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Interactions between urban and forest emissions in Manaus, Amazonia: The Brazilian component of GoAmazon

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Abstract

The GoAmazon experiment seeks to understand how aerosol and cloud life cycles are influenced by pollutant outflow from Manaus in the tropical rain forest. Particularly, the susceptibility to cloud-aerosol-precipitation interactions and the feedbacks among biosphere and atmosphere functioning and human activities. The scientific objectives are organized as Aerosol Life Cycle (ALC), Cloud Life Cycle (CLC), and Cloud-Aerosol-Radiation-Precipitation Interactions (CAPI). One of the focus is to understand the production of secondary organic aerosol (SOA) from the interaction of urban pollution emissions with VOCs emitted from the forest. Manaus is a 2 million people urban area surrounded by hundreds of kilometers of forest, and the study of atmospheric processes in this interaction is important to regional and global climate change assessments. A set of detailed aerosol, trace gases and cloud measurements will be performed over 6 different sites, followed by detailed meteorological transport studies. Atmospheric properties measurements will take place before the Manaus plume on three sites (ATTO (site T0), ZF2 (site T01) and EMBRAPA (site T02)), 2 sites will be located downwind of the Manaus plume (Iranduba (site T2), close to the Negro River and Manacapuru (site T3)) and one site will be operated downtown Manaus. This FAPESP proposal involves the installation and operation of all 3 upwind sites (ATTO, ZF2 and EMBRAPA) and Iranduba. The data analysis and modeling, nevertheless will make use of all GoAmazon sites and data. In Manacapuru, US DoE will operate the ARM Mobile Aerosol Observing System (MAOS-A and C) and the ARM Mobile Facility #1 (AMF1). In the sites operated by this proposal, a large set of measurements will be performed: aerosol optical measurements with spectral light scattering and absorption, aerosol size distribution, aerosol composition for organic and inorganic components, CCN (Cloud Condensation Nuclei), aerosol optical depth, radiation balance, atmospheric vertical thermodynamic

structure among other measurements. Four aerosol mass spectrometers will be deployed to measure organic and inorganic aerosol composition with 30 minutes time resolution in several locations. Raman Lidar will measure the vertical distribution of aerosols and water vapor up to 12 Km. Trace gases such as O_3, CO, CO_2, CH_4, SO_2 and detailed VOCs characterization will also be determined. Measurements of cloud properties including cloud cover fraction, droplet size distribution, precipitation, water vapor and others will be combined with cloud and precipitation radars for a regional assessment of cloud-aerosol-precipitation relationship. Boundary layer thermodynamic properties will be measured with radiosondes in several sites. High resolution BRAMS regional modeling will be performed daily with 2 km resolution and full aerosol and trace gas chemistry. High resolution cloud modeling will integrate aerosol, CCN, water vapor and thermodynamic conditions for a variety of conditions. The GoAmazon measurements and modeling framework will provide a dataset vital to constrain tropical forest model parameterizations for organic aerosols, cloud and convection schemes, and radiation balance. The dataset also will provide insights into how these are perturbed by pollution and how they influence climate regionally and globally.

Resumo (in Portuguese)

O experimento GoAmazon busca entender como o ciclo de vida dos aerossóis e das nuvens são influenciados pelo transporte de poluentes de Manaus para regiões de floresta tropical. Em particular verificar a susceptibilidade das interações nuvem-aerossol-radiação-precipitação e os “feedbacks” entre o funcionamento da biosfera e atmosfera e as atividades humanas. Os objetivos científicos estão organizados em temas correlatos: Ciclo de Vida dos Aerossóis (CVA), Ciclo de Vida das Nuvens (CVN) e Interações Nuvem-Aerossol-Precipitação (INAP). Um dos focos é entender a produção de aerossóis orgânicos secundários (SOA) a partir da interação das emissões urbanas com compostos orgânicos voláteis (VOC) emitidos pela floresta. Manaus está localizada em uma área urbana com cerca de 2 milhões de pessoas e é cercada por centenas de quilômetros de florestas e o estudo dos processos atmosféricos nesta interação é importante tanto para mudanças climáticas regionais quanto para as mudanças globais. Um conjunto detalhado de medidas sobre aerossóis, gases traço e nuvens serão realizados em 6 diferentes sítios de medidas, seguidos de estudos detalhados sobre transporte e processamento atmosférico. Três sítios medirão propriedades atmosféricas vento acima da pluma de Manaus (ATTO (site T0), ZF2 (site T01), e EMBRAPA (site T02)). Dois sítios realizarão medidas vento abaixo da pluma de Manaus (Iranduba (site T2), próxima ao Rio Negro, e Manacapuru (site T3)). Um sítio de medidas operará no centro da cidade de Manaus. Esta proposta FAPESP envolverá a instalação e operação dos 3 sítios vento acima (T0, T01 e T02) e Iranduba (site T2), mas a análise dos dados e a modelagem envolverão todos os sítios e dados do experimento GoAmazon. Em Manacapuru, o US DoE operará o “ARM Mobile Aerosol Observing System (MAOS-A e C) e o Laboratório Móvel 1 do ARM (AMF1). Nos sítios operados nesta proposta um grande conjunto de medidas será realizado: medidas ópticas de aerossóis com absorção e espalhamento espectral de luz, distribuição de tamanho de partículas, composição do aerossol para os componentes orgânicos e inorgânicos, NCN (Núcleos de Condensação de Nuvens), espessura óptica de aerossol, balanço radiativo, estrutura termodinâmica vertical da atmosfera, entre outras. Quatro espectrômetros de massa para aerossóis serão utilizados para medir a composição orgânica e inorgânica dos aerossóis, com alta resolução temporal em várias localidades. Um

Raman LIDAR medirá a distribuição vertical de aerossóis e vapor d´água até uma altitude de 12 km. Gases traço como O_3, CO, CO_2, CH_4, SO_2 e uma caracterização detalhada dos VOC também serão determinadas. Medidas das propriedades das nuvens, incluindo a fração de cobertura de nuvens, distribuição do tamanho de gotas, precipitação, vapor d´água, entre outras, serão combinadas com informações obtidas de radares meteorológicos para um melhor entendimento sobre as relações nuvem-aerossol-precipitação. As propriedades termodinâmicas da camada limite serão obtidas através de radiossondas em vários locais. Modelagem regional de alta resolução com o modelo BRAMS será realizada diariamente com 2 km de espaçamento de grade com aerossóis e química dos gases traço ativada. Modelagem de produção e evolução de nuvens serão realizadas em alta resolução. As observações e modelagem do GoAmazon fornecerão um conjunto de dados vital para a formulação de parametrizações para aerossóis orgânicos, esquemas de convecção e formação de nuvens, balance de radiação e componentes da vegetação terrestre em modelos para a floresta tropical. O conjunto de dados também fornecerá informações sobre como essas parametrizações são perturbadas pela poluição e como esta influencia o clima regional e global.

1 - Justification and Rationale

Amazonia is one of the few continental areas where it is still possible to observe very pristine atmospheric conditions (Andreae et al., 2009). Wet season atmospheric conditions for aerosol particles resembles background conditions typical of pre-industrialization (Andreae et al., 2009, Davidson et al., 2012), with particle number concentrations bellow 300 #/cc and fine mode aerosol concentration at approx. 3 ug/m^3 (Rizzo et al., 2013). The Amazon Basin can be pictured as a biogeochemical reactor using the feedstock of plant and microbial emissions in combination with high water vapor, solar radiation, and photo-oxidant levels to produce secondary organic aerosol (SOA) particles and primary biological aerosol particles, with strong interactions between the forest and the atmosphere (Pöschl et al. 2010) (Figure 1). This reactor produces the nuclei for clouds and precipitation and partially sustains the hydrological cycle (Prenni et al. 2009). The Basin has been dubbed the “green ocean” because of the similarities in particle concentrations and cloud microphysics between it and remote oceanic regions (Williams et al., 2002). At the same time, large scale biomass burning emissions as well as urban pollution changes this picture with very high aerosol and trace gases concentrations (Martin et al., 2010). The effects of aerosol particles on the radiation balance and cloud microphysical properties, cloud cover, precipitation, and regional climate over the Amazon are significant, as several studies from the LBA Experiment (The Large Scale Biosphere-Atmosphere Experiment in Amazonia) have demonstrated (e.g. Artaxo et al., 2002, Silva Dias et al 2002, Procópio et al., 2004, Davidson, et al., 2012, Martin et al., 2010a). The low background aerosol concentrations, high water vapor levels and intense radiation make the Amazon region particularly susceptible to changes of its trace-level atmospheric composition. The climatic implications for strong tropical aerosol-cloud dynamic interaction are profound, ranging from modulation of local precipitation intensity to modifying large-scale circulations and energy transport associated with deep convective regimes.

Climate models have great difficulty in simulating deep convective clouds and their radiative effects. The convective activity and the atmospheric circulation of tropical South America are part of an American monsoon system, and any changes in tropical precipitation can have significant, potentially global consequences because of non-linear interactions of tropical waves with tropical precipitation in the Amazon, leading also to possible changes in the tropical Atlantic intertropical convergence zone (ITCZ).

This study, proposes understanding the present-day effects of a tropical megacity on a pristine environment. . Such understanding, however, shall provide an insight on a wider, global scale. Human activities by the year 2050 are projected to greatly increase the megacity count worldwide, particularly in tropical regions (Molina et al., 2004). Manaus with its 2 million people, high automobile fleet and several power stations is a large tropical source of aerosol and trace gases. The city of Manaus electricity is produced by burning high-sulfur fuel oil. The plume from the city has high concentrations of SO_2, NO_x, and soot, among other pollutants.

The production mechanisms for secondary particle components involve many trace gases, in particular biogenic volatile organic compounds, aromatics, nitrogen oxides (NOx), ozone (O_3), hydroxyl radical (OH), and sulfur species including dimethyl sulfide (DMS) and sulfur dioxide (SO_2) (Andreae et al., 1988, 2002, 1990). DMS and SO_2 are oxidized to form particle sulfate. BVOCs and aromatics react with O_3 and OH to produce oxidized organic products, a fraction of which have low enough volatility to condense and serve as particle components. BVOCs, aromatics and NOx together influence the concentrations of O_3 and OH, thereby influencing the production of BVOC oxidation products. Reactions both in the gas phase and in cloud waters are important.

Amazonian BVOC emissions and the major remaining uncertainties are described in detail by Kesselmeier et al., 2009. BVOCs are emitted from plants during growth, maintenance, decay, and consumption, and average emission rates account for more than 2% of net primary productivity in the Basin and other regions (Kuhn et al., 2007, Rasmunssen et al., 1988, Zimmerman et al., 1988). Major BVOCs emitted include isoprene (C_5H_8), monoterpenes (i.e., compounds composed of two isoprene moieties), sesquiterpenes (i.e., three isoprene moieties), ethane, and oxygenated VOCs (OVOCs). Tropical forests are the dominant global source of atmospheric BVOCs and the Amazon Basin is a major contributor, yet BVOC emissions have been studied more extensively in temperate regions. The high species diversity in the Basin is coupled with an ecological complexity and a seasonality that is, however, very different from temperate regions, yielding significantly different emission trends with different forest types. For example, because of the consistently high temperatures over the Basin, BVOC emissions do not exhibit a well pronounced seasonality. Isoprene and monoterpene emissions and aerosol concentrations are also strongly correlated in the Amazon. The explanation for the different diel monoterperene emission pattern in the Amazon rain forest compared to temperate regions is, as well, not yet fully known (Karl et al., 2009).

After emission, some fraction of the oxidized BVOCs yields secondary particle mass (Jimenez et al., 2009, Kanakidou et al., 2000). The OH oxidation pathway is particularly important for BVOC oxidation in the tropics given the high radiation levels and H_2O concentrations. Emissions of BVOCs have been incorporated into global chemical transport models, and the contribution of low-volatility BVOC oxidation products to the mass concentration of organic particles has been predicted. Heald et al. 2008 estimate that the conversion of South American BVOCs into secondary particle mass contributes 40% of the annual global production of this particle component. Knowledge of the composition, the sources, the chemistry, and the role of the secondary organic components of particles in the atmosphere and earth’s climate system is, however, still extremely limited. Even for the well-studied compound isoprene, recent analysis suggests that state-of-the-art atmospheric chemistry models greatly underpredict OH concentrations (Lelieveld et al., 2008), possibly implying important missing chemistry. The OH concentrations measured in flights by Lelieveld et al. over the Amazon forest (i.e., $5.6 \pm 1.9 \times 10^6$ molec cm^{-3} in the boundary layer and $8.2 \pm 3.0 \times 10^6$ molec cm^{-3} in the free troposphere) are significantly higher than anticipated from model calculations, suggesting an overlooked pathway mediated by organic peroxy radicals for OH production. Higher OH estimates change greatly our understanding of photochemistry in the tropics and the rate of transformations of BVOCs into aerosol particle mass.

