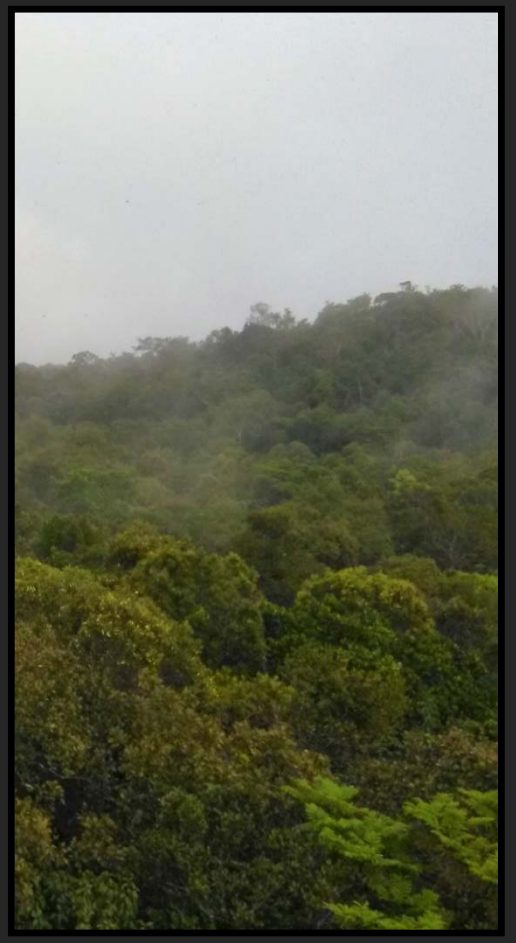
Tropical forest CH_4: from termite mounds to tower measurements

Hella van Asperen[1], Thorsten Warneke[1], Alessandro Carioca de Araújo[2,3], Bruce Rider Forsberg[4], Leonardo Ramos de Oliveira[2], Thiago de Lima Xavier[2], Marta de Oliveira Sá[2], Paulo Ricardo Teixeira[2], Robson Azevedo de Oliveira[2], Veber Sousa de Moura[2], João Rafael Alves-Oliveira[5], Leila do Socorro Monteiro Leal[2], Santiago Botia[6], Jošt Lavrič[6], Shujiro Komiya[6], Arnoud Frumau[7], Arjan Hensen[7], Pim van den Bulk[7], Danielle van Dinther[7], and Justus Notholt[1]

1 University of Bremen, Institute of Environmental Physics (IUP), Remote Sensing, Bremen, Germany
2 Instituto Nacional de Pesquisas da Amazônia (INPA), Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), Manaus, Brazil
3 Brazilian Agricultural Research Corporation (EMBRAPA), Embrapa Amazônia Oriental, Belém, Brazil
4 Instituto Nacional de Pesquisas da Amazônia (INPA), Coordenação de Dinâmica Ambiental (CDAM), Manaus, Brazil
5 Coordenação de Pesquisas em Entomologia (CPEN), Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus, Brazil
6 Max Planck Institute for Biogeochemistry (MPI-BGC), Hans-Knoell-Straße 10, 07745 Jena, Germany
7 Netherlands Organisation for Applied Scientific Research (TNO), Environmental Modelling Sensing and Analysis (EMSA), The Netherlands

Tropical forest CH_4

- Natural sources of methane (CH_4) are still not well understood and quantified.
- The Amazon rainforest is expected to be a significant source of methane, but in situ CH_4 flux measurements are rare.
- By combining different instruments and measurement techniques, we aimed to identify the different CH_4 sources and sinks in the ecosystem, and tried to estimate the overall net CH_4 flux.



Field site

- Fieldsite ZF2 (LBA, INPA) is located 60 km northwest of Manaus (Brazil), in the middle of the Amazon rainforest (Fig. 1). The area consists of plateaus and waterlogged valleys (Araújo et al, 2002).

- The 50m high K34 tower, located on the plateau, is a micrometeorological tower, providing environmental and flux (CO_2 and H_2O) data.

In 2018, 2 additional instruments were added to the K34-tower:

- a FTIR-analyzer (CO_2, CH_4, CO, N_2O and $\delta^{13}CO_2$);
- a Los Gatos ultraportable analyzer (CO_2 and CH_4).

