Cloud optical properties in the Amazon derived from ground and satellite based instruments

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Contents

I. ABSTRACT

This research proposal focuses on the determination of cirrus cloud optical properties in the Amazon region from different ground and satellite based instruments before and during GoAmazon/CHUVA Experiments. Understanding the behavior of the optical characteristics of clouds and their lifecycle will allow us to evaluate their interaction with solar and terrestrial radiation. A second objective of this proposal will be the evaluation of the cloud radiative effects. Cloud optical depths (COD) will be evaluated from the LIDAR and radiometer instruments, both installed in experimental sites upwind and downwind from Manaus city. Results will be compared with those obtained from satellite instruments. An evaluation of the cloud radiative forcing on the solar radiation will also be obtained by two different methods in the different sites of measurements: modeling and direct solar radiation measurements. These activities will be involved directly with the Green Ocean Amazon (GoAmazon) 2014/2015 experiment from ARM. This research on optical and radiative properties of cirrus clouds should allow, in the future, improving the representation of clouds in the atmospheric models, what is direct related to FAPESP Thematic project *"CHUVA - Cloud processes of tHe main precipitation systems in Brazil: A contribUtion to cloud resolVing modeling and to the GPM (GlobAl Precipitation Measurement)"*. PhD. Boris Barja González is a researcher in the Atmospheric Optics Group of Camagüey, Meteorological Institute, Cuba. He has long experience in these proposed topics.

II. SCIENTIFIC JUSTIFICATION

Clouds have a considerable influence on the radiative energy balance in the climate system. For instance, cirrus clouds are highly translucent to shortwave solar radiation but absorb and reemit infrared radiation emitted from the Earth's surface, thereby warming the surface (cloud greenhouse effect). On the other hand, low thick clouds cool the Earth's surface by reflecting the incident solar radiation (cloud albedo effect). The tropical deep convective clouds produce significant cloud albedo and greenhouse effects with the first dominating and hence having a net weak cooling effect. On the global average, satellite measurements indicate that the shortwave cooling dominates the longwave warming, resulting in a net cooling effect of clouds (Ramanathan et al., 1989; Cess et al., 1997; Webb et al., 2001; Bony et al., 2004; Su et al., 2010; Allan, 2011). This is a very important effect and it has been estimated that a small increase of 4% in cloud cover, and hence in surface cooling, would completely balance the global warming due to increase global concentration of greenhouse gases (Slingo, 1990).

The cloud radiative forcing (CRF, Charlock and Ramanathan, 1985) depends on the macro and microphysical properties of clouds, including cloud amount, height, thickness and characteristics of droplets and ice crystals that form the cloud, but also on properties of the aerosol field that surround the cloud and on the cloud condensation nuclei where the droplets formed. Despite their importance, these parameters are yet hard to measure and hence are yet not very well known on a global scale. A direct consequence of this lack of knowledge is that cloud parameterization schemes in the General Circulation Models (GCMs) do not simulate many cloud processes and feedbacks (Stephens, 2005; Zhang et al., 2005; IPCC, 2007), and hence cloud-climate-interactions still constitutes to be the largest source of uncertainty in future climate projections (e.g., Intergovernmental Panel on Climate Change - IPCC, 2007). Different studies over the last decade have evaluated the top of the atmosphere (TOA) CRFs of these climate models. Potter and Cess (2004) showed that the good agreement between the different climate models in the southeastern Pacific is a result of compensating errors in cloud vertical structure, cloud optical depth or cloud fraction. Siebesma et al. (2004) showed that almost all the GCMs they examined strongly underestimated stratocumulus clouds and local shortwave CRF; meanwhile most of these models overestimate clouds over trade wind regions and the ITCZ and thereby shortwave CRF there. More recently, Teixeira et al. (2011) showed that lack of stratocumulus clouds continues to be a significant problem in weather and climate prediction models. Ichikawa et al. (2012) using the International Satellite Cloud Climatology Project (ISCCP) and the Earth Radiation Budget Experiment (ERBE) observations showed that most of the compared models systematically overestimate shortwave CRF and underestimate longwave CRF over tropical convective regions with weak vertical motion, where cirrus clouds are generally found. They also found that over these regions most of the models have lower high-cloud amount and hence stronger shortwave cooling than observed.

It is important here to make a clear distinction between the anthropogenic induced changes on the cloud forcing, e.g. the cloud albedo effect which the IPCC report to be -0.7 W/m^2 with a low level of confidence (Forster et al., 2007), and the actual global averaged cloud forcing which is about -47±8 W/m^2 in the shortwave and +28±2 W/m^2 in the longwave (e.g. Barbosa and Chagas, 2006). Furthermore, the instantaneous and local impacts of clouds, even cirrus clouds, may reach much higher values. This is of particular relevance in the Amazon region where all phases of convection and the associated cloudiness occur on a daily basis. The WETAMC-LBA campaign in 2002 showed that the nocturnal boundary layer, which is very thin but also strongly stable, is eroded in just a few hours once the sensible heat flux starts to increase (Betts and Jakobs, 2002). This is followed by the development of a shallow convection phase when humidity is transported from the boundary layer to the convective layer, and then above that layer as clouds start to grow deeper. Occurrence of scattered showers at local noon is then followed by more organized deep convection in early afternoon, around 2pm local time, depending on the low level winds regime (Machado et al., 2002). Deep convection is the principal formation mechanism of cirrus clouds in the tropical region, and indeed the latter are present in lidar observations in the Amazon quite often. The boundary layer is then stabilized by the intrusion of air masses with low equivalent potential temperature from the compensating subsidence and, after the nighttime radiative cooling which depends strongly on the night time low and high cloud covers, the layers closer to the surface become very stable again (Adams et al., 2009).