Chen et al., 2009 characterized the submicron atmospheric particles in the Amazon Basin using an Aerodyne high-resolution aerosol mass spectrometer (AMS) during the wet season of 2008, as part of the AMAZE-2008 project. Patterns in the mass spectra closely resembled those of secondary-organic aerosol particles formed in environmental chambers from biogenic precursor gases. High-resolution mass spectra of SOA particles, obtained in the Harvard Environmental Chamber for the oxidation of isoprene, the monoterpene α-pinene, and the sesquiterpene β-caryophyllene, can be linearly combined to largely reproduce the patterns observed in AMAZE-2008. The organic mass concentration of the Amazonian ecosystem had an average value of 0.6 μg m^{-3} and an average elemental oxygen-to-carbon (O:C) ratio of 0.42. This average O:C ratio is also similar to that of laboratory SOA particles at realistically-low precursor concentrations. For comparison, urban-combustion primary emissions (O:C < 0.10) and aged regional particles (O:C ≈ 0.9) observed nearby Mexico City had significantly different values. Graham et al. 2003 noted that the fine-fraction organic-carbon loading is greater in the day than at night, suggestive of active SOA production enhanced by the photochemical oxidation of biogenic precursor gases. Speciation studies by chromatography show the presence of methyltetrols, which are produced by the oxidation of isoprene, in the fine fraction (Clayes et al., 2004).

The undisturbed central Amazon presents very low CCN particle concentrations, on the order of 150-250 CCN cm^{-3} (Artaxo et al., 1994, Pöschl, et al., 2010, Gunthe et al., 2009). These particles are mainly natural primary biogenic particles as well as SOA produced from oxidation of naturally emitted VOCs (Martin et al., 2010a, b). CCN concentrations are increased relative to local background by one to two orders of magnitude in the plume of daily pollution outflow from Manaus. These increases in CCN concentration are due not only to higher particle number concentrations but also to increased particle diameters and greater water-soluble fractions (Andreae, 2009). During repeated aircraft transects of the urban plume, Kuhn et al. (2010) observed that within the plume core of the Manaus outflow aerosol concentrations were strongly enhanced, with particle number concentrations reaching 30,000 cm^{-3} compared to background conditions of 300 cm^{-3}. Furthermore, only about 15% of the plume particles served as CCN, compared to 60 to 80% in background conditions. Moreover, the CCN concentrations increased with plume age, indicative of the condensation of water-soluble and water-insoluble species on particles.

The optical properties of natural biogenic aerosol particles changes with the interaction of Manaus urban plume. Several recent papers have observed strong absorption properties of natural biogenic aerosols (Schafer et al., 2008; Rizzo et al. 2011). Because of the intricate shapes and composition, biogenic particles can absorb significant amounts of visible light (Andreae and Gelencsér, 2006; Després et al., 2012). Rizzo et al. (2013) showed that the aerosol single scattering albedo (SSA) in a forest site in Amazonia is rather constant along the year even though there is variability in the presence of biomass burning aerosols, especially during the dry season. Under the influence of the Manaus plume, aerosol scattering and absorption coefficients measured at the same forest site were 2.5 and 5.0 times greater, respectively, than those measured for clean conditions during the wet season. The single scattering albedo decreased by 5% under the influence of the Manaus plume. SSA is one of the most important parameters for defining the climatic effects of aerosols (Forster et al., IPCC 2007) and is strongly influenced by urban and biomass burning aerosols. The surface radiative forcing of aerosol particles have important effects on the ecosystem, including reducing the total radiation fluxes and increasing the ratio of diffuse to direct radiation (Oliveira et al., 2007; Doughty et al., 2010). These changes directly affect plant photosynthetic rate (Mercado et al., 2011), specially on tropical forests, where enhanced photosynthesis was observed to reach 30-40 % of Net Ecosystem Exchange (NEE) for Manaus, Santarem, and Rondonia. Unknown are the overall effects of aerosols on photosynthetic rate in Amazonia, and this is a critical subject for global carbon balance that this study will develop in quantitative detail.

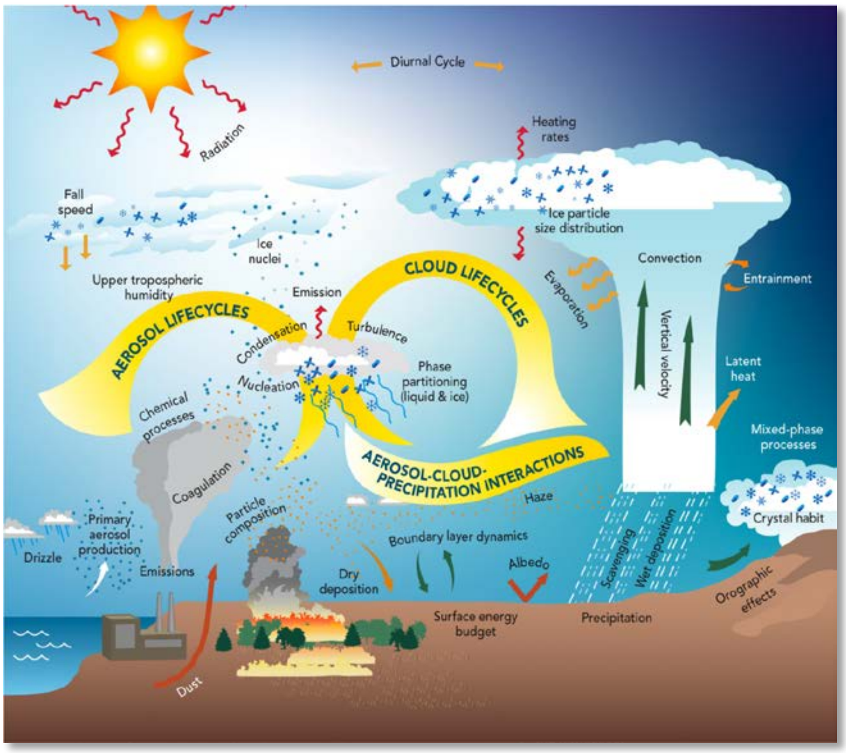

Figure 1 - Atmospheric system depiction showing connections between the aerosol life cycle interacting with the cloud life cycle thought surface and thermodynamic processes. The role of surface fluxes, including natural and urban emissions is very important for both life cycles. The role of convection and atmospheric thermodynamic conditions is also critically important. Interaction with solar radiation and precipitation makes critically important impacts on the ecosystem

1a - Aerosol Life Cycle

Aerosol particles exert important influences on climate and climate change by scattering and absorbing solar radiation with strong impact on radiation balance and by influencing the properties of clouds. The aerosol life cycle determines the spatial and temporal distribution of atmospheric particles and their chemical, microphysical, and optical properties. It is essential to improve understanding of the roles of aerosols in the climate system and specifically to decrease uncertainty in radiative forcing by aerosols (Forster et al., 2007). Current aerosol models require improvement in several areas: emissions,; mechanisms, new particle formation events, aerosol physical-chemical changes under biogenic and anthropogenic influences. The research that will be conducted by this proposal is usefully distinguished into four topical areas or elements: new particle formation, aerosol growth and aging, the direct radiative impacts of aerosol, and separating the natural vs. anthropogenic aerosol influences on aerosol properties.

New particle formation: Besides primary emissions of primary aerosol particles, another important source of atmospheric aerosols is the chemical conversion of gas-phase atmospheric precursors to new particles through nucleation and growth (Kulmala et al., 2012). New particle formation (NPF), which affects the number concentration of particles, is a key process in aerosol dynamics that governs size distributed composition and in turn the aerosol optical and cloud nucleating properties. Freshly nucleated particles are approximately a few nanometers in size and thus are too small to directly influence climate. But these particles can quickly grow, even over the course of a single day, to reach the size where they can serve as cloud condensation nuclei (CCN) or appreciably scatter light (heald et al., 2010). A strong coupling between nucleation and growth rates of nucleated particles further contributes to the climate importance of new particle formation. As particles grow their ability to serve as CCN or Ice Nuclei (IN) depends strongly on the size and composition of the particle (Fuzzi et al., 2007). Amazonia is a place where NPF is rarely observed naturally, but there are no studies on how urban pollution could enhance new particle formation in Amazonia (Artaxo et al., 2009).

Aerosol Aging and Mixing State: Aging of aerosols consists of modification of the composition, size, and surface properties of aerosol particles in the atmosphere by coagulation, condensation, and surface reactions (Seinfeld, 2007). These processes are important as they affect the optical and cloud nucleating properties of the aerosol. Measurements downwind of urban sources of aerosol particles and precursor gases have shown that the mass concentration of secondary organic aerosol (SOA) can be several-fold greater than can be explained on the basis of current model calculations using observed precursor concentrations. The dependence of SOA formation on nitrogen oxides and other factors will be examined in this proposal. This information is essential to the development of comprehensive chemical mechanisms that can contribute to a better understanding of the aerosol life cycle (Heald et al., 2008, 2010).

Direct radiative impacts of aerosol: Scattering and absorption of solar radiation by aerosols modify the amount of incoming solar radiation taken up by Earth, and modify the vertical distribution of that absorption and the resultant heating profile of the atmosphere. (Trenberth et al., 2009). Aerosol optical properties depend strongly on particle size, composition, mixing state and morphology, all properties that will be measured in this study. Previous studies from the IFUSP group shows a large effect from biomass burning aerosol on regional direct radiative balance (Procópio et al., 2003, 2004, Sena et al., 2013). Aerosols containing black and “brown” carbon absorb radiation in the visible spectral region (Martins et al., 1998, 2009, 2010) and have a potential large impact on climate by reducing the net solar radiative flux at the Earth’s surface and by warming the air in their vicinity, possibly leading to cloud evaporation (referred to as the aerosol “semi-direct effect”) (Koren et al., 2004, 2008, 2012).

Natural vs. Anthropogenic Influences on Aerosol Properties: Measurements that distinguish natural and anthropogenic influences on aerosol properties are needed to determine the anthropogenic perturbation to radiative forcing (Andreae et al., 2007, Artaxo et al., 2008). Both anthropogenic and natural processes contribute to the atmospheric aerosol loading, influencing the new particle formation, the role of anthropogenically enhanced levels of atmospheric oxidants in SOA formation from natural and more volatile organic emissions, and the oxidation reactions on aerosol surfaces and within cloud droplets.

1b - Cloud Life Cycle

Especially in Amazonia, clouds are critically important to sustain a vigorous hydrological cycle, recycling water vapor and strongly influencing radiation balance (Martin et al., 2010). Specific cloud life cycle research areas are categorized into three broad areas: dynamics, the atmospheric motions that generally dominate cloud life cycles; microphysics, the properties of cloud droplets/ice particles and rain and snow hydrometeors and the processes that determine these properties and their interactions; and radiation, the impacts of cloud amount and properties on absorption, emission, and transport of shortwave and longwave radiation in the atmosphere at the surface, and at the top of the atmosphere (Rosenfeld et al., 2008).

Atmospheric dynamics: Vertical air motions play a central role in cloud life cycles. Whereas emissions and nucleation lead to new aerosol particles, it is primarily atmospheric dynamical conditions in a sufficiently humid environment that lead to new cloud particles. To simulate cloud life cycles, models must adequately represent the strength and depth of updrafts and downdrafts. Important parameters in clouds include vertical air velocity variability, the structure of turbulent motions, the skewness of the vertical air velocity distribution, and atmospheric stability profiles. This proposal will use a multi-instrument and -platform approach to study the covariability of these dynamical parameters with the cloud microphysics in order to reveal the important linkages between boundary layer dynamics, radiation, cloud formation, and cloud composition, all of which are crucial to understanding the life cycle of these clouds. Entrainment of environmental air into clouds is a key process that is poorly understood and we will use a modeling approach to better understand processes that regulates entrainment in shallow clouds in Amazonia (Willimas et al., 2002).

Cloud microphysics: Accurate knowledge of the hydrometeor number, size, surface area, volume or mass, dispersion, skewness, and phase are required in order to understand basic cloud processes such as the microphysical evolution through competition for available water vapor, formation of precipitation-sized particles, sedimentation, and collisions among cloud particles. Within mixed-phase clouds both liquid and ice size distributions exist within the same cloud system, interacting and coevolving through myriad, complex mechanisms. Several key parameters in cloud model simulations remains very poorly constrained by measurements.

Radiation: The amount of solar radiation that reaches the Earth’s surface is strongly influenced by cloud optical depth, especially in areas with high cloud cover such as Amazonia (Trenberth et al., 2009). Anthropogenic increases in cloud-activated CCN modify cloud microphysical properties by decreasing the average cloud droplet size thus increasing the number of droplets sharing the same amount of cloud liquid water. This process is known as the cloud albedo effect (Forster et al., 2007). A more general representation of cloud radiative effects requires knowledge of the 3D cloud extinction structure, whose simplest manifestation is cloud optical depth, the vertical integral of extinction. The extensive use of several types of radars in GoAmazon will allow a partial retrieval of 3D cloud structure. In the IPCC AR4 report the larger uncertainty in the radiation balance came from the several aerosol indirect effects (Forster et al., 2007).

