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GOAmazon2014 Workshop Report

July 26–27, 2011

U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Biological and Environmental Research

GOAmazon2014 Workshop

Convened by

U.S. Department of Energy
Office of Science
Office of Biological and Environmental Research

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GOAmazon2014 Workshop Report

July 26–27, 2011

Hyatt Regency Crystal City
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Prepared by the
Climate and Environmental Sciences Division
within the
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Climate and Environmental Sciences Division

Introduction

Tropical deep convection in the Amazon is primarily in its natural state during the wet season, with significant aerosol input from open biomass burning in the dry season. The underlying processes that drive convection and cloud formation in this region are poorly understood and modeled. This limited understanding, along with a lack of observational datasets, is insufficient for model constraint. Given the current state of the science, the U.S. Department of Energy (DOE) Office of Biological and Environmental Research's (BER) Climate and Environmental Sciences Division (CESD) will conduct an integrated experiment to study the coupled atmosphere-cloud-terrestrial tropical systems that drive tropical deep convection in the Amazon. The overarching goal is to advance the understanding of how land-atmosphere processes affect tropical hydrology and climate.

This experiment, Green Ocean Amazon 2014 (GOAmazon2014), will extend through the wet and dry seasons for 1 year, from January 1 to December 31, 2014. BER's Atmospheric Radiation Measurement (ARM) Climate Research Facility, Environmental Molecular Sciences Laboratory (EMSL), and Terrestrial Ecosystem Science (TES) programs will provide observational resources for deployment in the Amazon Basin downwind of the Brazilian megacity of Manaus. The Regional and Global Climate Modeling (RGCM), Earth System Modeling (ESM), Atmospheric System Research (ASR), and TES programs will support research using these and other data to evaluate and improve the representation of these coupled processes in climate models.

The scientific focus of GOAmazon2014 is on atmospheric, terrestrial ecosystem, carbon cycle, and coupling questions concerning tropical systems in the Amazon. The experiment is designed to enable the study of how aerosols and surface fluxes influence cloud cycles under clean conditions, as well as how aerosol and cloud life cycles, including cloud-aerosol-precipitation interactions, are affected by pollutant outflow from a tropical megacity. These observations will provide a dataset vital to constrain tropical forest model parameterizations for organic aerosols, cloud and convection schemes, and terrestrial vegetation components. The dataset also will provide insights into how these are perturbed by pollution and how they influence climate.

The GOAmazon2014 campaign represents an opportunity to study interactions among often separated components of the Earth system: the atmosphere and biosphere. Further, it will enable us to expand our understanding of important tropical climate processes and to collect an extensive benchmark dataset. The results will be used to improve and validate climate models at a range of scales.

This report summarizes the outcomes of a workshop sponsored by BER and held July 26–27, 2011, at the Hyatt Regency Crystal City in Arlington, Virginia. The workshop brought together process and modeling scientists with expertise in atmospheric and terrestrial ecosystem research who were charged to identify key scientific challenges and potential goals to be addressed by GOAmazon2014. In particular, workshop participants sought to identify mechanisms and opportunities for integrating ARM, EMSL, and TES observations; process science; and climate model development and evaluation.

The workshop opened with presentations from the lead campaign scientist explaining the goal of the ARM Mobile Facility deployment and from invited speakers with a systems-level focus on areas of potential scientific synergy. Breakout sessions were structured to identify modeling and process research needs and opportunities from the atmospheric and terrestrial ecosystem areas of interest that were informed by a number of science questions developed by the BER programs.

Breakout session objectives were to brainstorm and catalog science drivers (Day 1) and technical approaches (Day 2), with the intent of enhancing the planned ARM GOAmazon2014 deployment with other CESD observations and leveraging these measurements in BER research activities. Leveraging opportunities will focus on the critical scientific uncertainties that would benefit from integrated efforts of the RGCM, ESM, ASR, and TES activities of CESD. Opportunities for other programs and agencies also may be considered (e.g., remote sensing, specialized instrumentation, and additional measurements). Participants were divided into two parallel breakout sessions and assigned to groups such that each had a diverse set of scientific expertise and research interests. DOE moderators along with participant discussion leaders sought to balance "blue sky" discussions with pragmatic consideration of BER's research foci and practical limitations. At the end of each breakout session, discussion leaders presented summaries to the entire group in a plenary session.

With this general charge, breakout sessions were asked to address the following specific questions:

Breakout Session 1 (Day 1)

Identify and discuss important unresolved science questions concerning relationships among the terrestrial biosphere, aerosols, and cloud properties under pristine and polluted conditions associated with GOAmazon2014.

- What are the priority gaps in understanding and representing the cloud-aerosol-precipitation interactions that can be addressed in GOAmazon2014?
- What are the priority gaps in understanding and representing the terrestrial ecosystem (e.g., biogenic aerosol production) that can be addressed in GOAmazon2014?
- What are the relative roles of large-scale dynamical vs. local biosphere-atmosphere effects on hydrology, and what are the potential influences of local pollution?

