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DOE/SC-ARM-16-044

Green Ocean Amazon 2014/15 – Scaling Amazon Carbon Water Couplings Field Campaign Report

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August 2016

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CLIMATE RESEARCH FACILITY

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August 2016

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acknowledgments

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We acknowledge the support from the Central Office of the Large Scale Biosphere Atmosphere Experiment in Amazonia (LBA), the Instituto Nacional de Pesquisas da Amazonia (INPA), and the Universidade do Estado do Amazonia (UEA). The work was conducted under 001030/2012-14 of the Brazilian National Council for Scientific and Technological Development (CNPq).

Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement Climate Research Facility
Caltech	California Institute of Technology
CCRD	Climate Change Resilient Development, a U.S. Agency for International Development program
CLM	Community Land Model
CNPq	Brazilian National Council for Scientific and Technological Development
DOE	U.S. Department of Energy
ESRL	Earth System Research Laboratory
FTS	Fourier Transform Spectrometer
GoAmazon	Green Ocean Amazon 2014/15
GOSAT	Greenhouse gases Observing SATellite
ILAMB	International Land Model Benchmarking, a DOE OBER project
INPA	Instituto Nacional de Pesquisas da Amazonia
INPE	Instituto Naciional de Pesquisas Espaciais
IOP	intensive operational period
JPL	Jet Propulsion Laboratory
kg	kilogram
km	kilometer
LANL	Los Alamos National Laboratory
LBA	Large Scale Biosphere Atmosphere Experiment in Amazonia
LBNL	Lawrence Berkeley National Laboratory
m	meter
MPI	Max Planck Institute
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NGEE	Next-Generation Ecosystem Experiments, a DOE OBER program
NOAA	National Oceanic and Atmospheric Administration
OBER	Office of Biological and Environmental Research
OCO	Orbiting Carbon Observatory
ORNL	Oak Ridge National Laboratory
PM	project manager
ppm	parts per million
TCCON	Total Carbon Column Observing Network
TES	Terrestrial Ecosystem Science, a DOE Office of Science program
UEA	Universidade do Estado do Amazonia
WMO	World Meteorological Organization

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1.0 Summary

Forests soak up 25% of the carbon dioxide (CO_2) emitted by anthropogenic fossil energy use (10 Gt C y^{-1}), moderating its atmospheric accumulation. How this terrestrial CO_2 uptake will evolve with climate change in the 21st Century is largely unknown. Rainforests are the most active ecosystems, with the Amazon basin storing 120 Gt C as biomass and exchanging 18 Gt C y^{-1} of CO_2 via photosynthesis and respiration and fixing carbon at 2-3 kg C m^{-2} y^{-1}. Furthermore, the intense hydrologic and carbon cycles are tightly coupled in the Amazon where about half of the water is recycled by evapotranspiration and the other half imported from the ocean by Northeasterly trade winds. Climate models predict a drying in the Amazon with reduced carbon uptake while observationally guided assessments indicate sustained uptake. We set out to resolve this huge discrepancy in the size and sign of the future Amazon carbon cycle by performing the first simultaneous regional-scale high-frequency measurements of atmospheric CO_2, H_2O, HOD, CH_4, N_2O, and CO at the T3 site in Manacupuru, Brazil, as part of DOE's GoAmazon 2014/15 project. Our data will be used to inform and develop DOE's Community Land Model (CLM) on the tropical carbon-water couplings at the appropriate grid scale (10-50 km). Our measurements will also validate the CO_2 data from Japan's Greenhouse gases Observing Satellite (GOSAT) and NASA's Orbiting Carbon Observatory (OCO)-2 satellite (launched in July, 2014). Our data addresses these science questions:

1. How does ecosystem heterogeneity and climate variability influence the rainforest carbon cycle?
2. How well do current tropical ecosystem models simulate the observed regional carbon cycle?
3. Does nitrogen deposition (from the Manaus, Brazil, plume) enhance rainforest carbon uptake?