Aerosol-Cloud-Precipitation Interactions: Aerosols and clouds are inextricably coupled throughout their life cycles in processes that dictate cloud formation and development, spatial coverage, persistence, and precipitation efficiency (Khain, 2009). Cloud processing of aerosols plays an important role in aerosol chemical and microphysical properties through aqueous-phase chemistry, aerosol removal and vertical redistribution mediated by precipitation and vertical motions, especially in a convective region as Amazonia. Several of the climate models participating in the IPCC 4AR did not include anthropogenic aerosol-cloud interactions owing to lack of process understanding and of reliable approaches to model representation. There is a critical need for improved understanding in several areas: (1) the impact of aerosols on cloud particle formation processes that affect the concentration and size-distribution of cloud particles, (2) radiative impacts determined by the microphysical and macrophysical structure of clouds influenced by aerosol, and (3) precipitation efficiency dictated by a myriad of related processes including cloud depth, collision/coalescence, and entrainment. The light-absorbing properties of aerosols can have a strong influence on cloud dynamics though heating. Typically, the presence of absorbing aerosol is thought to induce atmospheric stability, suppress vertical motion, and decrease cloud formation (e.g., Koren et al., 2004).

1c - The plume of Manaus influencing aerosol and trace gas chemistry

Kuhn et al. 2010 reported the impact of the pollution plume of Manaus in the central Amazonia on aerosol concentrations, the oxidant cycle, and other measures of air quality on the otherwise pristine conditions of the central Amazon Basin. The experiment was based on the Brazilian Bandeirante aircraft measurements (Figure 2), and important results were obtained, including an ozone production of 15 ppb h^{-1}, with strong secondary organic aerosol production. Additionally, particle growth by condensation of soluble organic or inorganic species was observed. CCN fraction to total particles was strongly reduced, from 60-80% in pristine conditions to 16% in the urban plume (Figure 3) (Kuhn et al., 2010). The city of Manaus in the center of the Amazon Basin represents a unique scientific environment to study and understand how changes in human actions influence the interactive physical, chemical, and biological processes that regulate atmospheric chemistry and climate. At present, however, most knowledge of the influence of pollution outflow is based on studies carried out for cities at northern latitudes. The tropics represent a different regime of actinic flux, water vapor, temperature, and plant emissions. Trebbs et al., 2012 measured the mixing ratios of NO, NO_2, O_3, and volatile organic carbon as well as the aerosol light-scattering coefficient on a boat platform cruising on rivers downwind of the city of Manaus. Under pristine atmospheric conditions σ_s (light scattering) was below 11 Mm^{-1} NOx was measured below 0.6 ppb, coinciding with midday O_3 mixing ratios often lower than 20 ppb. As the boat got under the Manaus plume, far from the city, the polluted air masses were characterized by σ_s values of about 30 Mm^{-1}, NOx mixing ratios between 2 and 4 ppb, and by O_3 mixing ratios of up to 35 ppb. Photochemical production was very strong.

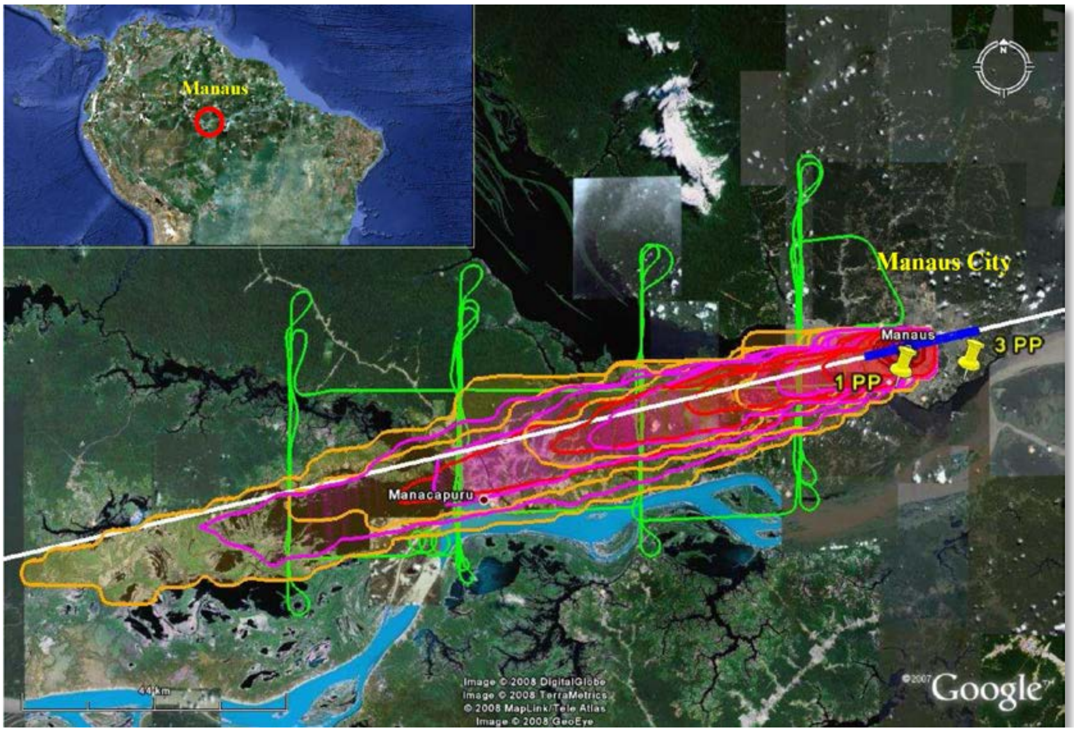

Figure 2 - The Plume of Manaus reaching pristine forest areas. Land cover image (from Google Earth) with an overlay of a flight pattern on 19 July 2001 from 10.00-14:00 (local time) that samples the Manaus plume. Flight track GPS data are shown in green line. The output of a HYSPLIT dispersion model run from the Manaus plume is indicated by the red/orange contour lines. The two yellow pins indicate the locations of power plants (3 PP, 560 MW capacity; 1 PP, 125 MW). Figure is adapted from Kuhn et al. 2010.

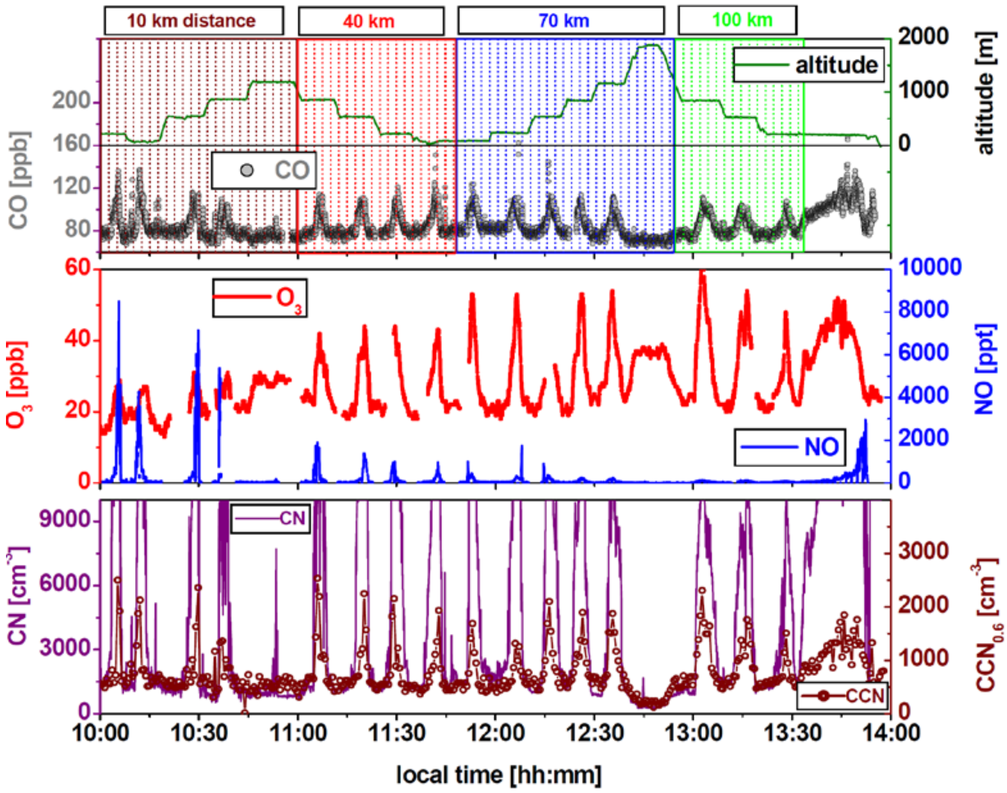

Figure 3 - Time series of trace constituent measurements on plume transects during Flight #18 on 19 July 10:00–14:00 LT. Vertical profiles of crosswind transects in the urban outflow are shown for successive distances (10, 40, 70 and 100 km) downwind of Manaus City. The rightmost sections of the diagrams show the flight back to Manaus at the 200m level (crossing the plume approx. perpendicularly). CN data shows particle concentrations up to 30,000 cm^{-3}. Figure adapted from Kuhn et al., 2010

Similar urban plume aging studies were also investigated in Mexico City, as part of the Milagro and MAX-Mex experiments. A strong production of secondary organic aerosols was observed, shown in the figure 4 bellow.

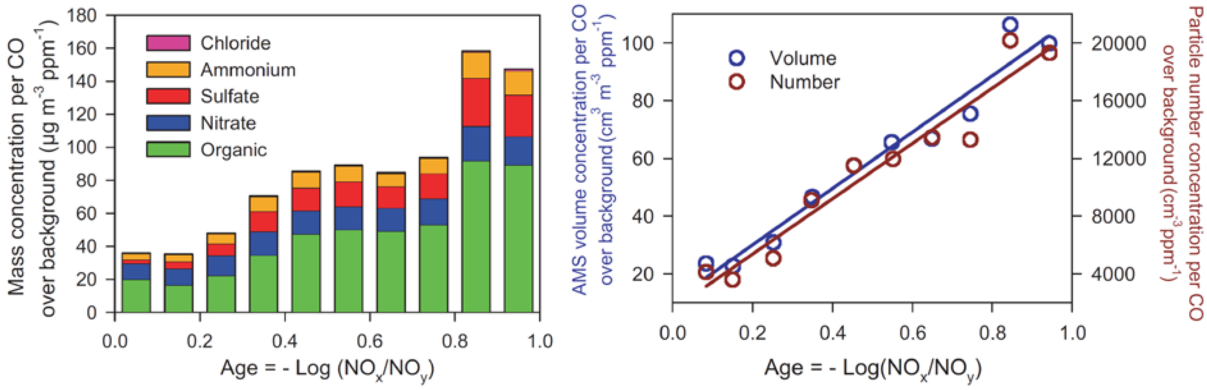

Figure 4 - Aging of aerosols measured in Mexico City during the 2006 MAX-MEX field campaign as function of photochemical age. Right: similar plot for aerosol volume and accumulation mode number concentration with linear regression lines.

1d - Clouds in Amazonia

In the tropical to equatorial regions, particularly in the heart of the Amazon Basin, clouds play a major role in several processes spanning a range of scales. Clouds are also the main cause of uncertainty in numerical modeling of the atmosphere from activities that range from weather forecasting, to seasonal forecasting, to climate projections and in a broader sense to Earth Climate System Modeling. As shown by recent modeling studies (Raupp and Silva Dias, 2009, 2010) the diurnal life cycle of clouds in atmospheric models is the basis for resonant wave interactions that excite slower modes in the atmosphere (e.g. Maden-Julian Oscilation).

Clouds are important features in the radiative balance of the atmosphere and at the surface (Trenberth et al., 2009), thus they directly impact dynamic processes providing an upscale interaction. Release of latent heat of condensation during cloud droplet formation provides a source of energy and moisture to the free troposphere (Houze, 1993; Dai et al., 1999). The radiative and thermodynamic effects of clouds combined interact with atmospheric dynamics providing the basis for upscale energy transport. Clouds impact on the aerosol concentration by providing regional to large scale transport (e.g. Freitas et al., 2009) and wet deposition by rainfall, thus having an effect on biogeochemical cycles. At the same time, aerosol interacts with clouds in the microphysical scale by acting as Cloud Condensation Nuclei and Ice Nuclei, but also by their effect on the radiative balance of the atmosphere and surface.

Aerosols and clouds are two features that are at the basis of uncertainty of climate models as stated by the IPCC (2007). The complex interactions between clouds and aerosol have been the focus of hundreds of studies in the last decade or so. Local observations, remote sensing data and modeling have been combined to unravel the microphysical, thermodynamic and dynamic causes for observed behavior and to reduce uncertainty of model simulations. However, still no final answer has been reached on the overall, global impact of aerosols on clouds, and to a certain extent of clouds on aerosol.

In the case of the Amazon Basin, other complications arise. The rainforest has singular behavior due (1) to its large extent, covering more than 5 million km^2, (2) to the average height of tree canopy, around 35 m, (3) to the very complex ecosystem below canopy, (4) to the sheer amount of clouds that form daily, and (5) in the last 4 decades, due to human intervention through deforestation, land use change and urban development.

