Closeout Report for Project DE-SC0008311

Fluxes of CO_2, CH_4, CO, BVOCs, NOx, and O_3 in an Old Growth Amazonian Forest: Ecosystem Processes, Carbon Cycle, Atmospheric Chemistry, and Feedbacks on Climate

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Summary

The goal of the "Fluxes of CO_2, CH_4, CO, BVOCs, NOx, and O_3 in an Old Growth Amazonian Forest" project was to address the following scientific questions:

1. **Carbon cycle, greenhouse gases, ecosystem processes, and interaction with climate:** What are the responses to long term trends in climate, episodic events (droughts, excessive rain), and recovery from prior and contemporary disturbance (i.e. wind throw) in an Amazonian forest? Particular focus was on ecosystem fluxes of CO_2, CH_4, O_3, NOy, and CO. Our study focused on biogenic NO, with attention to the relationships between cycles of soil nutrients (N, P) and detritus (organic carbon), NO emissions, and large-scale ecosystem processes, such as productivity, drought and excessive heat vegetation responses, physical disturbance, and litterfall.

2. **Biogenic VOCs and biogenic NOx:** What are the emission rates for BVOCs and NOx, and what controls them? What is the response to changing environmental conditions such

as precipitation, temperature, radiation, soil moisture, plant community composition, and physical disturbance?

3. **Biomass burning, photochemical ozone, and ecosystem process and carbon flux:** How do gases and aerosols from biomass burning influence the production of photochemical O_3 and the quality of radiation? How do these environmental changes affect CO_2 uptake and BVOC emissions? What are the effects of pollutant stressors such as elevated ozone or NOx on the forest carbon budget and BVOC emissions? How does the response of Amazonian ecosystems to ozone and NOx, influence the forest responses to climate variability and change?

The start-up of the project was delayed by damage to the instrumentation due to lightning in December 2012 and September 2013. Measurements the Tapajos National forest k67 site have been carried out since the early 2000s, with two major interruptions: the first one in 2006 due to a fallen tree that destroyed the tower and damaged instruments (data acquisition was resumed in 2008), and a second interruption due to the aforementioned lightning strike and damage to both the instrumentation and the electrical system (diesel generator and underground power lines). The ecological and soil measurements were not interrupted, but the system for atmospheric measurements on the tower was severely impaired. However, in conjunction with the support of the Brazilian LBA office at the Brazilian National Institute for Research in Amazonia (INPA), the electrical system was replaced (new generator and new power cables and transformer), and we were also able to reinstall repaired instrumentation, which was put into service in August 2014 – much later than we has anticipated. We obtained contract extensions from DoE and we were able to substantially address key goals of the project. We have compelling results of the research, notwithstanding the delays that often attend field research in this hostile environment.

In parallel with the necessary repair and deployment of previous and new instrumentation in the research site, we completed a full reanalysis of past data (2001-present) from the tower. This assessment provided strong evidence of stress and forest damage which may be due to recent droughts and very wet periods. The reanalyzed dataset was made publicly available in January 2016 in the Oak Ridge National Laboratory, Distributed Active Archive Center for Biogeochemical Dynamics (ORNL/DAAC) repository:

https://mercury.ornl.gov/ornldaac/#fq=datasource%3A%22ORNL%20Distributed%20Active%20Archive%20Center%22&fq=km67&q=*%3A*

The most recent dataset (2015) is in its final phase of analysis, with some preliminary results presented in the AGU Fall Meeting in December 2016 (a pdf file with the poster is attached to the documents). These results are summarized below. In addition, the PhD thesis of M. Hayek (2017) was defended in March, 2017, and two papers are submitted for publication.

CO_2 and H_2O fluxes and concentration measurements:

Across the Amazon basin eddy covariance sites, the seasonal H_2O flux (energy used for evapotranspiration expressed as latent heat, LE) has been shown to be driven mainly by net radiation (e.g. R^2=0.60, $p<0.01$ linear regression), indicating environmental rather than biological controls over water fluxes. However during the 2015 and 2016 period, we observed low LE values and higher evaporative fraction (LE+H/LE, where H is sensible heat flux) than previously recorded at the site (Fig 1.). Similarly, canopy conductance was lower indicating a significant vegetation control (stomatal

conductance). We suspect that the ecosystem is responding to long term stresses by drought, which we are currently testing via modelling.

