Collaborative Research in Support of GOAmazon Campaign

Summary of projects awarded in Fall 2013 under Funding Opportunity Announcement DE-FOA-0000919.

Funding Opportunity Announcement (FOA) Overview

Tropical deep convection in its natural state and the underlying processes that drive it are poorly understood and modeled, often with insufficient observational data sets to advance scientific understanding and model representation. Given the current state of the science, the Office of Biological and Environmental Research's Climate and Environmental Sciences Division (CESD) is providing support to the community to conduct a major field experiment to advance the scientific understanding of coupled atmosphere-cloud-terrestrial tropical systems.

The GreenOceanAmazon2014 (GOAmazon) field experiment, (http://www.arm.gov/campaigns/amf2014amazon), will extend through the wet and dry seasons for a one-year period, January 1 - December 31, 2014, with a planned extension through 2015. The Department of Energy's ARM Climate Research Facility, Environmental Molecular Sciences Laboratory, and Terrestrial Ecosystem Science Program will provide support for observational resources to be deployed in the Amazon Basin. Starting in 2014, both the ARM Mobile Facility (AMF) and ARM Aerial Facility (AAF) airborne platform will be on location near Manaus, Brazil for the GOAmazon campaign. Under this FOA, the Atmospheric System Research (ASR), Regional and Global Climate Modeling (RGCM), and Terrestrial Ecosystem Science (TES) programs supported research using data collected as part of GOAmazon to evaluate and improve the representation of these coupled processes in climate models.

The scope of GOAmazon is derived from scientific questions involving interactions and interdependencies among tropical atmospheric, terrestrial ecosystem, and carbon cycle processes, from both an experimental and modeling context. More specifically, the GOAmazon experiment will address how organic 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 influenced by pollutant outflow from a tropical megacity. Observations will provide a data set vital to constrain tropical rain forest model parameterizations for organic aerosols, cloud and convection schemes, and terrestrial vegetation components, and evaluate how process interactions are perturbed by pollution.

In view of the mutual interest in the GOAmazon science goals of both U.S. and Brazilian science agencies, this FOA was coordinated with announcements issued from the Brazilian state research funding agencies FAPEAM (Fundação de Apoio à Pesquisa do Estado do Amazonas, or Amazonas Research Foundation) and FAPESP (Fundação de Apoio à Pesquisa do Estado do São Paulo, or São Paulo Research Foundation). Proposals submitted to this announcement were required to be collaborative with a Brazilian research scientist employed by an institution qualified to submit proposals and receive funding from either FAPEAM or FAPESP.

While the ASR, TES, and RGCM programs support a broad spectrum of fundamental research and considered research applications within this scope, this FOA particularly encouraged applications in the following Science Areas:

Atmospheric System Research (ASR): The goal of the ASR program is to improve the treatment of clouds, aerosols, and radiative transfer processes in atmospheric models, that in turn are combined with ocean, terrestrial, and ice sheet models to make projections of climate change. For this solicitation, ASR focused on tropically-relevant science in the context of the GOAmazon campaign in the following specific Science Areas:

- Improved understanding of the life cycle of aerosols in the Amazon basin during the GOAmazon 2014-2015 timeframe, including the interaction of pristine and polluted air masses;
- Improved understanding of the interaction of aerosols and clouds over the Amazon basin, including aerosol impacts on precipitation and tropical convective processes, as well as cloud impacts on aerosol transport, chemistry, and removal; or
- Improved understanding of the evolution of tropical convective systems in the GoAmazon domain and the processes driving these transitions.