Land-use change due to deforestation in the Amazon modifies surface properties that translate into a annual radiative forcing of about -7.3±0.9 Wm^{-2} (Sena et al., 2013). Some studies (Durieux et al., 2003, Negri et al., 2004, Saad et al., 2010, among others) have pointed out that deforestation has an impact on cloudiness through changes in surface fluxes of sensible and latent heating that change cloud base properties (Fisch et al., 2004) and also generate local circulation. Deforestation is usually achieved through biomass burning that generates enormous impact on aerosol concentration (Artaxo et al., 2002, Martin et al., 2010). Urban development in the tropics has been shown to affect rainfall (Silva Dias et al., 2013). Large cities in the heart of the Amazon Basin, like Manaus, provide a heat island effect (Souza and Alvala, 2012) with potential impact in the local circulation and cloudiness. Large rivers like the Amazon, Negro and its main tributaries like the Tapajós, have also been shown to produce an impact on the local circulation and on cloudiness and rainfall (Oliveira and Fitzjarrald, 1993; Silva Dias et al., 2004; Fitzjarrald et al., 2008, Paiva et al., 2011).

Recognizing the scientific challenge provided by the very complex scenario of intervening processes affecting cloud features in the Amazon Basin, the GoAmazon project has been funded by the US Department of Energy and approved by the Brazilian Federal Government (see appendix A, attached as a separate document in Fapesp/SAGE website, gives an overview for the GoAmazon project).

The aim of this part of the present proposal is to complement the measurements and the scientific objectives from GoAmazon and build up from the knowledge gathered in previous programs (Betts and Silva Dias, 2010) to contribute to the understanding and modeling of clouds.

1e - The Transition from Shallow to Deep Convection in Amazonia

During the TRMM/LBA campaign in the Amazon (Silva Dias et al., 2002; Williams et al., 2002), it became clear that shallow convection plays a critical role in the modulation of the diurnal cycle of precipitation and convection. The observations reported by Betts et al. (2002b) and Machado et al. (2002) showed a typical and consistent cloud life cycle picture. Firstly, a shallow cumulus cloud field establishes in the first hours after sunrise. The presence of these fair weather clouds reduces the shortwave radiation flux incident at ground level yielding a delay in deep convection. These shallow clouds also transport humidity from low levels to above the convective boundary layer. Next some light rain typically occurs at about noon, shallow convection evolves into deep convection and heavy rainfall ensues at about 14hs (LT). The daily cycle of rain rate may be seen in Figure 5 for the wet season (DJF and MAM). The dry season shows a more concentrated diurnal maximum in the afternoon.

A completely different picture is shown by numerical models. It has been known for some time (e.g. Betts et al., 2002a) that the ECMWF analysis, for instance, systematically produces heavy precipitation in the wet season much earlier than recorded observations, about two hours after sunrise. To test the hypothesis whether this issue was due to problems with the simulated dynamics of the atmosphere, Betts et al. (2002a) performed simulations with single column and 3-D models, under the same atmospheric conditions, and obtained the same results. The authors concluded that the difference between the observed and modeled precipitation diurnal cycle was more related to limitations of convection parameterizations than with atmospheric dynamics in the models.

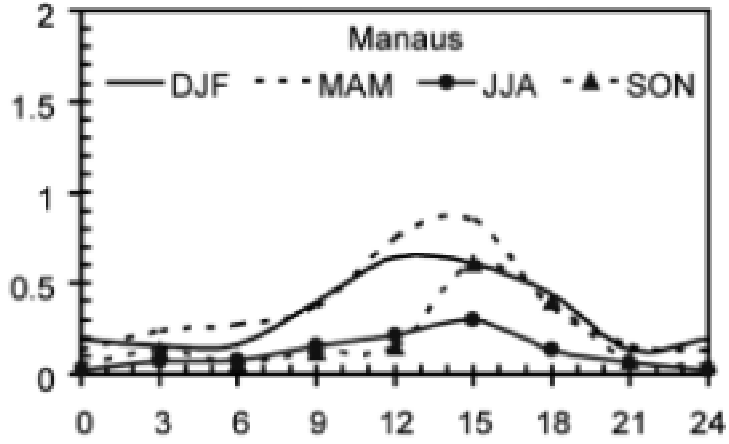

Figure 5 - Mean LT Hourly Rain Rate (mm/h) from TRMM radar data (Angelis et al., 2004)

This issue has still not been settled and is not exclusive of Amazonia, but rather common to other tropical regions (Rapp et al., 2011). The physical properties of shallow clouds, such as their cloud cover extent, albedo, lifetime, their relationship with land surface features, seasonality, interaction with large scale circulation, radiative balance, humidity transport and other processes, are far from well understood. In particular, the correct understanding and representation of the transition of shallow to deep convection is critical to a better understanding of the intense convective activity that characterizes the tropical regions of the globe. Moreover, this gap in the knowledge of shallow convection life cycle is critical for the performance and reliability of both regional and global modeling, that still rely on parameterizations of convective processes.

The shallow to deep convection transition in the Amazon region has been shown (Wu et al., 2009) to depend, from the modeling point of view, of two control parameters: the free troposphere stability and the relative humidity. The emergence of a distinct transition between shallow and deep convection is seen as an intrinsic property of the system. The authors show that the transition coincides with the time when the lapse rate of the virtual potential temperature of the clouds becomes larger than that of the environment. Shallow cloud formation and evolution in the tropics are usually simulated as a sub-grid feedback interaction in models. For example, Alapaty et al. (2012) incorporated such processes in the WRF model and obtained more realistic simulations of the attenuation of downward surface shortwave radiation. This reduction feeds back into clouds, as it modulates changes in latent and sensible heat fluxes, resulting in a notable reduction in modeled precipitation biases. However, improvement in simulations in some cases can be the net result of errors that compensate each other. Nam et al. (2012) analyzed the outputs from multiple climate models (CMIP5, Coupled Model Intercomparison Project) and compared them with different satellite data sets (CALIPSO lidar observations, PARASOL mono-directional reflectances and CERES radiative fluxes at the top of the atmosphere). They showed that current state-of-the-art climate models predict overly bright low clouds, even for a correct low-cloud cover. The impact of these biases on the Earth's radiation budget, however, is reduced because those models have the tendency to underestimate the low-cloud cover and to overestimate the occurrence of mid- and high-clouds above low clouds (Cesana and Chepfer, 2012).

Another difficulty is the diurnal partition of energy at the surface by sensible and latent heat fluxes, which is associated with the erosion of the nocturnal boundary layer and can influence the properties of the mixed layer (moisture, daytime mixed layer height, level of cloud base, etc.) and the development of cloud system. These conditions are expected to influence the occurrence and strength of deep convective cells and are usually not well represented in models. Wind shear instability also appears to link to the transition from continental to maritime convective type (e.g., Petersen et al., 2006). Its role needs to be clarified in order to isolate the influences of land surface changes on convective organization.

Yet another difficulty is to understand aerosol-cloud interactions, even if one restrains oneself to shallow non-precipitating cumuli. The usual platform for such studies is typically in situ (e.g., Brenguier et al., 2000) or remote sensing (e.g. Martins et al., 2011) airborne instrumentation suites. However, aircraft campaigns are costly and not suited to long-term monitoring purposes. On the other hand, while satellite remote sensing is able to give a more global view on the subject, the results typically refer to aerosol in cloud-free regions, and cloud top properties, such as mean drop size or reflectance, in adjacent cloudy regions (e.g., Kaufman and Nakajima, 1993; Bréon et al., 2002). This leads to biases as it is, for instance, yet unclear to what extent the cloud-free aerosol are representative of the aerosol actually entering the clouds (Feingold et al., 2003, McComiskey and Feingold, 2012). In the Amazon basin, the effect of aerosol on deep convection has been analyzed by Albrecht et al. (2011) from the observational point of view and by Martins et al. (2009) from a modeling point of view. The main conclusion of these studies is that deep convection is sensitive to aerosol concentration, in the sense that the convective systems are more intense, but there is saturation of the effects for very polluted scenarios. These results were obtained for SW Amazon, however, and it remains to be seen whether the same applies to other regions within the basin.

1f - Central Amazon as a Natural Laboratory for Studying Clouds

The region of Manaus in central Amazon is particularly well-suited to studying the evolution of tropical convective systems and their regional and global upscale feedbacks since it experiences a wide range of convective storm types and environmental conditions throughout the year. There is a strong seasonal cycle in rainfall over Manaus with a maximum in March-April and a minimum in August-September. Large mesoscale convective systems are predominant in the wet season while more isolated but intense thunderstorms are predominant in the dry season (Machado et al., 1998; Machado et al., 2004; Romatschke and Houze, 2010; Rasmussen and Houze, 2011). In the dry season large squall lines originated at the Northern Coast of South America propagate throughout the Basin passing over Manaus

(Alcântara et al., 2011). Manaus is a large city and creates an isolated urban area within the otherwise pristine Amazon basin that extends for thousands of kilometers in all directions. The region downwind of Manaus switches between a very clean environment to one strongly influenced by the meandering pollution plume of the city, with particle number and mass concentrations being on the order of 10 to 100 times greater when the plume is present (Kuhn et al., 2010). Given the prevailing easterly flow, the plume extends westward from Manaus, and exists over Manacapuru at least 50% of the year. Manaus provides a heat island effect (Souza and Alavala, 2012) with potential impact in the local circulation and cloudiness. Local circulation is formed where contrasting surface features impose local gradients of temperature, moisture and atmospheric pressure. In the Amazon these conditions have been associated with deforestation (Silva Dias et al., 2009, Saad et al., 2010) and with large rivers (Silva Dias et al., 2004, Lu et al., 2005). Paiva et al. (2011) have shown that rainfall is reduced over large Amazonian rivers, and the authors point to reduced surface sensible heat and the occurrence of local circulation as the reason. Thus, the region around Manaus is a natural laboratory, not only to observe the characteristics of the tropical continental convective life cycle, but also to study cloud-aerosol precipitation interactions, and the role of land surface processes.

2 - Objectives of the proposed work

This work is the Brazilian component of the GoAmazon experiment, and as such, responds to the white paper of the experiment: GoAmazon 2014 Workshop Report (GoAmazon2014 DoE SC-0141 Report, 2012), and the document on the Intensive operating periods: “Effects of Anthropogenic Pollution on the Atmospheric Chemistry of the Tropical Rain Forest: Intensive Operating Periods (IOPs) of GoAmazon2014”.

A large set of **key scientific questions** were formulated at the several GoAmazon preparation workshops. The ones relevant for this proposal are:

1. Secondary Organic Aerosol (SOA) formation: Interactions of Biogenic and Anthropogenic Emissions

a. What are the chemical and physical processes of anthropogenic-biogenic interactions that affect the production of SOA?

b. How are new (organic) particles formed (e.g., nucleation and SOA formation)? What are the potential roles of primary particles (fungal spores, bacteria, and leaf cuticle) as cloud condensation nuclei (CCN)?

c. What are the influences of revised BVOC oxidation mechanisms (especially isoprene) on SOA production?

d. What are the effects of urban emissions of NOx, VOCs, SO2 and H2SO4 formation on SOA production in an otherwise natural region?

2. Influence of the Manaus Pollution Plume on Aerosol Microphysics: Particle Size Distributions, Optical Properties, and Cloud Condensation Nuclei (CCN) Activity

a. 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?

b. Why is there an absence of new particle formation in pristine Amazon right above the canopy, and what is the influence of Manaus pollution plume on new particle formation?
c. What is the influence of the Manaus pollution plume on the cloud condensation nuclei (CCN) activities of the aerosol particles and the secondary organic material in the particles?
d. What is the influence of the Manaus pollution plume on the aerosol optical properties and radiative forcing?

3. Biogenic Volatile Organic Compound (BVOC) Emissions and impact on atmospheric chemistry and aerosol production

a. What are the characteristics of volatile organic carbon (VOCs) production from vegetation, and how do they vary with season and climate conditions?
b. 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?
c. What is the impact of the megacity pollution plume on BVOC production?

4. Impact of aerosol particles on cloud processes and precipitation in Amazonia.

a. How are cloud microphysics, aerosols, and cloud dynamics coupled as a function of scale and regime in the Amazon Region?
b. How are precipitation, water vapor, and cloudiness coupled and what controls the transition from a shallow cloud regime to a deep cloud regime in the Amazon?
c. How do clouds and precipitation couple with surface properties, particularly to the large rivers and land use features such as the Manaus urban area and patterns of deforestation?
d. How do local circulation and clouds affect the Manaus urban plume and the downwind interaction with the biogeochemistry of the rainforest?
e. What are the relative roles of aerosols, dynamics, and thermodynamics on clouds?
f. How do aerosols affect precipitation and microphysics in deep and shallow convection?
g. What is the diurnal evolution and seasonality of shallow to deep convection from mesoscale storm organization?

We propose to use observations from a range of instruments, remote sensing from surface and satellite based sensors, and numerical modeling of physical processes acting in several spatial and temporal scales as tools to advance the understanding of the underlying processes expressed in the above questions.

Detailed objectives based on these critical questions and issues are as follows:

Aerosol Life Cycle

1. Study process and interactions of the Manaus pollution plume with biogenic emissions of VOCs, especially the impact on the production of secondary organic aerosol (SOA) and the formation of new particles;
2. To measure the aging of biomass burning plumes and the subsequent formation of additional SOA;

3. The influence of anthropogenic emissions i.e., (a) the Manaus pollution plume and (b) biomass burning aerosols on aerosol microphysical, optical, CCN, as obtained by comparing the aerosol properties between pristine and anthropogenically influenced air masses; and
4. Determine the optical properties of aerosols from the interaction of the Manaus plume and the natural vegetation atmosphere and obtain the aerosol radiative forcing.