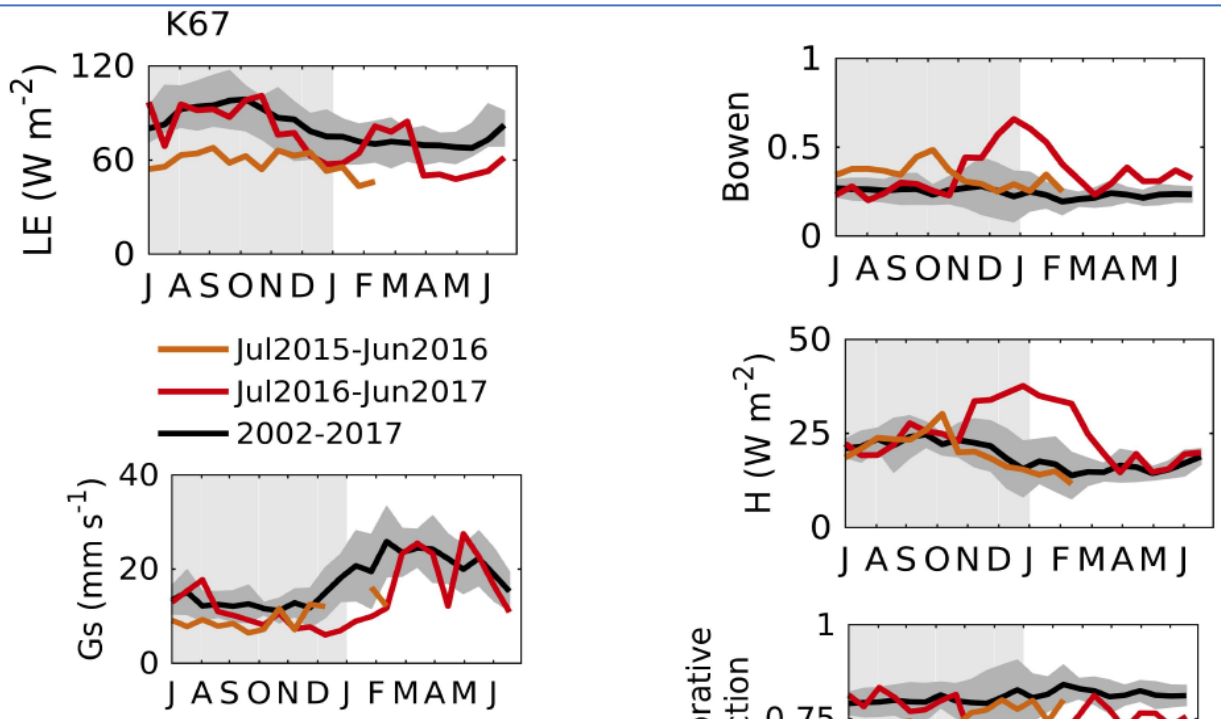

Figure 1. Seasonal cycle (16-day average) for K67 mean (black line) and standard deviation (shaded grey area) of all available EC measurements (2002-2005,2008-2012 and 2015-2017), and hydrological years 2016 (July 2015 – June 2016) (red line) and 2017 (July 2016 – June 2017) (orange line). Latent heat (LE), canopy conductance (Gs), sensible heat (H), evaporative fraction (EF) calculated as the ratio of latent over the sum of latent and sensible heat and Bowen ratio calculated as H/LE.

Methane measurements:

CH_4 measurements were obtained with a RMT200 unit (Los Gatos®), deployed in collaboration with Dr. Humberto da Rocha, from the Institute of Astronomy, Geophysics and Atmospheric Sciences of the University of Sao Paulo (IAG-USP, Brazil), which collected data through 2015.

The forest at this site was a methane sink throughout the year, a surprising result that helps to reinterpret observations of CH_4 during GO-Amazon. Methane fluxes showed no statistical difference between 2015 wet and dry seasons. The vertical profiles suggest that if a

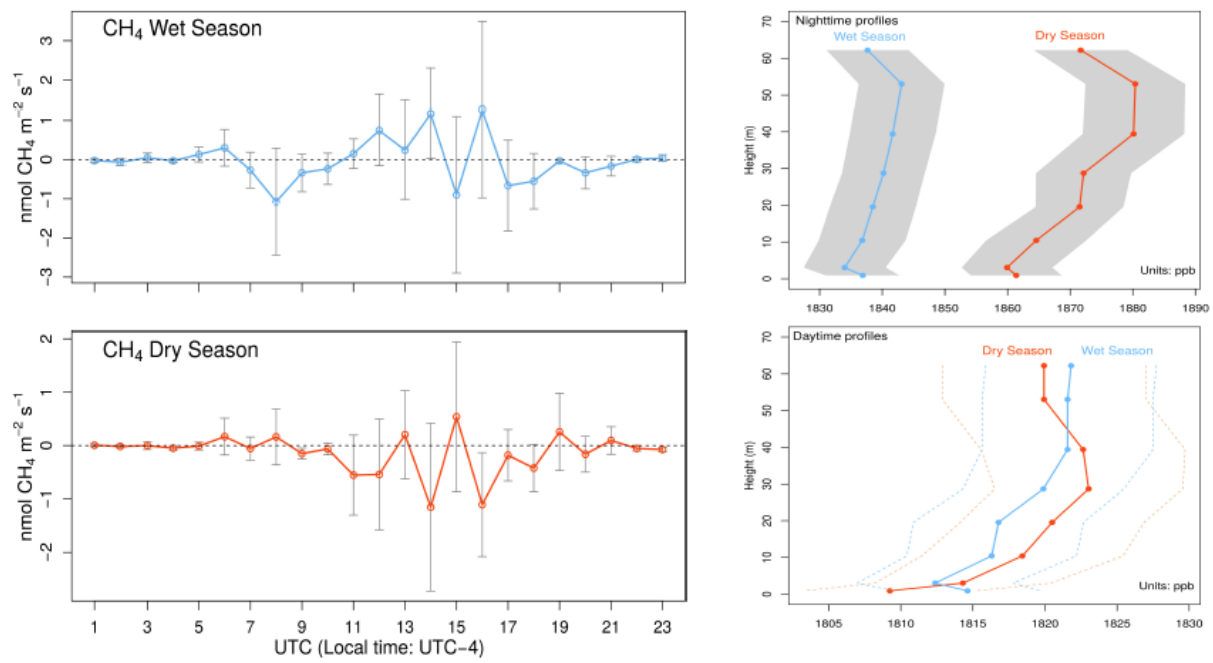

Figure 2: Methane fluxes show no significant difference between 2015 wet and dry seasons, and the forest at this site appear to be a methane sink throughout the year. The vertical profiles suggest that if a methane source exists in this forest, it might be in the canopy, around 35 m height, and due to limited biological activity (e.g. by arboreal termites).

methane source exists in this forest, it might be in the canopy, but soil uptake is dominant. There was much debate in the past about methane emission by plants, but to date, there is no evidence of significant emission of CH_4 by plants in aerobic conditions (e.g. Keppler et al., 2006, Dueck et al., 2007, Nisbet et al., 2009). Our results suggest that relatively weak biological activity might exist in the canopy level due to biological activity, such as by termite communities.