Breakout Session 2 (Day 2)

Determine the measurement and modeling strategies needed to address each of the questions identified on Day 1.

- What existing measurements and modeling platforms or datasets can be leveraged and included?
- What new measurement and modeling strategies need to be developed or implemented?
- How can the efforts of modelers and measurers be integrated to optimize outcomes?

BER staff developed this workshop report based on materials presented by participants, breakout session summaries from discussion leaders, and extensive notes taken by a group of rapporteurs. BER will use this report to guide its plans for the GOAmazon2014 campaign's observational and research activities.

Important Unresolved Science Questions – from Day 1 Breakout Sessions

Area 1: Biosphere and Aerosols

a. What are the characteristics of volatile organic carbon (VOC; including isoprene) production from vegetation, and how do they vary with season and climate conditions?

b. How are new (organic) particles formed (e.g., nucleation and secondary organic aerosol formation)? What are the potential roles of primary particles (fungal spores, bacteria, and leaf cuticle) as cloud condensation nuclei (CCN) and ice nuclei (IN)? Which genomic and proteomic methods can be used to identify IN?

c. What is the life cycle of aerosols in the Amazon, and what are the impacts of the Manaus pollution plume on this life cycle? How do pollution and terrestrial systems affect oxidation, particles, and CCN?

Area 2: Chemistry, Aerosols, and Clouds

a. How do clouds impact aerosol (and aerosol precursor) transport, chemistry (including aqueous organic aerosol production), and removal?

b. How do aerosols affect precipitation and microphysics in deep and shallow convection? What effects do aerosols have on lightning and nitrogen oxides (NO_x)?

c. What is the diurnal evolution and seasonality of shallow to deep convection from mesoscale storm organization?

d. What is the role of hydroxyl radical (OH)/isoprene in aerosol formation, and how is this influenced by dense forests?

e. How important is vertical advection on aerosol precursors?

f. What is the role of lightning in NO_x formation?

g. What is the distribution of NO_x and NO_y in the pollution plume from a tropical megacity?

Area 3: Meteorology and the Biosphere

a. How do the cycles of net primary production (NPP), carbon dioxide (CO_2), and biogenic volatile organic compounds (BVOCs) interact with radiation, temperature, and precipitation in clean vs. polluted conditions?

b. What are the effects of chemistry, mixing, ventilation, variation within the canopy, and litter sources on the precursors of NO_x?

c. In BVOC production, what are the roles of the physical environment (e.g., temperature, rainfall, radiation, and nutrients), environmental perturbations (e.g., drought, nutrient deposition, and temperature extremes), and disturbance (e.g., blowdowns)? How does the pollution plume from a megacity influence these processes? What is the spatial variability of vegetation in the Manaus vicinity, and how does that relate to the above factors?

Area 4: Large Scale vs. Local Scale

a. What is the relative importance of model resolution, cumulus parameterizations, and land surface in regard to Amazon cloud and precipitation model biases?

b. How can the heat, moisture, and surface energy budgets needed to differentiate small vs. large scale be obtained? How do or will changes in temperature affect precipitation and sensible and latent heat fluxes?

c. What are the relative roles of aerosols, dynamics, and thermodynamics on clouds?

d. How can we gain sufficient understanding of large-scale forcing to attribute changes?

Area 5: Ecological Aspects

a. What is the impact of the megacity pollution plume on BVOC production?

b. What is the basin-wide carbon balance (including CO_2 and CH_4), and to what extent do different natural and anthropogenic factors contribute to it (attribution)?

c. How is nutrient limitation expressed in a pristine tropical forest, and how is it altered by exposure to a megacity pollution plume? Effects of interest include NO_y deposition, ozone exposure, and plume-associated changes in cloud cover and radiation environment.

d. What are the roles of natural and anthropogenic disturbances in establishing carbon balance in the vicinity of the megacity?

e. What is the influence of rivers on the ecosystem and BVOC production? What is the impact of blowdowns on the carbon cycle?

Modeling Activities and Measurement Strategies –
from Day 2 Breakout Sessions

Based on the Important Unresolved Science Questions identified by the breakout sessions on Day 1 (see p. 3), two parallel breakout sessions were convened on Day 2 to consider the modeling activities and measurement strategies needed to address each question. Resulting discussions were wide ranging and diverse, and the following sections attempt to capture the key points from both the modeling and measurement perspectives.

Modeling Activities

An improved ability to represent tropical atmospheric and terrestrial processes in regional- to global-scale models is the goal of GOAmazon2014. The intent is to use this experiment to take steps toward reaching the next generation of high-resolution, coupled climate models. This vision will require expanding the complexity and sophistication with which today's coupled models treat the interplay of relevant atmospheric, biological, and chemical processes. Early inclusion of the modeling community in the design of the GOAmazon2014 activity is seen by BER as vital to the campaign's success. Such input will ensure that measurements inform key uncertainties and errors in current formulations of convective dynamics and related processes in tropical regions.