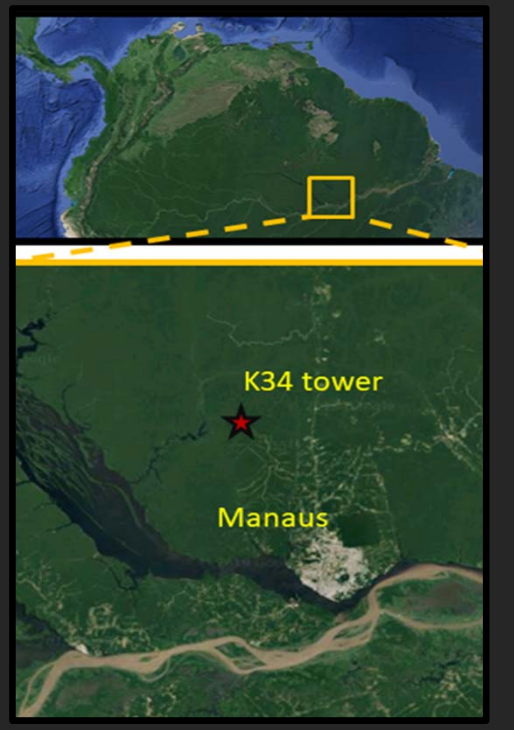


Figure 1 show the location of the K34 tower, 60 km northwest of Manaus

Instruments

- A Spectronus-FTIR analyzer (CO_2, CH_4, CO, N_2O and $\delta^{13}CO_2$)
  - continuously measures concentrations at the K34 tower (on the plateau) at the heights: 5, 15, 36 and/or 51 m (canopy height ~28 m);
  - measures bag samples from soil and termite flux chamber measurements, and bag samples from nighttime valley air.

- A Los Gatos Ultraportable analyzer, measuring CO_2, CH_4 and H_2O:
  - Nighttime valley tower profile measurements (campaign-based);
  - Flux chamber measurements on soil, tree stems, valley stream, and termite mounds;
  - Termite incubations experiments.

- In the following slides, we will show a selection of case studies, performed with a combination of instruments and set ups, each focusing on a different component of the ecosystems CH_4 budget.

Case study 1: Ecosystem CH_4 flux
Can we estimate the net ecosystem CH_4 flux?

Tower profile data can be used to estimate the CH_4 flux, for example by the **nocturnal storage-ratio technique.**

- At night, if the atmosphere is stable, forest respiration leads to a gradual CO_2 accumulation in the forest so that 'dCO_2/dt' is positive.
- If the CH_4 concentrations also show a concentration increase over time, a CH_4 source can be expected. If the sources of CO_2 and CH_4 are spatially similarly distributed, the CH_4 emission can be estimated as follows:

$$PCH_4 = PCO_4 * \frac{dCH_4/dt}{dCO_2/dt}$$ (based on Laubach et al. (2015)).