NOx and NOy measurements:

The NOy and the NOx sensors experienced degradation in the Amazonian environment, nevertheless, we were able to obtain sufficient data in several long intervals to characterize the fluxes of NO and NO_2 in this environment. This measurement represents the first time that these data have been available. These gases are strongly emitted by the soils at this site, with significant effects on the chemistry of the atmosphere and on the processes of primary interest in GO-Amazon.

A vertical gradient is established in the mixing ratio of NO because it is emitted at the soil surface and mixed upward in the atmosphere. Once in the atmosphere, the NO reacts rapidly with O_3 to produce NO_2 ($NO + O_3 \rightarrow NO_2 + O_2$). Therefore, as shown in our earlier work (Kaplan et al., 1989), by measuring the vertical profiles of the mixing ratios of NO and O_3 at night, when there is no recycling of NO_2 to NO, the surface flux of NO may be determined. If any other reaction removes NO (e.g., deposition on leaves), F_{NO} determined in this way should estimate the lower limit to the NO flux from the soil in this forest:

$$F_{NO} = \int_0^h k[O_3][NO]dz$$

Our measurements during GO-Amazon show fluxes of NO averaging 133 x 10^9 molec cm^{-2} s^{-1}, a factor of 4 higher than fluxes previously observed in white sand soils in the Amazon (Kapaln et al., 1989), and a factor of 3 to 14 higher than fluxes observed for yellow clay soils (Bakwin et al., 1990 and references therein). Evidently the emission rates of NO from Amazonian soils may be higher than expected from earlier measurements. Our *daytime* data indicate that not all of this NOx escapes to the atmosphere, however.

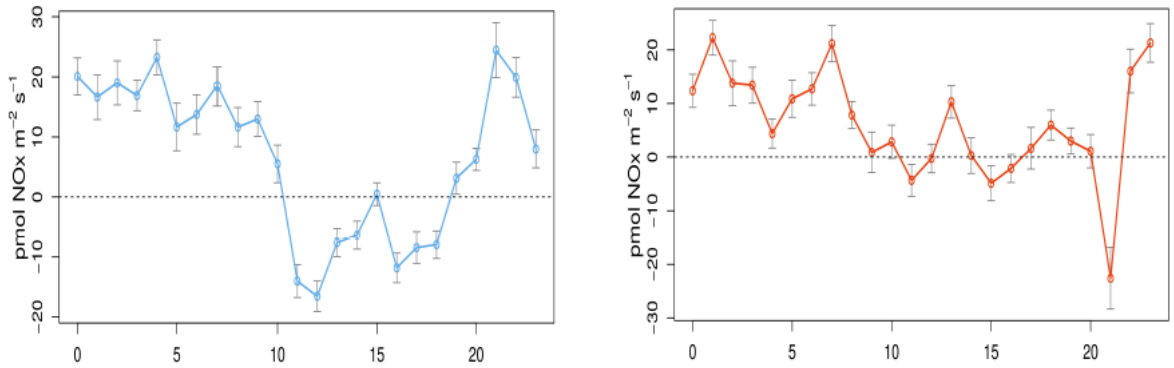

Figure 3: NOx concentrations through 2015, by the hour of the day for both wet (blue) and dry (red) seasons.

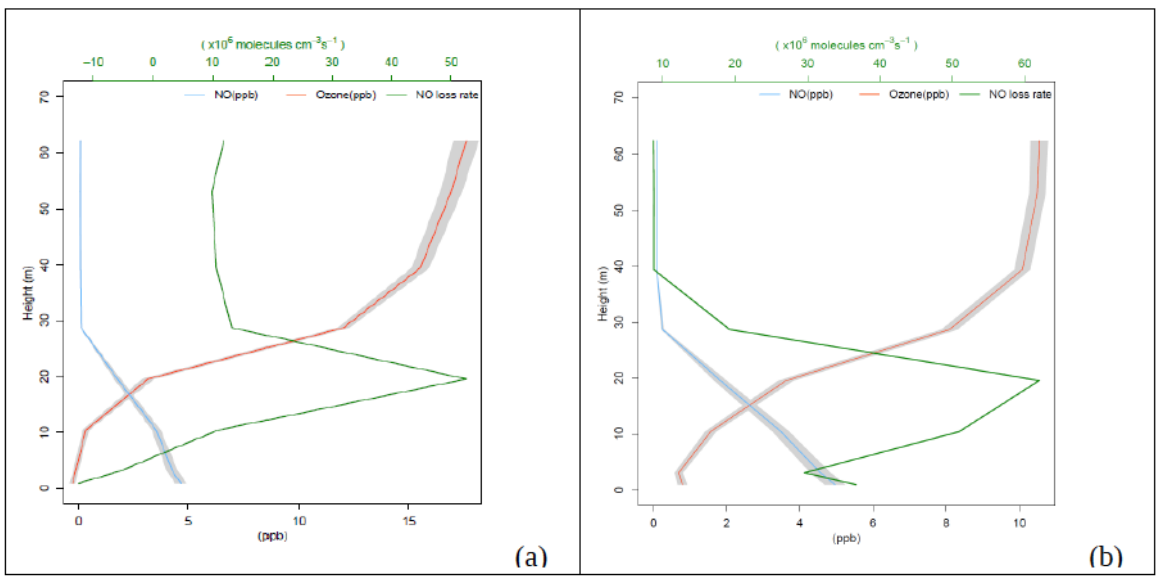

Figure 4: If the vertical profiles of the mixing ratios of NO and O_3 are known, the surface flux of NO may be determined. Our preliminary results show fluxes of NO averaged 133 x 10^9 molecules cm^{-2} s^{-1}, summing both dry (a) and wet (b) seasons.

The soil in the km 67 site is predominately oxisol with pockets of sandy ultisols, both having low reduced nutrient contents, mostly due to efficient microorganism decomposition and acid leaching by rain water. Oxisols contain both oxidized and reduced forms of nitrogen, with concentrations that are variable and with most part of the cycling processes occurring in the top layers. The present work confirms our early studies in the 1980s showing that upland soils in

Amazônia.