The complex location of the experiment includes an urban heat island, aerosol and pollution sources, and a complex river basin. Isolating the impacts of aerosol and chemistry on clouds thus will be very difficult without a suite of idealized models and high-resolution simulations. The challenge of the experiment's environment motivates the modeling and observational strategy.

Pre-Experiment Modeling Analysis

The relationship between measurements and models most often is discussed in terms of using measurements to validate or improve models. However, models can also be used to support measurements in a variety of ways. For GOAmazon2014, high-resolution (~1 to 5 km) simulations of the Manaus region have been proposed as potentially valuable for planning aircraft missions, siting instruments, and designing ecosystem observations and potential manipulations.

Running a detailed simulation of the Manaus region—perhaps driven by larger-scale numerical weather prediction analyses—would provide the best possible estimate of expected cloud and plume evolution over the course of a year. Data from these simulations could be analyzed first to design sampling strategies. For example, the simulations would provide estimates for the expected boundaries of the plume and the frequency and seasonality of convection. These simulations also would facilitate sampling optimization (including aircraft flights).

The ground-based observation strategy for GOAmazon2014 currently is envisioned to center around a line of sites following the expected transport of pollutants from Manaus. Using auxiliary sites to characterize the larger environment also was suggested. High-resolution modeling, including off-line simulations of biogenic processes and coupled atmosphere-chemistry simulations, would provide guidance for the number and location of auxiliary sites to best sample the region's heterogeneity.

Pollution outflow from Manaus is a complicated mix of primary emissions of gases and particles followed by rapid conversions of many of these constituents during the 2- to 6-hour transport time to Manacapuru, the T3 site (see Fig. 1, p. 7, and Fig. 2, p. 8). Power plants provide electricity to Manaus by burning high-sulfur fuel oils, and automobiles in the region largely use gasoline for fuel because of the high transportation costs of ethanol. Consequently, the T3 site offers the scientific prospect of understanding and quantifying the effects of pollution on a range of climatically important endpoints in the tropics. These include, but are not limited to, (1) new particle formation; (2) anthropogenic influence on the production of secondary organic aerosols (SOA); (3) alterations in the atmospheric oxidant cycle including OH radical recycling; and (4) the effects of direct emissions and further atmospheric processing on particle optical, hygroscopic, and cloud-nucleating properties.

Designing the experiment to make these advances is complicated by several meteorological factors for which pre-experiment modeling analysis can make especially valuable contributions. Specifically, such modeling can provide statistics on the occurrence of Lagrangian advective flow from T2 to T3 and—more importantly for experiment design—can provide information on convective outflow of pollutants from the boundary layer. Understanding changes between observations at T2 and T3 requires knowing how closed the system is and to what extent chemical tracers would be conserved (in the absence of reaction) vs. how open the system is, permitting dilution of chemical pollutants. This information on the relative extent of closed vs. open should be known as quantitatively as possible. Results of the pre-experiment modeling analysis can be used to develop sonde sampling strategies for airborne sensors and to contribute to optimization of G1 flight paths.

Pre-experiment modeling of the structure and function of pristine forest ecosystems and the potential impact of a megacity pollution plume on these ecosystems would result in quantitative and testable hypotheses regarding controls on vegetation growth, canopy structure, and biogenic volatile organic compound (BVOC) production. Examples of forcing factors that pre-experiment ecosystem modeling could help elucidate include surface weather variability (e.g., temperature, precipitation, and radiation variation on multiple time scales), ozone exposure, nutrient availability, and natural and anthropogenic disturbances such as land clearance and blowdown. These early modeling results would provide a foundation for preliminary sampling strategies. They also could inform development of manipulative experiments to explore ranges of the most important factors that, though currently not observed, might appear under a future climate.

Development of a Fully Coupled Regional and Global Model

Several existing models couple the atmosphere with the biosphere or with chemistry but typically use simplifying assumptions to run efficiently because of limited information on processes. Since a goal of this experiment is to explore the coupling among these climate system elements, having a regional model that couples the systems will be important. Participants proposed that one or more coupled modeling systems be selected to simulate the Manaus region. These models would then be tested and improved using the knowledge and dataset obtained during GOAmazon2014.

Prior to the experiment, global models also could be used to conduct an initial analysis of the relative importance of aerosol processes via simulations with and without aerosol impacts and aerosol-cloud effects. Land-carbon interactions could be analyzed as well by conducting simulations with and without interactive land. The differences among these simulation results can be used to guide the experimental program.

During the campaign, regional and global models could be employed to guide measurement strategies, particularly for aircraft. Strategic conditions could be targeted, or deleterious conditions avoided (e.g., unwanted biomass burning plumes and precipitation events).

