Final Research Report 2016

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

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**Studentship**

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Final research report

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# Contents

# I. Project Summary

This research project focuses on the determination of cirrus cloud optical properties in the Amazon region from different ground and satellite based instruments before and during GoAmazon Experiment. 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 the project 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, downwind and near 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 are involved directly with the Green Ocean Amazon (GoAmazon) 2014/2015 experiment from ARM. The project also contributes directly to the FAPESP Thematic project *"AEROCLIMA - Direct and indirect effects of aerosols on climate in Amazonia and Pantanal"*. 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)"*.

The present partial research report is focused on the project activities and achievements during their second year (August 2014 to July 2015). During the second year the analysis of the cirrus behavior during the period before the GoAmazon experiment with ground based and satellite onboard lidar was continued. Also, the data from MFRSR was handled in order to obtain the cloud optical depth dataset. During this year the lidar measurements in one experimental site not planed was conducted during the intensive observational period.

# II. Project Objectives

The main objective of the present research Project 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 for 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.

## II.1. Planned objectives to be accomplished with data prior to GoAmazon/CHUVA and planed project tasks for the first year.

***Objectives***

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.

**II.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.

***Planned Tasks***

1) Characterize the behavior of the cirrus clouds in the Amazonia region from the CALIOP and MODIS data from the period before GoAmazon. The CALIOP database is from 2006 to present. MODIS dataset is from 2002 to present. Cirrus cloud optical depth and frequency of occurrence can be characterized.

2) Comparison of COD obtained from ground based instruments with data from satellite instruments (CALIPSO and MODIS) during the period previous to GoAmazon experiment.

3) Characterize the cirrus clouds optical depth and altitude with raman lidar and MFRSR in the period prior to GoAmazon in the Embrapa (ACONVEX) site. There are less of two years of measurement.

4) Calculate the radiative forcing during the period preceding GoAmazon using radiative models

5) Study the seasonal variability of the occurrence frequency of cirrus clouds and their radiative effect in the period previous to GoAmazon
6) Design the study of the lifecycle of the cirrus clouds using the synergy of the measurements in the different measurement sites during GoAmazon in order to select the study cases.
7) Select the cirrus clouds study cases during GoAmazon using the synergy of the advanced instruments measurements and conventional meteorological measurements available in the different sites.
8) Characterize the behavior of cirrus clouds during GoAmazon using both ground-based lidars and satellite-based instruments (CALIOP and MODIS).
9) Evaluate the radiative effect of the cirrus clouds using radiative models and radiation measurements during GoAmazon.

There was an additional task in the project that required some extra efforts fundamentally during the second year. The installation of other lidar system in the TIWA (T2) experimental site was a difficult challenge. It was a joint effort with the "Centro de Aplicações Laser do IPEN". Initially, this mission was not planned in the project. But the idea of three lidar system operated at the same time in different points in Manaus region was an amazing task. Also this instrument in an intermediate point between the others lidar system give potentially the opportunity to study the behavior of the cirrus cloud systems with more details. This lidar system installed in the T2 site was operational during two months and was operated manually. Also the analysis of the obtained dataset was an extra task in the project schedule.

Section III is devoted to a brief description of the results and fulfillment of tasks are explained. The section IV is devoted to list the publications and presentation in conferences relates to the project.

# III. Results and fulfillments.

## III.1. CALIOP AND MODIS, BEFORE GOAMAZON.

The first specific objective of the Project was to characterize the behavior of the cirrus clouds in the Amazonia region from the CALIOP and MODIS data from the period before GoAmazon. The CALIOP database is from 2006 to present. From this dataset, Cirrus cloud optical depth and frequency of occurrence were characterized.

For this assignment, at the moment of the report the CALIOP dataset was processed in order to obtain the mean behavior of the COD and the occurrence frequency of the optically thin clouds around the Empbrapa site of measurement. The results from the CALIOP measurements were showed in previous yearly partial reports. The studied region was selected 2 degrees centered in the Embrapa site of measurements, in this way Manacapuru (T3) and T2 sites are inside of this region (Figura 1). ***The results***

***obtained for CALIOP measurements in this task were presented at the 2014 AGU Fall meeting, in December 2014 (Barja et al., 2014).***

The MODIS dataset was not possible to process in through the project time. This database extends from 2002 to the present. The planned time to complete this task was short in comparison with the extension and assimilation of the database.

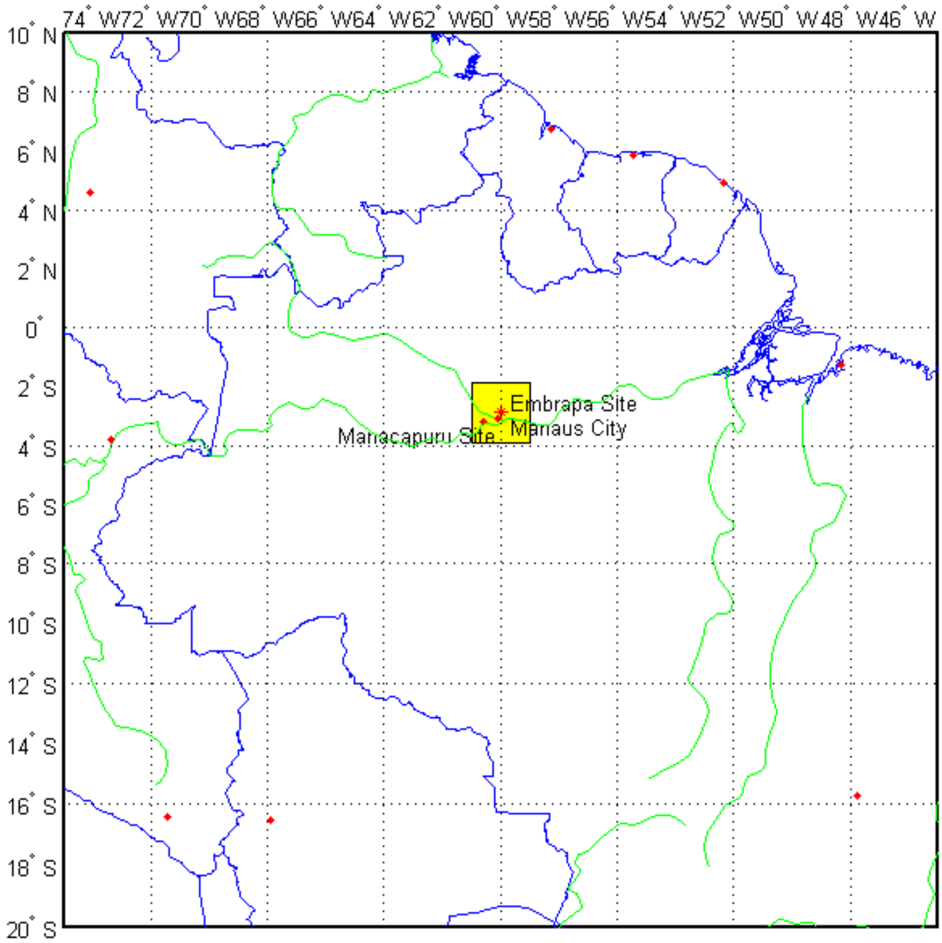


Figure 1: a) Selected region for the analysis in the study. Quadrangular region of 2 degres centered in Embrapa Site (Lat: 2.891 °S, Long: 59.970 °W). Also Manacapuru Site (Lat: 3.213 °S, Long: 60.598 °W) is inside the selected region.