Cloud Life Cycle

5. Study the role of landscape heterogeneity (e. g., the urban area of Manaus or km-long scale of rivers) on the dynamics of convection and clouds;
6. The evolution of convective intensity from severe storms in the dry season to moderate storms in the wet season, and to consider how changes caused by local deforestation lead to similar transitions;
7. The transition from shallow to deep cumulus convection during the daily cycle of the Amazon Basin, with comparison and understanding to other ARM sites; and
8. Development of a knowledge base and test cases that will improve tropical cloud parameterizations in regional and global climate models (GCMs).

Cloud-Aerosol-Precipitation Interactions

9. Aerosol effects on scattered cumulus clouds, especially the aerosol radiative effect, with a special focus on the impact of biomass burning aerosols;
10. Aerosol effects on deep convective clouds, precipitation, and lightning under different aerosol and synoptic regimes, including the roles of aerosols in changing regional climate and atmospheric circulation; and
11. Improvement of parameterizations of aerosol-cloud interactions in the regional and global climate models

The theme uniting these objectives is the development of a data-driven knowledge base for predicting how the present-day functioning of energy flows in the Basin might change from internal forcing from projected urbanization changes in the Basin. The ultimate goal is to estimate future changes in direct and indirect radiative forcing, energy distributions, regional climate, and feedbacks to global climate. A challenge of GoAmazon experiment 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.

3 - Measurement strategy of the study of the Manaus outflow into the forest

The proposed work focus on the study of the interaction between the Manaus plume and the natural forest around it. It is necessary to have a few observational sites upwind and downwind of the urban area. We plan to implement the operational period for two years continuously from January 2014 to December 2015. This is necessary to capture the different seasonal meteorological and thermodynamic conditions as well as a large statistics on aerosol and cloud properties over the region. We will also have several IOP (Intensive Operational Periods) where we will do more detailed measurements that are not feasible continuously over 2 years. These IOPs will have participation of several international groups focusing on specific processes.

This particular FAPESP Thematic project will focus on aerosol, trace gases and clouds observations at 3 measurement stations before the Manaus plume: at ATTO (Amazon Tall Tower Observatory) (site T0), ZF2 (Cuieiras Ecological Reservation) (site T01) and EMBRAPA (site T02), a site were the Lidar and several could observation instruments will be operational (site T02). After the Manaus plume we will have two sites: Manacapuru (site T3) and Iranduba (site T2). The site T2 in Iranduba will be fully operational trough this FAPESP proposal. Table 2 shows coordinates and responsibility for each of the GoAmazon sites. An additional site downtown Manaus (site T1) will be operated by a separate project from UEA (State University of Amazonas). The Manacapuru will be operated and maintained by US DoE (United States Department of Energy). Figure 6a bellow shows the site locations as well as the average wind direction, showing the East predominant direction. The transit time between Iranduba (T2) and Manacapuru (T3) is approximately 2 hours. The table bellows summarize the coordinates and who will be responsible for each site. Of course all data will be shared with all GoAmazon researchers from all sampling stations.

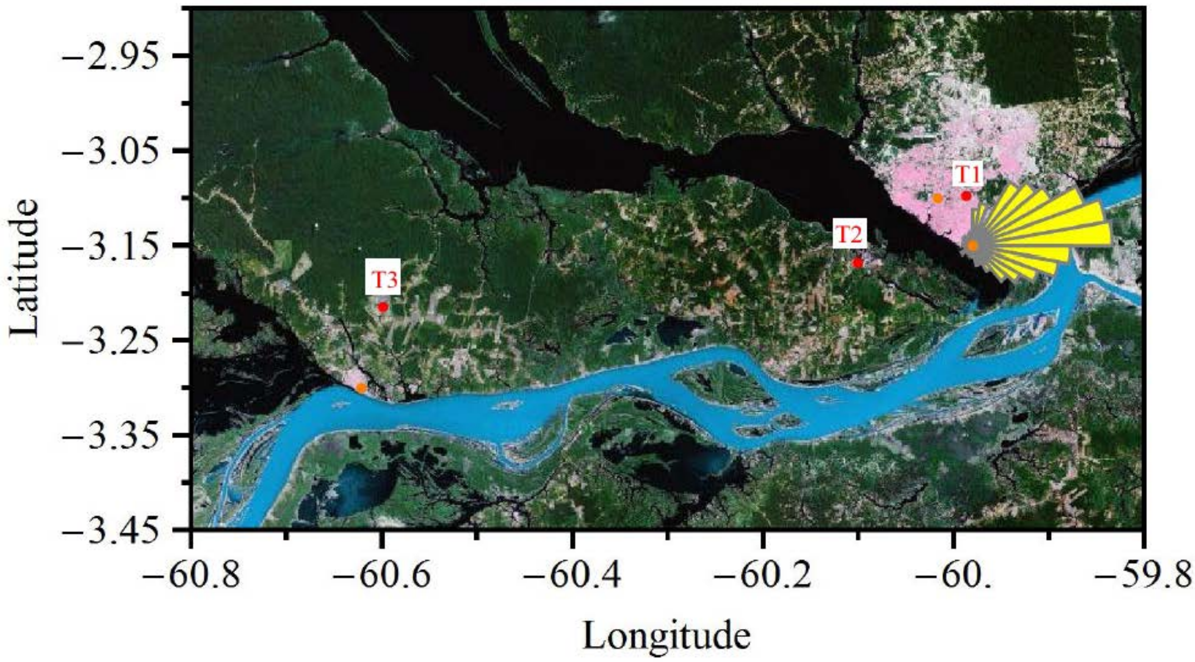

Figure 6a - Location of downtown Manaus site (T1), Iranduba (T2) and Manacapuru (T3). Also shown the eastern prevailing wind direction.

Table 1 - Coordinates and operational responsibility for each observation site in GoAmazon. The last column makes clear the contribution of this FAPESP proposal and the other partners. DoE and Max Planck already have full funds to run their GoAmazon component.

Sampling site	Degrees	Decimals	Site operated mostly by
ATTO (Site T0)	S 02° 8' 38.8", W 58° 59' 59.5"	-2.14663 S, -59.005 W	**This proposal** and Max Planck
ZF2 TT34 Tower(T01)	S 2° 35' 40.1", W 60° 12' 33.42"	-2.59458 S, -60.2093 W	**This proposal**
Downtown Manaus T1	S 3° 6'27.07", W 60° 1'32.25"	-3.09722 S, -59.9867 W	UEA
Iranduba (Site T2)	S 03° 09' 58.0", W 60° 05' 09.9"	-3.16667 S, -60.100 W	**This proposal**
Manacapuru (Site T3)	S 03° 12' 46.7", W 60° 35' 53.0"	-3.21328 S, -60.5987 W	US - DoE

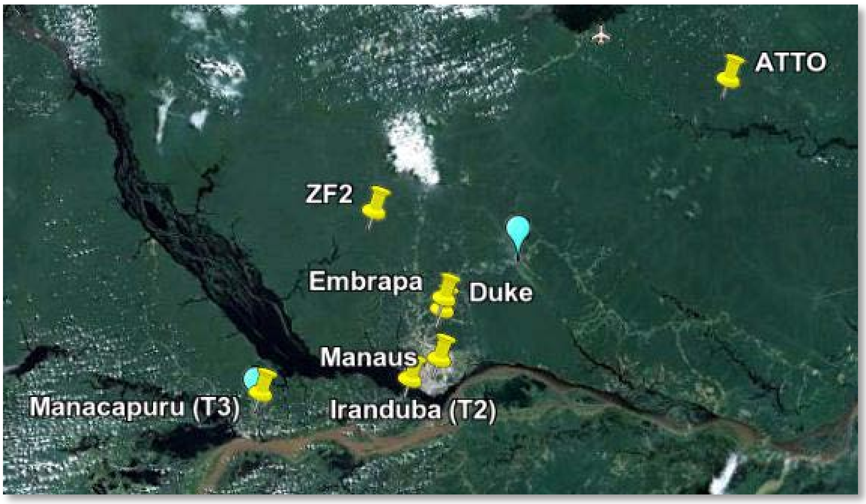

Figure 6b - Larger scale picture showing the location of the ATTO site (T0), ZF2 (T01), Embrapa (T02) and the downwind sites. ARM will operate Manacapuru (T3) only, while the Brazilian team involved in the current proposal will operate the sites: Iranduba (T2), Embrapa/Duke and Rebio Cuieiras/ZF2, besides having instruments deployed at the Amazonian Tall Tower Observatory (ATTO).

3a - Characteristics of each sampling site

ATTO – Amazon Tall Tower Observatory (Site T0)

The ATTO site is located in one of the most pristine sites in continental areas in the world. At this site a German-Brazilian cooperation built four 85 meters towers and a 320 meters tall tower will be built. The site is already fully operational and aerosol and trace gases are being measured in one of the 85 meters towers (Figure 7).

Figure 7 - ATTO site: Picture of the 85 meters tall tower at the left that is being used for aerosol and trace measurements and the proposed 320 tall tower (right) under construction.

The figure 7 illustrates the actual 85 meter tower as well as the proposed 320 meters tower. Aerosol physical and chemical properties are being measured at ATTO including the organic aerosol composition with an Aerosol Mass Spectrometer from IFUSP. The site will be kept with continuous measurements in a long term basis (>20 years). The very pristine condition of this site makes it perfect for background aerosol characterization. The site is very difficult to access, requiring at least 8-10 hours for a trip from Manaus to the site.

ZF2 (TT34 tower) and EMBRAPA sites (Site T01)

At the ZF2 sampling site we have operated continuously a instrumented tower (called TT34) for the last 4 years as part of the FAPESP Thematic project AEROCLIMA. The AMAZE 2008 experiment (Martin et al., 2011) was also operated at this site. Most of aerosol physical and chemical properties are being measured at this site, and it will continue to be operational for GoAmazon. The site is much easier to access than the ATTO site, and daily visits for samples collection are feasible, since it can be reach with a trip of about 2 hours from Manaus. The site also operates a special dryer built by the University of Leipzig that allows drying the aerosol at 30-25% relative humidity, important for hygroscopic aerosols. (Figure 8).

Figure 8 - External view of the atmospheric observation container in operation at the TT34 site. The container has air conditioning and a large dryer to allow dry sampling conditions for aerosol (left). On the right picture we can see an internal view of the container with several instruments in operation. The site operates continuously from February 2008, as part of the FAPESP Thematic Project AEROCLIMA.

Manacapuru (Site T3): This is the site of the DoE GoAmazon project. The facility will be located downwind of the city of Manaus, Brazil (3° 6' 47" S, 60° 1' 31" W) from Jan 2014 to Dec 2015. The proposed site is situated so that it experiences the extremes of (i) a pristine atmosphere when the Manaus pollution plume meanders and (ii) heavy pollution and the interactions of that pollution with the natural environment when the plume regularly intersects the site. About 19 different containers will be operated at the site continuously for 2 years, analyzing radiation, aerosol, trace gases and cloud properties.

The Mobile Aerosol Observation System (MAOS) and the ARM Mobile Facility (AMF1) will be used for ground-site characterization of chemistry and cloud-nucleating properties of aerosol particles. A scanning mobility particle sizer (SMPS) and an ultra-high sensitivity aerosol spectrometer (UHSAS) will provide size distributions, ranging from 15 nm to 1 micron. Size-resolved aerosol mixing state and hygroscopicity will be measured using a humidified tandem differential mobility analyzer (HTDMA). A particle-into-liquid sampler (PILS) coupled to chromatographic analysis and an aerosol chemical speciation monitor (ACSM) will provide aerosol chemical composition. A cloud condensation nuclei counter (CCNC), coupled to a differential mobility analyzer (DMA), will measure the size-resolved CCN activation of aerosol particles. In addition to aerosol particles, trace gases including carbon monoxide (CO), sulfur dioxide (SO_2), ozone (O_3), oxides of nitrogen (NOx), and volatile organic compounds (VOCs) will be measured by trace gas analyzers and a high-resolution proton-transfer mass spectrometer (PTR-MS). Accurate CO measurements are essential for distinguishing natural air masses (60 to 90 ppb CO in the Amazon Basin) from those influenced by anthropogenic activities. During some intensive measurement periods, OH measurements will also be performed. A high-resolution time-of-flight aerosol mass spectrometer will be operated at the site for characterization of the organic material to allow multivariate analysis of the time series of the mass spectra, e.g., to provide information on the sources and the processing of organic material. Table 2 shows the instrumentation that will be operational at the Manacapuru (T3) GoAmazon site.