O_3 measurements:

An Ozone Analyzer 49i (Thermo® Environment) was deployed by Brazilian colleague Dr. Luciana Rizzo, from the Federal University of Sao Paulo (UNIFESP). Funds for the ozone measurements came from the Sao Paulo State Research Foundation (FAPESP, Brazil), and a Brazilian counterpart, enabling measurements of fluxes of NOx and O3 in the Tapajos Forest.

Figure 5 shows the vertical profiles of O_3 mixing ratio observed during the day and at night. There was no significant difference in the vertical gradients observed during dry and rainy seasons. Note a practically null concentration gradient from the top of the tower (~65 m) to ~20 m, which is below the canopy. This result suggests the presence of effective turbulent mixing processes that generate a homogeneous surface layer with respect to O_3. Below 20 m, the O_3 concentration decreases gradually during the day, reaching concentrations typically lower than 10 ppb near the ground (~3 and ~1 m). This result is in agreement with the expectations and with previous studies (Kirkman et al., 2002; Rummel et al., 2007), since below the canopy the vegetation provides abundant surface area for the deposition of O_3, shading causes a reduction in the photochemical production and the proximity to the soil provides chemical losses of O_3 through the reaction with NO.

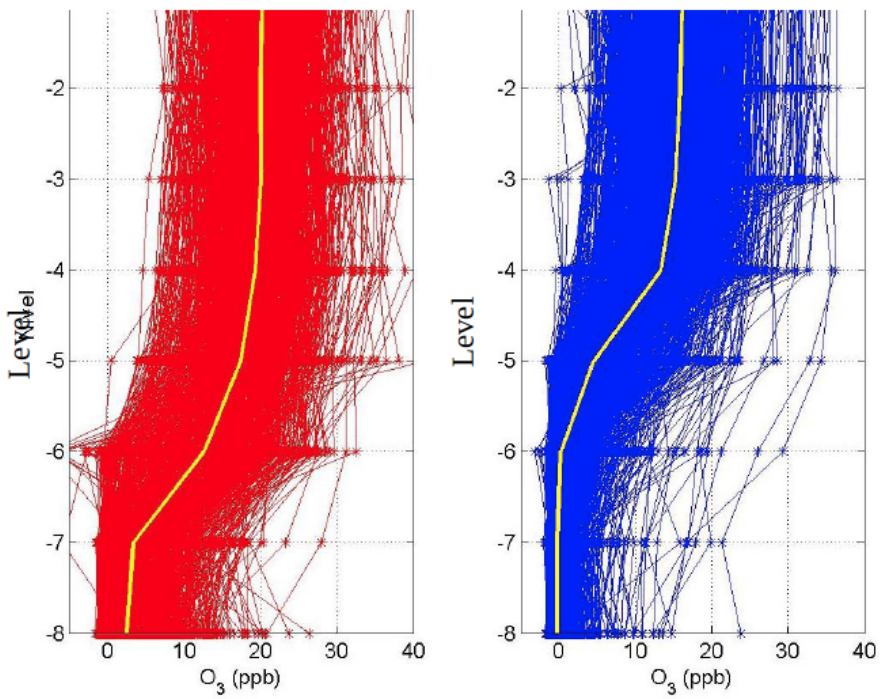

Figure 5: Vertical O3 profiles observed during the day (red) and at night (blue) at km67 site. The yellow lines represent the medians. The y-axis represent the correspondent height of the eight levels from 1 to 8 : 64 m, 53 m, 40 m, 29 m, 20 m, 10 m, 3 m, and 1 m above ground.

Hyperspectral camera measurements and assessment of underlying mechanisms:

Canopy-scale reflectance was acquired with a hyperspectral vegetation imaging system (HVIS), built around an advanced camera from Surface Optics Corporation (SOC-710VS, spectral range: 400-1000 nm, 4 nm spectral resolution). The KM67 SOC710 camera was mounted at the top of the flux tower on 07/18/2012. The programmable camera system views the canopy at angles from near nadir (15o) to oblique (75o), compositing its images into a vertical rectangle, with horizontally level reference plates allowing canopy signals to be normalized to incoming radiation to calculate reflectance.

The camera was operative until beginning of December 2012, when it had to be brought

back to U.S. for repairs (likely damaged by the same electrical discharge as the rest of the system). It was reinstalled in March 28th, 2014 and provided excellent data return through the end of field activities in 2015. See Wu *et al.*, Leaf development and demography explain photosynthetic seasonality in Amazon evergreen forests. *Science* vol. 351, Issue 6276, p. 972 (2016) , and Hilker et al. (2017, "Vegetation chlorophyll estimates in the Amazon from multi-angle MODIS observations and canopy reflectance model"). Hilker et al (2017) used our camera data to validate satellite-based remote sensing estimates of chlorophyll content.

Data analysis:

A comprehensive, merged data set of trace gases (NO, NO_2, CO_2, CH_4 and O_3) along with has been tabulated and subjected to meticulous quality assurance and quality control (QA/QC). The merged data set is being submitted to the ARM website dedicated to the Green Ocean Experiment:

https://www.arm.gov/research/campaigns/amf2014goamazon

Analysis using the final dataset is in progress to determine the magnitudes of the fluxes for CH_4, H_2O, CO_2, O_3, NOx, sensible and latent heat, momentum, and their seasonal variations. Here are summary statements, from the discussion above:

Total NO fluxes were calculated following Keller et al., 1986. A vertical gradient is established in the mixing ratio of NO because it is emitted at the soil surface and mixed upward in the atmosphere (see above). Once in the atmosphere, the NO reacts rapidly with O_3 to produce NO_2 ($NO + O_3 \rightarrow NO_2 + O_2$). Therefore, if the vertical profiles of the mixing ratios of NO and O_3 are

known, the surface flux of NO may be determined. If any other reaction removes NO (e.g., deposition on leaves), FNO should estimate the lower limit to the NO flux from the soil in this forest. Our preliminary results show fluxes of NO averaged 133 x 10^9 molecules cm^{-2} s^{-1}, a factor of 4 higher than fluxes previously observed in white sand soils in the Amazon, and a factor of 3 to 14 higher than fluxes observed for yellow clay soils (Bakwin *et al.*, 1990 and references therein). The soil in the km 67 site is predominately oxisol with pockets of sandy ultisols, both having low reduced nutrient contents, mostly due to efficient microorganism decomposition and acid leaching by rain water. Oxisols contain both oxidized and reduced forms of nitrogen, of which concentrations vary independently of leaching (Jordan *et al.*, 1982), with most part of the cycling processes occurring in the top layers.