Terrestrial Ecosystem Sciences (TES): The goal of the TES program is to improve the representation of terrestrial ecosystem processes in Earth system models thereby improving the quality of climate model projections and providing the scientific foundation needed to inform DOE's energy decisions. For this solicitation, TES focused on tropically-relevant science in the context of the GOAmazon campaign in the following specific Science Areas:

- New or improved understanding of the drivers and feedbacks of drought and related natural disturbances on tropical forests. Particular emphasis is placed on hydraulic properties, understanding of temperature thresholds and sensitivities of photosynthesis and respiration, and forest carbon allocations;
- Improved understanding of belowground processes and mechanisms across scales associated with a changing climate in the Amazon basin. Particular emphasis is on plant, mycorrhizal and soil biogeochemical processes impacted by changes in temperature, precipitation, and carbon allocation;
- Improved understanding of physiological and environmental factors (e.g., light quality) that control the cycling of carbon and nitrous oxides through tropical forest ecosystems; or
- Improved understanding of fungal derived aerosols and their interactions with atmospheric processes beyond the vegetative canopy.

Regional and Global climate Modeling (RGCM): The goal of the RGCM program is to advance the predictive understanding of Earth's climate, its variability, and change by focusing on analysis of regions critical to climate; evaluating robust methods to obtain higher spatial resolution; and diagnosing and analyzing state-of-the-science for coupled climate and Earth system models to understand climate variability and change, at regional and global scales. For this solicitation, RGCM focused on tropically-relevant science in the context of the GOAmazon campaign in the following specific Science Areas:

- Enhanced understanding of the interactions between multi-scale processes that relate the local precipitation and hydrological processes to the large-scale climate;
- The relative importance of model resolution, cumulus parameterizations, and land surface with respect to Amazon cloud and precipitation model biases, and remote teleconnections;
- Understanding how net primary production (NPP) interacts with radiation, temperature, and precipitation in clean vs. polluted conditions; or
- The relative roles of local and large-scale, both terrestrial and atmospheric influences, on processes controlling diurnal, seasonal, and interannual variability of convection and precipitation.

Six awards were made through this Funding Opportunity Announcement totaling $5,663,246 over three years.

Funded Projects

Atmospheric System Research

Brazil-USA Collaborative Research: Modifications by Anthropogenic Pollution of the Natural Atmospheric Chemistry & Particle Microphysics of the Tropical Rain

- **Principal Investigator:** Scot Martin (Harvard University)
- **US Collaborators:** Saewung Kim (University of California, Irvine); Jose Jimenez (University of Colorado, Boulder)
- **Brazilian Collaborators:** Henrique Barbosa (University of São Paulo); Rodrigo Souza (University of the State of Amazonas)
- **Award:** $1,349,999 over 3 years

Manaus, a city of nearly two million people, represents an isolated urban area having a distinct urban pollution plume within the otherwise pristine Amazon Basin. The plume has high concentrations of oxides of nitrogen and sulfur, carbon monoxide, particle concentrations, and soot, among other pollutants. Critically, the distinct plume in the setting of the surrounding tropical rain forest serves as a natural laboratory to allow direct comparisons between periods of pollution influence to those of pristine conditions. For this purpose, we propose a Brazil-USA collaborative project during the two Intensive Operating Periods of GoAmazon. The project addresses key science questions regarding the modification of the natural atmospheric chemistry and particle microphysics of the forest by present and future anthropogenic pollution. The first objective of the proposed project is to understand and quantify the interactions of biogenic and anthropogenic emissions with respect to the production of secondary organic aerosol (SOA). The second objective is to test the hypothesis that new particles under natural conditions are produced as a result of evaporation of primary particles emitted by fungal spores as well as to investigate any shifts in this mechanism under pollution conditions, e.g., in consequence to the high concentrations of SO_2 in the pollution plume. Combined, the number-diameter distribution is the key connection to upscaling the effects of aerosol particles on clouds and climate. Understanding this upscaling under clean and pollution conditions, including differences, is the third objective. The objectives will be addressed both by data sets obtained by to-the-purpose instrumentation deployed only during the IOPs as well as by baseline data sets of the ARM Mobile and Aerial Facilities. The additional IOP instrumentation will include a chemical ionization mass spectrometer for OH, H_2SO_4, and HO_2^+ RO_2 concentrations, an oxidation flow reactor and temperature profiler in front of an aerosol mass spectrometer as well as a proton-transfer gas mass spectrometer to define mechanisms of SOA production and VOC chemistry, and a thermal desorption chemical ionization mass spectrometer to study the chemical composition of freshly nucleated particles. The data sets will be put to use in several different upscaling analyses.