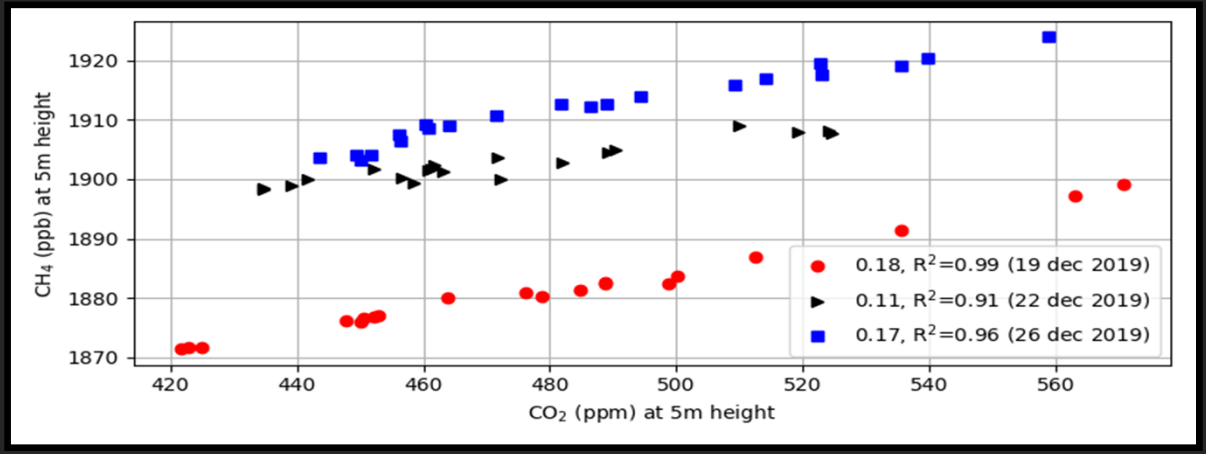


Figure 2: the figure shows the CO_2 and CH_4, concentrations of three example nights at the K34 tower (plateau) in December 2019. For each night, the '$(dCH_4/dt)/(dCO_2/dt)$' was calculated for concentrations at 5 m altitude. The found ratios were 0.18, 0.11, and 0.17 for CH_4, all with an R^2>0.90.

Case study 1: Ecosystem CH_4 flux
Can we estimate the net ecosystem CH_4 flux?

On the plateau, the '*dCH_4 /dt / dCO_2/dt*' was found to range between 0.1 and 0.2.

- By assuming an ecosystem respiration of ~8 µmol m^{-2} s^{-1} (Chambers et al. (2004)), a nighttime plateau CH_4 production of <u>0.8-1.6 nmol m^{-2} s^{-1}</u> can be estimated.

- This value is similar to what was measured by Eddy Covariance measurements at this fieldsite by Querino et al (2011).

- Analyses of this dataset, and of the valley dataset, are still ongoing. In addition, this method will be applied to different heights, and to the different measured gases.

- Furthermore, different nighttime accumulation flux estimation methods will be applied and tested, such as the methods described by Carmo et al. (2006) and by Querino et al. (2011).

Case study 2: Soil CH_4 fluxes

Are soil CH_4 fluxes different along the topography?

- 40 soil collars were installed at 8 topographical locations (Fig. 3b).
- CO_2 and CH_4 fluxes were measured by use of the Los Gatos analyzer, connected to a portable flux chamber (4.7 L, Fig. 3a).