Table 2 - Instrumentation to measure aerosol, trace gases, radiation fluxes and cloud properties at the ARM Mobile Facility Instruments - Aerosol Observing System operational continuously for 2 years at the Manacapuru T3 site

Cloud Condensation Nuclei CCN from DMT – Droplet Measurement Technology.	Eddy Correlation System – Latent and sensible heat fluxes
Nephelometer from TSI model 3563	Microwave Radiometer
Particle/Soot Absorption Photometer – PSAP – Spectral light absorption	High-Frequency (183 GHz) Microwave Radiometer
C_ L_ Absorption Photometer	1290 MHz Radar Wind Profiler
Downwelling Radiation	Microwave Profiler
Shaded Black and White Pyranometer	35 GHz/94 GHz Scanning ARM Cloud Radar
Normal Incidence Pyrheliometer	Vaisala Ceilometer (range ~7 km)
Precision Infrared Radiometer	94 GHz Vertically Pointing Cloud Radar
Precision Spectral Radiometer	Total Sky Imager
Infrared Thermometer	TSI 3776 Cloud Nuclei Counter
Multi-Filter Rotating Shadow Band Radiometer	Aerodyne Aerosol Chemical Speciation Monitor
Narrow Field of View Radiometer	Photo-Acoustic Soot Spectrometer (PASS-3)
Solar Array Spectrometer – Hemispheric irradiance	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)
Solar Array Spectrometer – Zenith radiance	PTR-MS Real-time VOC
Upwelling Radiation (from 10 m tower)	Carbon Monoxide Analyzer from Picarro
Precision Infrared Radiometer	Trace Gas – CO, O_3 , SO_2 , NOx
Precision Spectral Radiometer	Vaisala Meteorology Station
Infrared Thermometer	Micropulse Lidar with Dual Polarization

Surface Meteorology	Aethalometer for Black Carbon
Barometer	Single Particle Soot Photometer (SP2)
Optical Rain Gauge	TSI 3772 Cloud Nuclei Counter
Present Weather Sensor	SMPS – Scanning Mobility Particle Sizer
Temperature and Humidity Sensor	Cloud Condensation Nuclei Counter
Anemometer	Particle into Liquid Sampler (PILS)
Cimel Sun Photometer for AOD	Humidigraph
Radiosonde System (4 launches per day from AMF site)	Hygroscopic Tandem Differential Mobility Analyzer (HTDMA)
Doppler Cloud Lidar	

FAPESP Project CHUVA Measurements. The FAPESP Thematic Project coordinated by Luiz Augusto Machado will operate during the field studies of GoAmazon a large set of instruments focusing on clouds and precipitation observations (Table 3).

Table 3 – Instruments available for GoAmazon for one year in Manaus from the FAPESP Thematic project CHUVA

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

3b - Bridging Models and Observations

For a better understanding of cloud life cycle it is critical that long-term measurements of cloud and related atmospheric properties be performed. Therefore, the CLOUDS AND MODELING component of this proposal will have an observation framework where continuous measurements capable of relating atmospheric thermodynamics, aerosols and cloud properties to the diurnal cycle of convection in Central Amazonia will be performed allowing for water vapor-cloud-convection-aerosol-climate feedbacks to be investigated. These measurements will be carried out in two sites, one upwind from Manaus and operated by this project and another downwind and operated by the GoAmazon/DOE ARM team.

At the same time, a myriad of physical, chemical and meteorological processes that range from the sub micrometer to the continental scale drives the clouds' life cycle making modeling of clouds extremely challenging. To address this issue models were developed to represent different scales, ranging from parcel to meso (or even global). Therefore, the adequate representation of the entire life cycle of clouds demands several different models, and we propose to use parcel, LES and regional models. Regional models (BRAMS and WRF) with various land surface scenarios under different aerosol loads and large-scale dynamic lateral boundary conditions will also be used to shed light on the scientific questions raised in the previous sections. High resolution simulations will also be used for forward and back trajectories of air parcel to help the interpretation of data collected in our sites. For this goal, a simplified photochemical model developed by Freitas et al. (2005) with a detailed description of the urban heat island (Freitas et al., 2007) and urban emissions will also be used to simulate the Manaus urban plume behavior. Model results will be compared to observations at the EMBRAPA and Manacapuru sites. While modeling will serve as research tool for the overall objectives of this proposal, it is expected that model improvements will also be obtained by the comparison/validation of model output to the special measurements proposed in this project and those from GoAmazon and CHUVA.

3c - Clouds observation framework

Our general aim is to better understand the processes that modulate the formation of shallow convection and its subsequent conversion to deep convection in Central Amazonia, and what role do aerosols have in this process. In the context of the Go Amazon proposal, we will operate an upwind site from Manaus where cloud formation occurs under undisturbed conditions (i.e. no significant land use change neither pollution plumes during the wet season). It is situated at S 2.89057 and W 59.96983, inside the campus of Embrapa. Similar measurements will be performed at the DOE ARM mobile facility in Manacapuru. The instruments deployed at the Embrapa site will include: (1) remote sensing ranging profilers with lidar, ceilometer, microwave radiometer, thermal infrared imager, and a vertical pointing rain radar; (2) ground observation with disdrometers (JOSS, Parsivel and Thies) and three different meteorological weather stations with P, T, RH, wind and radiation; and (3) column integrated measurements including a multi filter shadow band radiometer, a Cimel AERONET sunphotometer and a Global Navigation Satellite System (GNSS) receiver. Table 4 lists the main instruments to be used by this component and whether the exact same instrument or a similar one is available or not on the ARM site. Appendix B, attached as a separate document in Fapesp/SAGe website, gives a brief overview of each instrument. Table 5 shows the new instruments that we intend to acquire with this proposal.

Continuous and long term observations such as these enable the characterization of the diurnal cycle of different cloud types, convection and precipitation. For instance, the use of the GNSS stations allowed Adams et al. (2011) to describe the typical pattern of afternoon deep convection events. Figure 9 shows an example of PWV time series derived from the GNSS station at INPA. It is clear that there is an increase in PWV before the precipitation event, a decrease afterwards, and that there are concurrent variations of cloud top and surface temperatures. The authors, however, could say very little on the possible role played by moisture convergence during the event. This could be tackled by the integrated use of all GNSS stations (Figure 10) and soundings that will allow precise derivation of the vapor convergence and transport while different types of radars from both CHUVA and GoAmazon projects observe the formation of deep convection over the sites. The dense network will be operated at least until the end of 2014 and more details are given in Appendix B. **Local operation and maintenance of the dense GNSS network will be partially covered by this**

proposal. Data from the network will be used to document the diurnal cycle of precipitable water close to and away from the boundaries of Amazon and Negro rivers and around the urban area.

Table 4 – List of instruments at our upwind clouds site (EMB-Embrapa). Second column indicates instrument status. Third column shows if the downwind ARM site will have exactly the same instrument (=) or similar (DIF) instrumentation.

Instrument	EMB	ARM	Quantity Provided
UV Raman Lidar (Raymetrics)	1	DIF	Vertical profile of aerosol extinction and backscatter; night only: water vapor, lidar ratio
THIES Disdrometer	1	DIF	Raindrops size distribution (optical) at ground.
Multi Filter Radiometer (MFR)	1	=	Spectral shortwave radiation (direct and diffuse), optical depth of water vapor, ozone and clouds
Aeronet Sunphotometer	1	=	AOD, size distribution, phase function, water vapor, Angstrom coefficient, 7 wavelengths
Thermal infrared imager	1	DIF	Brightness temperature on cloud sides and cloud base
Thies Met station	1	DIF	P, T, RH, wind and radiation
Ceilometer (Jenoptix CHM15k)	2	DIF	Cloud base, Cloud amount, Penetration depth, Vertical visibility, Height of mixing layer
Micro Rain Radar (Metek MRR-2)	2	DIF	Vertical profile of reflectivity, raindrop size distribution and rain rate.
MP3000 Radiometer (Radiometrics)	3	=	Vertical profile of T, RH and liquid water of non-precipitating clouds
JOSS Disdrometer	3	=	Raindrops size distribution (acoustic) at ground.
PARSIVEL Disdrometer	3	DIF	Raindrops size distribution (optical) at ground.
Davis Met station	4	=	P, T, RH, wind and precipitation
GPS/GNSS + Vaisala Met station	4	=	Integrated Precipitable Water (IPW), P, T, RH

[1] Acquired by our previous Fapesp Thematic Project AEROCLIMA (08/58100-2)
[2] Partnership with Max Plank Institute, already installed and will stay until the end of 2015
[3] Partnership with Fapesp Thematic Project CHUVA, between March and October 2014
[4] Partnership with UEA, dense GNSS network, already installed and will stay until the end of 2014

Table 5 – List of instruments to be acquired and operated within this FAPESP component, to be operated at Embrapa. Justification is included in the discussion above.

Instrument	ARM	Quantity Provided
Sky imager (YesInc TSI-880)	=	Cloud cover, Sun shine duration
Campbell CNR4-L Net Radiometer	=	up/down pyranometers and pyrgeometers for net short and thermal radiation
IRGA SON Integrated Gas Analyzer and Sonic Anemometer	DIF	latent and sensible heat fluxes

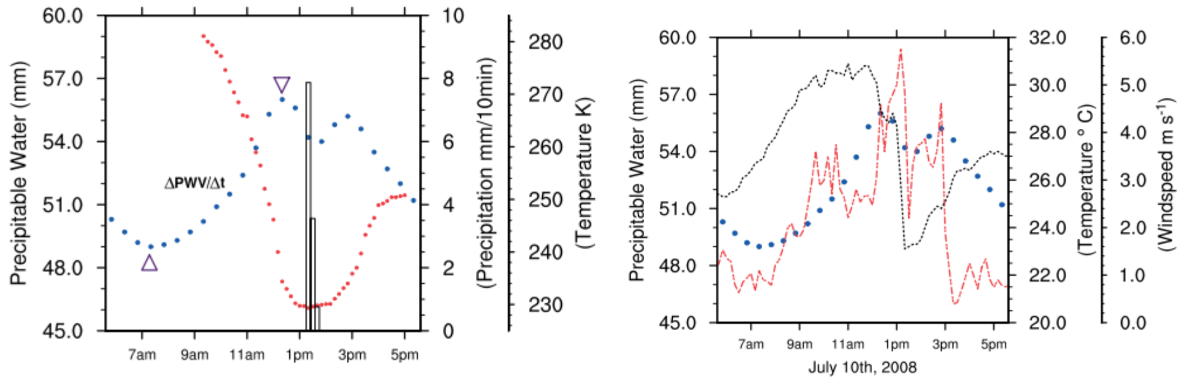

Figure 9 - A typical afternoon deep convective event over INPA GNSS/meteorological station. The left plot contains PWV (blue dots) versus average cloud top temperature (red) and precipitation rate (bars). The 'ramp-up' time calculated for the average dPWV/dt (between triangles) represents the timescale of column convergence. The bottom graph plots wind speed (red), temperature (black) and PWV (blue) for the deep convective event. Figure 3 in Adams et al. (2011).

Moreover, with radar observations from GoAmazon and CHUVA Projects we plan to document the daily evolution of clouds around Manaus, assessing the continental versus maritime characteristics of the convection. Vertical profiles of diabatic heating associated with continental and maritime convective systems derived from sounding (Yanai et al., 1973) and radar (Schumacher et al., 2004) measurements, and the connection of heating profiles to the reversal of the large-scale wind pattern derived from the radiosonde network, wind profilers, and reanalysis data will shed light on how convective heating is linked to moisture transport to central Amazonia.

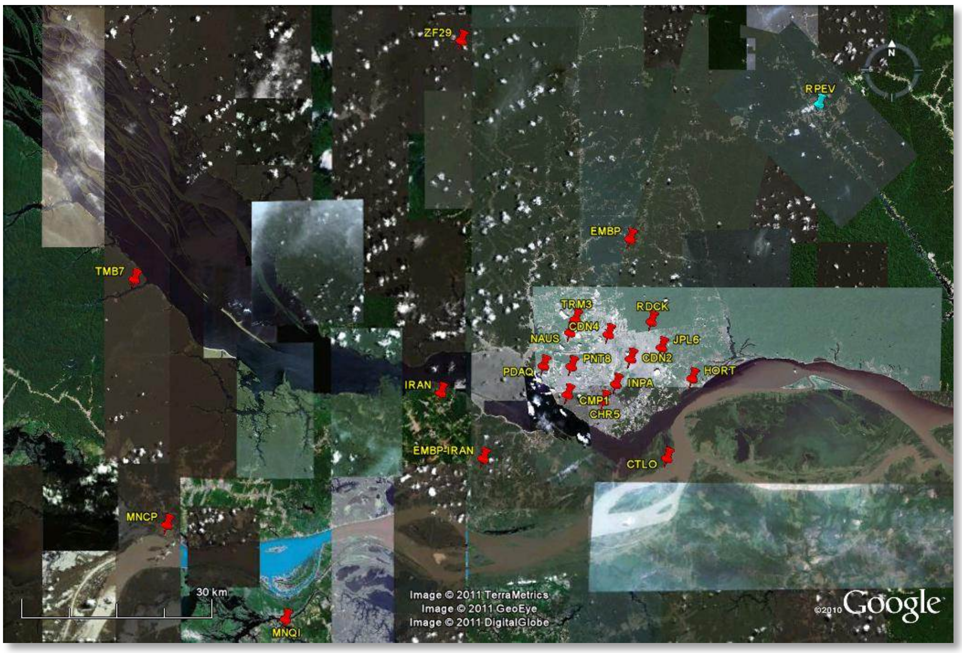

Figure 10 – Position of GNSS stations in the dense meteorological network (Adams et al., 2011)

The soundings will be made using the Vaisala system (sondes RS92-SVP) and all the sites (Manaus Airport, DOE ARM and EMBRAPA) have the same ground station equipment.