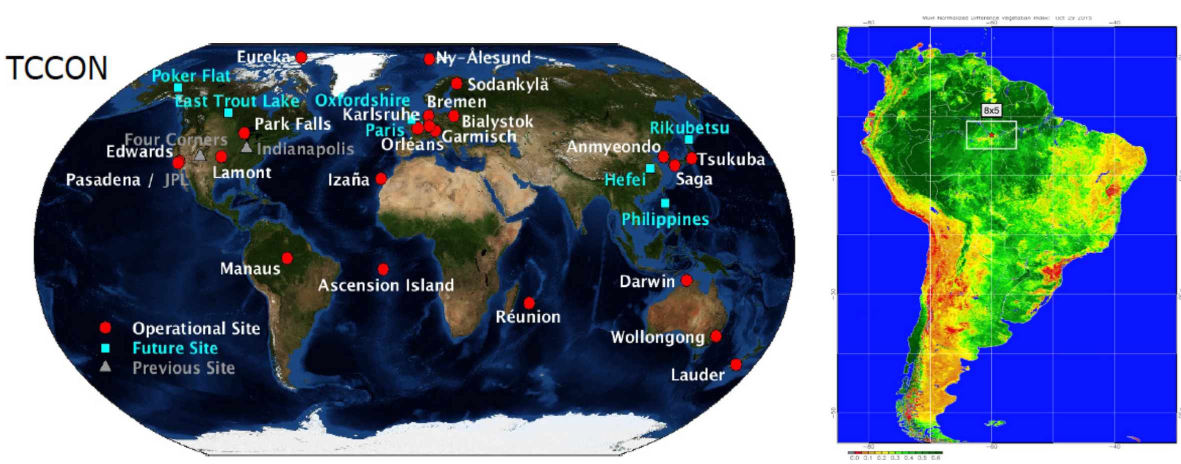

Figure 1: Total Carbon Column Observing Network (TCCON) sites (left). Our LANL solar Fourier Transform Spectrometer (FTS) Manaus intensive operational period (IOP) site (red star with box for OCO-2 sampling) filled a gap in North American rainforest carbon where image shows Normalized Difference Vegetation Index (NDVI) colors.

The core activity entailed the deployment of a solar tracking Fourier Transform Spectrometer (FTS, Bruker 125HR) that records high-resolution solar spectra in the near infrared in Manaus, Brazil, during the collaborative multi-program, OBER-funded, GoAmazon 2014/15 field campaign. The automated system locks in and continuously tracks the sun-collecting spectra in the near infrared every 1-2 minutes from sunrise to sunset and measures regional column concentrations averaged over 10-50 km scales. The atmospheric solar absorption spectra are fitted using laboratory spectra of species to retrieve atmospheric column abundances of constituents that include CO_2, CH_4, N_2O, H_2O, HOD, and CO. The LANL solar FTS is part of the global Total Column Carbon Observing Network (TCCON) and uses stringent operational and retrieval protocols that achieve very accurate and precise observations (better than 0.25% or 1 ppm for CO_2) necessary to evaluate regional carbon-cycle mechanisms and models. We were the first and only ground-based regional column trace gas monitoring site in the tropics that filled key gap in the international TCCON (https://tccon-wiki.caltech.edu)[1-7].

Figure 2: The LANL solar FTS deployed on the left from the T3 site in Manacupuru, Brazil, for GoAmazon in 2014-2015 (left), Manvendra Dubey and Dean Green during installation (middle), and operational FTS (right).

Our IOP expanded DOE's Atmospheric Radiation Measurement (ARM) Climate Research Facility GoAmazon aerosol campaign to include carbon cycle and ecosystem science in partnership with Brazilian scientists. The IOP logistics were supported by ARM (Sally McFarland, Project Manager [PM]) and the deployment and research were funded by DOE's Terrestrial Ecosystem Science (TES) program (Dan Stover, PM) and integrated. The project entailed collaboration with NASA, by which our site was targeted routinely for OCO-2 satellite and our data used for validation of column CO_2 over the tropics. We collaborated with NOAA-ESRL Boulder to perform airborne vertical profiles using World Meteorological Organization (WMO) standard in situ instruments. We have collected and compiled the first regional-scale column CO_2 and other trace gas column composition over a season above the Amazon rainforest. Our data is being used to evaluate tropical ecosystem carbon-cycle models and is synergistic with DOE's Office of Biological and Environmental Research (OBER) Next-Generation Ecosystem Experiments (NGEE)-Tropics and International Land Model Benchmarking (ILAMB) programs.