The picture gets more complicated when one consider that Amazonia is under continuous and constant changes, with important climatic implications (Davidson et al., 2012). The tropical forests are very important to the global hydrological cycle (Arraut et al, 2012) and to the global balance of carbon (Davidson e Artaxo, 2004). Moreover, the aerosol concentration has a wide range of variation, from pristine conditions to heavy polluted, following a seasonal impact of deforestation and agriculture practices. These high concentrations of aerosols play an important role in the atmospheric composition modification (Bowman et al., 2009) but also on convection, cloud formation and the precipitation regimes (Andreae et al., 2004, Koren et al., 2008). These biomass burning aerosols have been also linked to a delay in the beginning of the dry season in Amazonia (Bevan et al., 2009, Butt et al., 2011). During the dry season, when the region is generally considered to be pristine, there have been reports of Saharan dust transport (Talbot et al., 1990) sometimes mixed with African biomass burning (Kaufman et al, 2005), which act as ice condensation nuclei and contribute to increase the local convection. This transport has been recently confirmed by Lidar observations in a site near Manaus (Baars et al, 2011 and 2012). Last but not least, the Amazon region also suffers the impact of urban pollution. The capital, Manaus, is located in the central Amazon and has approximately 2 million inhabitants, 400 thousand vehicles and still uses thermoelectric plants which emit high quantities of particle matter, SO_2, NO_X and others pollutants. As a matter of fact, the GoAmazon project will take place in the region downwind from Manaus to understand how pollution plumes from the city interact with the biogenic particles, and how they could change the natural aerosols. During the same period, the CHUVA project which has a strong observational component for better understanding cloud microphysics, its relation to precipitation and to how this precipitation is seen by satellite instruments, will have its last field campaign at Manaus. These, however, are intensive campaigns and do not allow for a climatological perspective. To overcome this lack of long term observations, a new site was recently implemented near Manaus. The ACONVEX experiment started in 2011 and will run continuously a series of cloud and aerosol instrumentation during the next years.

After the previous discussion, the importance of studying cirrus clouds is self-evident, particularly in the Amazon region where the frequency of occurrence of deep convection events and cirrus clouds formation are very high. The main objective of the present proposal is to study cirrus clouds, their lifecycle and its effect on the Earth´s radiation budget using satellite and ground-based observations, in preparation to and during the GoAmazon and CHUVA campaigns in the next years.

II.1. The GO Amazon experiment 2014/2015

The Green Ocean Amazon (GoAmazon) 2014/2015 experiment will be conducted at Manacapuru city, approximately 100 km downwind from Manaus (Figure 1), between January 1st, 2014 and December

31st, 2015. This location was selected exactly because it shows pristine conditions when the pollution from Manaus is deviated by the wind to others directions, and a much polluted condition otherwise. A large set of instruments mounted in 19 containers will be supplied by Department of Energy – Atmospheric Radiation Measurement Program (DoE-ARM) from the American Government. These instruments will be in continuous operation, measuring gases and particles physical and chemical properties, as well as clouds macro and micro physical properties, both with high temporal resolution. Regarding the cloud instrumentation, many remote sensing instruments located in the ground will be available, such as, cloud radars, ceilometers, an elastic single lidar with 532 nm of wavelength, etc. These advanced sensors will be used jointly with traditional observation tools, such as passive microwave radiometers, longwave hemispheric radiometers, four radio sounding launches per day and meteorological observations. The second year of measurements will give the opportunity to study the inter-annual differences and their impacts in the atmosphere and regional ecosystem. The collected observations during GoAmazon will be a fundamental database to produce parameterization of urban and burning aerosols, convective processes and vegetation components to be included climatic models.

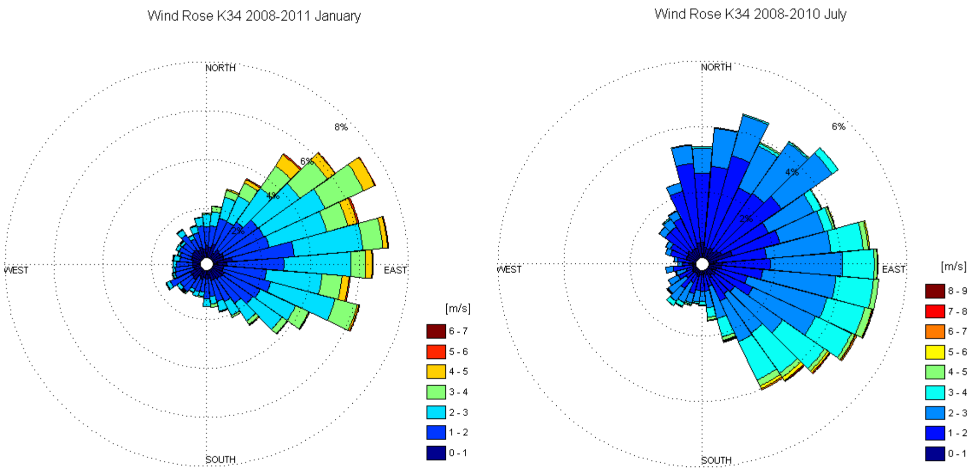


Figure 1: Experimental sites for the 2014/15 campaigns are shown. The DOE-ARM instruments will be located at Manacapuru, while CHUVA's will be spread among Manaus, Iranduba and Embrapa. A Lidar Raman, vertical pointing radar, ceilometer and other instruments are already in operation at Embrapa. Aerosol in-situ measurements will be done at ZF2 and ATTO. The lower panel shows the windroses for January and March at K34 tower at ZF2 (courtesy of Dra. Luciana Riso).

II.2. The CHUVA campaigns in 2014

The CHUVA (Cloud processes of tHe main precipitation systems in Brazil: A contribUtion to cloud resolVing modeling and to the GPM (GlobAl Precipitation Measurement)) project aims to understand the physical process inside the clouds, contributing both to a better description of these in numerical models and to a better precipitation estimation by satellites. Both are particularly important over Brazil, where despite warm clouds being responsible for a large amount of the precipitation in the tropics, especially in coastal regions, they are also little studied and not considered in satellite rainfall retrievals. The project will carry out field experiments at seven sites to investigate the different precipitation regimes in Brazil. The field campaigns will make use of dual polarization radar, lidar, microwave radiometers, disdrometer, radiosonde and various other instruments. Four radiosondes will be launched from Biological Reserve of Cuieiras (ZF2 in figure 1) and another two will complement the measurements at the military airport during the two intensive operation periods (IOP) in feb-mar and sep-oct 2014. Vertical profiles of moistening from radiosonde triangle, and moisture convergence from the Dense GNSS meteorological network (Adams et al. 2011) will provide the environmental conditions where convections develops. The analysis will be performed considering the microphysical evolution and the cloud life cycle, the different precipitation estimation algorithms, the development of thunderstorms and lightning formation, the processes in the boundary layer and cloud microphysics modeling. This project intends to progress in the knowledge of the cloud processes to reduce the uncertainties in the precipitation estimation, mainly from warm clouds and consequently improving the knowledge of the water and energy budget and cloud microphysics.