The soundings will be made at 00, 06, 12, 18 UTC (local time is UTC-4 hours) in order to describe the time evolution of the properties of the boundary layer. These soundings will also be useful for the initialization of the numerical simulations. The DOE ARM has guaranteed the 4 soundings per day during the whole GoAmazon Experiment in 2014 and 2015. The EMBRAPA sounding will be performed during the same period by the team of this proposal. The two-daily operational soundings already performed at the Ponta Pelada Airport by the Brazilian Air Force will be complemented by CHUVA project for four per day. Manpower for the intensive campaign will be partially fulfilled by local researchers and students. At Manaus area, there are several public organizations (federal and state levels) that are working with Meteorology (INPA, UEA, SIVAM/CINDACTA, SIPAM, FUA, etc.) and can be involved in the field campaign as well as the data analysis. In particular, the post graduate programmer (CLIAMB/ INPA, Geografia/FUA) and the graduation course on Meteorology at UEA will be strongly associated with this research.

Looking at the water vapor content in the atmosphere is only one aspect of the shallow to deep transition. At the same time, ceilometers and lidar will provide the vertical thermodynamic profile, distribution of aerosols and position of cloud base/top. This was done by Bourayou et al. (2011) with data from CHUVA's campaign in Fortaleza. They compared cloud base heights from MP3000, MRR and LIDAR and found that only the LIDAR gives a reasonable measurement. On the other hand, as pointed out by Barbosa et al. (2012), it is very hard to translate the time evolution of a single vertical profile to what shall be the horizontal distribution of clouds and their instantaneous development stage. A possibility to derive shallow cloud cover with ground based instruments is a milimiter-wave scanning cloud radar, as the one on the ARM site, but it is very expensive and its operation is far too complicated. On the space born side, geostationary satellites have a too coarse resolution and/or are biased towards higher cloud covers, while polar orbit satellites, such as those in the A-TRAIN, fly only twice a day over the site. **Hence, as a cost/benefit alternative a Sky imager (YesInc TSI-880) will be bought and operated at Embrapa (upwind site) within this proposal.** This instrument is able to derive the horizontal distribution of cloud cover and type during day time and is the same imager that will be operational at the downwind ARM site.

Another important aspect is the vertical redistribution of sensible and latent heat exchanged at the surface which sets up the thermodynamic conditions for the development of deep convection later during the day (Houze, 1993; Dai et al., 1999). At the same time, deep convection itself is sensitive to the distribution of humidity in the free troposphere, developing more vigorously in humid environments. Hence it is fundamentally important to measure the latent, sensible, solar and terrestrial heat fluxes at the surface. **Our proposal is to buy and operate at the Embrapa site a net pyranometer and pyrgeometer (e.g. Campbell CNR4-L) and an eddy covariance flux instrument such as Campbell's Integrated Gas Analyzer and Sonic Anemometer**. These observations of the vertical structure of humidity, temperature and wind from profiling ground sensors, mobile platforms, and soundings from GoAmazon, CHUVA and the present proposal will be used to assess the increase of boundary layer and tropospheric humidity.

The proposed detailed measurements will also be able to address fundamental aspects of aerosol and cloud microphysics and can be used to advance our understanding of the aerosol-cloud interactions. For instance, using a very limited dataset acquired at the Southern Great Plains (SGP) ARM site, Feingold et al. (2003) identified 7 cloudy cases for which they made the first measurements of the Twomey indirect effect using a Raman lidar, a microwave radiometer, an optical particle counter and a cloud radar. They have found that the indirect effect is much larger than previous satellite based estimates, which invariably mix scenes with different aerosol composition, size distribution and cloud dynamics. The authors have also shown that the magnitude of the indirect effect depends on the degree of cloud turbulence (correlation r = 0.67), hence a different effect on different stages of the shallow to deep convection transition should be expected. For this specific study, however, we will use only instruments in the ARM site because the Embrapa site does not have a cloud radar to derive profiles of cloud droplets effective radius.

3d - Modeling framework for the Cloud life cycle

Clouds have their life cycle determined by a myriad of physical, chemical and meteorological processes that range from the sub micrometer to the continental scale. This is why the (numerical) modeling of clouds is a challenge: it is almost impossible to include the whole set of mechanisms that control the life cycle of clouds. To address this issue, models were developed to represent different scale magnitudes, ranging from parcel to meso (or even global). As a consequence, the adequate representation of the entire life cycle of clouds demands several different models. Modeling will serve as research tool for the overall objectives of this proposal. However, it is expected that model improvements will also be obtained by the comparison of model output to the special measurements proposed by the combined measurements of project GoAmazon, CHUVA and this proposal. Next we shortly describe the models that will be employed in this component.

A. Parcel models

Parcel models take advantage on its limited dynamics to go deep into microphysical processes that occur inside a cloud. They are well-suited to represent initial steps of cloud life cycle and situations where entrainment is not dominant. In this proposal we will employ two types of parcel models. The first one is a parcel model with detailed computation of droplet activation and condensational growth. This model is suitable to simulate the initial droplet activation at cloud-base, especially for stratiform clouds and/or the central axis of cumulus clouds (where entrainment is reduced). It is a bin model where each bin corresponds to a category of initial aerosol size. During the simulation, the nominal size of each bin changes, following the evolution of each aerosol size after its activation (or not) when the Lifting Condensation Level is crossed, and the subsequent increase due to water vapor diffusion. The initial inputs to the model are: (1) Size distribution of dry aerosol; (2)

Temperature and Relative Humidity at the beginning of the ascension; (3) Size resolved kappa (k) parameter (Petters and Kreidenweiss, 2007, 2008), which represents the ability of the aerosol to act as CCN. During the run the model solves the diffusion equation of vapor for each time step and each bin in a supersaturated environment, as shown in equation below:

$$D_p \frac{dD_p}{dt} = 4 \times \frac{\left[(S-1) - \left[\frac{D_p{}^3 - D_d^3}{D_p{}^3 - D_d^3(1-\kappa)} \exp\left(\frac{\sigma_w M_w}{\rho_w RTD_p}\right)\right]\right]}{\left[\frac{L\rho_w}{KT}\left(\frac{LM_w}{RT} - 1\right) + \frac{\rho_w RT}{D_d M_w p_\infty}\right]}$$

where D_p is the droplet diameter, D_d is the dry diameter, κ is the size-resolved *CCN* hygroscopicity parameter, M_w is the molecular weight, σ_w is the surface tension, ρ_w is the density of water, R is the universal gas constant, T is air temperature (where it is assumed that the temperature of the liquid/vapor of water are at the same temperature), L is the latent heat of condensation, K is the heat diffusivity in the air, p_∞ is the saturation vapor pressure far from the droplet, and D_d is the diffusion coefficient in the air.

This model performs its simulations with up to 100 bins. The initial bins size range is from 10 nm to 10 µm, which is enough to represent both ultrafine as well as giant CCN. The model comprises the same physics and chemistry as described by Reutter et al. (2009), and allows one to simulate several issues related to aerosol effect on the initial cloud droplet number concentration (CDNC), as well as its relationship with updraft velocity.

The second parcel model is one to simulate droplet growth by coalescence. CCN particles are activated at cloud base and subsequently grow up by condensational growth. However, droplets do not reach precipitable size by vapor diffusion but by coalescence, which means collision between droplets to form less and larger droplets. Thus the evolution of coalescence is what determines the occurrence or not of rain. In fact, from a precipitation point of view, cloud lifetime is not as important as the Lagrangian time scale (t_p), which is the time it takes a parcel of air to enter and exit a cloud. This is the time available for initiation of precipitable particles. Once initiated, precipitation may continue over the remaining lifetime of the cloud. For several types of clouds such as stratiform, ordinary cumulus and severe storms the lagrangian times does not differ significantly (ranging between 300 s – 700 s). The main advantage that an ordinary cumulonimbus cloud experiences over that of a cumulus cloud in forming precipitable particles is associated with the greater amounts of condensate that is produced as moist air ascends through the depth of the troposphere. Because precipitation growth by collection is a non-linear function of the amount of condensate in a cloud (Kessler, 1969; Manton and Cotton, 1977), precipitation proceeds quite rapidly in cumulonimbus clouds relative to low liquid water content cumulus clouds.

In order to correctly simulate this kind of phenomenon we need a model that includes droplet growth by coalescence. Our parcel model simulates that by employing the Method of the Moments (Tzivion et al., 1987, 1989; Feingold et al., 1988) and produces an ascending parcel similarly to the previous model (Feingold and Siebert, 2009). The main difference among them is that the activation is simplified and does not include size and chemistry of CCN. On the other hand it simulates very efficiently the further evolution of cloud droplet size distribution until it precipitate, or not. It is especially suitable to simulate shallow cumuli, which is one of the foci of this proposal with respect to understand better the role of shallow clouds and its role in the shallow-to-deep convection transition.

<u>B. Column model</u>

The column model to be used in this proposal is a 1-D version of the parcel model (2) described above. Whereas parcel model (2) is better to simulate the beginning of precipitation, its column version is more adequate to simulate the whole life cycle of warm cumuli under situations without significant wind shear. This is a common condition to cloud formation in the Amazon Basin during the morning, and clouds formed under such conditions play a critical role in shallow to deep convection, as explained in the introduction. The main difference between parcel and column versions is that it is possible in the latter to assign a vertical profile of the atmosphere (for example from a radio sounding) and investigate the relationship between CAPE, CINE and cloud life cycle. With respect to physical processes the column model also includes sedimentation, which is critical to sustain the precipitation once it was initiated. The dynamic framework of the model was originally obtained from the KiD ("Kinematic Driver") model (Shipway and Hill, 2012). KiD is a dynamical framework designed to compare different algorithms to simulate detailed cloud microphysics. An example of simulation with the column model is shown in Figure 11. This simulation is the case of an updraft that oscillates sinusoidally as $w = w_1.\sin(\pi t/t_0)$., where w is the magnitude of the updraft velocity and t_0 is a characteristic time (assumed as 600 s in this case).

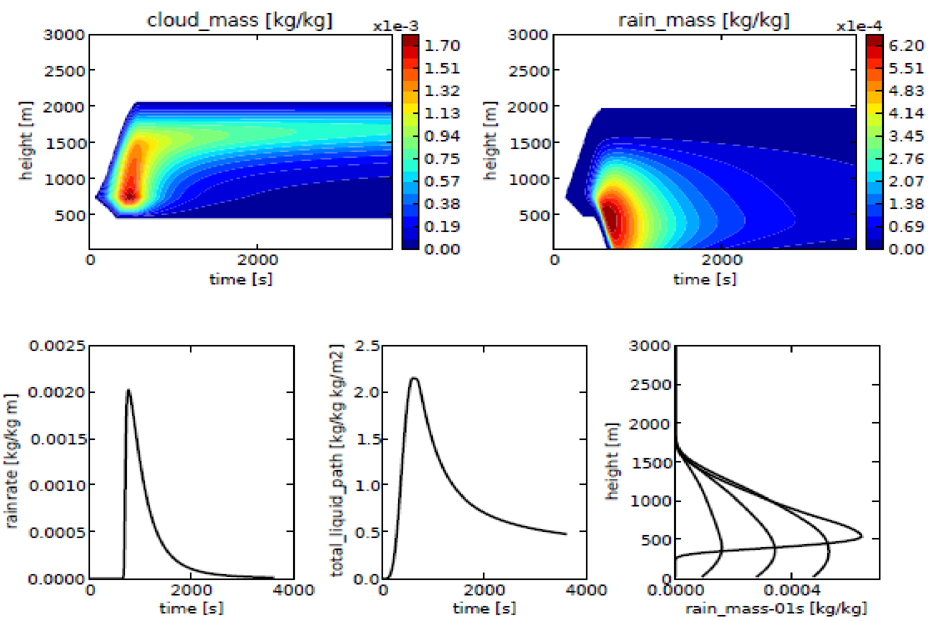

Figure 11: output from column model. Contour plots of cloud mass and rain mass, line plots of surface rain rate, total liquid water path and profiles of rain mass at 10, 15, 20 and 30 minutes.

3e - High Resolution Cloud Modeling

A. Large Eddy Simulation (LES) Models

Large eddy simulation (LES) is a mathematical model for turbulence used in computational fluid dynamics in order to simulate the atmospheric boundary layer properties. It is being used widespread by the scientific community, resolving explicitly the larger eddies while the smaller one was parameterized. The LES model operates based on the Navier-Stokes equations to reduce the range of length scales of the solution, reducing the computational cost. The use of LES has been grown very rapidly due to computational improvements and it has elucidated many problems found in micrometeorology.