Post-Experiment Modeling Activities

Following the experiment, a broad range of modeling activities is anticipated to be carried out over scales ranging from cloud permitting (~1 km) to regional (~25 km) to global (~100 km, perhaps also in single-column mode). These modeling experiments will fully use the new knowledge and benchmark dataset developed during GOAmazon2014, including the forcing dataset derived from the radiosonde array and associated constraints on large-scale meteorology. Model experiments will explore a variety of science questions using multiple model configurations:

- **Cloud Microphysics.** Two-moment bulk and bin representations will be compared to assess and test the importance of using detailed microphysics.
- **Aerosol and Chemistry Treatments.** Models will investigate aerosol chemical evolution and include various levels of detail in SOA formation and aerosol microphysics, modal vs. sectional aerosol representation, gas-phase precursors, aqueous-phase production, and pollution impacts. By isolating aerosol processes and changing model sophistication, aerosol and chemistry treatments can be tested and improved.
- **Aerosol-Cloud Interactions.** Aerosol influence on liquid, ice clouds, and precipitation will be examined to determine whether and how aerosols impact precipitation and to test aerosol-precipitation schemes.
- **Terrestrial Ecosystem.** BVOC emissions, primary gas and aerosol emissions, sensitivity to climate variation, and response to changes in nutrient availability will be analyzed, along with the impact of BVOC variations on aerosol populations.
- **Radiation.** Radiative transfer (RT) calculations on aerosol distribution and optical (cloud and aerosol) properties will be performed, and heating rates and diffuse and direct radiation examined. Models could explore the importance of feedbacks from aerosols to the terrestrial ecosystem by conducting simulations with and without aerosol impacts on surface radiation.
- **Convection, especially in global circulation models (GCMs).** Currently, there are no parameterization schemes for aerosol effects on convection. The field study will provide a testbed for schemes whereby aerosols affect convection and convective precipitation.

Measurement Strategies

DOE BER seeks to leverage its unique experience and capabilities in data collection and advancement of understanding for atmospheric systems and terrestrial ecosystems. The breakout sessions were asked to focus on DOE-centric science in the context of the Important Unresolved Science Questions (see p. 3).

Several breakout sessions suggested using the natural east-to-west gradient established by the prevailing winds and locations in and downwind of Manaus for sampling. Figure 1, p. 7, shows the relative locations of Manaus, the anticipated ARM Mobile Facility (AMF) deployment site, and a potential site between these two areas. Also shown are other existing and planned measurement locations that could be used to leverage data obtained by GOAmazon2014. Figure 2, p. 8, shows a conceptual representation of how this gradient could be exploited to understand the role of natural and anthropogenic aerosols and aerosol precursors in and around Manaus. It also identifies potential locations for Tier 1 and 2 sites. Tier 1 sites would be well equipped with instruments for observing as much as possible key physical and biological parameters. The less-instrumented Tier 2 sites would serve as controls or possible locations for only periodic sampling. Specific descriptions for Tier 2 sites did not emerge from these discussions; they remain as concepts that would be used to augment or control for process measurements made along the Tier 1 gradient.

Fig. 1. Maps showing Manaus and proposed experimental sites. [Images © 2011 Google and TerraMetrics]

Characterizing the Large-Scale Environment

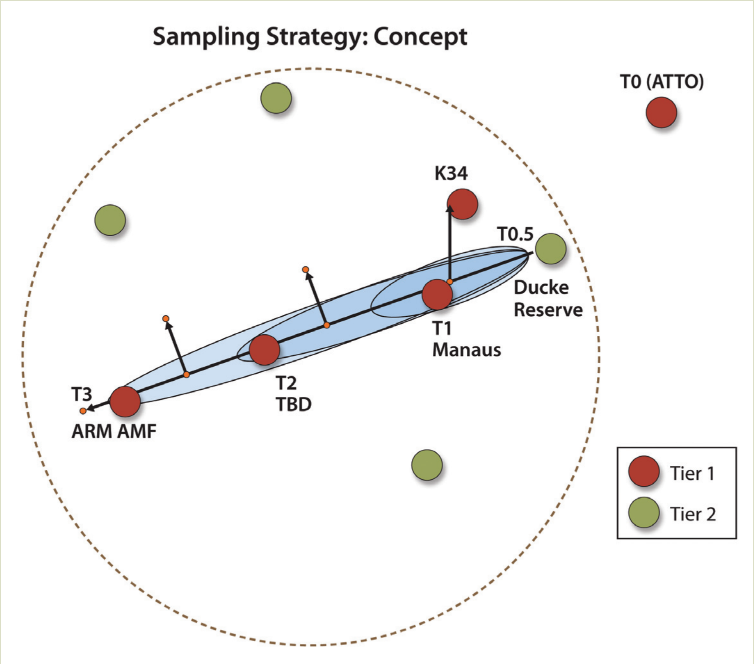
A challenge of GOAmazon2014 will be to attribute cloud life-cycle characteristics to large-scale dynamic forcing, local thermodynamics including the influence of the Manaus heat island, and aerosols. To appropriately identify the relative impacts of these different forcing elements, characterizing the large-scale meteorology and providing the means of high-resolution modeling of the local environment will be important.

Spatial Distribution of Precipitation

A key resource needed to characterize the large-scale meteorology is a scanning C-band or S-band (centimeter wavelength) precipitation radar. A radar of this class would provide spatial observations of precipitation over an area with a radius of ~150 km. This precipitation dataset would be critical for describing the regional-scale meteorology and placing local measurements in context. It also would provide an important constraint for atmospheric model simulations. The radar should be sited so that it scans over the AMF site at a distance of ~30 to 100 km, enabling quantitative precipitation and hydrometeor profiles over that site.