II.3. ACONVEX – Aerosols, Clouds, Convection Experiment

A new experimental site was recently implemented near Manaus and will run continuously during the next years applying a synergy of different instruments to help understanding the interactions and feedback mechanisms between humidity, convection, clouds and aerosols. It was initially implemented by FAPESP AEROCLIMA thematic project but received contributions from FAPESP CHUVA, form Amazonian Dense GNSS Meteorological Network (Adams et al. 2011), and more recently from the Max Planck Institute. The site is located up-wind from Manaus-AM, Brazil, inside the campus of Embrapa Amazônia Ocidental (figure 1). Instruments available, with installation date and project responsible, are listed below:

- 24 Ghz micro rain radar (MRR), MPI-M, May 2012
- Ceilometer, MPI-M, August 2012
- Metstation PTUV + radiation THIES, AEROCLIMA, April 2012
- Disdrometer THIES, AEROCLIMA, April2012
- 24 Ghz micro rain radar (MRR), CHUVA, August-September2011
- Davis met. Station, UEA-AM, July 2011
- Trimble GNSS Receiver/Vaisla met. Station, DenseGNSS, July 2011
- Multi filter shadow band radiometer (MFR) , AEROCLIMA, July2011
- Cimel sun photometer (AERONET), AEROCLIMA, February2011
- UV Raman Lidar, AEROCLIMA, July 2011

III. OBJECTIVES

The main objective of the present research Project proposal is to study, evaluate and understand the behavior of the cirrus clouds, and their effect on the solar and terrestrial radiation in preparation to and during the experiments GoAmazon and CHUVA, using satellite-based, and ground-based observations.

The specific objectives of the project are detailed below. It is important to emphasize that the specific objectives and work plan of the present Project are inside the great activities set associated to the GoAmazon project, to the thematic Project FAPESP CHUVA and to the efforts of transport modeling that will be carried out by the IAG-USP and some research groups from USA.

III.1. Objectives that can be accomplished with data prior to GoAmazon/CHUVA

1) Characterize the cirrus clouds in the Amazon region from the CALIOP and MODIS data. The CALIOP database is from 2006 to present. MODIS dataset is from 2002 to present.

2) Characterize the cirrus COD and altitude with raman lidar and COD with MFRSR at the Embrapa (ACONVEX) site. There are less of two years of measurement, but these will be important to validate the satellite measurements.

3) Comparison of cloud optical depth (COD), altitude, thickness and so on obtained from ground based instruments with data from satellites (CALIPSO and MODIS).

4) Calculate the radiative forcing of cirrus clouds using radiative models.

5) Study the seasonal variability the before mentioned aspects.

6) Design the study of the lifecycle of the cirrus clouds using the synergy of the measurements in the different measurement sites during GoAmazon.

III.2. Objectives that will be accomplished with data from GoAmazon/CHUVA

7) Select the cirrus clouds study cases during GoAmazon using the synergy of the advanced instruments and conventional meteorological measurements available in the different sites.

8) Characterize the life cycle of cirrus clouds during GoAmazon/CHUVA using both satellite-based instruments (CALIOP and MODIS), and ground-based instrumentation, particularly the cloud radars (at Manacapuru), microwave radiometers (at Manacapuru and Embrapa) and lidars (at Mancapuru, Embrapa and Iranduba).

9) Evaluate the radiative effect of the cirrus clouds during their life cycle using radiative models and radiation measurements during GoAmazon/CHUVA.

IV. METHODOLOGY

The methodology to be used in the project is the one develop by Dr. Barja during the last years, as discussed in Barja (ILRC, 2002), Barja and Antuña (WLMLA, 2005), Antuña and Barja (OPA, 2006), Barja (ILRC, 2006), Barja and Antuña (OPA, 2008), Barja and Antuña (ACP, 2011), Barja et al. (OPA, 2011), Barja and Antuna (IRLC, 2012), and Barja et al (CHUVA, 2013). Details are given in the next sessions.

IV.1. Basic Instrumentation

IV.1.1. UV Raman Lidar

The UV Raman Lidar is operational on the ACONVEX site since July 2011. It uses a Quantel CFR-400 Nd-YAG laser at 355 nm with 95 mJ per pulse and 10 Hz repetition rate. Beam is expanded by 4 and final laser divergence is 0.25 mrad. The optical system uses a bi-axial setup with a 400 mm separation between the cassegrain telescope and the laser axis. The telescope's primary mirror has 400 mm diameter, while the secondary has a diameter of 90 mm. Focal length is 4000 mm resulting in a f/10 system. An iris is used at the focal plane which gives a field of view (FOV) of 1.75 mrad and an initial overlap at 85 m and full overlap at 450 m. This is adaptable, however, and during the first year of measurements data were taken with a fieldstop of 4.5mm resulting in a much narrower FOV and overlap starting at 400m and full at 1.5 km. This configuration shifts the dynamical range upward, allowing for better discrimination of sub-visual cirrus clouds. Figure 2 shows some details of the instrument.

Figure 2: A view of the LIDAR cabinet showing the telescope, laser and acquisition system is shown. On the right, a photo of the inside of the telescope shows the primary mirror and the field stop.

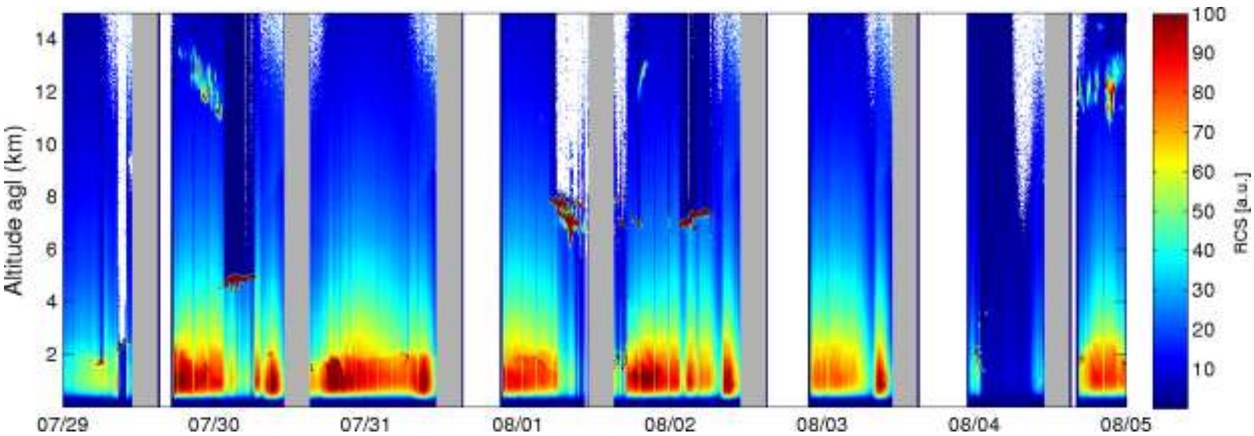


Figure 3: A week of **m**easurements starting on 29th July 2011 is shown.