2.0 Results

Our project has produced a unique high quality of the regional greenhouse and trace gas composition of the atmosphere above the Amazon rainforest.[1-7] The high-time-resolution (1-2) minute data enables the examination of daily to monthly to seasonal (wet/dry) changes and the evaluation of model parameterizations of the tropical ecosystem response to natural variations and potential climate change.

Our results were calibrated by WMO-calibrated in situ airborne profiles by NOAA and Brazilian collaborators and then used to validate the OCO-2 satellite that targeted us periodically (Figure 1). Our quality-controlled data set has been uploaded to the ORNL DOE TCCON and ARM IOP data centers for use by the international climate research community. We are actively leading research and collaborating with DOE (NGEE-Tropics, ILAMB), NASA (OCO-2 validation) and academics (tropical land model evaluation) on projects that leverage our data. Results have been presented at program, national, and international meetings and publications are beginning to appear, some of which are cited here.

The cloud cover over the Amazon posed a key observational challenge for OCO-2 since it requires a cloud-free scene that is rare in the afternoon during the overcast. In contrast, our Brazil FTS can observe during broken clouds and also during the less cloudy morning period. We were therefore able to combine our dense high-resolution FTS data with coarser overpass target criteria (within 5 x 10 degree and 1 day of satellite) to validate the OCO-2 data. The OCO-2 column CO_2 data in various observational modes correlates well with our FTS data with a slope of 0.90 +/- 0.35 and a R2 of 0.35[7]. Our results provide confidence in the OCO-2 retrievals (that are empirically calibrated by TCCON[6]) over the Amazon for the 2014-2015 period and will be invaluable to extend the data into future years.[7]

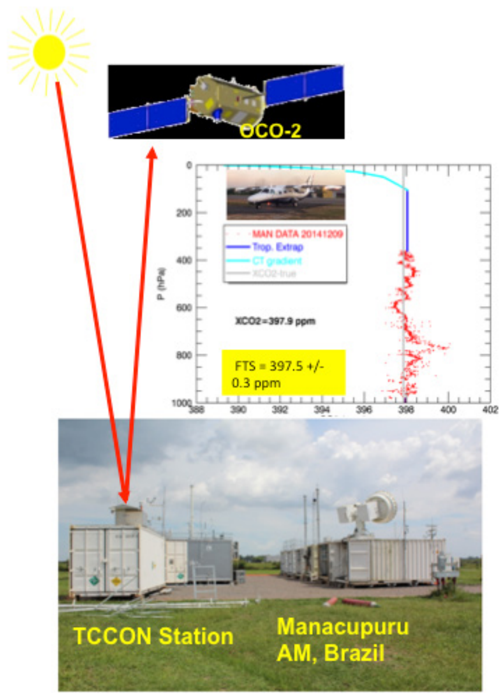

Figure 3: Our TCCON station observations were validated by in situ airborne profiles using WMO standards and then used to validate OCO-2 column CO_2 observations.

Our data also captures the regional Amazon carbon seasonal cycle showing high CO during the dry biomass-burning season and low CO during the wet clean season. We have used this regional column CO signal to separate the biomass burning contributions and biological (photosynthesis and respiration) components of the seasonal column CO_2 cycle. Furthermore, we have also used our robust detection of the daily photosynthetic drawdown to clearly separate it from the respiration fluxes. The IOP data are being mined extensively to evaluate tropical ecosystem models and help DOE guide TES and NGEE - Tropics model development.