Bridging Land-Surface Fluxes and Aerosol Concentrations to Triggering Convective Rainfall

- **Principal Investigator:** Marcelo Chamecki (Pennsylvania State University)
- **US Collaborators:** Paul Stoy (Montana State University); David Fitzjarrald (State University of New York, Albany); Gabriel Katul (Duke University)
- **Brazilian Collaborators:** Celso von Randow (Brazilian National Institute for Space Research); Antonio Manzi (National Institute for Research in the Amazon)
- **Award:** $854,311 over 3 years

The proposed research explores the lifecycle of secondary aerosols in pristine and polluted environments at the three sites of the GoAmazon project. The investigation spans the biological, chemical, and physical conditions influencing emissions and reactions of precursors (biogenic and anthropogenic volatile organic compounds, VOCs), formation, transport of aerosols out of the atmospheric boundary layer and their role on cloud formation and precipitation triggers. The main hypothesis to be evaluated is that in rural environments, secondary organic aerosols principally form as the result of the photo-oxidation of VOCs whereas in polluted environments, aerosols originate from both direct sources and reactions entailing biogenic and anthropogenic VOCs. To address the main research hypothesis, four research objectives frame the compass of this project:

Q1: "What are the vegetation and the atmospheric controls on the turbulent fluxes of mass and energy between forests and the atmosphere, and to what extent do the resulting energy fluxes trigger convection initiation and govern the growth rates of the convective boundary layer in the GoAmazon study region?" Q2: "To what degree are emissions, surface deposition, and chemical transformation of gases and aerosols in forested areas controlled by biotic versus abiotic factors?" Q3: "To what extent locally emitted or formed gases and aerosols escape the atmospheric boundary layer capping inversion and enter the cloud layer over the diurnal cycle?" Q4: "What is the significance of secondary organic aerosols and how do their consequent cloud condensation nuclei (CCN) affect cloud formation? As a corollary: Can the concentration of nitrogen oxide levels and aerosol hygroscopicity be used to 'fingerprint' the impacts of urbanization on the attributes of CCNs?"

Research methods include intensive field experiments within the roughness sublayer and the entire atmospheric boundary layer, large eddy simulation studies to unfold the three dimensional flow and aerosol concentration fields, low-dimensional modeling that allows for long-term integration and theoretical analysis of bifurcation delineating the 'rain-no rain' parameter space, and integration efforts to infuse findings into the larger Brazilian Earth System Model (BESM). A main feature of the experimental setup is tethered balloon observations that will provide distributions of aerosol precursors and aerosols in the atmospheric boundary layer and how these distributions are perturbed by pollution. The generated data sets will permit determination of the influence of anthropogenically influenced secondary organic aerosols in cloud formation processes.

Terrestrial Ecosystem Sciences (TES)

Collaborative Research on Ecophysiological Controls on Amazonian Precipitation Seasonality and Variability

- **Principal Investigator:** Jung-Eun Lee (Brown University)
- **US Collaborators:** Joe Berry (Carnegie Institute of Washington); Pierre Gentine

(Columbia University); Benjamin Lintner (Rutgers University)
- **Brazilian Collaborators:** Laura De Simone Borma (Brazilian National Institute for Space Research)
- **Award:** $974,900 over 3 years