No fiber optics is used and light passing through the iris goes directly in the optical detection box. Interferometric filters separate the elastic backscattered signal and the inelastic signals due to the Raman cross-section of N_2 (387 nm) and H_2O (408 nm) which are read collected in different photo-multiplier-tubes. Signals from 355 and 387 nm were recorded in analog and photon-count modes, while 408 nm only in photon count. The optical system was designed to give a uniform signal on the cathode surface almost independent of height of the detected signal. A neutral density filter is used to attenuate the elastic signal avoiding saturation, and a good signal to noise ratio (S/N) is found above 15 km depending on the atmospheric conditions. The N_2 channel, 1-min average signals have good S/N up to 15 km but only during night time. For the H_2O channel, 1-min average signals have good S/N only up to 6 km during night time.

The LIDAR has been taking data almost continuously since July 2011, between 14pm and 11am of the following day, what excludes de period when the sun crosses the FOV. Figure 3 shows and example of measurement over the ACONVEX site. The gray bars indicate the periodic shutdown around noon. Cirrus clouds can be observed on July 30th and August 2nd and 5th. Besides measuring the backscatter and extinction coefficients, this lidar system is also able to measure the amount of water vapor. Barbosa et al. (2012) calibrated the water vapor channel by a simple least square fits between the uncalibrated Lidar profiles and eight independent collocated soundings, performed during an intensive campaign between August 30th and 7th September 2011. The largest correlations were found 8 min after the sonde launching (i.e. ~2 km height) when using 5-min temporal and 30-m vertical averages. The top panel of figure 4 shows the vertical variability of the calibration constants. The valued to be used corresponds to the vertical average, which was found to be 0.681±0.045 g/g. The figure also shows more wet layer below the cloud base and more dry above it.

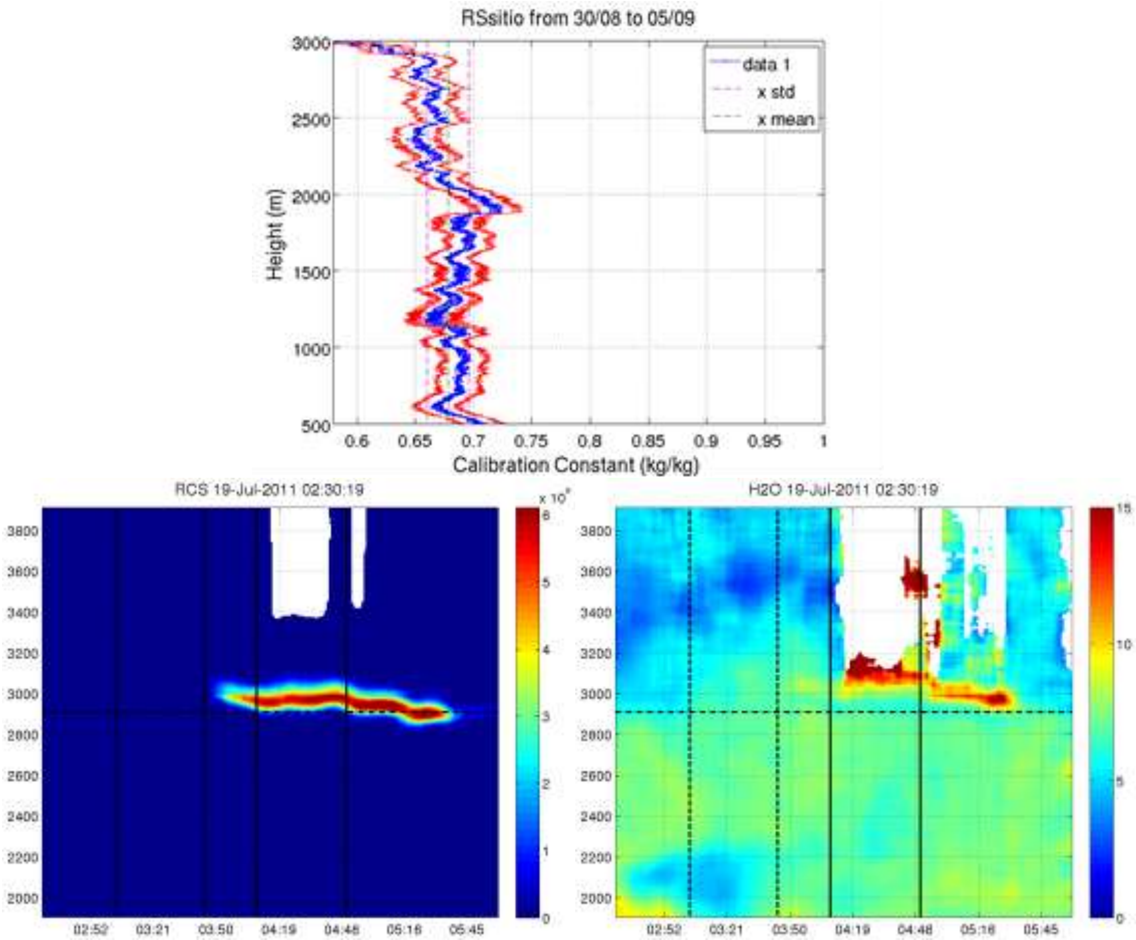


Figure 4: LEFT: Ratio between uncalibrated Lidar profiles and reference water vapor measurements for collocated soundings. Data shown is the average of 8 sounding between August 30 th and September 5th 2011. CENTER: range corrected signal and (RIGHT) water vapor mixing ratio (right, g/kg) around a cloud.

IV.1.2. Multi Filter Rotating Shadowband Radiometer

The Multi Filter Rotating Shadowband Radiometer (MFRSR) is operational on the ACONVEX site since July 2011. It is a MFR-7 model developed by Yankee Environmental Systems, Inc. (YES). The MFRSR makes simultaneous measurements of the solar direct normal global and diffuse horizontal irradiances at six wavelengths (415, 500, 615, 673, 870, and 940 nm) and one broadband channel, at time intervals of 1-min during the day. An automated rotating band is used to shade and expose the entrance aperture of the instrument (Figure 6a). The global and diffuse horizontal irradiances are measured directly and direct normal component is obtained from the difference of the two measured components. Figure 6b shows the three solar radiation components measured at broadband channel during the day August 22, 2011. The variability of these components allows us to detect different weather conditions in the site. In the example shown, at the first time of the day, a dense cloudy conditions is present, no direct normal radiation component is present, and a there are low values of diffuse horizontal radiation. After 9 hours there is great variability of the solar components, denoting a change in the cloudiness conditions.

The selection of wavelengths allows the determination of optical depths of water vapor (940 nm), NO_2 (at 415, 500, and 615 nm), and ozone (at 500, 615, and 670 nm). Aerosols and Rayleigh scattering contribute to atmospheric extinction in all MFRSR channels. Besides these quantities, it is possible to obtain the cloud optical depth (415 and 870 nm).