## III.2. Raman lidar and MFRSR

The second objective of the project was to characterize the cirrus clouds optical depth and altitude with raman lidar and MFRSR in the period prior to GoAmazon in the Embrapa site. There are less of two years of measurement for doing that, as the lidar did not operate during 2013 because the laser was broken. The results from the analysis and processing algorithms were presented in the report of the last year ***also was presented in 2 publications (Barbosa et al., 2014; Gouveia et al., 2014a) also 4 papers was presented in scientific conference (Barbosa el al., 2014a; Barja et al., 2013; Gouveia et al., 2013a; 2013b).***

The results related with the characterization of the cirrus clouds in Embrapa (T0e) site were discussed in the partial report of the last year. Also these results ***was published in a Master Degree Thesis or Dissertation (Gouveia, 2014) and presented in 3 conferences (Gouveia et al. 2014b; Gouveia et al. 2014c, Gouveia et al., 2015a).*** The results also are in publication steps in Atmospheric and Chemistry Physics **(*Gouveia et al., 2016*)**

The COD datasets from photometers in T0e e T3 were showed in the report of the last year and also *in the 95th annual Conference of AMS* ***Barja et al., 2015a****.*

The part of the task related with the MFRSR data processing from Embrapa was not finished we are implementing an algorithm to calibrate the instrument. The spent time in assimilate and implement the algorithm for a calibration was not planned in the beginning of the project and the task will be finished out of the scope of the project.

## III.3. Comparison of COD from different instruments previous to GoAmazon

The third objective of the project was the comparison of COD obtained from ground based instruments with data from satellite instruments (CALIPSO and MODIS) during the period previous to GoAmazon experiment. This objective was completed but not finished with the ambitious purposes from the beginning of the project. Some comparisons were conducted with ground and satellite based lidars.

## III.4. Radiative effect of cirrus clouds during the period preceding GoAmazon using radiative models.

The fourth objective is to calculate the cirrus cloud radiative effect during the period preceding GoAmazon using radiative models. Cirrus clouds radiative effects on shortwave radiation spectrum (CRE) have been studied combining lidar measurements with a radiative transfer code and solar radiation measurements at ground.

For this purpose, during one day October 17, 2012 with persistent cirrus clouds over the Lidar at the T0e experimental site was analyzed. Figure 2 shows in the upper panel the lidar backscattering coefficient from the lidar in surface, the second panel shows the backscattering coefficient from CALIOP showing the region measured in the orange box. Also in these two panels the mean COD values are informed and similar results are obtained.

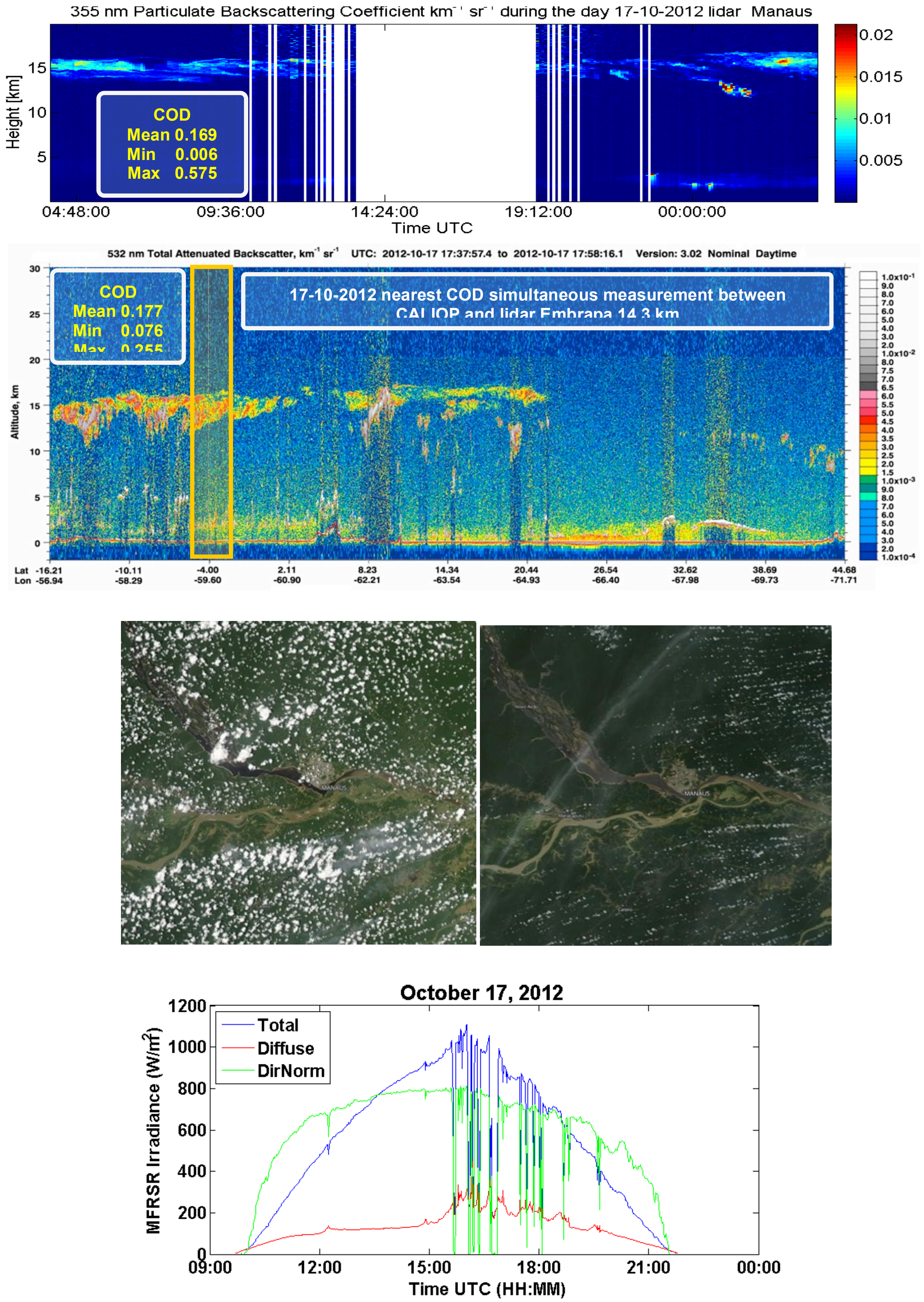


Figure 2: Different measurements to the day October 17, 2012, selected by the persistent presence of cirrus clouds. First panel the surface lidar backscattering coefficient, second backscattering coefficient from CALIOP, third the MODIS images, and the fourth panel the solar irradiances from MFRSR.

