Abstract for the Atmospheric Carbon, Water and Nitrogen Observations to Elucidate Amazonian Ecosystem-climate Mechanisms and Scale Heterogeneities

Principal Investigator: Dr. Manvendra Dubey, LANL.

Postdoctoral Fellow: Dr. Rodica Lindenmaier, LANL.

Field Deployment Coordination: Kim Nitschke, LANL-ARM FIDO team.

Science Collaborators: Dr. Jeffrey Chambers, LBL; Dr. Peter Thornton, ORNL; Prof. Gretchen Keppel-Aleks, University of Michigan; Prof. Steven Wofsy, Harvard; and Dr. Nathan McDowell, LANL.

Program Manager: Dr. Daniel Stover, DOE TES.

1. Motivation

Tropical ecosystems (rainforests and grasslands) play a dominant role in regulating the global gross primary productivity, contributing 85 PgC/year, which is 70% of the global value of 122 PgC/year [Malhi 2012]. They account for about 60% of the total terrestrial land surface metabolism, which is much greater than the 8 PgC/year and 10 PgC/year values for boreal and temperate forests, respectively. However, predicting their response to future climate change (warming and increased precipitation) is highly uncertain due to limited observations, complex ecosystem-hydrologic-atmospheric couplings, and the primitive state of the parameterizations of tropical ecosystem interactions in climate models. For example, the release of carbon (as CO_2 and CH_4) and nitrogen (N_2O) from warming and wetting may exacerbate future climate change. Current coupled climate-carbon-cycle models generally agree that carbon storage on land will increase due to enhancements in photosynthesis (fertilization) and water-use efficiency under high CO_2, but will decrease due to higher respiration rates due to warming. However, the balance between these varies significantly amongst current coupled climate models, leading to a range of 330 PgC in the projected change of carbon stored in tropical lands by 2100 [Figure 1, Cox et al. 2013]. This large uncertainty arises from different parameterizations of the vegetation and/or hydrological responses in the models. It shows that uncoupled models (black line) have larger storage than coupled models (red line), due to the dominance of CO_2 fertilization and increases in water-use efficiency. A variant of the Hadley (CM3LC)

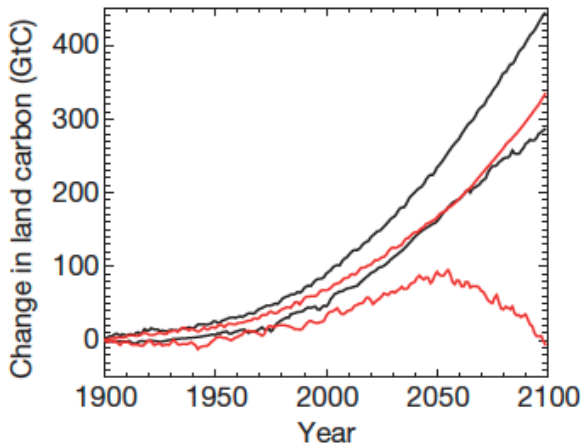

Figure 1. Projected changes in land carbon storage in the tropics from coupled climate-carbon-cycle models. Upper and lower estimates from the C4MIP models for uncoupled (black) and coupled simulations (red).

model predicts a tropical forest dieback tipping point around 2050 (lower red line). However, limited observations of CO_2 and temperature correlations in the tropics show that this is unlikely [Cox et al. 2013].

Figure 2. LANL's atmospheric carbon observatory housed in a 20 foot building (left) includes a solar FTS with a sun-tracker and *in situ* sensors (left) that monitor CO_2, CH_4, CO, H_2O, and HOD. The observatory is designed for remote long-term automated operations in remote locations.

2. Research Methodology and Science Goal

The goal is to gather the first "regional scale" (10-50 km) observations of atmospheric column CO_2, CH_4, H_2O, HOD, N_2O, and CO concentrations over Amazonian tropical forests (downwind of the Manaus urban plume) to measure the atmospheric variability arising from the coupled carbon-water-nitrogen terrestrial cycle on time scales that span minutes, hours, days, seasons, and years. This first-of-its-kind data in the Amazon will provide "new constraints" to develop process-level mechanisms and evaluate terrestrial ecosystem parameterizations in climate models. Variability in temperatures (from seasons) sunlight (from cloud cover), soil water (from rainfall), and nitrogen (from fires and urban plumes) will be used to diagnose specific responses of the model to these parameters. Furthermore, there will be evaluation of how the heterogenic response of the carbon fluxes to variations in forest and subsurface properties observed by long-term *in situ* tower measurements near Manaus averages (smears out) in larger-scale observations. The observed scale dependence of atmospheric composition will provide a new metric to link ecosystem processes to larger scale parameterizations in coupled land-atmosphere models (e.g., CLM/ESM).

Figure 3. Map of the current TCCON station locations. LANL FTS that was at Four Corners for 3 years will be deployed to Manaus in 2014 to fill a key gap in tropical ecosystem carbon-water-nitrogen cycle observations.