(a) 

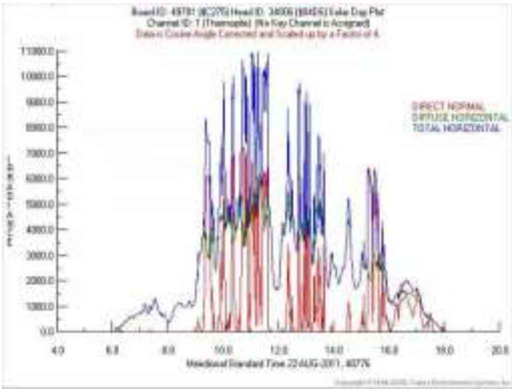
(b) 

Figura 6: a) A view of the MFRSR showing the sensor head and the rotating shadowband driven by motor, mounted in a same base, b) Measurements of the three solar radiation components at the broadband channel of the MFRSR during 22th August 2011.

The MFRSR has some advantages over the traditional method of using two detectors. That method requires one detector to measure the global irradiance and another detector, with a narrow field of view and mounted on a sun-tracking mechanism, to measure the direct- normal component. In addition, the three irradiance components are derived from a single optical detector. Finally, the MFRSR instrument ensures that the measurements of the irradiance components are synchronous.

IV.2. Data Analysis

In the Amazon, there were a few but important field campaigns focusing on some aspects of deep convection and mesoscales systems, or trace gases and biomass burning and biogenic aerosols (e.g., TRMM/LBA, WETAMC, ABLE2, SCAR-B, LBA-SMOCC and SAMBBA-2012). Some had airborne or ground instrumentation for cloud microphysics but it was not their primary goal. Moreover, these were short-intensive observation periods not allowing for a seasonal or climatological perspective. The next campaigns from CHUVA (Feb-Oct 2014) and GoAmazon (Jan2014-Dec2015) will be very important as they will provide data on a seasonal scale from measurements ranging from aerosol chemistry to thunderstorms and lightening. At the same time, the permanent ACONVEX site at Embrapa which started in 2011 with a more limited instrumentation will enter into the climatological scale.

On the other hand, satellite measurements allow us to study the cloud optical depths from a global perspective, but with low spatial and temporal resolutions due to limited swath and local overpass time (for polar orbit satellites, as A-TRAIN). Most important, however, will be the combined use of a variety of ground and satellite based instruments to obtain clouds optical properties, what allows for studding different cloud types in a range of weather situations. Therefore, while establishing a methodology for obtaining and evaluating the cloud properties from the continuous measurements being performed at the ACONVEX site will be very valuable, defining an approach for integrating different ground based, or ground and satellite based instruments will be as important.

IV.2.1. Cloud Optical depth determination with lidar and radiometers.

A comprehensive knowledge of the effects and interactions of clouds in the climatic system requires measurements of their optical properties from satellite and ground-based methods. Our knowledge of the physical and, in particular, of optical characteristics of clouds is essential in describing and predicting potential cloud feedbacks that may affect the climate. Cloud optical depth (COD) and effective radius of the droplet size distribution are the most relevant cloud optical properties. Experimental determination of these properties is based either on measurements of reflected radiation within the visible or the near-infrared bands, or on ground measurements of radiation transmitted through the clouds (Clothiaux et al. 2005).

Several methods are suggested in the literature for determine the COD from ground based broadband shortwave irradiance measurements (Leontieva and Stamnes 1994, Dong et al. 1997, Barnard and Long 2004, Qiu 2006, Barnard et al. 2008). These methods have been applied to thick and thin clouds, but since they assume a plane-parallel atmosphere, they are most appropriate for stratiform clouds. Therefore, COD for inhomogeneous clouds obtained by these methods is taken as “effective” COD. On the other hand, other methods use spectral measurements of radiation to obtain the COD. Leontieva and Stamnes (1996), Min and Harrison (1996) and Turner et al. (2004) introduced different approaches for COD determination using Multifilter Rotating Shadowband Radiometer (MFRSR) data. Chiu et al. (2010) extended the work of Baker et al. (2000) and proposed a method for obtain the COD from the sunphotometer zenith radiance measurements. These methods have been extensively applied to study a mid and long term behavior of COD. Barja et al. (2011) used the COD data from sunphotometer to study their characteristics in Camagüey, Cuba. An alternative method was also developed where the COD could be obtained from the aerosol optical measurements rejected by AERONET algorithm due to cloud contamination.

Using data from a Lidar, an active remote sensing instrument that uses the laser radiation to probe the atmosphere, Ansman et al. (1992) proposed a method to obtain a cirrus cloud optical characteristic profile. With their method it is possible to obtain the extinction coefficient profile of cirrus clouds and their optical depth. Barja (2002), Barja (2005) and Antuña and Barja (2006) used lidar data to obtain cirrus COD, and study the behavior of these clouds from 1993 to 1998 in Camagüey. Barja (2002) employed the slope method to obtain the COD, while Barja (2005) and Antuña and Barja (2006) selected a backscattering to extinction coefficient to convert the backscattering coefficient to extinction coefficient and latter obtained the COD as the integral of the coefficient extinction inside the cirrus clouds. With data from Camagüey lidar a similar instrument in Buenos Aires, Argentina, Lavorato et al. (2008) evaluated several methods to determine the cirrus optical properties. **A methodology to obtain the cirrus cloud base and top altitude, and optical depth was developed during a visit Dr. Barja to the Physics Institute of USP between November 2012 and April 2013.** First results were presented during the Internal CHUVA Workshop, were we analyzed data from the elastic lidar measurements at the Santa Maria campaign (Barja et al, 2013). Cirrus were found from 6.8 to 11.9 km, with COD varying from 0.84 to 1.95.

IV.2.2. Comparison of COD from ground based instruments with data from satellites

There are studies evaluating the correspondence between ground and satellite measurements of cloud optical characteristics (eg.: Dupont et al. 2010, Thorsen et al. 2011). The validation of the information provided by instruments with different geometry, resolution and techniques is an important cross-check exercise. Cloud−Aerosol Lidar with Orthogonal Polarization (CALIOP) is the primary instrument on the Cloud−Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), launched in April 2006 [Winker et al. 2007]. CALIOP profile information is used to calculate COD producing a global view of the cloudiness [Winker et al. 2010]. Moderate Resolution Imaging Spectroradiometer instrument (MODIS) is a key instrument aboard the Terra and Aqua satellite and provide the cloud optical depth (King et al. 1997). Dr Barja has worked in the comparison of lidar with satellite data of cirrus clouds. Barja (2006) compared coincident profiles of cirrus clouds from Stratospheric And Gas Experiment II (SAGE II) and lidar in Camagüey. Based on the differences between the instruments, the coincidence criteria had to consider ±6º in latitude, ±25º in longitude, and ±24 hours in time. In a more recent work, Barja and Antuna (2012) compared COD from Caliop and sunphotometer operating in cloud mode at Camagüey from one year and half of measurements from both instruments. In this case, the coincidence criterion was a spatial window with 0.5 degree centered in the site, with a time window of 6 hours in order to have enough statistics. They found that the probability density function of the observed COD from both instruments to be very similar above COD=0.3. Discrepancies found for smaller values were attributed to cloud contamination as the Aeronet algorithm was not able to distinguish subvisual cirrus clouds.