The third in the Figure 2 shows the presence of this day of cirrus clouds in the area and the low levels clouds also in the images from MODIS Terra (left) and MODIS Aqua (right). In the bottom panel of the Figure 2 the MFR solar radiation was depicted showing the reducing of the solar radiation by the low cloud levels and the diffuse solar radiation during the day in the presence of the cirrus clouds.

The radiative transfer code was run with the local conditions at the site, using water vapor and temperature profiles from the operational radiosondes (~30 km) as well as locally measured surface albedo (0.16). The radiative transfer model was developed by Geophysical Fluid Dynamics Laboratory by the researchers Freidenreich and Ramaswamy. This model considers particulate scattering and absorption, Rayleigh scattering, and gaseous absorption by O2, O3, CO2, and H2O. The spectrum is divided in 25 pseudo-monochromatic bands. The code uses δ-Eddington method and the ''adding'' technique to solve the radiative transfer equation. Temperature and water vapor mixing ratio vertical profiles obtained from the mean aerological sounding in the site. The Fu´s parameterization represents the solar radiative properties of cirrus clouds. The Inputs to the model are the optical depths and the generalized effective size (Dge).

$$D_{ge} = 7.698 \exp\left(\frac{T+75}{39}\right)$$

We use the extinction profile of the cirrus clouds obtained with lidar to get the "optical depth profile" of the cirrus cloud that was introduced in the radiative transfer code. Assuming, the same cirrus clouds characteristics during the midday period without Lidar measurements. Aerosols were considered in the altitude below 2 km, with an aerosol type clean continental and optical depth of 0.2.

Runs of the atmospheric radiative transfer code were conducted both under the presence of cirrus clouds and in clear sky conditions. The calculated CRE values have negative sign, the instantaneous cloud radiative effect during the day ranging from −0.003 W/m2 to −9 W/m2, at the top of atmosphere and lower modular values in the surface. The CRE vary according to the different optical depths of thin cirrus clouds. Figure 3 shows the CRE to the shortwave and the different spectral bands.

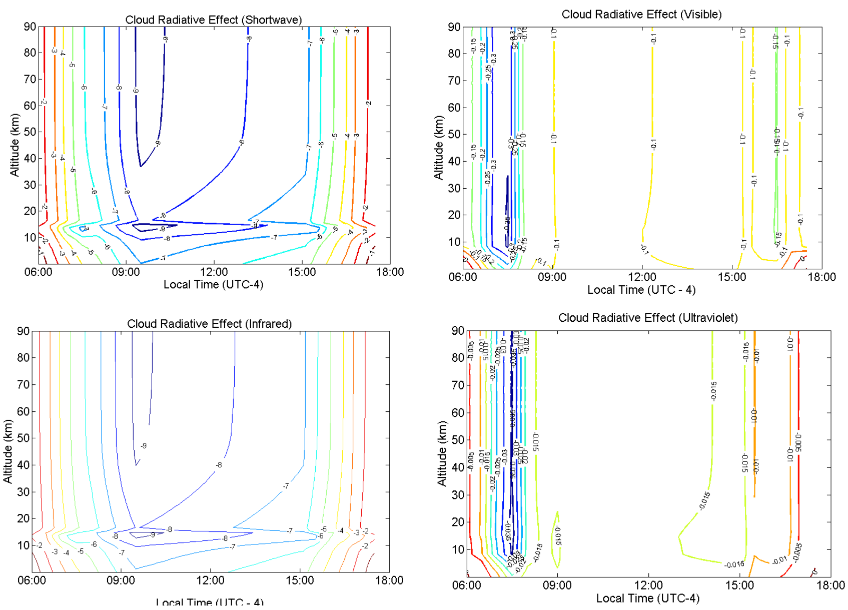


Figure 3: Cloud Radiative Effect (CRE) profiles in the column for the shortwave radiative spectrum and the visible, infrared and ultraviolet bands.

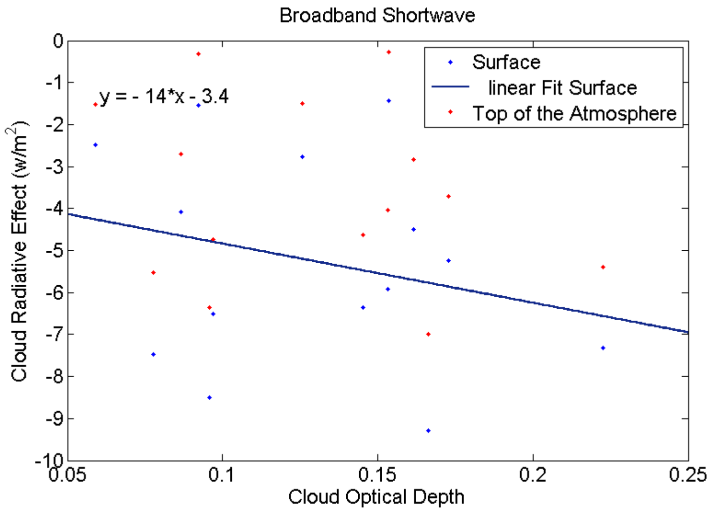


Figure 4: Cloud Radiative Effect (CRE) related with COD in the top of atmosphere and surface during the day October 17, 2012.

There are no data during the midday time, the highest CRE occurs during near the midday in the Top of the Atmosphere and Surface. The higher contribution to the CRE in the solar spectrum is in the near infrared wavelength interval. The lower contribution is in the ultraviolet wavelength range. There is necessary to extend the study to more number the cases. And evaluate the possibility to obtain measurements during the midday with lidar.

A close correlation between the negative cirrus radiative effect and optical depth (anticorrelation) was found at the top of the atmosphere and at the surface when broadband solar irradiances calculations are analyzed, Figure 4. This was found also for different intervals of wavelength in the solar spectrum (near infrared, visible, and ultraviolet).