An S-band radar (SIPAM) near Manaus currently is part of the Brazilian operational weather radar network. This radar may prove to meet the needs of GOAmazon2014. However, several issues need to be understood, including whether the data are readily available in digital format and how the radar is being scanned. A scanning radar is needed for the duration of the experiment. Thus, if the data quality, data availability, or scanning of the operational SIPAM

Fig. 2. Proposed layout of sites in the Manaus region for the GOAmazon2014 campaign. Tier 1 sites have more comprehensive sets of instrumentation than Tier 2 sites, which represent significantly reduced sets of instruments intended to increase spatial sampling. Tier 2 sites are currently unfunded.



radar are not suitable, adding another radar to the measurement suite is critical. Candidates include the National Science Foundation's S-PolKa (dual polarimetric S- and Ka-bands); the SMART-R (truck-mounted C-band) operated by Texas A&M University, Texas Tech University, the University of Oklahoma, and the National Severe Storms Lab; or another portable C-band (such as the recently decommissioned Ron Brown radar).

Temperature, Humidity, and Wind Profiles at the Experiment Domain Boundaries

Measurements of temperature, humidity, and the horizontal wind field also are needed to characterize the large-scale meteorological environment. These are most readily obtained through a radiosonde network. The AMF will include four radiosonde launches per day throughout the campaign. However, to characterize the large-scale environment, an array of radiosondes is needed. In addition to vertical and coarse horizontal structure, this array will provide dynamic and thermodynamic boundary constraints for model simulations over the Manaus region. The separation of points in the radiosonde array should be on the order of 200 km. To resolve the diurnal cycle, a minimum of four radiosondes per day is required, but six to eight is highly preferred to sample a rapidly changing convective environment. Participants proposed using a denser array and higher launch frequency during two, two-month intensive operation periods; fewer radiosondes would be launched outside these intensive periods.

Canopy Properties

The tropical forest is a dominant characteristic of the GOAmazon2014 experiment domain, and characterizing the spatial attributes of the forest canopy will be very useful. Measuring gradients in surface roughness associated with canopy variations would help in determining whether there are preferred regions for convection initiation. Meanwhile, ecosystems studies will rely on a spatial survey of canopy characteristics. Participants proposed that a survey be carried out prior to the GOAmazon2014 campaign using a high-resolution airborne lidar that can characterize the relevant physical characteristics of the canopy. Such surveys have been conducted in this region in support of at least one previous field campaign.

Tier 1 Sites: Thermodynamic and Radiative Measurements

In addition to the spatial distributions of precipitation and atmospheric state parameters provided by the radar and radiosondes, respectively, detailed measurements at a few fixed sites are needed to characterize the atmospheric column.

Profiles of Water Vapor and Aerosol Extinction

A Raman lidar would provide high-resolution vertical profiles of water vapor and aerosol extinction (except where the signal is attenuated by clouds). Water vapor measurements from the Raman lidar are not possible with a high solar background, so retrievals are restricted to night and medium to high solar zenith angles. Participants recommend that a Raman lidar be deployed at the AMF site.

Boundary Layer Height

The height of the boundary layer—an important quantity for studying convection and boundary layer chemical processes—can be obtained by several means. A relatively inexpensive approach would be to use a ceilometer, whereby differences in aerosol concentrations in the boundary layer and free troposphere can be used to identify the top of the boundary layer. Deployment of a ceilometer is proposed for each of the Tier 1 sites (T0, T1, T2, and T3).

Vertical Velocities in Deep Convection

Several instruments will be available for measuring vertical velocities under certain conditions as part of the AMF suite. A Doppler lidar will provide clear-air vertical velocities below clouds, and the vertically pointing 35 GHz cloud radar will provide vertical velocities in clouds. However, in deep convection, attenuation due to liquid water will prohibit vertical velocities in heavy precipitation. A vertically pointing S-band radar profiler would provide vertical velocities in deep convection as well as information about hydrometeors to aid the study of deep convection precipitation processes.

Boundary Layer Thermodynamic Profiles

The expense of radiosondes and the time required to complete a launch limit the time resolution possible for boundary layer sampling. Obtaining more frequent profiles of the boundary layer is possible by flying a radiosonde package on a tethered balloon. Such a package could be flown at the AMF site to observe the detailed evolution of the boundary layer under a variety of conditions.

Tier 1 Sites: Chemical and Biological Measurements

Carbon Dioxide (CO_2) and Methane (CH_4) Fluxes

Measurements of CO_2 and CH_4 fluxes within the experiment domain are necessary, including aerial observations of trace gases and CO_2 flux. Aerial measurements can be augmented by Fourier transform spectrometry (FTS) measurements of CO_2 and CH_4 column concentrations.