When the ground and satellite based data are compared it is necessary a carefully selection of the criterion of coincidence or collocation of the measurements (interval or window of spatial and time variables). The criterions are selected considering the site of measurement conditions, cloud types and other assumptions**. This task will require some discussions to decide upon a useful criterion for Manaus region. The results will contribute to the verification of the information about cirrus cloud optical characteristics in the site, but will also be helpful to GoAmazon and CHUVA projects for the evaluation of the accuracy of the aerosol and cloud information from the ground and satellite instruments.**

IV.2.3. Evaluation of the cirrus cloud radiative effect on the radiation budget

The evaluation of the net cirrus cloud effect on the radiation is necessary for the climatic system understanding. There are some methods to evaluate this effect (e.g., Charlock and Ramanathan 1985, Gauthier and Landsfeld (1997), Khvorostyanov and Sassen 2002, Barja and Antuña 2011) in the literature. Cloud Radiative forcing (CRF) is defined as the difference of radiative fluxes between clear-sky and all-sky conditions. Net Cloud Radiative Forcing (NCRF) is basically the sum of the contributions from SWCRF and longwave cloud radiative forcing (LWCRF).

SWCRF = (SWF↓clear-sky - SWF↑clear-sky) – (SWF↓all-sky - SWF↑all-sky)
LWCRF = (LWF↓clear-sky - LWF ↑clear-sky) – (LWF↓all-sky - LWF↑all-sky)
NetCRF = SWCRF + LWCRF

We will obtain the radiative forcing from measurements and modeling. From the previous tasks information will be available about clouds optical characteristics in the studied site, which will feed an atmospheric radiative transfer model to simulate the propagation of short and long radiation in different levels of the atmosphere, and derive the cloud radiative forcing.

The profile of cirrus CRF, instead of just the values at TOA and SFC, will be calculated as in Barja and Antuña (2008). They used the extinction profile of the cirrus clouds derived from lidar backscattering profile to obtain the optical depth profile of the cirrus cloud that was then introduced in the radiative transfer code. The resolution of the lidar measurements is higher than the resolution used in the radiative code at the altitude of the cirrus clouds, thus multiple lidar layers had to be combined, while the vertical structure of the cirrus was still kept. The profile of the ice crystal generalized effective size (*Dge*) was estimated to the cirrus clouds particles by an empirical relation reported in the literature for the tropical oceans. The temperature was interpolated from the NCEP reanalysis. This methodology is similar to the one applied by Khvorostyanov and Sassen (2002) for midlatitude regions. They have evaluated the NetCRF in three midlatitude cirrus cloud cases, with different characteristics, including an unusual cold and high thin cirrus cloud case. This cirrus cloud caused a strong modulation of the heating rates. The NetCRF is negative during the day and positive at night. The 24 hours average NetCRF is −1.2 W/m^2 at the SFC and 1.5 W/m^2 at TOA, so this thin cirrus cools the surface and heats the whole tropospheric column.

Barja and Antuña (2011) calculated the downward and upward irradiances, heating rates, and cloud forcing profiles for each hour of the cirrus measurements' day at Camaguey. It was considered that the measured cirrus clouds were present at all hours of the day, with the same characteristics. In the night hours, solar irradiance zero values were considered and the diurnal cycles of the SW-CRF and the heating rate for 132 profiles were derived. Three cases of diurnal cycle of cirrus clouds were selected for discussion, representing different types of optically thin cirrus clouds. The frequency of occurrence of three types of thin cirrus clouds in the 132 cases is 8 %, 67% and 25% for opaque, thin and subvisible cirrus clouds, respectively (Antuña and Barja, 2006). Daily mean values of upward and downward irradiance at the TOA, SFC, cloud base and top were calculated for the 24 h of the day with the 132 lidar profiles. Also, the mean values of SCRF at TOA and SFC were calculated for each 132 day simulations, three categories of cirrus clouds, and all the 132 cirrus cases.

Barja et al. (2011) calculated SWCRF in the surface by the difference between measured net solar irradiance in cloud presence ($F_{net}^{cloud\ med}$) and the modeled net solar irradiance with clear sky conditions at the same time ($F_{net}^{clear\ mod}$) (Gauthier and Landsfeld 1997). The authors compared both methods to calculate SWCRF for two cloud types (Cumulus Type and Stratocumulus-cumulus combination) in one year and half of measurements. There are similar results using both methods. So, the authors propose to use one or other methods in dependence of the measurements availability. **For the already mentioned elastic lidar measurements at the Santa Maria campaign, Barja et al (2013) also estimated the cirrus CRF, both in the SW as in the LW.** Particles were assumed to be spherical ice crystals with 70µm, surface temperature to be 305 K and albedo 0.18, and precipitable water vapor to be 4cm. For the case with base at 9.78 km and top at 11.9 km and with AOD=1.23, we calculated and instantaneous forcing at TOA of -42.3 W/m^2 in the shortwave, and +80.4 W/m^2 in the longwave. **With the long stay of Dr. Barja in Brazil we expect to improve the method and make it automatic, allowing for a systematic determination of cirrus CRF in the SW and LW from the lidar data at Embrapa.**

IV.2.4. Study of the lifecycle of the cirrus clouds and selection of the study cases.

There are case studies of the lifecycle of cirrus clouds in the literature (e.g. Szantai et al., 2001; Luo and Rossow, 2004; Garret et al., 2005), none however over the tropical forests. These reports employed ground and satellite based instruments to track the development of the cirrus clouds and in some cases the cumulonimbus or anvil. With all the instrumentation that will be available from CHUVA and GoAmazon, this will be a unique opportunity to study the lifecycle of cirrus clouds over the Amazon. For these activities we plan employ measurement from two lidars, one lidar raman (355 nm, 387 nm) located in the Embrapa site (ACONVEX) upwind from urban area of Manaus. The second lidar is an elastic micropulse lidar (532 nm) to be located in Manacapuru, downwind from urban area from Manaus, inside a container from ARM. We will also use radio sounding in different sites to evaluate the temperature profiles. A cloud and meteorological radars will be used to track the convective systems, cirrus clouds formation and development. To complement, satellite data will be used to track the systems.