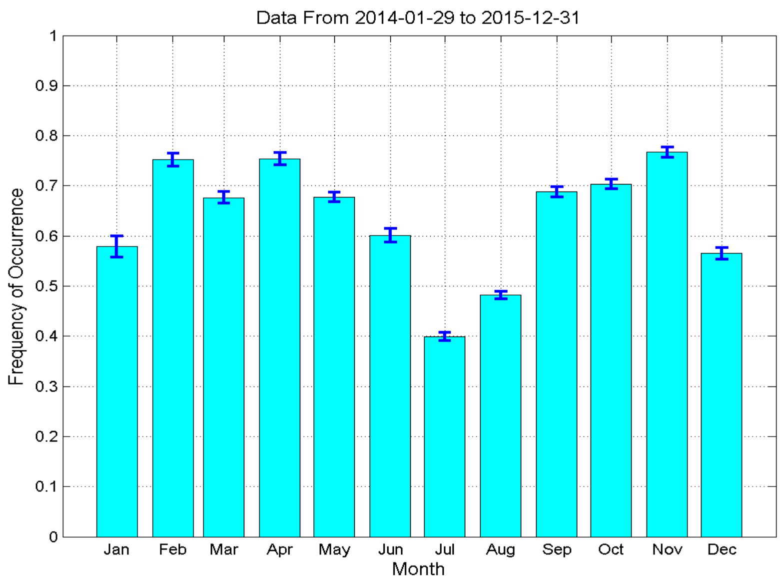


Figure 5: Cirrus clouds occurrence in T0e during GoAmazon (between 2014 and 2015).

This task is still running, two radiative transfer models were implemented and tested with measurements and theoretical values. Also the algorithm to determine the radiative effect with radiation measurement from MFRSR is being implemented.

### III.5. Comparison of COD from different instruments during GoAmazon

During GoAmazon period the characteristics of cirrus clouds with lidar in Embrapa was analyzed. Figure 5 show the frequency of occurrence of the cirrus clouds detected with lidar in Embrapa during GoAmazon period (between 2014 and 2015). Highest frequency of cirrus clouds was in November months with 74 % of time with presence of cirrus clouds. There is a seasonal cycle; during wet season (January, February, March and April) we have higher frequency (71 %) than during the dry season (June, July, August and September) (53 %). The lowest frequency was in July months with 40 % of cirrus clouds over the time.

Diurnal cycle of cirrus clouds frequency during GoAmazon in different seasons is shown in Figure 6. Wet season (red color) have the higher hourly frequency and dry season (blue color) the lower hourly frequency. In the middle we have the transition period (May, October, November and December) with green color. The minimum during the day is around midday at 10 hours local time, there are no measurements during the midday period, because the sun intercepts the field of view of the lidar. The maximum frequency of occurrence is during the afternoon hours after 19 horas local.

Figure 7 shows the macrophysical characteristics of cirrus clouds during GoAmazon period (black line) and the wet (red line) and dry seasons (blue line). The upper-left panel shows the histogram of the base height. With maximum frequency of occurrence of currus clouds base height during dry season near to 12 km. Also around this altitude the maximum of frequency of occurrence to whole period is found. During wet season the frequency of occurrence of base height is around 13 km also with a secondary maximum around 16 km.

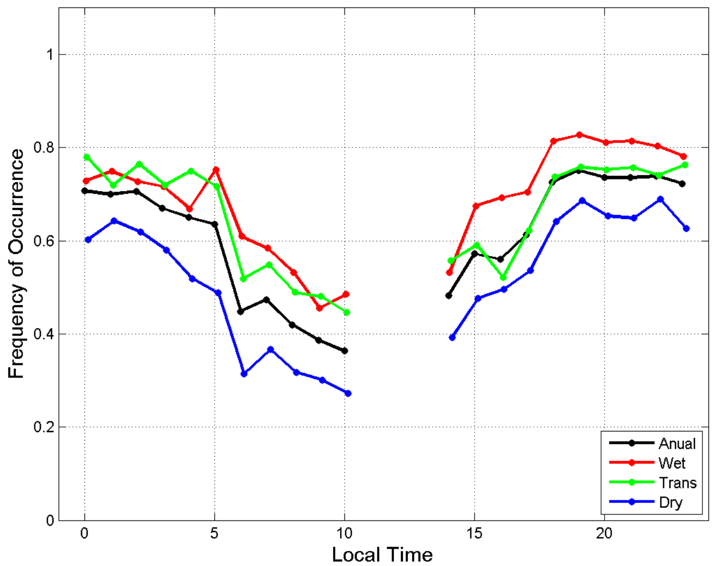


Figure 6: Diurnal cycle of cirrus clouds occurrence in T0e during GoAmazon (between 2014 and 2015).

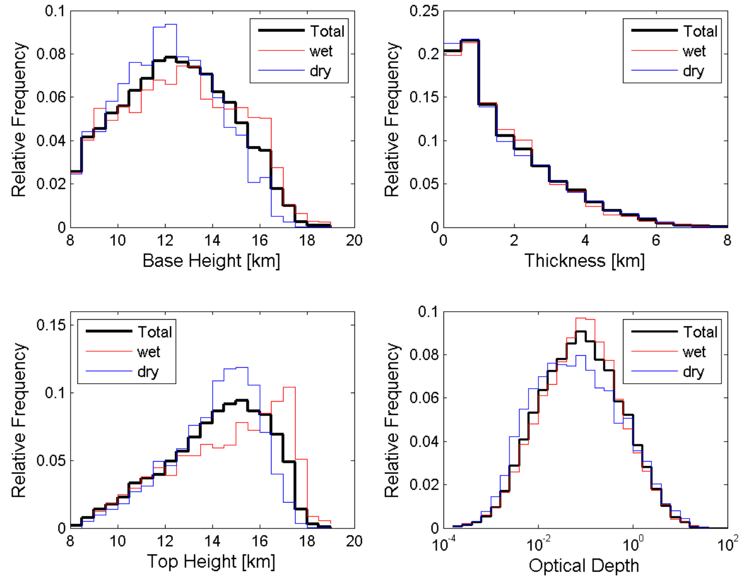


Figure 7: Histograms of macrophysical characteristics and optical depth of cirrus clouds during GoAmazon period and wet and dry seasons.

The below-left panel shows histograms for the cirrus clouds top height. As the base height behavior but more visible tops show the seasonality. The highest frequent top height is around 17 km in the wet period. This value is higher than the maximum frequency of top altitude during dry season, around 15 km.

The right side of the figure 7 shows the geometrical and optical depths in the upper and lower panel, respectively. We can see from this Figure that during dry season the cirrus clouds are geometrical and optically thinnest than the cirrus clouds during wet season.