Differentiating Clean and Polluted Environments

Deploying a new measurement tower near Manaus will provide an understanding of key ecosystem-atmosphere interactions that vary between polluted and nonpolluted environments in the Amazon. This tower would be positioned in the Manaus pollution plume, enabling comparison with the relatively pristine K34 control tower north of Manaus. Important measurement parameters are light quality, transpiration and photosynthesis, sap flux, transpiration scaling, and understanding the nitrogen and ecosystem fertilization effects of long-term deposition along the transect from Manaus to the ARM site.

To better parameterize land-atmosphere models, characterization of the energy budget near the Manacapuru site can be extended by augmenting existing towers and taking additional measurements of diffuse and direct radiation and light sensors, soil moisture, and transpiration flux. Enhanced sites include the K34 tower (50 km

Climate and Environmental Sciences Division north of the AMF site) and a new small tower at Manacapuru. Additionally, a tower co-located with AMF is essential for meaningful measurements of coupled atmospheric and terrestrial processes. One suggested option involves DOE developing a mobile tower that could be deployed for these experiments. This effort would help to scale the understanding and functioning of the broader ecosystem near the AMF site.

Volatile Organic Carbon (VOC) and Biogenic VOCs

The AMF Aerosol Observation system should be extended to provide insights into the fraction of VOCs that convert to aerosols, a process which is a function of the pollution within the measurement volume. Carbon 14 can be used as a tracer for determining the ratio of biogenic to fossil carbon to improve the understanding of VOC interactions with aerosols and biosphere particles (e.g., viruses, fungal spores, and bacteria). Quantifying the gas and particle phase solubility is important.

Characterization of BVOC production between the clean and plume sites will be evaluated through measurements of net ecosystem exchange. These measurements include leaf and stand scale, CO_2 fluxes, latent and sensible heat, micrometeorology, shortwave and longwave radiation, biometric characterization, ambient ozone, and NO_x concentrations.

The tower network will enable understanding of the regional variation of atmospheric constituents in the Amazon. Atmospheric chemistry will be measured by new sensors deployed at the K34, Santarém, and São Gabriel da Cachoeira or Tefé towers; these data will complement AMF measurements at Manacapuru. Constituents to be measured include VOCs, ozone, NO_x, CH_4, aerosol deposition, multilayer soil moisture, and sap flux (transpiration). Aircraft can be deployed to augment measurements and provide the spatial variability of VOCs and other constituents. Measurements of total column trace gas concentrations using FTS (combined with other measurements) can address total basin CO_2 and CH_4 budgets. These new measurements will provide inputs for atmospheric modeling and surface forcing as well as BVOC estimates. For the modeling domain, these additional data will be integrated into a fine-resolution (<2 km), gridded, land-surface model including a land-cover dataset with soils and meteorology. Data-model integration goals must be defined, along with strategies for modeling and integrating models with observations.

High-Resolution Aerosol Composition

Because organic compounds are expected to be key aerosol precursors in the Amazon environment, characterizing their distribution is important. A high-resolution time-of-flight aerosol mass spectrometer (HR-ToF-AMS) would be valuable for determining this distribution.

Size-Resolved Cloud Condensation Nuclei Activity

An important connection between chemistry and climate is that SOA production changes particle size and chemistry, both of which influence CCN activity. Therefore, making size-resolved CCN measurements will be critical.

Ecosystem

Ecosystem Measurements

Developing process knowledge and evaluating hypotheses regarding how the Manaus pollution plume and other anthropogenic disturbances influence ecosystem structure and function will require ecophysiological and ecological measurements at multiple sites along and orthogonal to the plume. Critical measurements include leaf-scale BVOC fluxes, foliar carbon-nitrogen-phosphorus (C-N-P) concentrations, specific leaf area, leaf-area index, and A/C_i curves (net CO_2 assimilation rate, A, vs. calculated substomatal CO_2 concentration, C_i) in relation to canopy depth. C, N, and P concentrations need to be characterized in aboveground biomass, coarse woody debris, litter, and soil organic matter (at multiple depths), along with nutrient mineralization (using resin core methods).

Ecosystem Manipulation Experiment

A possible future manipulative experiment may be developed based on the following hypothesis:

If BVOC production responds to net primary production (NPP), and if NPP responds to nutrient status, ozone exposure, radiation environment, and precipitation, then variation in these factors as caused by the pollution plume should be evidenced as differences in ecosystem structure and function along and orthogonal to the plume.

This hypothesis could be tested using a manipulative experiment that modifies the nutrient status through N, P, and N + P additions at multiple sites along and orthogonal to the plume, while measuring the impact on BVOC and other ecosystem states and fluxes. Nutrient status is selected as a factor relatively inexpensive to modify, and pre-experiment modeling would be used to define specific hypotheses regarding the interaction of multiple factors, providing an expectation for the influence of a single factor that could be evaluated experimentally. Disturbance history is likely to be a confounding factor in forest response to changes in nutrient status, and sites would need to be selected carefully to address this expected interaction.