V. EXPECTED RESULTS AND PERFORMANCE INDICATORS

GoAmazon 2014/2015 and CHUVA-Manaus experiments will be a unique opportunity to study clouds, particularly because of the wide range of instruments looking into the clouds' microphysical and optical properties. These unprecedented experiments in the tropical region due their temporal extension (two years) will provide a very rich dataset that we want to use to study cirrus clouds.

The combination of the measurements from different instruments located in different sites, and their combination with satellites, will increase the knowledge about tropical cirrus clouds, their lifecycle and its effect on the radiation budget depending on the thermodynamic and dynamic conditions of the atmosphere. The principal expected results with the project implementation will be:

1) Characterization of the cirrus clouds in the Amazonia region from the satellite and ground based instruments.
2) Account of the cirrus clouds lifecycle with the study cases from GoAmazon and CHUVA in different seasons.
3) Evaluation the effect of the cirrus clouds on the radiation budget in the Amazonia region.
4) Publication of the results in peer-reviewed quails-A journals
5) Training of Brazilian students at the under-grad and graduation levels

The last two items are actually the best performance indicators of the good progress and ultimate success of the project after the three year period.

VI. SCHEDULE

The duration of the present project is 3 years. Two years during the GoAmazon/CHUVA experiment and the last year to analyze and process the data. Also in this last year we will finish the results and produce the reports and publications. Table below details the programmed activities on the project in six semesters.

Activity	1	2	3	4	5	6
To be accomplished with data prior to GoAmazon/CHUVA						
	SEMESTERS					
	1	2	3	4	5	6
1. Characterize the behavior of the cirrus clouds in the Amazonia region from the CALIOP and MODIS. The CALIOP database is from 2006 to present. MODIS dataset is from 2002 to present.	X					
2. Comparison of COD obtained from ground based instruments with data from satellite instruments (CALIPSO and MODIS).	X					
3. Characterize the cirrus clouds optical depth and altitude measured with raman lidar and COD with MFRSR at the Embrapa (ACONVEX) site.	X					
4. Calculate the radiative forcing using radiative models.		X			X	
5. Study the seasonal variability of the occurrence frequency of cirrus clouds and their radiative effect.		X				
6. Design the study of the lifecycle of the cirrus clouds using a synergy of measurements in the different sites during GoAmazon/CHUVA.	X	X	X			
To be accomplished during or with data from to GoAmazon/CHUVA						
	SEMESTERS					
	1	2	3	4	5	6
7. Participation in the GoAmazon/CHUVA IOP		X	X	X		
8. Select the cirrus clouds study cases during GoAmazon/CHUVA using the synergy of the advanced instruments measurements and conventional meteorological measurements available in the different sites.	X	X	X	X		
9. Characterize the life cycle of cirrus clouds during GoAmazon/CHUVA using both satellite-based instruments (CALIOP and MODIS), and ground-based instrumentation, particularly the cloud radars (at Manacapuru), microwave radiometers (at Manacapuru and Embrapa) and lidars (at Mancapuru, Embrapa and Iranduba).			X	X	X	
10. Evaluate the radiative effect of the cirrus clouds during their life cycle using radiative models and radiation measurements during GoAmazon/CHUVA.				X	X	
11. Writing reports and publication of the results.			X		X	X

VII. BUDGET

For the development of this project, the table below describes what will be necessary and how it will be spent. We are requesting the “auxílio instalação” as Dr. Barja is married and has a 3 year old boy, and the whole family will move to Brazil during the period of the project. We are also requesting an IC scholarship for a student be supervised by Dr. Barja. The total sum requested is not fixed as the value of the BJT scholarship and the research grant will be decided by the CsF committee. It would be strongly important, however, that Dr. Borja be classified at Level 2, because of his expertise and experience. This is a level that will allow him to come to Brazil and work for the full 3 years within our research group, and to seriously consider a future position in Brazil.

BJT SCHOLARSHIP	For Dr. Barja	Level A or B, according to the decision of the committee
To be used for the maintenance of Dr. Barja in Brazil.		
RESEARCH GRANT	For the science team	Between R$10.000,00 and R$20.000,00 per year according to the decision of the committee
To be used by members of the science team to travel to Manaus during the field campaigns. In case of R$10.000,00 / year => R$5000,00 / year for air tickets and R$5000,00 for "diárias" In case of R$20.000,00 / year => R$10000,00 / year for air tickets and R$10000,00 for "diárias"		
TRAVEL GRANT	For Dr. Barja	US$ 736 or BRL$ 1.472,00 according to: http://www.cnpq.br/web/guest/no-exterior
Ground transportation from Camaguey to Havana, and air ticket from Havana to São Paulo.		
RESIDENCE GRANT	For Dr. Barja	Equivalent to 1 month of the scholarship
The "auxílio instalação" will be important to get him properly installed at São Paulo with no delay.		
ADDITIONAL QUOTA OF IC-SCHOLARSHIP	For a student to be supervised by Dr. Barja	3 years with the value determined by the agencies (CNPQ and CAPES)
The description of the activities that the student will develop are given in the next session		

VIII. ROLE OF EACH PARTICIPANT

As part of the present Project, are requesting an undergraduate scholarship (bolsa de iniciação científica) to work in different tasks during the three years duration of the Project. The scholarship will be supervised by Dr. Boris Barja and Dr. Barbosa. If this scholarship is not obtained from CsF program, it is not problem. The research team is listed below and includes individuals from the University of São Paulo (USP), the State University of Amazon (UEA), the Postgraduate Program in Climate and the Environment (CLIAMB-INPA) in Manaus and the Cuban Meteorological Institute (INSMET).