Methane fluxes showed no statistical difference between 2015 wet and dry seasons, and the forest at this site appear to be a methane sink throughout the year. The vertical profiles suggest that if a methane source exists in this forest, it might be in the canopy.

Next steps include modeling and analysis using the Master Chemical Mechanism (Jenkin et al., 1997; Saunders et al., 2003 (A/B); http://mcm.leeds.ac.uk/MCM/) and the Ecosystem Demography-2 (ED-2) model. A final manuscript with the results from this work is in preparation and expected to be submitted for publication within the next several months. Publications to date are listed below.

Publications of the grant DE-SC0008311: "Fluxes of CO_2, CH_4, CO, BVOCs, NOx, and O_3 in an Old Growth Amazonian Forest: Ecosystem: Processes, Carbon Cycle, Atmospheric Chemistry, and Feedbacks on Climate"

Hayek, M. N., Drivers of Long-Term Variability in Amazon Forest Carbon Fluxes, *PhD. Thesis*, Harvard University, 2017 120pp.

Hayek, M.N., Marcos, L., Wiedemann K.T., Wu, J., Smith, M.N., Restrepo-Coupe, N., Tapajós, R., da Silva, R., Fitzjarrald, D.R., Camargo, P.B., Hutyra, L.R., Alves, L.F., Daube, B., Munger, J.W., Saleska, S.R., and Wofsy, S.C., Factors Influencing Carbon Exchange in an Eastern Amazon Forest: from Hours to Years, *Journal of Geophysical Research – Biogeosciences, submitted*.

Hayek, M.N., Wehr, R., Hutyra, L.R., Longo, M., Wiedemann, K., Munger, J.W., Bonal, D., Fitzjarrald, D.R., and Wofsy, S.C., A novel correction for biases in forest eddy covariance carbon balance: the MS-PEARL correction. *Agricultural and Forest Meteorology*, submitted.

Hilker et al. (2017). Vegetation chlorophyll estimates in the Amazon from multi-angle MODIS observations and canopy reflectance model. International Journal of Applied Earth Observation and Geoinformation, 58C: 278-287.

Saleska, S.R., J. Wu, K. Guan, A.C. Araujo, A. Huete, A.D. Nobre, N. Restrepo-Coupe. 2016. Brief Communications Arising: Dry-season greening of Amazon forests. *Nature*. 531(7594): E4-E5. doi:10.1038/nature16457.

Wu, J., L.P. Albert, A.P. Lopes, N. Restrepo-Coupe, M. Hayek, K.T. Wiedemann, K. Guan, S.C. Stark, B. Christoffersen, N. Prohaska, J.V. Tavares, S. Marostica, H. Kobayashi, M.L. Ferreira, K.S. Campos, R. da Silva, P.M. Brando, D.G. Dye, T.E. Huxman, A.R. Huete, B.W. Nelson, and*S.R. Saleska*, 2016. Leaf development and demography explain photosynthetic seasonality in Amazon evergreen forests. *Science*, 35 (6272): 972-976.

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Presentations:

Munger, J. W., Eliane Gomes Alves, Sarah Suely Alves Batalha, Helber Freitas, Alex B Guenther, Matt Hayek, Scot T Martin, Jeong-Hoo Park, Luciana Varanda Rizzo, Humberto Rocha, Scott R Saleska, Roger Seco, James N Smith, Julio Tota, Kenia T Wiedemann and Steven C Wofsy, Fluxes of reactive trace gases from Tapajos forest: Upwind precursor emissions to complement the GoAmazon campaign. Poster A23A-3200 presented at 2014 Fall AGU meeting.

Wiedemann, Kenia, J. William Munger, Steven Wofsy, John Budney, Luciana Rizzo, Kleber Campos, Humberto Rocha, Helber Freitas, and Scott Saleska, Biosphere-Atmosphere Exchange of NO_X, O_3, and CH_4 in Central Amazon, AGU Annual Meeting, San Francisco, Dec. 2016.

American Geophysical Union (AGU), San Francisco Fall Meeting, December 2015:

Up-regulation of Amazon forest photosynthesis precedes elevated mortality under El Niño drought. (Author list: Scott R. Saleska, Brad Christoffersen, J. Wu, L. Alves, M. Longo, S. Stark, M. Hayek, P. Meir, Cosme Oliveira, R. da Silva, P. Camargo.