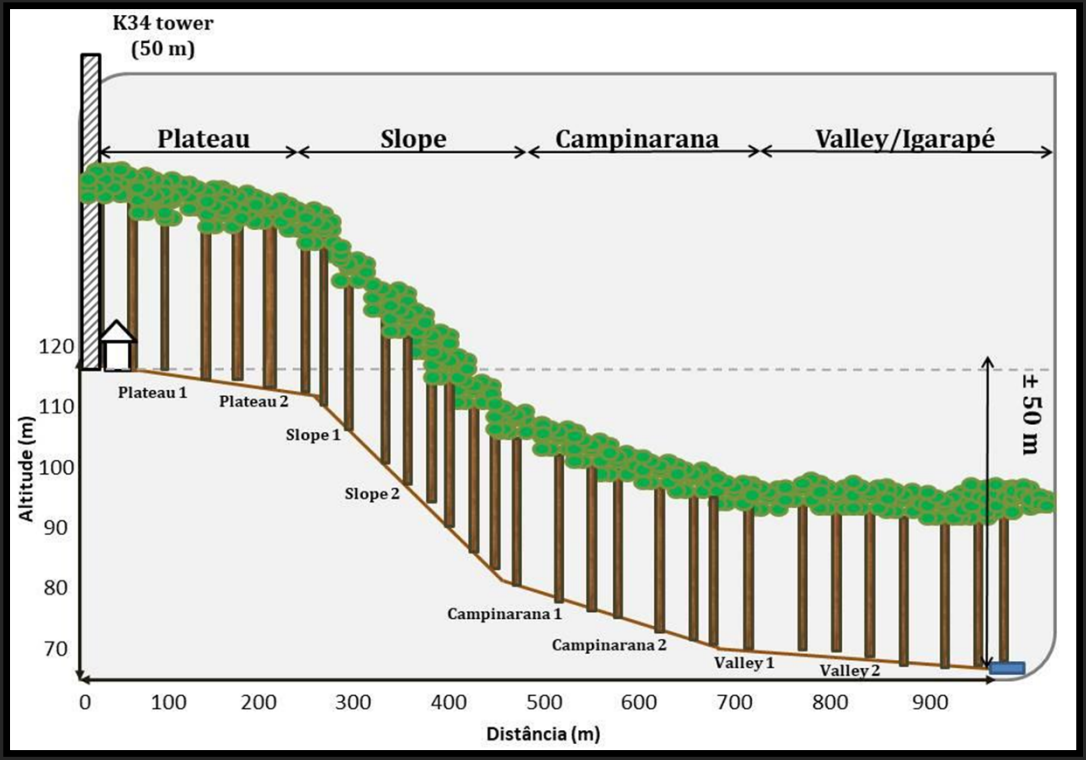


Figure 3a: Picture of the Los Gatos analyzer, measuring the soil flux chamber

Figure 3b: Overview of the topography of the transect, with the 8 soil flux locations indicated.

Case study 2: Soil CH_4 fluxes

Are soil CH_4 fluxes different along the topography?

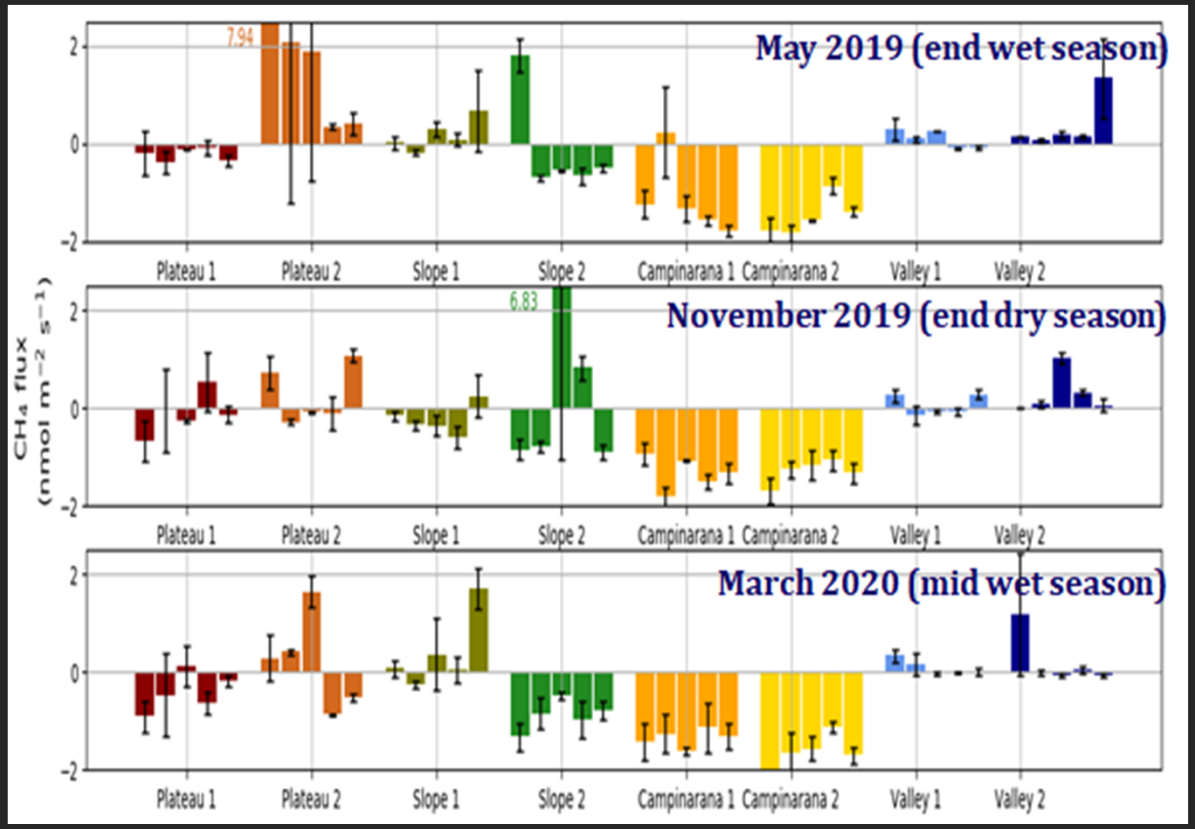


Fig 4: Soil CH_4 fluxes measured in the different seasons: upper figure is wet season (May 2019), middle figure is dry season (November 2019), and lower figure is wet season (March 2020). Every bar stands for the average of the 3 measurements.