Aerial Facility Measurements

Black Carbon

Needed measurements of black carbon could be obtained with a Single Particle Soot Photometer (SP2) that, if flown on the G1 aircraft, would require removal of another instrument. The G1 payload already has been submitted to the Brazilian government for approval, so this change would have to be considered carefully and requested soon. Another possible option is a Brazilian aircraft ideally suited to carry the SP2.

Volatile Organic Carbon

Because VOCs are aerosol precursors, obtaining spatial measurements of them from aircraft would be very useful. A National Oceanic and Atmospheric Administration flask system would be well suited for this task, but (as with the SP2) it could not be flown on the G1 without a payload change. The flask system, however, could be flown on the Brazilian aircraft if available.

Ice Microphysics

Deep convection will be a dominant meteorological feature during GOAmazon2014. However, with the G1 focusing on boundary layer processes, ice processes will not be measured. A German G5 aircraft possibly will be available for the campaign. The G5 could provide valuable measurements of ice cloud properties and ice nuclei. Much remains to be understood about tropical deep convection, and sampling the ice cloud outflow from deep convection would be an important addition to the experiment.

Appendix 1: Agenda

Agenda

Tuesday, July 26

8:30 a.m.	Welcome and program goals – Sharlene Weatherwax, Associate Director of Science for Biological and Environmental Research (BER)
8:50 a.m.	Workshop objectives, agenda, and output – Gerald Geernaert, Director of BER's Climate and Environmental Sciences Division (CESD)
9:10 a.m.	Green Ocean Amazon 2014 – Scot Martin, Harvard University
9:40 a.m.	Modeling the Earth system – Peter Thornton, Oak Ridge National Laboratory
10:10 a.m.	Break
10:30 a.m.	Tropical aerosols, clouds, and precipitation – Paulo Artaxo, University of São Paulo
11:00 a.m.	Overview of the DOE Joint Genome Institute – Daniel Drell, BER
11:15 a.m.	Guidance to breakout groups – Chair: Wanda Ferrell, BER
11:30 a.m.	Breakout Sessions (two groups) – Identify and discuss important unresolved science questions concerning relationships between aerosols and cloud properties under pristine and polluted conditions in the target region
12:30 p.m.	Working lunch
3:30 p.m.	Break
4:00 p.m.	Plenary session featuring reports from breakout sessions by group discussion leaders – Chair: Dorothy Koch, BER
5:00 p.m.	Moderators and rapporteurs convene to summarize workshop discussions

Wednesday, July 27

8:30 a.m.	Consolidated summary of Day 1 breakouts and instructions for Day 2 – Chair: Dorothy Koch, BER
9:00 a.m.	Breakouts sessions (two groups) – Identify and discuss observation and modeling strategies to address gaps in understanding
10:30 a.m.	Break
11:00 a.m.	Breakouts reconvene
12:00 p.m.	Working lunch
1:00 p.m.	Plenary session featuring reports from breakout sessions by group discussion leaders – Chair: Michael Kuperberg, BER
3:00 p.m.	Summary of workshop – Chair: Michael Kuperberg, BER
3:30 p.m.	Adjourn
3:30 to 5:00 p.m.	Moderators and rapporteurs remain and draft summary report

Appendix 2: Participants

Participants

Research Community

Dr. Thomas Ackerman
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Dr. Paul R. Moorcroft
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Dr. Athanasios Nenes
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Dr. Michael W. Palace
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Dr. David Parsons
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Dr. Joyce Penner
University of Michigan

Dr. Scott Saleska
University of Arizona

Dr. Courtney Schumacher
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Dr. Peter Thornton
Oak Ridge National Laboratory

Dr. Margaret S. Torn
Lawrence Berkeley National Laboratory

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Mr. Rick Petty
ARM Program Manager

Dr. Dorothy Koch
Earth System Modeling Program Manager

Dr. Renu Joseph
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Dr. Michael Kuperberg
Terrestrial Ecosystems Program Manager

Dr. Daniel Stover
Terrestrial Ecosystems Program Manager

Dr. Ashley Williamson
Atmospheric System Research Program Manager

Mr. Paul Bayer
Environmental Molecular Sciences Laboratory (EMSL) Program Manager

Dr. Daniel Drell
Joint Genome Institute Program Manager

Dr. Todd Anderson
Subsurface Biogeochemical Research Program Manager

Dr. Arthur Katz
Genomic Science, Subsurface Biogeochemical Research Program Manager

Mr. Patrick Horan
Science Assistant

Observers

Dr. Beat Schmid
PNNL, ARM Aerial Facility Manager

Dr. Raymond Teller
EMSL

Rapporteurs

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PNNL, ARM Technical Director

Mr. Kim Nitschke
Los Alamos National Laboratory, ARM Mobile Facility Manager

Mr. Jimmy Voyles
PNNL, ARM Chief Operations Officer

Appendix 3: Current Measurement Capabilities

1. ARM Mobile Facility Instruments

Aerosol Observing System

- Cloud Condensation Nuclei
- Nephelometer
- Particle/Soot Absorption Photometer
- C_ L_ Absorption Photometer