Phd. Boris Barja González ***Bolsa Jovens Talentos***	**Atmospheric Optics Group of Camagüey, INSMET Cuba**
He will be the beneficiary of the BJT Scholarship. He will be involved in all tasks of the project. He will participate in the analysis of the cirrus clouds data (lidar, radiometer, radio-sounding and radar data from ground and satellite based instruments), the life cycle of the cirrus clouds, their effect on the radiation, the design of the study cases, and the comparison of ground base and satellite data. The knowledge and experience of Dr. Barja will be crucial for the development of the project.	
Dr. Henrique de Melo Jorge Barbosa **Coordinator**	**Institute of Physics, University of São Paulo - IFUSP**
He will be a coordinator of the project and participating in most of the analysis tasks. He will be responsible of the analysis of raman lidar data and comparison with CALIPSO. The study cases will be a task with a fundamental contribution from Dr. Barbosa.	
Prof. Paulo Eduardo Artaxo Netto	**Institute of Physics, University of São Paulo - IFUSP**

<table>
<tr><td colspan="2">He is responsible for the infrastructure on all the sites, except those instruments from CHUVA or GoAmazon. His Fapesp Thematic project will provide complementary funding for the participation in the field campaigns for some members of the research team. He will be involved in the comparison of aerosol measurements with aeronet, lidar and satellites.</td></tr>
<tr><td>Dr. Rodrigo Ferreira de Souza</td><td>State University of Amazonas - UEA</td></tr>
<tr><td colspan="2">He will be responsible for the tasks related with satellite data, the analysis and inter comparison between them. He is a local scientist at Manaus and will be involved in the characterization and study cases tasks. He also coordinates the students that will give technical support to the research sites.</td></tr>
<tr><td>Msc. Glauber Cirino</td><td>Phd student at CLIAMB – INPA – advisor: Prof. Artaxo</td></tr>
<tr><td colspan="2">He has used Aeronet, MODIS data and flux tower data in his master thesis to evaluate the impact of direct and diffuse radiation on net ecosystem exchange. He will be involved in the comparison of aeronet, lidar and MODIS data. He will be responsible for the maintenance of the Embrapa site.</td></tr>
<tr><td>Bsc. Diego Alves Gouveia</td><td>Master student at IFUSP – advisor: Dr. Barbosa</td></tr>
<tr><td colspan="2">He is a Graduate student in a master degree program at IFUSP. He will be involved in the characterization of cirrus clouds with the two lidar instruments. He and Dr. Barja have developed the cloud detection algorithm that the project will use.</td></tr>
<tr><td>Bsc. Bruno Takeshi</td><td>Master student at CLIAMB – INPA</td></tr>
<tr><td colspan="2">Bruno is a meteorologist doing his master thesis on carbon cycle in the Amazon soil. He has large experience working on LBA campaigns and logistics of field work. He is responsible for the maintenance of Manacapuru, Iranduba and ZF2 sites.</td></tr>
<tr><td>Jorge Rosas Santana</td><td>INSMET Cuba – advisor: Dr. Barja</td></tr>
<tr><td colspan="2">Jorge Rosas is research assistant in Cuban team, in a young research formation program. He will be involved in the characterization of cirrus clouds with lidar instruments. Also he will participate in the characterization of the effect of the cirrus clouds on the radiation and back trajectory analysis of the cirrus life cycle study cases.</td></tr>
<tr><td>Undergraduate scholarship</td><td>IFUSP – advisors: Dr. Barja / Dr. Barbosa</td></tr>
<tr><td colspan="2">Undergraduate scholarship will be necessary for the implementation of the project. The beneficiary will participate in the preparation, processing and analysis of the lidar, radio-sounding, radiometer and radar data for the project. Also, the beneficiary will participate in the study cases analysis, processing and writing different parts of the reports.

The first year the beneficiary will work with the existing lidar and satellite data for the period before the GoAmazon/CHUVA. The statistical analysis will be a fundamental task in combination with the writing of the used procedures and graphics production. He or she will also be involved in the field campaigns for which he or she will receive the proper training for operating the raman lidar.

For the second year the undergraduate student will be enrolled with case studies, doing the analysis of the meteorological fields and radar data.

For the third year, the beneficiary will work in the statistical analysis of seasonal variation of the cirrus radiative forcing.

As this is a 3 year project, it might be the case the initial student become a master student and a new undergrad has to be selected.</td></tr>
</table>

IX. AVAILABLE INFRAESTRUCTURE AND SUPPORT

This project will be developed at the Laboratory of Atmospheric Physics of Physics Institute of the University of São Paulo. Our group has 4 technicians that will be fully dedicated for the GoAmazon/CHUVA activities in Manaus during the next years:

- Alcides Ribeiro – Responsible for all our instruments at the ATTO tower.
- Fernando Morais – Responsible for 8 cimel sun photometers part of the Aeronet network and the instruments at the ZF2 and Embrapa sites.
- Msc. Ana Loureiro – Responsible for the chemical analysis, standard analysis of aerosol filters, pixe, x-ray fluorescence and organic carbon/elemental carbon measurments.
- PhD. Fabio Jorge – Expert in electronics, is responsible for the instruments at Iranduba site

Moreover, two students from the CLIAMB-INPA program in Manaus, Msc. Glauber Cirino and Bsc. Bruno Takeshi are responsible for the weekly visits at all sites and their general maintenance. Local support is also available from UEA and the LBA office. Prof. Paulo Artaxo's Fapesp Thematic project will provide all aerosol instruments at ZF2, most of the instruments at Embrapa (see section I.3) and for complementary funding for the participation of technicians and students in the field campaigns.

X. FORSEEING BENEFITS FROM THE PROPOSED VISITING

Establishing a methodology for obtaining and evaluating the cloud properties from the continuous measurements being performed at the ACONVEX site will be crutial to better understand the role of clouds in the climate system, particularly important for both CHUVA and GoAmazon projects. The comparisons between ground and satellite measurements will validate the satellite products over the region, thus allowing the extensive use and comparisons at all four experimental sites. However this is not the most important benefit of the proposed visiting.

Dr. Barja visited the Laboratory for Atmospheric Physics (LFA) at IF-USP between October 2012 and April 2013 with a Fapesp visiting researcher scholarship. It was a very productive 6 months, and we were able to: (1) implement the inversion routines for the analysis of lidar signals with the elastic channel and with the raman channel; (2) develop a cloud detection algorithm that works for low, mid and high level clouds; (3) implement routines for the calculation of the geometrical overlap factor for the lidar system operating at Manaus; (4) analyze the noise characteristics of lidar system at Manaus; (5) analyze lidar data from the CHUVA-SUL campaign and compute the COD and CRF for the cirrus clouds. A short communication was presented on the CHUVA international workshop and a paper was just submitted to AMT: Barbosa, Barja, Gouveia and Artaxo, 2013: "A permanent raman lidar station in the Amazon: description, characterization and first results". We are also working on a second paper, from the analysis of the cirrus clouds during the ACONVEX intensive campaign in 2011: Barja, Barbosa and Gouveia, in prep: "Optical properties of Cirrus clouds over central Amazon derived with ground based raman lidar".

In summary, our group would still be working on these reconstruction algorithms if it was not for the cooperation with Dr. Barja. From our previous experience, we expect to work at least on 3 or 4 original research papers from the concrete collaboration during the 3 years project stay of Dr. Barja in our laboratory. A longer stay will also allow him to interact more with the students and possible engage as an advisor. He is a bright young scientist, with blazing intelligence, determination and energy. He visiting and possible future permanence in Brazil would definitely boost the development the Brazilian Lidar and atmospheric optical properties communities.

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