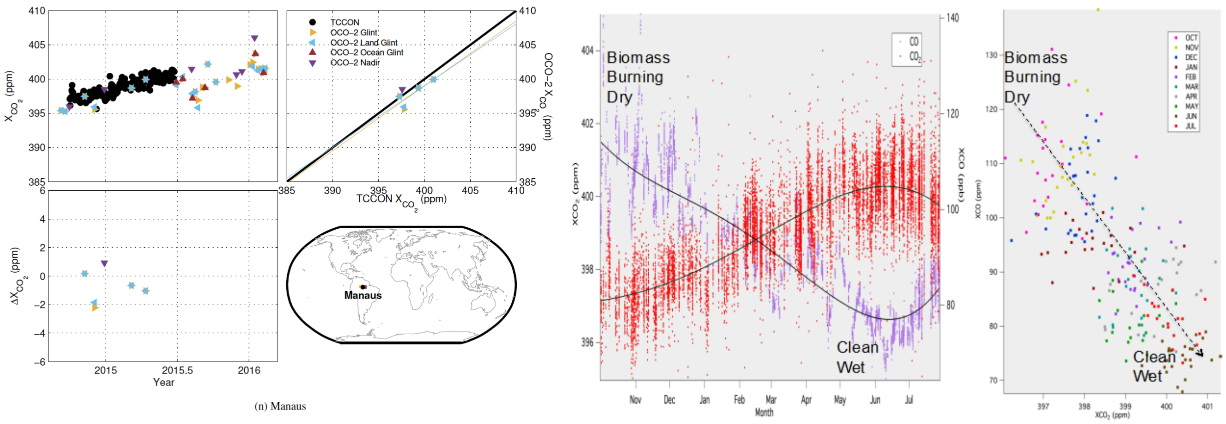

Figure 4: Left: Validation of OCO-2 using our Brazil ground FTS column CO_2 data.[7] Right: Observed daily, monthly, and seasonal variations in column CO_2 and CO trace during the biomass burning/dry and the clean/wet seasons.

Our data can be integrated with other ARM GoAmazon data to quantify contributions of trade wind import and local evapotranspiration to the Amazon water cycle by using our water isotope data. Analysis of the Manaus plume aerosol deposition on the Amazon carbon cycle could also be elucidated by this data. Finally, our 2014-2015 campaign serendipitously overlapped with a strong El Nino year for which we have succeeded in generating a good data set that will be valuable for follow-up studies as it wanes. Our breakthrough experiences from the IOP are being shared with groups in Belgium and Germany (Max Planck Institute [MPI]) to deploy other TCCON-like stations in South America. We have also built portable solar FTSs that are well calibrated, suitable for deployment here, and could be leveraged in collaboration with NGEE - Tropics if resources are made available. Our IOP has created strong scientific synergy within DOE climate programs, and between observations, models, and the international community.

3.0 Publications and References

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6. Notholt, J, MK Dubey, et al. 2015. “Remote sensing of the atmospheric composition in the infrared spectral region within the Network for the Detection of Atmospheric Composition Change (NDACC) and the Total Carbon Column Observing Network (TCCON).” Presented at the 36th International Symposium on Remote Sensing of Environment “Observing the Earth, Monitoring the Change, Sharing the Knowledge.” Berlin, Germany.

7. Wunch, D. 2016. ”Comparisons of the Orbiting Carbon Observatory-2 (OCO-2) X_{CO2} measurements with TCCON.” *Atmospheric Measurement Techniques Discussions*, in review.

4.0 Lessons Learned

The significant challenge for this IOP was that it was secondary to the main GoAmazon project and consequently shipment took longer and site support was more challenging. Despite this, we were able to work the issues and execute a fruitful campaign. There was strong interest in Brazil and by the international climate science community to continue the monitoring for a longer term. However, atmospheric elements could not be successfully mapped onto NGEE-Tropics, ecosystem science, or ARM due to the cross-cutting nature of project. This challenge could be addressed by OBER/CCRD (Climate Change Resilient Development, a U.S. Agency for International Development program) by promoting collaboration.

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