In order to evaluate the relation of the cirrus cloud height and cloud optical depth we examine the

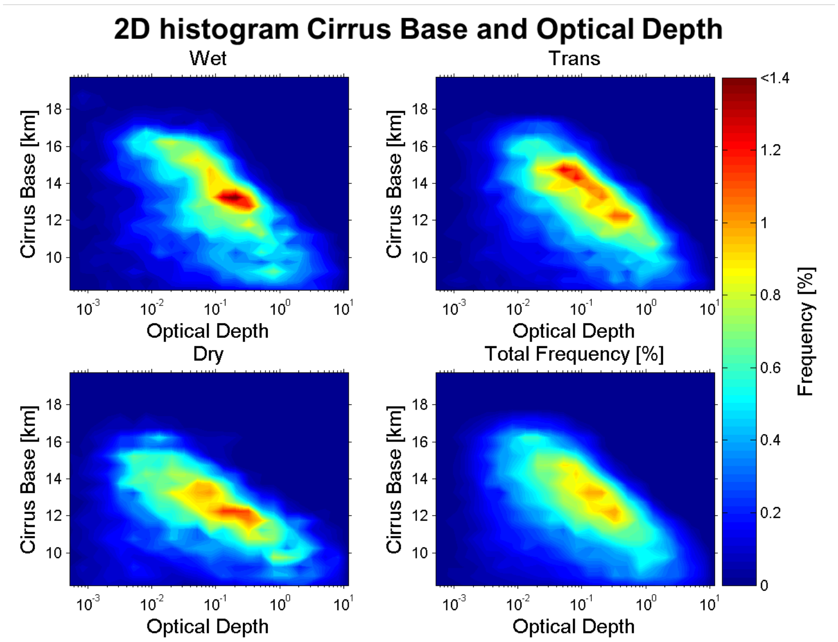


Figure 8: two dimensional histograms of base height and optical depth of cirrus clouds during whole GoAmazon period and seasons.

frequency of occurrence of the base height and cloud optical depth through two dimensional histograms showed in Figure 8 for the whole period of GoAmazon and different seasons. The result found above in the analysis of Figure 7 is confirmed. Cirrus clouds during wet season are higher and optically thicker than during dry season. There is an altitude that divides the cirrus clouds characteristics (14 km) cirrus clouds optically thinnest with higher altitude and optically thicker cirrus with lower altitude.

Following this ideas we inspect the lidar ratio of the studied cirrus clouds. In Figure 9 the lidar ratio are

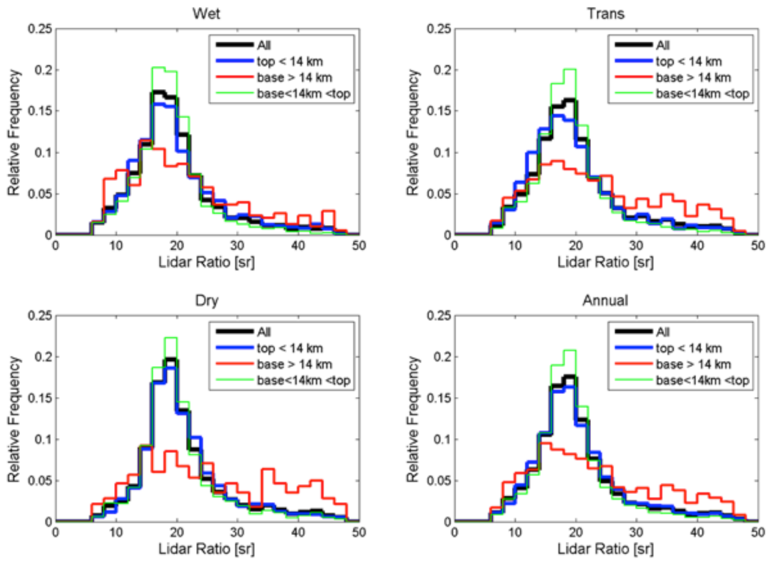


Figure 9: Histograms of lidar ratio of cirrus clouds during whole GoAmazon period and seasons. Cirrus clouds are divided by the 14 km altitude in cirrus above and below 14 km and cirrus with altitude of 14 km inside the cloud.

showed for the whole GoAmazon period and different seasons (panels). The histograms of lidar ratio of cirrus clouds are classified in the different periods in dependence of the location of cirrus clouds in relation with 14 km altitude. Red line represent the cirrus clouds completely above 14 km, blue line the clouds completely below 14 km, and the green line the cirrus with 14 km altitude inside the clouds (with top above and base below 14 km). The histogram of lidar ratio for the clouds above 14 km is different of the other clouds histograms. The histograms of lidar ratio for the cloud above 14 km have two or more maximums of frequency of occurrence. The others cloud types has only one principal maximum between 16 and 20 sr. The clouds above 14 km have lidar ratios with values around 35 and 45 sr. This behavior is more accentuated during the dry season in the lower – left panel.

We decide to compare the results from lidar in Embrapa during GoAmazon period with Caliop lidar measurement during the same period. Figure 10 shows the profile of the monthly (left panels) and hourly (right panels) frequency of occurrence of cirrus clouds (upper panels) and deep convective clouds (lower panels) during GoAmazon period.