Downwelling Radiation

- Shaded Black and White Pyranometer
- Normal Incidence Pyrheliometer
- Precision Infrared Radiometer
- Precision Spectral Radiometer
- Infrared Thermometer
- Multi-Filter Rotating Shadow Band Radiometer
- Narrow Field of View Radiometer
- Solar Array Spectrometer – Hemispheric irradiance
- Solar Array Spectrometer – Zenith radiance

Upwelling Radiation (from 10 m tower)

- Precision Infrared Radiometer
- Precision Spectral Radiometer
- Infrared Thermometer

Surface Meteorology

- Barometer
- Optical Rain Gauge
- Present Weather Sensor
- Temperature and Humidity Sensor
- Anemometer

Atmospheric Emitted Radiance Interferometer (AERI)
Cimel Sun Photometer
Radiosonde System (4 launches per day from AMF site)
Micropulse Lidar with Dual Polarization
Doppler Lidar
Eddy Correlation System – Latent and sensible heat fluxes
Microwave Radiometer
High-Frequency (183 GHz) Microwave Radiometer
1290 MHz Radar Wind Profiler
Microwave Profiler
35 GHz/94 GHz Scanning ARM Cloud Radar
Vaisala Ceilometer (range ~7 km)
94 GHz Vertically Pointing Cloud Radar
Total Sky Imager
Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)
TSI Nephelometer
Photo-Acoustic Soot Spectrometer (PASS-3)
SMPS
PTR-MS
Trace Gas – CO, O_3, SO_2, NO_x

2. ARM Mobile Aerosol Observing System

- Vaisala Meteorology Station
- Particle/Soot Absorption Photometer
- Aethalometer
- Aerodyne Aerosol Chemical Speciation Monitor
- TSI 3772 Cloud Nuclei Counter
- Hygroscopic Tandem Differential Mobility Analyzer (HTDMA)
- Cloud Condensation Nuclei Counter
- Particle into Liquid Sampler (PILS)
- Humidigraph
- TSI 3776 Cloud Nuclei Counter
- Single Particle Soot Photometer (SP2)

3. ARM Aerial Facility (G1) Instruments

Atmospheric State

- Rosemont 102 – Temperature
- Rosemont 1201F1 – Static pressure
- Rosemont 1221F2 (3) – Differential pressure
- GE-1011B Chilled Mirror Hygrometer – Dew point
- AIMMS-20 (5-port air motion sensing) – True air speed, altitude, angle-of-attack, side-slip, T, RH

Aerosol

- TSI 3025 – Total particle concentration (>3 nm)
- TSI 3010 – Total particle concentration (>10 nm)
- FIMS – Aerosol size distribution (30 to 100 nm)
- PCASP – Aerosol size distribution (100 to 3,000 nm)
- PSAP – Aerosol absorption, 3 wavelengths
- TSI 3563 Nephelometer – Aerosol scattering, 3 wavelengths
- HR-ToF-AMS – Size-resolved aerosol composition
- Dual Column Cloud Condensation Nuclei Counter

Cloud Microphysics

- HVPS-3 – Cloud droplet size distribution (400 to 50,000 microns)
- 2DS – Cloud droplet size distribution (10 to 3,000 microns)
- Fast-CDP – Cloud droplet size distribution (2 to 50 microns)
- CPI – Cloud Particle Imager (~2 to 1,000 microns)

Gases

- PTR-MS – Real-time VOC
- Carbon Monoxide Analyzer
- NO, NO_2, and total NO_y
- Ozone Monitor
- Cavity Ringdown Spectrometer – CO_2, CH_4, H_2O

Platform Position/Velocity/Altitude

- Trimble DSM – Position and velocity
- Trimble TANS – Pitch, roll, and azimuth

Water Content

- SEA WCM-2000 – Liquid water and total water content

Radiation

- SPN-1 – Downwelling direct, diffuse, and total shortwave radiation
- SPN-1 – Upwelling shortwave radiation

4. Terrestrial Ecosystem Science

- Los Alamos National Laboratory Fourier Transform Spectrometer

5. CHUVA Measurements

K34 Tower Area

- Electric Field Mill Instrument
- GPS Device (network)
- Microwave Radiometer – Temperature and humidity profiles (MP3000)
- Joss and Parsivel Disdrometers (network)
- Rain Gauge (network)
- Micro Rain Radar (MRR)
- Temperature and Soil Moisture Profile
- Radiation (short- and longwave) Components, Upward and Downward
- Eddy Correlation System – Heat, moisture, and CO_2 flux
- Automatic Weather System Mast

Two additional radiosonde systems to be implemented to form a triangle with the AMF site. During IOP periods, CHUVA's project will run radiosondes (up to six sondes per day) to complete this triangle in order to compute divergence and convergence of moisture properties.

6. Center for Weather Forecasting and Climate Studies (CPTEC) Model Contributions

Operational mode (twice a day) results from a GCM (45 by 45 km) and the mesoscale model ETA (20 by 20 km) will be available for the experiment.

A very detailed resolution (1 by 1 km) model (BRAM) centered at the AMF site will be run with results available for the GOAmazon2014 experiment.