The Amazon currently plays a critical role in the terrestrial climate system. Over the last decade, Amazonian forests have begun experiencing more frequent dry periods, including two extreme drought episodes in 2005 and 2010. However, the future of the Amazon as projected by current generation climate or earth system models is highly uncertain: how global warming and other aspects of anthropogenic change such as deforestation and degradation will ultimately impact this system is far from clear. A dominant source of uncertainty regarding Amazonian climate and its future evolution is the role of land vegetation- atmosphere coupling, especially interactions between vegetation and precipitating deep convection occurring during the late dry season/early wet season when land-vegetation-atmosphere coupling has been shown to be stronger. Quantitative understanding of this coupling is critical since forest productivity is sensitive to the duration and intensity of the dry season. Thus, in the present proposal, our principal objective is to address how vegetation influences climate variability and precipitation over Amazonian rainforests, with an emphasis on plant physiological controls on deep convection triggering along a geographical water stress gradient. To support this objective, our proposed research comprises three interrelated activities: (i) in situ measurements of plant physiological water stress with a focus on fluorescence as a proxy for water stress and its control on surface energy and water budgets as observed at existing flux tower sites; (ii) diagnostic analysis of basin scale plant stress by remote sensing, observed surface turbulent fluxes, boundary layer properties, and cloud cover and precipitation along a moisture gradient; and (iii) process- based model studies of the pathways through which the surface energy partitioning (Bowen ratio) and transpiration, as modified by water stress, influence convection both locally and non-locally.

Understanding the Response of Photosynthetic Metabolism in Tropical Forests to Seasonal Climate Variation

- **Principle Investigator:** Dennis Dye (US Geological Survey)
- **US Collaborators:** Valeriy Ivanov (University of Michigan); Scott Saleska (University of Arizona)
- **Brazilian Collaborators:** Luiz Aragao (Brazilian National Institute for Space Research); Marciel Ferreira (Federal University of Amazonas)
- **Award:** $970,020 over 3 years

Researchers at the U.S. Geological Survey, the University of Michigan, the University of Arizona and the University of Technology Sydney (Australia) are collaborating with scientists in Brazil on a 3-year research project in support of the Department of Energy's Green Ocean Amazon (GOAmazon) experiment. The project investigates a basic yet unanswered question in Earth system and global carbon cycle science: What controls the response of photosynthesis in Amazon tropical forests to seasonal variations in climate? This question, despite its apparent simplicity, is the subject of an ongoing scientific puzzle that has so far been remarkably difficult to answer with confidence. For example, seasonal patterns of photosynthesis simulated by several state-of-the-art, computer-based models of the Earth system, and seasonal patterns of vegetation "greenness" recorded by Earth-observing satellites, disagree with patterns seen in measurements of ecosystem-atmosphere carbon dioxide exchange at monitoring sites in the central Amazon. The project is designed to resolve these disagreements by developing new knowledge and deeper understanding of seasonal climate-photosynthesis relations in Amazon tropical forests. The project focuses on existing tropical forest study sites near Manaus and Santarem, Brazil. The research methodology includes intensive field campaigns to measure physiological and hydrological properties of leaves and trees, innovative remote sensing instruments to monitor forest optical properties and the effects of clouds and smoke on solar radiation, and photosynthesis modeling that accounts for 3-dimensional variation in the forest structure and light environment. The results from the research project will help guide improvements in the treatment of tropical forest photosynthesis and related processes in Earth system models, and help establish a foundation for future tropical studies.

Regional and Global Climate Modeling (RGCM)

Multi-Scale Processes Driving Tropical Convection and Influence of the Aerosol

- **Principal Investigator:** Carlos Mechoso (University of California, Los Angles)
- **Brazilian Collaborators:** Tercio Ambrizzi (University of São Paulo)
- **Award:** $722,973 over 3 years