The plateau, slope and campinarana (white sand area) locations generally showed CH_4 uptake, although emissions were also detected. This could point at local hotspots, possibly caused by anaerobic conditions, rotting wood, or termite activity. The valleys were a weak but consistent CH_4 source (Fig. 4).

Calculating an simple area-coverage weighted average, gives a CH_4 flux of -0.6 nmol m^{-2} s^{-1} (Luizão et al. 2004, Zanchi et al. 2014).

Case study 3a: Termite mound CH_4 fluxes
What are the CH_4 emissions of termite mounds?

- 5 mound of the species *Neocapritermes brasiliensis* were selected for termite mound measurements
- Emission were measured by placing a large bucket over the mound, and measuring the CH_4 increase in the bucket by use of the Los Gatos analyzer

More details about this part can be found in van Asperen et al. (2021)

Case study 3a: Termite mound CH_4 fluxes

What are the CH_4 emissions of termite mounds?

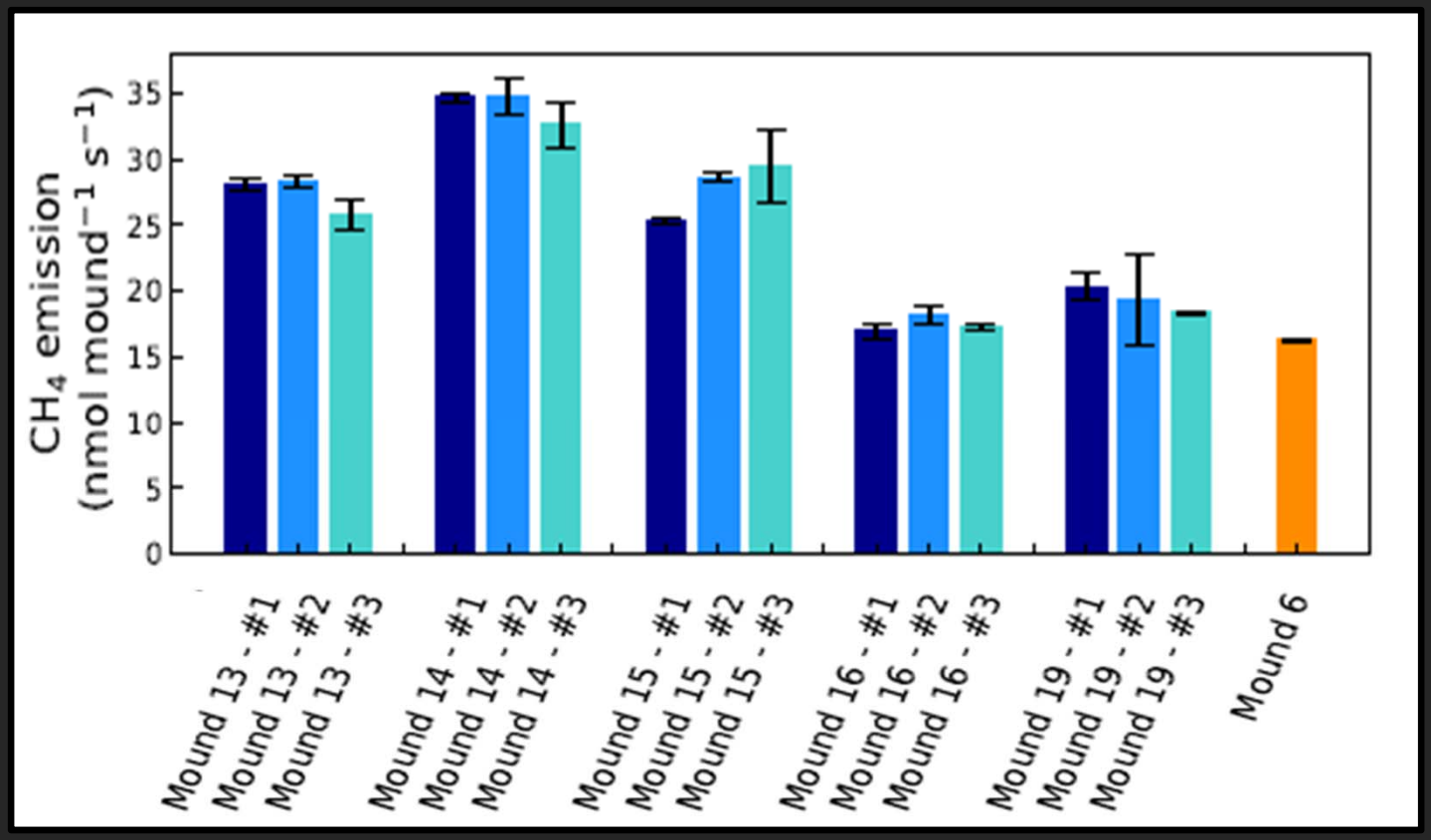


Fig 5: Measured mound CH_4 emissions of 5 mounds of the same termite species, all located in the valley. Mound 6 was a mound of a different species on the plateau.

Termite mounds were found to be hotspots of CH_4, with on average fluxes of **25.2 nmol mound^{-1} s^{-1}** (Fig. 5).

More details about this part can be found in van Asperen et al. (2021)

Case study 3b: Individual termite CH_4 fluxes

What is the CH_4 emission per termite?