A core activity entails the deployment of a solar tracking Fourier Transform Spectrometer (Bruker 125HR) that records high-resolution solar spectra in the near infrared in Manaus, Brazil, during the collaborative multi-program OBER-funded GOAMAZON 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. 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

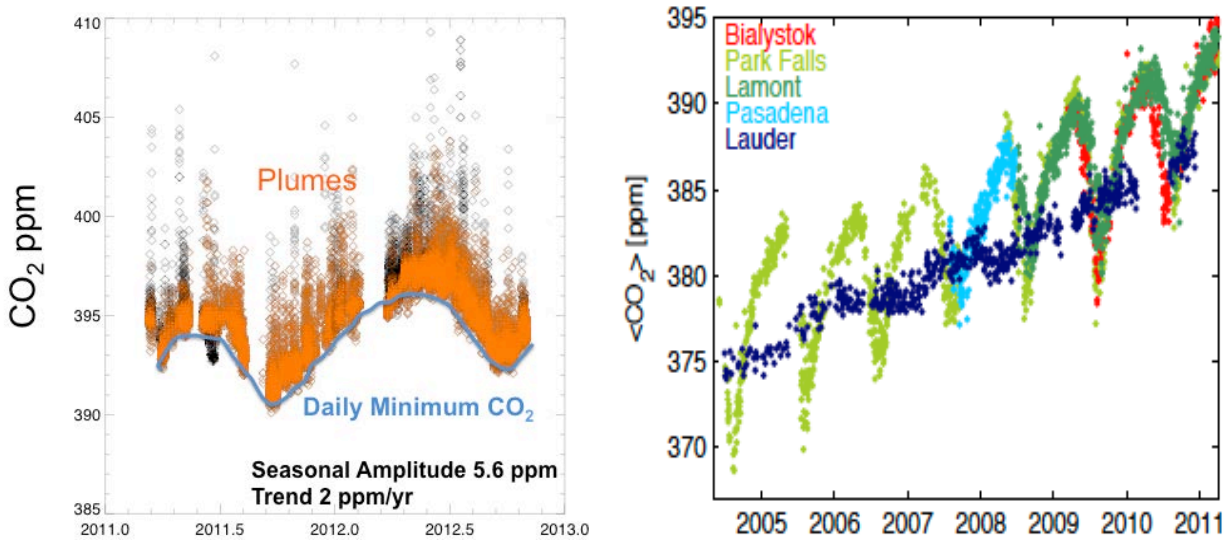

Figure 4. (left) Four Corners FTS column CO_2 data resolves the power plant plumes (orange, black) as well as the natural variations including the seasonal cycle (blue, daily minimum). (right) Longer TCCON site (daily mean) data resolve the seasonal cycles that depend on the latitude and the global trends.

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 [https://tccon-wiki.caltech.edu/]. TCCON is also crucial for the calibration of satellite observations of CO_2 that are being made by Japan's GOSAT and will be made by NASA's OCO-2 starting in middle of 2014. Unfortunately, while TCCON has good coverage at high- and mid-latitudes, it has a critical gap in the tropics. Therefore, the Manaus FTS deployment will have a very high impact on NASA and Japanese satellite products for global-scale model evaluation and will fertilize inter-agency and international collaborations. The observatory also has *in situ* sensors to measure local meteorology. In addition, it has the capability to monitor CO_2, CH_4, CO, and H_2O *in situ* at the site, which is valuable for separating boundary layer signals from the total column observations.

The LANL FTS has been deployed at Four Corners, New Mexico, for the past three years, where it has been focused on monitoring the emissions from two large power plants. This system has been validated by vertical airborne *in situ* measurements made by NCAR aircraft during the HIPPO campaign in June 2011. In addition, it has been certified by TCCON and the data meet the high accuracy criteria. Data displayed in Figure 4 clearly show that in addition to the large power-plant plumes, there is the ability to capture the seasonal CO_2 cycle in Four Corners. Shorter-term records are consistent with those made at longer-term TCCON sites.

As part of the GOAMAZON planning, the site has already been identified and prepped (Figure 5). The site is in a pasture surrounded by tropical forests downwind of the Manaus urban plume, allowing investigation of the role of nitrogen deposition as well as modulation of solar radiation (by aerosols and clouds) on ecosystems and their net effect on the carbon cycle.

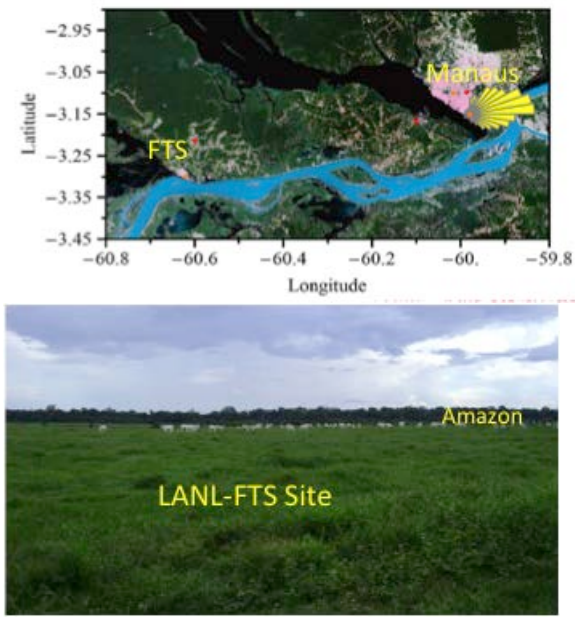

Figure 5. Location and photo of site ready for the LANL FTS deployment SE and downwind of Manaus.