Ecological Society of America (ESA), Ft. Lauderdale, FL, August 2016. Increased

photosynthesis precedes elevated mortality in Amazon forests under El Niño drought – a model for response to global change? Scott Saleska, Brad Christoffersen, Elizabeth Garcia, Abigail Swann, N. Restrepo-Coupe, K. Wiedemann, J. Wu, L. Alves, M. Longo, S. Stark, M. Hayek, P. Meir, Cosme Oliviera, Rodrigo da Silva, Plinio Camargo, David Breshears, Juan Villegas, Darin Law

Biosphere-Atmosphere Exchange of NO_x, O_3, and CH_4 in Central Amazon

B43B-0595

Kenia Wiedemann[1], J. William Munger[1], Steven Wofsy[1], John Budney[1], Luciana Rizzo[2], Kleber Campos[3], Humberto Rocha[4], Helber Freitas[4], and Scott Saleska[5]

1 John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA USA
2 Institute of Environmental, Chemical and Pharmaceutical Sciences, Universidade Federal de Sao Paulo, Sao Paulo, SP Brazil
3 Department of Atmospheric Chemistry, Universidade Federal do Oeste do Para, Santarem, PA, Brazil
4 Institute of Astronomy, Geophysics and Atmospheric Sciences, Universidade de Sao Paulo, Sao Paulo, SP Brazil
5 Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, AZ USA

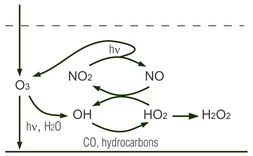
MOTIVATION

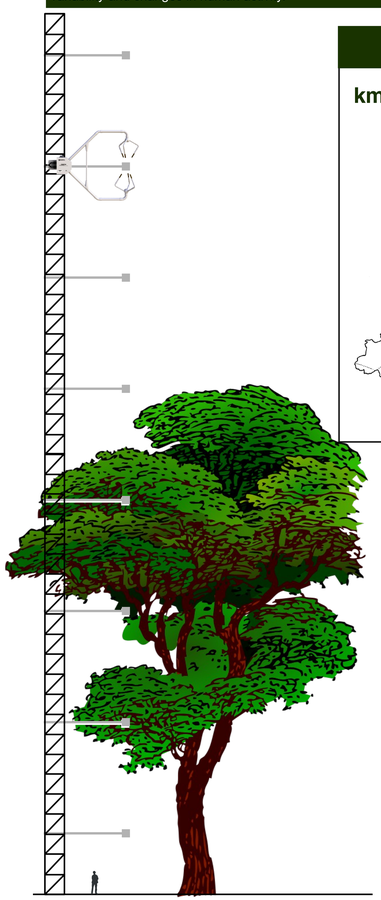
Oxidation by OH is the dominant pathway for removing important trace gases such as CH_4, CO, CH_3Br, and HCFCs. The primary source of atmospheric OH is the photolysis of O_3 in the presence of water vapor, and NOx are the main precursors of O_3 and OH. Thus, in NOx-rich environments that have both high humidity and high solar radiation, OH concentrations are enhanced, and therefore, tropical forests dominate global oxidation of long-lived gases.

The Amazon rain forest has a unique combination of vegetation with diverse characteristics, climate, and a dynamic land use, factors that altogether govern the emission and fate of trace-gases and control particle formation and atmospheric chemistry. Understanding the interactions among the mechanisms that govern local precursor emissions will lead to a better description of the local atmospheric chemistry, which have global impacts.

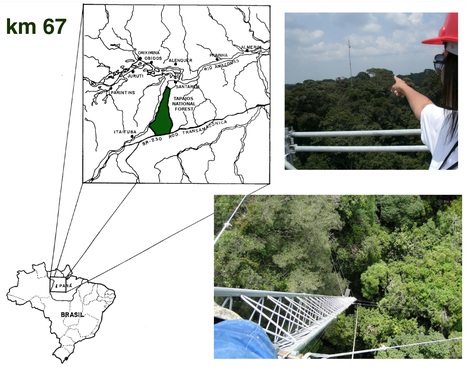
What do we want?

To quantify the effective flux of trace gases from primary tropical ecosystems, providing the baseline for measuring changes in those fluxes due to natural variability and changes in human activity.





MEASUREMENT SITE

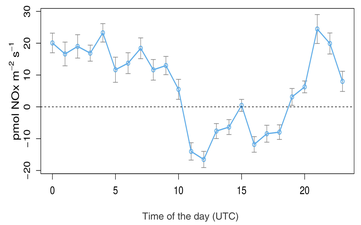


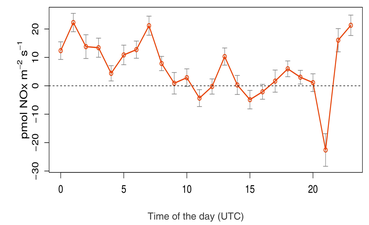
Research site: primary forest within the Tapajós National Forest, 67 km south of Santarém, Pará (Brazil), a city with a population of about 250,000, at the confluence of the Tapajós River with the Amazon River.

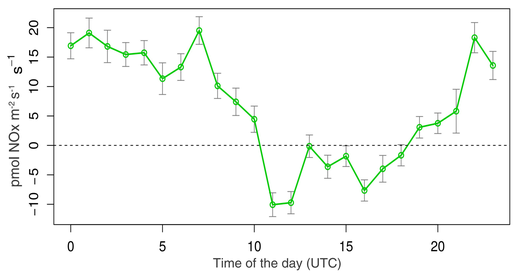
FANTASTIC VARIABLES AND WHERE TO FIND THEM

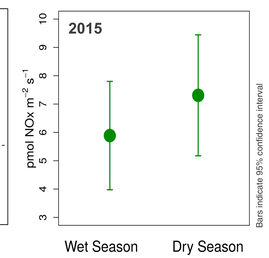
- Instrumented tower height: 67 m
- Canopy: 35 – 40 m
- Eddy covariance (CO_2, H_2O, Momentum, Heat)
- Eight-level profile measurements
- Meteorological variables: Precipitation, temperature, PAR, ambient pressure, etc.
- NO + NO_2: EcoPhysics CLD 780TR
- CH_4 : Los Gatos RMT 200
- O_3 : Thermo Sci. 49i Ozone Analyzer
- CO_2, H_2O: Licor 6262