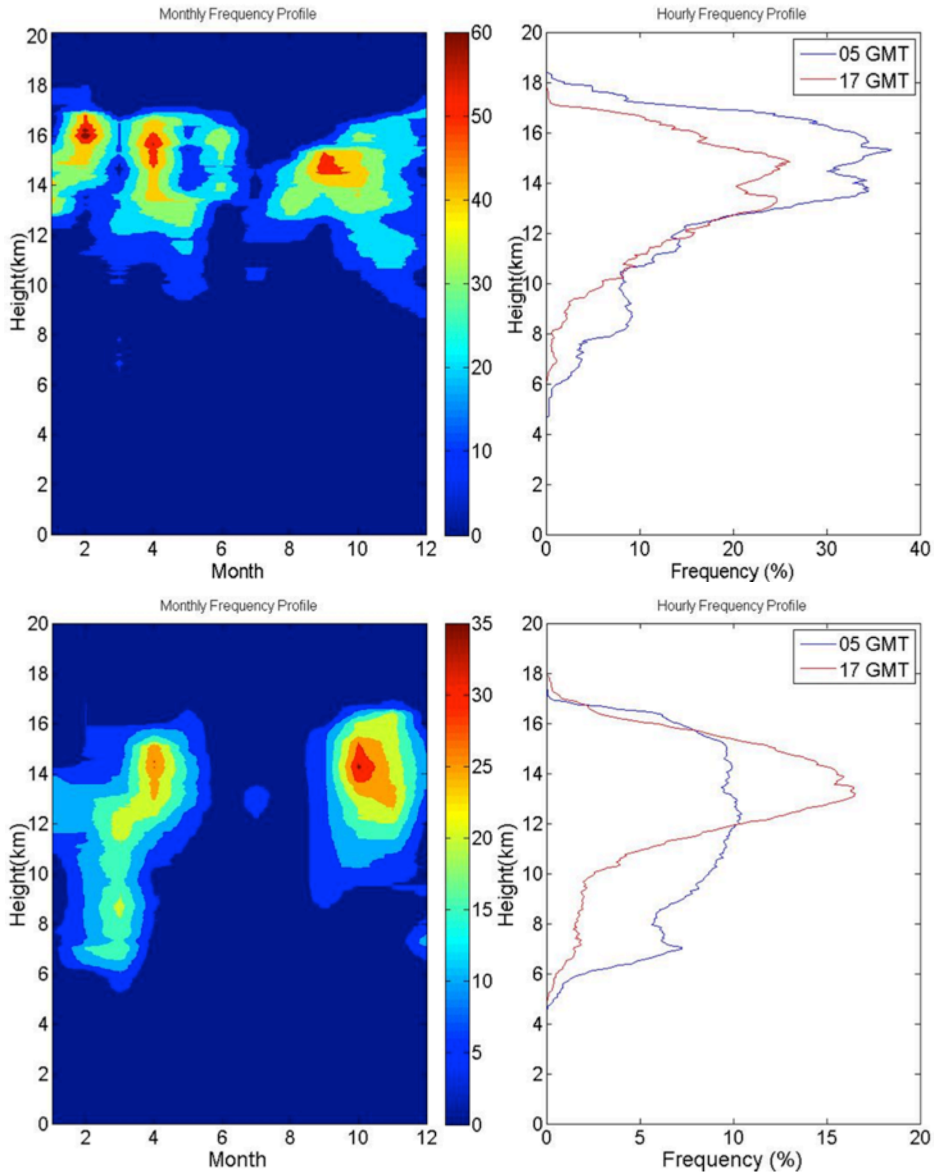


Figure 10: Profiles of frequency of occurrence of cirrus clouds (upper panels) and deep convective clouds (lower panels) monthly (left panels) and hourly (right panels) from Caliop measurements during GoAmazon period in Quadrangular region of 2 degres centered in Embrapa Site as Figure 1.

The same results are obtained as in the ground based lidar, the higher frequency of occurrence and higher altitude are during wet season (January, February, March and April). Also the cirrus clouds have higher frequency of occurrence during the night than during the local midday. These two results are showed in the upper panels. In the lower panels the annual profiles of the frequency occurrence and hourly profile of frequency of occurrence are showed for deep convective cloud type from the classification from caliop measurements.

The same behavior as cirrus is showed during the months with higer values of frequency during wet season than dry season. But the profile of hourly frequency of occurrence show that the maximum is during the local midday.

## III.6. Design the study of the lifecycle of the cirrus clouds using different measurement sites during GoAmazon.

The fifth objective was to design the study of the lifecycle of the cirrus clouds using the synergy of the measurements in the different measurement sites during GoAmazon in order to select the study cases.

This task was implemented, some *results and ideas for this task was discussed in the workshop ACRIDICON – CHUVA 2014 (Barja et al., 2014).* Also an additional task was implemented in order to achieve this objective, the installation of other lidar system in the T2 experimental site. T2 site are near the Manaus, crossing the Negro river, between the T0e and T3, 30 km from distant from T0e and 70 from T3. The lidar system was installed in collaboration with the Centro de Aplicações Laser from IPEN as part of the second Intensive Observational Period inside the GoAmazon experiment.

The installed system in T2 is a Raymetrics Raman lidar with a Nd:Yag laser - Quantel CFR 200 (150-330 mJ @ 532 nm), it was operated at a pulse repetition rate of 20 Hz. We use in the analysis of cirrus clouds the backscattering signal of the 532 nm channel. The lidar was on the site from the middle of August to the middle of the October of 2014. The lidar system need the manual operation, so one technician was always present during this period. We monitor with visual inspection the weather and the cirrus clouds systems measured during these two months. At the final of the measurement period we transport the lidar system from the T2 to T3 and T0e. To conduct some collocated measurements with the others lidar systems installed in these experimental sites. Two days of collocated measurements were conducted in each site. Fortunately cirrus clouds cases were measured with the couples of lidar systems.

Figure 11 shows the frequency of occurrence of cirrus clouds in both sites compared with the annual cycle of cirrus cloud occurrence measured with lidar in T0e. During the months of the IOP 2 August to October 2014 the occurrence follows the annual cycle increasing the frequency of the cirrus clouds from the beginning to the end of the period. The occurrence of the cirrus clouds in T0e and T2 sites during this period of measurements was 69 % and 72 %, respectively. But the monthly frequency was higher

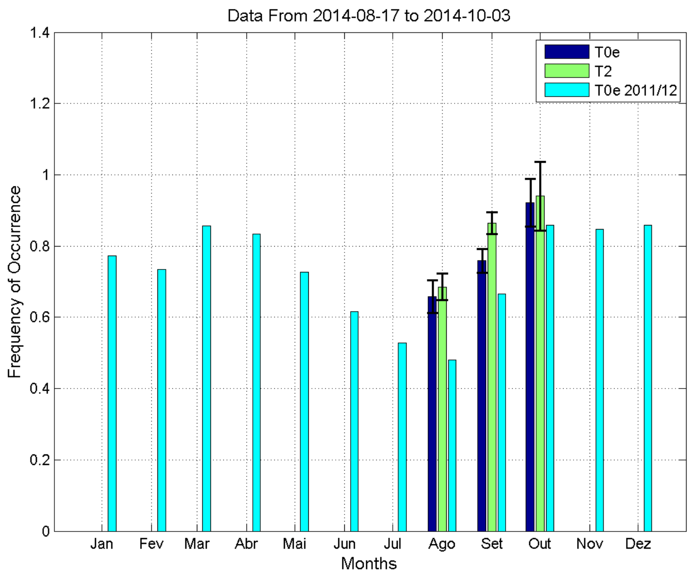


Figure 11: Cirrus clouds occurrence in T0e and T2 compared with annual cycle of cirrus cloud occurrence with lidar in the T0e experimental site during 2011 and 2012.

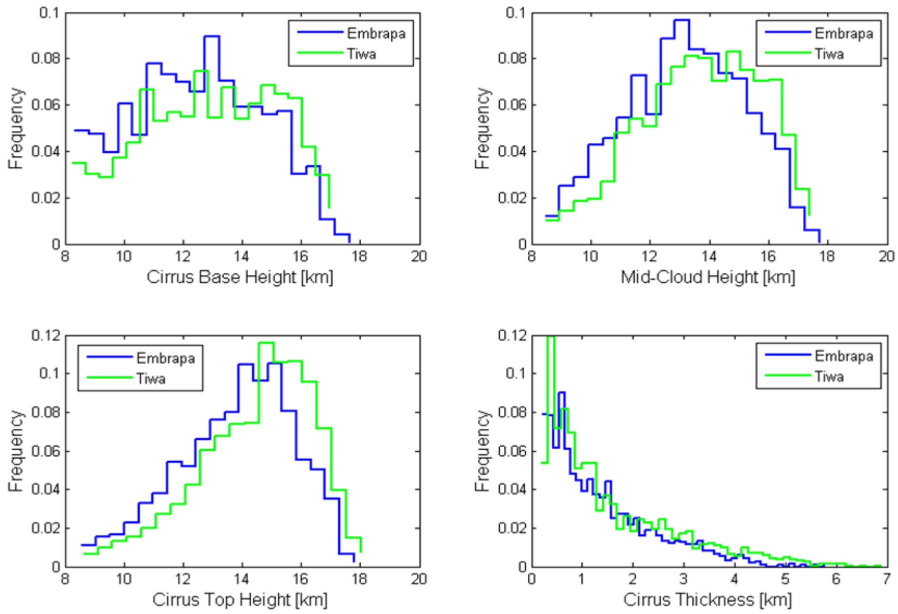


Figure 12: Histograms of macrophysical characteristics of cirrus clouds T0e (blue) and T2 (green) during the IOP from August to October of 2014.

than the mean annual cycle during 2011 and 2012 in T0e experimental site.