Sample piece from termite mound

Measure small pieces in mini chamber

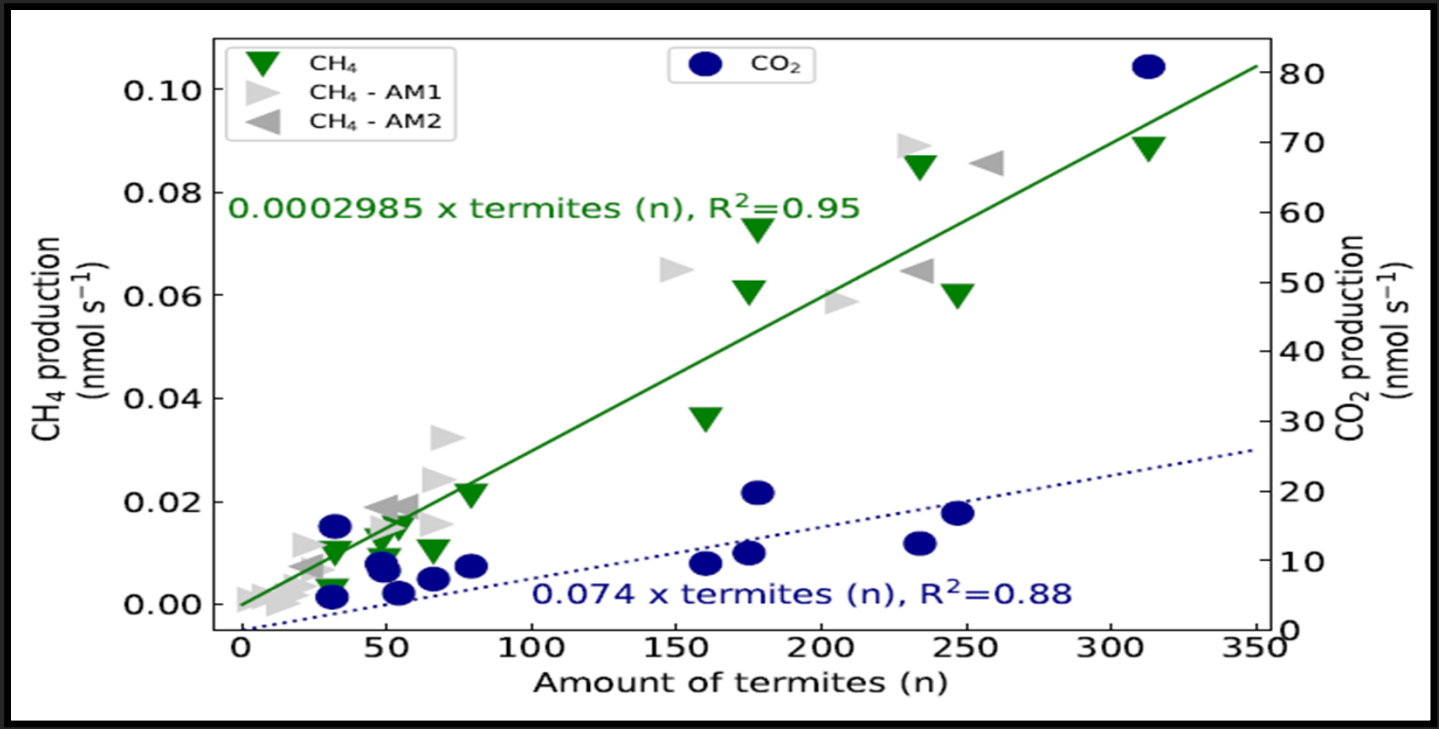
Break open mound material

Count all termites

More details about this part can be found in van Asperen et al. (2021)

Case study 3b: Individual termite CH_4 fluxes

What is the CH_4 emission per termite?



A termite emission factor of 0.0002985 nmol termite^{-1} s^{-1} (0.35 µmol $g_{termite}^{-1}$ h^{-1}) was determined. This is only the second termite emission factor measured for an Amazonian species, and the first one for a soil-feeding termite species. Our value is twice as high as the previously found value for the Amazon by Martius et al. (1993).

More details about this part can be found in van Asperen et al. (2021)

Case study 3c: Termite CH_4 on ecosystem scale

What is the role of termites in the ecosystem?

- Mound density values from **local** studies were used to upscale to ecosystem level.
- This estimate neglects termite activity outside mounds, and is therefore lower-bound.

Average mound emission:
25.2 nmol CH_4 $nest^{-1}$ s^{-1}

Mound density: 60-280 nests ha^{-1}

Ecosystem termite emission:
0.15-0.71 nmol CH_4 m^{-2} s^{-1}

- Estimated termite biomass for tropical rainforests (11 $g_{termite}$ m^{-2}) was combined with our measured termite emission factor.
- This approach is also used by global CH_4 budget studies (Kirschke et al. 2013).

Termite emission factor:
0.0002985 nmol CH_4 $termite^{-1}$ s^{-1}

Termite weight: 3.07 mg $termite^{-1}$

Termite biomass: 11 g m^{-2}

Ecosystem termite emission:
1.1 nmol CH_4 m^{-2} s^{-1}

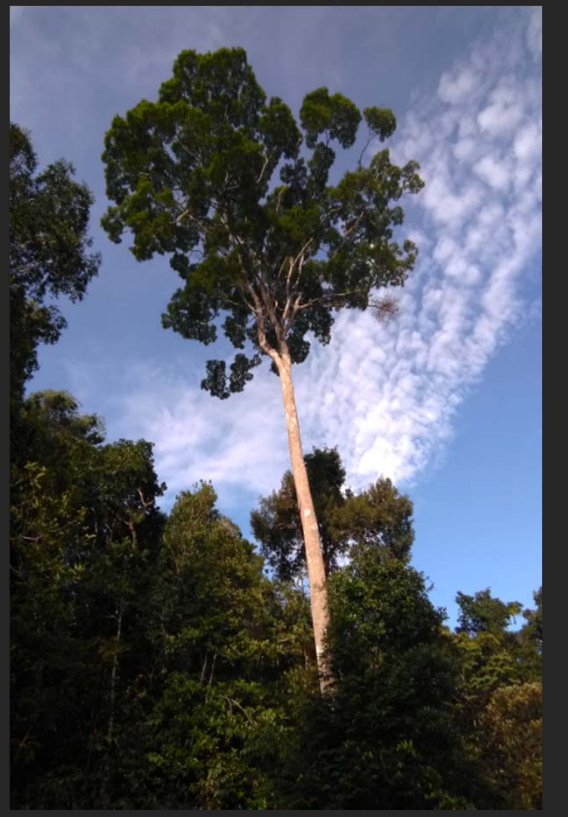
More details about this part can be found in van Asperen et al. (2021)

Preliminary conclusions

By combining different instruments and set ups, multiple components of the ecosystems CH_4 budget could be studied. In this presentation, just a selection of the measurements was shown:

- Case study 1 showed that the overall ecosystem is likely a net source of CH_4 (0.8-1.6 nmol CH_4 m^{-2} s^{-1});
- Case study 2 shows that soil CH_4 fluxes are heterogenous, but generally are showing uptake (-0.6 nmol CH_4 m^{-2} s^{-1});
- Case study 3 shows that termites are estimated to emit ~1 nmol CH_4 m^{-2} s^{-1}) on ecosystem scale.