This collaborative project between scientists in the US and Brazil addresses the fundamental processes that drive tropical deep convection and aerosol effects on these processes. A two-pronged approach is planned for the proposed research: (1) statistical analysis of data from the GOAmazon sites in view of properties of the atmospheric large scale environment that are relevant to convection and its interaction with aerosols, and (2) effects of aerosols on tropical precipitation for clean and polluted situations. In situ data collected by the GOAmazon campaign and output from a hierarchy of numerical models, ranging from general circulation models of the coupled atmosphere-ocean system to cloud resolving models, is available to the participants and will be used in the proposed research. In reference to approach (1), we will investigate the effect of free tropospheric humidity and vertical shear on deep convective onset. We will also investigate the intraseasonal variability in the characteristics of convection over the GOAmazon region. Approach (2) will use the results from step (1) to stratify the data from the GOAmazon sites according to aerosol information (e.g., mass loading, size distribution and chemical composition). Then the regulating effects of aerosols on selected cases of deep convection will be assessed by running simulations using a cloud resolving model (CRM) coupled with detailed spectral bin microphysics for cases of pristine and polluted conditions. The results from this project will contribute to improving the parameterizations of cloud and aerosol effects by increasing the knowledge of the processes that drive tropical convection and the aerosol influences on these processes. An important collaboration is expected among participants. The GOAmazon proposal gives both groups the opportunity to exchange knowledge and experience, with the US team learning more about the Amazon climate and the Brazil team learning more about large-scale numerical models. We are confident that the proposed scientific collaboration will be mutually beneficial in many senses.

Understanding the Causes of the Biases that Determine the Onset of the Rainy Season in Amazonia in Climate Models Using the GoAmazon-CHUVA Measurements

- **Principal Investigator:** Rong Fu (University of Texas, Austin)
- **Brazilian Collaborators:** Jose Orsini (Brazilian National Institute for Space Research)
- **Award:** $711,158 over 3 years

The onset of the Amazon rainy season has a large temporal and spatial variability, and strong impact on aerosols, ecosystems, fire, carbon fluxes, dry season length, agriculture, and hydropower. Two major droughts occurred in the region in the last 20 years, and the dry season has increased in length by about one month. These events highlight the urgency for improving our understanding and capability to project the rainy season onset and drought variability. However, global climate models (CMIP3 and

CMIP5) appear to underestimate the past variability, and also project virtually no future change of the onset of rainy season over the Amazon even when they are forced by strong greenhouse forcing under the RCP8.5 scenario. Why these models underestimate the variability of the rainy season onset, and whether this bias implies an underestimate of sensitivity of their dry season length to anthropogenic radiative forcing remain unclear. This proposal aims to explore use of the measurements provided by the Atmospheric Radiation Measurement (ARM) Mobile Facilities (AMF)-GoAmazon project and the Cloud processes of the main precipitation systems in Brazil (CHUVA) Field Experiments, along with global and regional model experiments, to explore the sources of the above described uncertainty, in order to improve the US CESM and the Brazilian Eta regional Model and the BESM (Brazilian Earth System Model). Based on previous and our ongoing studies, we hypothesize that the underestimation of changes of the rainy season onset over the Amazon and its climate variability and sensitivity to anthropogenic forcing are in part related to: a) The inadequate representation of the types of convection (i.e., maritime versus continental) and their relationships to aerosols, land surface and atmospheric circulation as represented in climate models, b) Inadequacies of the modeled oceanic variability, land surface processes and their coupling to the atmosphere.

To evaluate these hypotheses, we propose to clarify the following questions: a. How would changes of land surface conditions and aerosol influence the intensity and type of the convection over the Amazon? How adequately are these influences represented in NCAR/DOE CESM 1.2/CAM5.3/CLM4.5 climate model and the Eta regional Model and the BESM (Brazilian Earth System Model) as used by the Brazilian National Institute of Space Research (INPE)? b. How would a change of convective type influence the vertical profiles of diabatic heating, surface fluxes and large-scale circulation during the dry to wet season transition? c. What are the relative contributions from uncertainties of the local processes (land surface and aerosols) vs. those of Atlantic and Pacific ITCZ to the underestimation of the variability of the dry season length in CESM and BESM?

Further information on GOAmazon objectives along with current progress is available at http://www.arm.gov/campaigns/amf2014amazon.

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