Figure 12 shows the results of comparison between the histograms of cirrus clouds macrophysical characteristics in T0e (blue line) and T2 (green line) sites. These characteristics were obtained from the lidar signal analysis. It is shown in the Figure 12 at the upper left panel the cirrus cloud base height, mid-cloud height at the right side of the upper panel, the top height of the cirrus clouds in the left side of the bottom panel and finally the geometrical thickness at the right side of the bottom panel.

The mean value of cloud top height/cloud base height in T0e and T2 are 13.3 km/12.2 km and 13.9 km/12.8 km, respectively. There are statistically significant differences between the mean values of these altitudes in both sites. In the Figure 12 it can see the differences between and similarities between the histograms in both sites. The maximum values of frequency of the top height (bottom left side of figure) are in the intervals centered at 14 km for T0e and 15 km for T2. The occurrence frequencies in these maximum intervals are near to 12 % in both sites. The base height of the cirrus clouds histograms are shown in the upper left side of the Figure 12. The maximum values of frequency of occurrence of cloud base height occur with differences in both sites. In T0e site there is a maximum near to 13 km with 9 % and other secondary maximum near to 11 km with 8 %. In the other hand in T2 there are is a maximum at 12.5 km with 7.5 % and a secondary maximum at 15 km with 7 %. The mid cloud height follow similar behavior of the cloud base height. The right side of the bottom of Figure 12 shows the geometrical thickness of the cirrus clouds with similar behavior in both sites. There is higher occurrence of all geometrical thickness values in T2 experimental site. A maximum occurrences are found in T0e (9 %) and T2 (12 %) near to 0.5 km. In general, there are more frequent cirrus clouds in T2 during the observational period, with higher altitude in T2.

The histograms of the cirrus cloud optical depth in both sites are shown in the Figure 13, at the left panel. Also in the right panel of the figure there are the distributions of the cirrus cloud types (optically subvisual, thin and thick cloud). In the histogram it is possible to observe the similar behavior of the COD

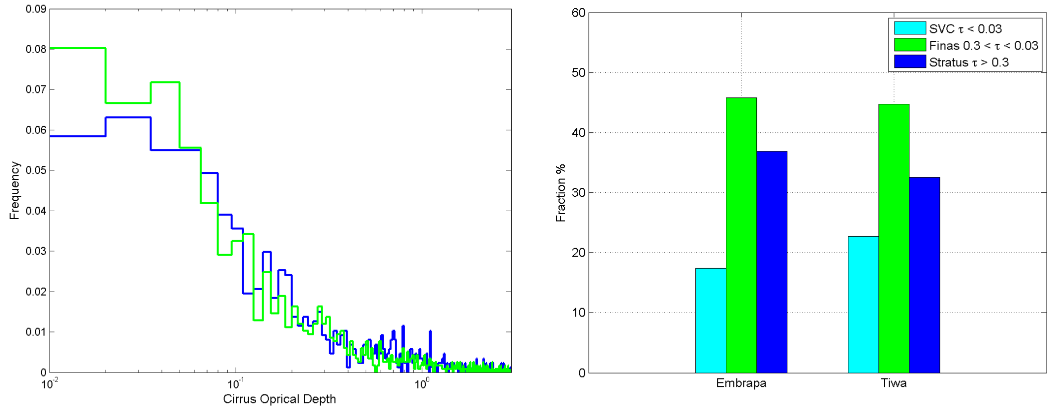


Figure 13: Histograms of cirrus cloud optical depth T0e (blue) and T2 (green), and distribution of cirrus cloud types, during the IOP from August to October of 2014.

in both sites, there are some intervals with differences, there is higher frequency of COD values below 0.03 in T2 site than in T0e.

These aspects are shown also in the right panel of the Figure 13 where the frequency of subvisual cirrus clouds in T2 is higher than T0e with difference of 6 %. There is higher occurrence of the other subtypes in T0e, with differences of 1 % (thin cirrus clouds) and 5 % (thick cirrus clouds). So, the cirrus clouds detected with lidar are optically thinnest in T2 site with mean optical depth of 0.5 lower than 0.8 for T0e, with about 65 % classified as subvisual and thin cirrus clouds.

Figure 14 show the lidar ratio frequency distribution, lidar ratio was determined for the cirrus clouds in the site T0e (blue) and T2 (green). The maximum occurrences were for the lidar ratio interval centered in 18 sr (T0e) and 24 sr (T2), with 27 % and 16 %, respectively. The distribution of lidar ratio showed a

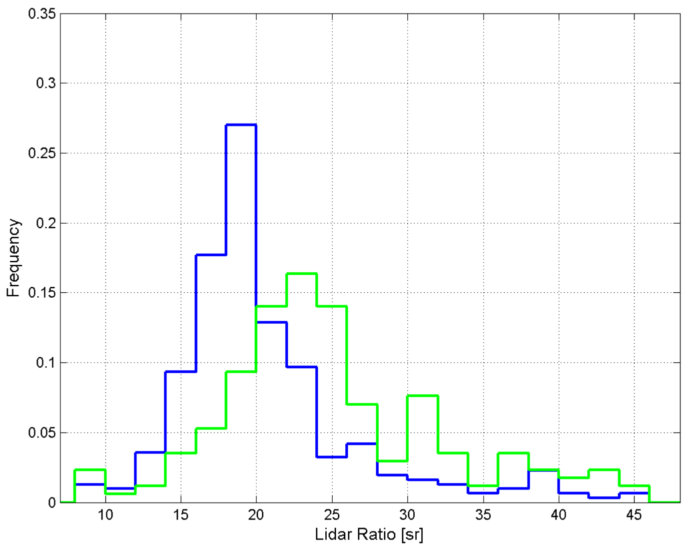


Figure 14: Histograms of cirrus cloud lidar ratio at T0e (blue) and T2 (green) during the IOP from August to October of 2014.