NITROGEN OXIDES MEASUREMENTS AND RESULTS

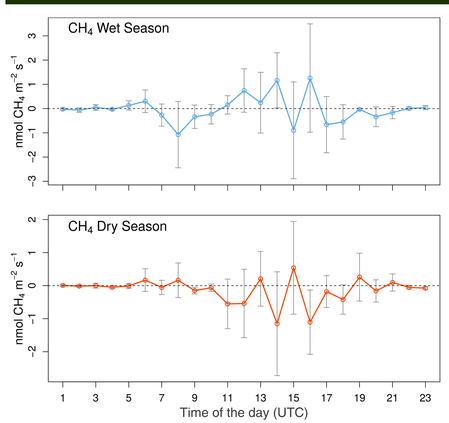


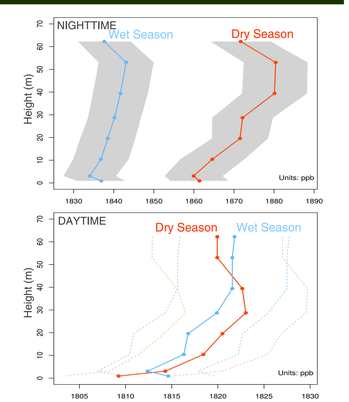






METHANE MEASUREMENTS AND RESULTS





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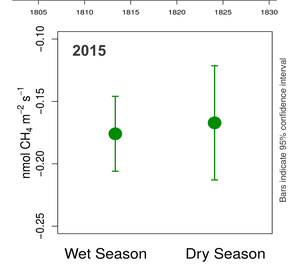


AND YET, MORE ABOUT THE NITROGEN OXIDES

We love nitrogen oxides.

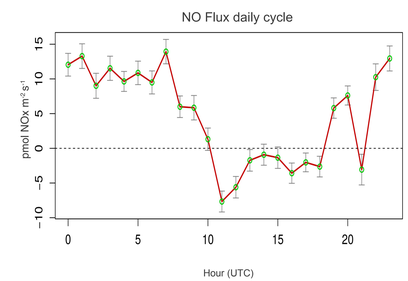
A vertical gradient is established in the mixing ratio of NO because it is emitted at the surface and mixed upward in the atmosphere. There the NO reacts rapidly with O_3 to produce NO_2.

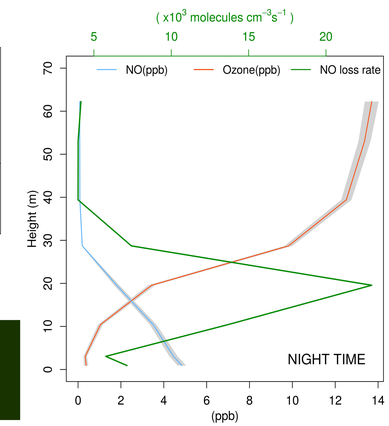
$$NO + O_3 \rightarrow NO_2 + O_2$$

If the vertical profiles of the mixing ratios of NO and O_3 are known, the surface flux of NO may be determined, because the rate of destruction of NO by the reaction with O_3 throughout a vertical column must be equal to the flux F_{NO} into the column from the soil surface (k is the rate constant for the NO + O_3 reaction):

$$F_{NO} = \int_0^h k[O_3][NO]dz$$

If any other reaction removes NO (e.g., deposition on leaves), F_{NO} should estimate the lower limit to the NO flux from the soil in this forest[1,2].





F_{NO} = 6.1 x 10^7 molecules NO cm^{-2} s^{-1}

102 pmol NO m^{-2} s^{-1}

- Soil appear to be a significant regional source of NO, with concentrations reaching a few thousand ppt.
- Profile measurements show that O_3 is being rapidly removed below the forest canopy
- Depletion of NO around the forest canopy height appear to be more dramatic during the night, possibly due to due to the low deposition velocity of O_3 at night, keeping O_3 mixing ratios "in check" above the canopy.

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Freedom is a beautiful thing

A23A-3200

See also;
A23A-3191,A23A-3198

Fluxes of reactive trace gases from Tapajos forest: Upwind precursor emissions to complement the GoAmazon campaign

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ABSTRACT

The Amazon Forest includes a diverse combination of vegetation characteristics, climate, and land usage that influence emission of the reactive trace-gases driving atmospheric chemistry and particle formation. A better understanding of atmospheric chemistry across this region requires consideration of variation in precursor emissions. To complement the intensive GoAmazon measurement campaigns that are focused on the interaction of Manaus urban plume with surrounding forest emissions we have established a suite of measurements at the km67 site in the Floresta Nacional do Tapajós, south of Santarem. The site is situated midway between the Tapajos River on the west and the BR 163 highway to the east (upwind). The nearby surroundings for up to 6 km on all sides is intact rain forest. A strip along the east side of the highway and adjacent roads has been cleared for agriculture, but the upwind area is otherwise sparsely populated. The km67 site was initially established in 2001 during the LBA campaign as carbon flux site and included CO measurements to identify influence from local and regional biomass burning. A 64 m tower extends above a 40-45 m closed canopy. In 2014 additional instrumentation including continuous NO/NO2, O3, SO2, and CH4 concentration profiles, NOy concentration and fluxes were added. Volatile organic compound (VOC) measurements using a PTR-HRTOF-MS (Proton Transfer Reaction-High Resolution-Time of Flight-Mass Spectrometer) and particle measurements using a nanoSMPS were added during a campaign in June-July 2014. This period was influenced by heavy precipitation; as a result O3 levels above the canopy were rather low, and declined further close to the ground. Even though there was no evidence of anthropogenic influence NO and NO2 concentrations were significant. Elevated concentrations beneath the canopy indicate soil NO emission is the dominant source. Eddy-covariance flux measurements of volatile organic compounds (VOC) above the Tapajós forest revealed concentrations and fluxes of more than 100 masses. Most followed a strong diurnal pattern with higher fluxes during the daytime. Some compounds (e.g., isoprene, acetone and monoterpenes) were emitted from the forest canopy while other compounds, primarily oxidation products of the emitted VOC, were deposited to the forest canopy.