Overall, it is expected that hotspots, such as termite mounds, dead wood, anaerobic soil spots and valley streams, play a crucial role in the ecosystems CH_4 budget.



Outlook

Additional measurements, which were not shown, but which will be included in this CH_4 budget study:

- Floating chamber measurements on the small stream;
- Tree stem flux measurements on plateau and valley;
- Spatial heterogeneity measurements by continuously measuring concentrations at 8 locations within 10 m^2, once performed on the plateau, and once in the valley;
- Nighttime concentration measurements above the valley stream;
- Determination of additional termite emission factors of different termite species.

For questions or comments, please reach out to me during the EGU session ☺. Or contact me by email:

v_asperen@iup.physik.uni-bremen.de

References

- Araújo AC, Nobre AD, Kruijt B, Elbers JA, Dallarosa R, Stefani P, Von Randow C, Manzi AO, Culf AD, Gash JH, Valentini R. Comparative measurements of carbon dioxide fluxes from two nearby towers in a central Amazonian rainforest: The Manaus LBA site. Journal of Geophysical Research: Atmospheres. 2002 Oct 27;107(D20):LBA-58.
- Carmo JB, Keller M, Dias JD, Camargo PB, Crill P. A source of methane from upland forests in the Brazilian Amazon. Geophysical Research Letters. 2006 Feb;33(4).
- Chambers, J. Q., Tribuzy, E. S., Toledo, L. C., Crispim, B. F., Higuchi, N., Santos, J. D., ... & Trumbore, S. E. (2004). Respiration from a tropical forest ecosystem: partitioning of sources and low carbon use efficiency. *Ecological Applications*, *14*(sp4), 72-88.
- Kirschke S, Bousquet P, Ciais P, Saunois M, Canadell JG, Dlugokencky EJ, Bergamaschi P, Bergmann D, Blake DR, Bruhwiler L, Cameron-Smith P. Three decades of global methane sources and sinks. Nature geoscience. 2013 Oct;6(10):813-23.
- Laubach, J., Barthel, M., Fraser, A., Hunt, J. E., and Griffith, D. W. T.: Combining two complementary micrometeorological methods to measure CH_4 and N_2O fluxes over pasture, Biogeosciences, 13, 1309–1327, https://doi.org/10.5194/bg-13-1309-2016, 2016.
- Luizão RC, Luizão FJ, Paiva RQ, Monteiro TF, Sousa LS, Kruijt B. Variation of carbon and nitrogen cycling processes along a topographic gradient in a central Amazonian forest. Global Change Biology. 2004 May;10(5):592-600.
- Querino CA, Smeets CJ, Vigano I, Holzinger R, Moura V, Gatti LV, Martinewski A, Manzi AO, De Araújo AC, Röckmann T. Methane flux, vertical gradient and mixing ratio measurements in a tropical forest. Atmospheric chemistry and physics. 2011 Aug 5;11(15):7943-53.
- Martius C, Waßmann R, Thein U, Bandeira A, Rennenberg H, Junk W, Seiler W. Methane emission from wood-feeding termites in Amazonia. Chemosphere. 1993 Jan 1;26(1-4):623-32
- van Asperen H, Alves-Oliveira JR, Warneke T, Forsberg B, Carioca de Araujo A, Notholt J. The role of termite CH4 emissions on ecosystem scale: a case study in the Amazon rain forest. Biogeosciences. 2021 (accepted for publication).
- Zanchi FB, Meesters AG, Kruijt B, Kesselmeier J, Luizão FJ, Dolman AJ. Soil CO2 exchange in seven pristine Amazonian rain forest sites in relation to soil temperature. Agricultural and Forest Meteorology. 2014 Jul 15;192:96-107.