3. Science Questions and Tasks

1. How does ecosystem heterogeneity and climate variability influence the rainforest's carbon cycle response?

2. How much (or less) does nitrogen deposition (from Manaus plume) influence the rainforest ecosystem's carbon cycle?

3. How well do current tropical ecosystem models (e.g., CASA, CLM, etc.) carbon cycle models do at simulating the observed regional carbon cycle and its variability?

Scaling ecosystem heterogeneity: Fortunately, long-term tower data are available at two towers northwest of Manaus, separated by 11 km. Analysis of the early part of the record has shown that the carbon cycle response of the ecosystems is different [Araujo et al. 2002]. The tower, which has less waterlogged valley areas in its footprint, measured a higher overall CO_2 uptake rate. Therefore, the heterogeneity in landscape and regional climatology is important. Part of the plan is to compare larger-scale FTS observations with these towers and others in Manaus (including planned airborne surveys) to systematically scale over the effect of such variations on the Amazonian rainforest carbon cycle.

Tropical Ecosystem Carbon Cycle Response to Climate Variations: Performing the first regional-scale total column CO_2, CH_4, H_2O, N_20, HOD, and CO observations in the tropical Amazon forests will be completed. The focus will be on the CO_2 variability in minutes to months to year time scales. This observed variability in CO_2 will be linked to changes in solar radiation (cloud cover, aerosols), rainfall or local evapotranspiration fluxes (using FTS column H_2O, HOD observations) that depend on topography and subsurface water transport, and variations in regional atmospheric circulation. Collected data will be used to evaluate the carbon cycle response of current tropical ecosystem models to changes. For example, the TCCON CO_2 data at mid-high latitudes has provided valuable assessment of the Boreal ecosystems. The analysis of the NH seasonal TCCON FTS data show that current carbon cycle models underestimate the seasonal springtime down-draw of CO_2 by the high-latitude Boreal forests by as much as 40% [Figure 6, Keppel-Aleks 2012]. Collected data will be used to perform similar evaluations for tropical ecosystems.

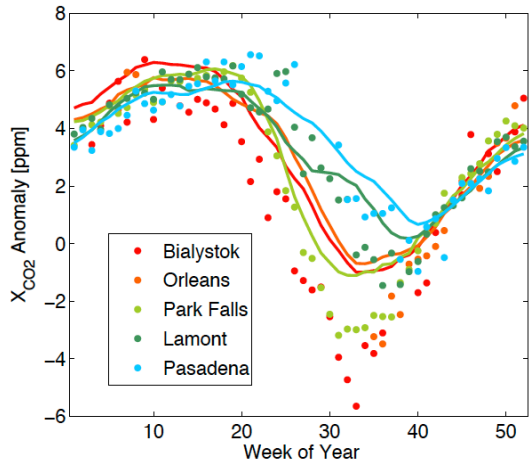

Figure 6. Seasonal cycle of CO_2 above several TCCON sites (dots) and the corresponding simulations from model (Carbontracker).

Tropical Ecosystem Control of Regional Evapotranspiration and Carbon Cycle in Dry Season: A large body of data shows that the tropical rainforests behave very differently in wet and dry seasons in the current climate. Climate change will change the mixture of these and likely shift the system to a wetter regime in the future. FTS data will capture this variability, not only in column CO_2, but also in H_2O and HOD that are tracers of water (as well as CH_4, which should correlate with water due its anaerobic biotic origin). In particular, there will be evaluation of the current view that evapotranspiration fluxes in tropical rainforests are determined by the ecosystems in the dry seasons and by the climatology in the wet season [Costa et al. 2010]. The fact that tropical forests can influence large-scale moisture by closing their stomata in response to drought is an important mechanism that needs to be evaluated and included in climate models. The data will be used to test this for the coupled water-carbon-cycle response during the dry season and contrast observed behavior during the wet season.

4. Plan, Tasks, Schedule and Milestones:

August 2013-October 2013

Prepare FTS-system for shipment including stabilization – Ship late October 2013

Develop remote operational and data transfer logistics from Manaus

Gather tropical tower data at Manaus and compare with model output.

November 2013–March 2014

Monitor FTS shipment and anticipate arrival in February 2013

Two-staff trip to Manaus for set-up and start-up February-March 2013.

March 2014–September 2014

Remote operations and data transfer begins April 2014

Retrieval of column CO_2 and other species – data products

Use data products for science with TES science team

Report to TES program meeting May 2014

Report on TES-Amazon FTS at TCCON meeting July 2014

Progress report to Dan Stover August 2014

Renewal proposal for 2015 in September 2014.

5. References

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