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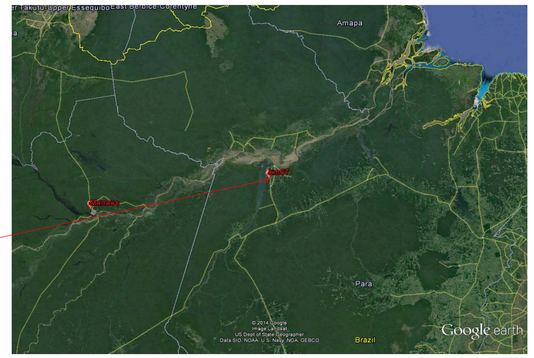
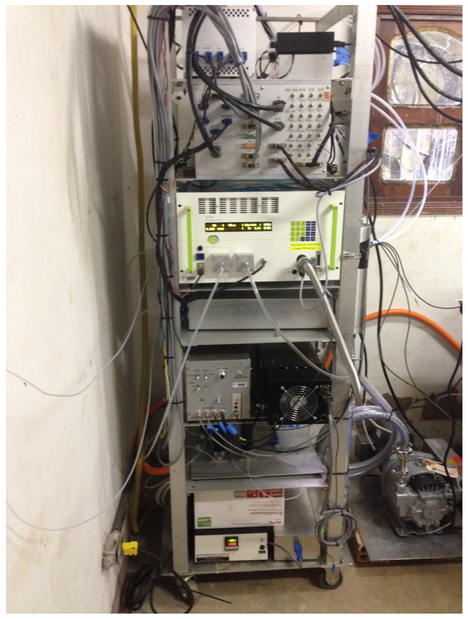


Image of eastern Amazonia showing the location of Tapajos km67 site , south of Santarem, relative to Manaus.
Km 67 site is surrounded on all sides for several km by intact forest. A narrow strip of agricultural development lines the BR 163 highway on the east, but land beyond that has minimal development



Continuous Measurements Suite

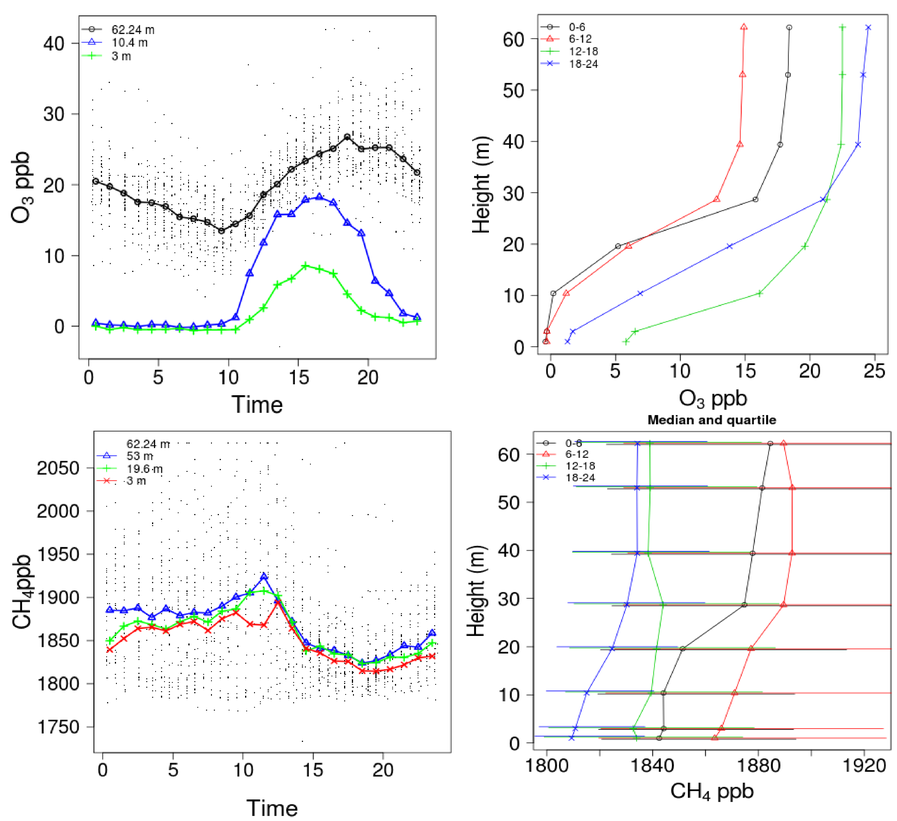
- CO_2 concentration gradients and fluxes
- CO concentration (above canopy)
- NO/NO_2 concentration gradients
- NO_y concentrations (above canopy) and fluxes
- O_3 concentration gradients
- SO_2 concentration gradients
- CH_4 concentration gradients

Harvard; L. Rizzo UFSP, ;H. da Rocha et al. IAG USP,

Added Campaign measurements NCAR/PNNL/UFOPA

- Nano SMPS (Particle size distribution ~4 < d < ~100 nm
- PTR-TOF-MS (VOC concentration and flux)
  - Planned for interim period between IOP in Manaus

Results for 9/15 – 10/25 2014



Local = UTC -3

Murphy's contributions

- Power failures necessitated complete replacement of generator, transformers, and some building rewiring
  - Power is stable now
- NO analyzer suffered initial damage, and subsequent complete failure – required repair at factory
  - Fixed now and ready to go
- Ongoing issues with lightning

Anticipated Results

- Average gradients above canopy are showing uptake of O_3 and CH_4. We will quantify the fluxes based on gradients and wind, and temperature profiles.
- NO and NO_2 are enhanced in the canopy layer relative to above canopy – soil NO emission.
- SO_2 is below detection at Tapajos site.
- May June campaign aerosol and VOC campaign was successful **A23A-3191,A23A-3198**