The use of a LES model to study the properties and characteristics of the boundary layer is becoming frequently. However, for the Amazonia case studies, very few researches (if any) were made using this tool so far. The model named PALM - A PArallelized Large-Eddy Simulation Model for Atmospheric and Oceanic Flows was developed by the University of Hannover by Prof. S. Raasch and it was described by Raasch and Schroter (2001). This model PALM is a large-eddy simulation (LES) model for atmospheric and oceanic flows which was especially designed for performing on massively parallel computer architectures. It can be used to study the behavior of heat, moisture and momentum fluxes (surface and top of the CBL) associated with the surface conditions (soil moisture and partition of energy). These results will give information to better understand/knowledge of the turbulence/convection. The characteristics of convection cells/structure and occurrence above two different types of surface (pasture – deforested and pristine forest will be studied, using the surface and boundary layer collected by the sites of GoAmazon and this proposal project.

There is a PhD student from INPE (Mr. Theomar Neves, advised by Dr. Gilberto Fisch) at the University of Hannover, working with the group from Prof. S. Raasch in a 1 year training period. He is doing some LES simulations with a model domain of 6.4 km x 6.4 km x 5.0 km dimensions with a resolution of 100.0 m x 100.0 m x 20.0 m. This configuration are the same used by Brown et al. (2002), which aimed to present results from a large-eddy model study of the development of shallow cumulus convection over land. The LES is simulating for 2-3 hours in different parts of the day, i.e., early morning (to investigate the erosion of the nocturnal BL, at noon (when the convection is fully developed) and late afternoon (when the turbulence BL is decaying or even ceased). The simulations will be made for dry and wet conditions. The model output data that are necessary in order to be able to analyze the boundary layer properties are the wind components (u, v, w), potential temperature, specific humidity, velocity friction, energy kinetics, Zi and turbulent flows ($w'\theta'$, $w'q'$ e $u'w'$) at the entire boundary layer (including surface and entrainment zone). The main goal of this LES model exercises within this project will be to simulate the erosion of the NBL and investigate its influence for the transition from the shallow to deep convection, using the surface and boundary layer meteorological data available.

3f - High Resolution Regional Scale Modeling

For regional scale modeling, the Brazilian developments on the Regional Atmospheric Modeling System (Freitas et al., 2009) will be used. Among other important features, the model is equipped with a simplified photochemical module (Freitas et al., 2005) which is intended to perform high resolution simulations of air quality features, especially over urban areas and its vicinities, where vehicular and industrial emissions are the main source of pollution. The model also has an appropriate parameterization for urban areas. The Town Energy Budget (Masson, 2000), which was modified to be compatible with the SPM parameterization and be able to represent the vehicular behavior in large urban areas, such as São Paulo and Rio de Janeiro. Most of the modifications are described in Freitas et al. (2007), which used the model to study the interactions of urban heat island and sea-breezes in São Paulo. This is a very important feature, since the urban area of Manaus is surrounded by large water bodies (Negro and Amazonas rivers), being subjected to river breeze circulations. Also, some evidences show that urban heat island effects in Manaus are very dependent on vehicular emissions of heat and moisture. Souza and Alvalá (2012) found that the strength of UHI are marked by two periods of the day, being one in the morning (around 8:00 Local time) and the other in the afternoon (around 16:00 Local time). These hours are coincident with rush hours in many large urban cities and the diurnal cycle presented in the paper (Souza and Alvalá, 2012) fits very well with that characteristic. Figure 12 shows the sensible heat fluxes diurnal cycle that is used in TEB to represent vehicular anthropogenic contribution. The same cycle is used for latent heat fluxes and for pollutant emissions in the SPM (CO, SO_2, $PM_{2.5}$, NO_x, VOC).

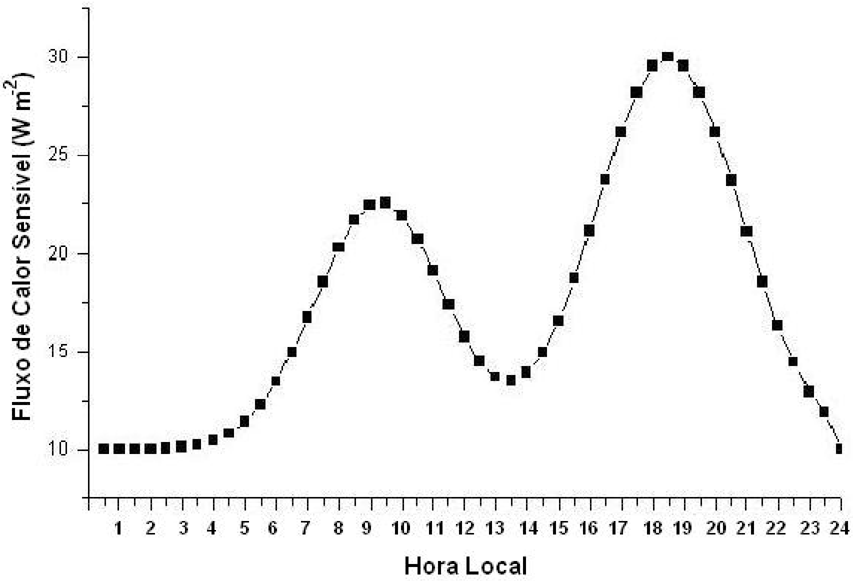

Figure 12: Diurnal cycle of sensible heat flux used in TEB Town Energy Budget Source: Freitas (2008)

Modeling of the local circulations in the area will be performed with BRAMS, with SPM and TEB activated, operating in high spatial resolution (≤ 500 m) to account for the steep gradients in a realistic way. BRAMS output will be used to calculate high resolution forward and backward trajectories to help the analysis of Manacapuru and EMBRAPA sites measurements. An operational version of BRAMS for the area is already running at the MASTER Lab at USP with 2 km resolution, as exemplified in Figure 13.

3g - Modeling the Manaus Urban Plume

. The plume from Manaus has high concentrations of SO_2, NO_x, and soot, among other pollutants. Background concentrations of aerosol particles and cloud condensation nuclei over the Amazon are more than 10 times lower than background conditions of polluted continental regions. The Amazonian concentrations are increased, however, by two orders of magnitude when influenced by episodic biomass burning and by an order of magnitude in the plume of chronic pollution outflow from Manaus. The simplified photochemical model (SPM) developed by Freitas et al. (2005) with a detailed description of the urban heat island (Masson, 2000, Freitas et al., 2007) and urban emissions will be used to simulated the Manaus urban plume behavior. The emissions in the area will be based on the work by Martins et al. (2010) and also based in the emissions of the Metropolitan Area of São Paulo (RMSP) considering the difference in the number of vehicles and population. Model results will be compared to observations at the EMBRAPA and Manacapuru sites and other locations with some observations available. Also, back trajectories previously mentioned will be compared to the concentration of some pollutants (namely, CO and PM) in order to verify possible influence of local circulations, such as UHI and river-breezes, in the pollution dispersion process. Eventually, nocturnal transport of ozone concentrations, causing the secondary ozone peaks, will also be investigated over the urban areas in Manaus.

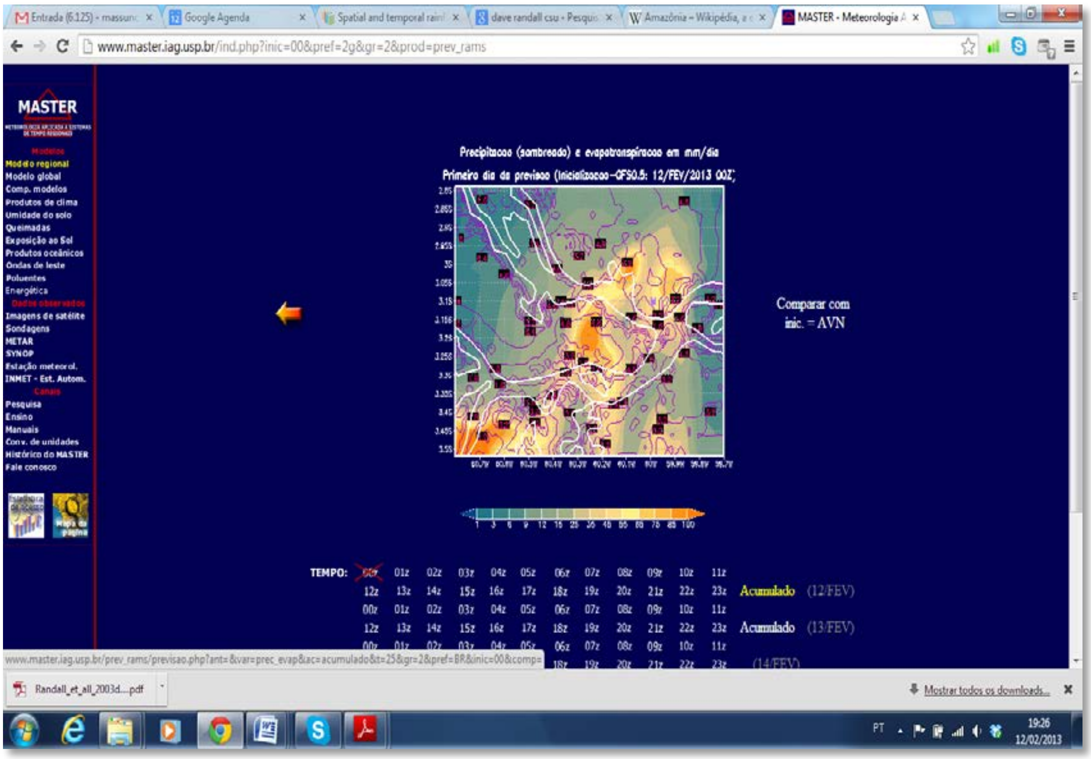

Figure 13 - Operational 2 km resolution regional forecast with BRAMS for the GOAMAZON.
http://www.master.iag.usp.br/ind.php?inic=00&pref=2g&gr=2&prod=prev_rams

4 - Time schedule of the project

This GoAmazon Thematic project is scheduled to start in August 2013 and last for 4 years. The set of activities can be summarized in a 33 months period schedule as on the table below for 2013, 2014 and 2015. The main field activities will be from January 2014 to December 2015. We need at least 6 months to import equipment and prepare the sites for sampling at the sites T2 (Iranduba), T0 (ATTO), T01 (ZF2) and T02 (EMBRAPA, according to the science plan.

Activity	2013		2014				2015				2016	
Importation of equipment	XX	XX	XX									
Installation of instruments for first measurements	XX	XX										
Full operation of the sampling stations at T2 and T0			XX	XX	XX	XX	XX	XX	XX	XX		
IOP – Intensive Operational Periods			XX		XX		XX		XX			
Modeling development	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX		
Integration aerosol cloud measurements				XX	XX	XX	XX	XX	XX	XX	XX	
GoAmazon workshops				XX		XX		XX		XX		
CHUVA workshops						XX		XX				
ATTO workshops		XX				XX				XX		
Publications				XX	XX	XX	XX	XX	XX	XX	XX	XX

5 - Expected Results

The results of this project can bring new insights into the effects of urbanization in tropical regions. This happens not only in Brazil, but also in Africa and Southeast Asia. One key area that will have important results is the mechanisms for secondary aerosol production in tropical areas. The experimental design of the GoAmazon allows study of different mechanisms of SOA production and calculations of rates for different NOx/VOCs conditions. The effects of aerosol into deep convective clouds in tropical regions are also expected to bring new issues into the critically important effects of clouds in the climate system. Process that we will study, model and measure will certainly be important in terms of integration of formation and evolution of tropical clouds. They are on line with the “GEWEX Grand Challenges” in terms of a better understanding of the key links between aerosol-clouds and precipitation. The studies of the effects of aerosols and clouds on the radiation balance can help constrain the studies in this area, since there is difficult in the closure of the radiation balance. The photochemistry of tropical areas is another area that will also gain from this project, since we will study the mechanisms of ozone production from NOx and VOCs emissions from urban area and the forest. The joint use of Lidars, radiosondes, cloud radars and meteorological radars was never used in any tropical area experiment so far. This powerful combination of measurements will add a critical knowledge on the vertical structure of the aerosol-clouds interactions, together with the thermodynamics and dynamical atmospheric conditions.

6 – Other financial support

The US Department of Energy (DoE) is the main funding agency for GoAmazon, but it is important to notice that DoE pays only for the infrastructure, not for actually do the research. They are only responsible for the deployment of the 19 containers at Manacapuru and its operation from January 2014 to December 2015. The cost of the containers and deployment is possibly close to 15 million dollars. The American PIs have submitted a number of proposals to US NSF, that could came close to about 1 million dollars for research. This FAPESP proposal will allow Brazilian scientists to fully participate in the GoAmazon experiment, and take part on data sharing and a large number of scientific collaboration son data analysis.

It is important to emphasize that without this FAPESP Brazilian component, the comparison of situations before and after the Manaus plume will be just impossible, since we are responsible to run the sites that will characterize the aerosol, trace gases, clouds and radiation before the exposure to the Manaus plume.

We have NOT submitted any proposal to fund the Brazilian component of GoAmazon, and the Brazilian team is in general not eligible to receive funds from US funding agencies. We are supporting several scientific projects submitted in the US for GoAmazon, but we will not receive funds from them.

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