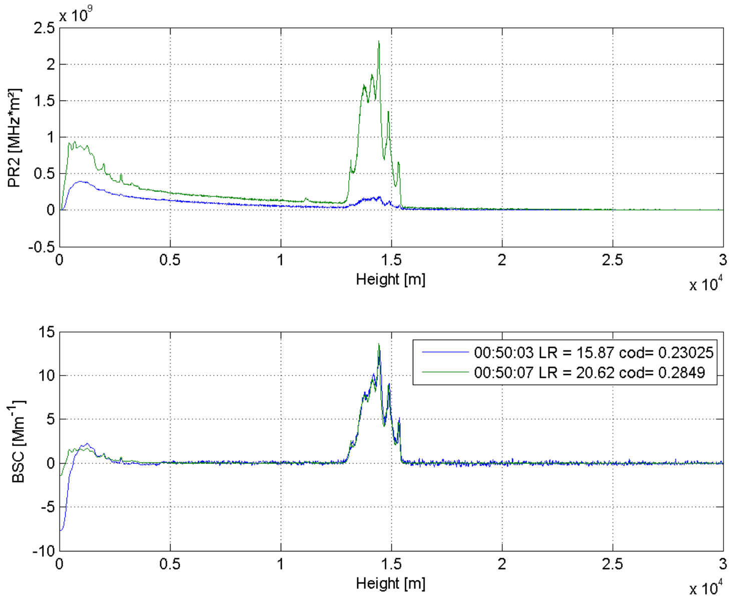


Figure 15: Range corrected lidar signal (upper panel) and backscattering coefficient (bottom panel) from two raman lidar (355 nm (blue) and 532 nm (green)) measuring the atmosphere simultaneously in T0e experimental site.

wide range of values indicating crystal shapes between thick plaques (lidar ratio ~ 11 sr) and long columns (lidar ratio ~ 26 sr) as the main shape of ice crystal.

Cirrus clouds during the Intensive Observational Period shows slight differences between both experimental sites. Cirrus clouds are higher, more frequent and optically thinnest in T2 experimental site distant 30 km from the T0e experimental site.

These results were presented in the VII Workshop on lidar Measurements in latinoamerica, Cayo Coco, Cuba, April 6-10, 2015 (Barja et al., 2015b), and the Harvard GoAmazon 2014/15 Science meeting, May 18, 2015 (Gouveia et al., 2015c).

The other achievement in the 2nd IOP 2015 was the intercomparison of the lidar systems. There were conducted some tests to calibrate the raman lidars from raymetrics of 355 nm and 532 nm. Figure 15 shows the two signals from raymetrics lidars collocated in T2 experimental site. The upper side shows the range corrected lidar signal (355 nm (blue) and 532 nm (green)) for each lidar. It is notable the presence of cirrus clouds in both signals, at the same altitude, low values of backscattered signal in the 355 nm lidar. Also it is visible the different overlap altitude in both lidars. The bottom panel of the Figure 15 shows the retrieved backscattering coefficient from both lidars. The coincidence between both lidar signals is evident with some minor differences, showing the correspondence of both signals in measure the same atmosphere. The COD are similar in two signals 0.23 (355 nm) and 0.28 (532 nm), with lidar ratios 15.9 sr and 20.6 sr respectively. These results show the agreement between two lidars in measure the same cirrus cloud.

In order to analyze the cirrus cloud properties measured with both lidars (355 nm and 532 nm) the signals were processed to retrieve the cloud optical depth and the Figure 9 was obtained. This Figure 16 shows the cloud optical depth (left-upper panel) and the lidar ratio (left-bottom panel) retrieved from the both lidars during one day of measurements. There is a gap of measurements during the midday due the sun interference in telescope. There is notable the lower values of the COD for 355 nm wavelength.

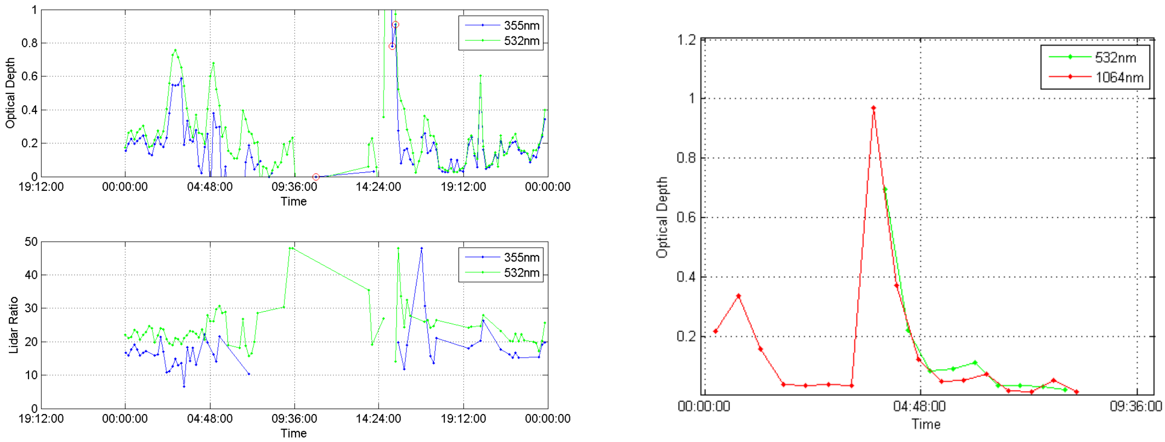


Figure 16: COD and lidar ratio during the simultaneous measurements in T0e with 355 nm and 532 nm lidars (left panel). COD values from simultaneous measurements in T3 with 532 nm raymetrics lidar and 1064 nm MPL lidar.

But in some intervals of time there are low values of differences between both COD, principally at the end of the day. In the left-bottom panel of the Figure 16 shows lower Lidar ratio values for 355 nm almost all the time. Also, Figure 16 right panel shows the COD values from the ARM version of the processed MPL lidar signal (red) and the COD retrieved from the raymetrics 355 nm lidar to the measurements collocated at T3. There are some agreements between the COD from both instruments.

In general were conducted some test to calibrate the raman lidars and show the quality of the raman lidars signals. Also there is correspondence between the cirrus clouds measured with different lidas simultaneously, However, there are still more tests to be done, it is still conducted the analysis of the signal from de MPL lidar located in Manacapuru (T3) experimental site, in order to evaluate the characteristics of the cirrus clouds in this site. Also to analyze the collocated measurements with the lidar raman signal.

Some of these results were presented in the **VII Workshop on lidar Measurements in latinoamerica, Cayo Coco, Cuba, April 6-10, 2015 (Gouveia et al., 2015b) also in the technical report of the ARM (Barbosa et al., 2016)**

## III.7. Select the cirrus clouds study cases during GoAmazon.

The sixth objective is to select the cirrus clouds study cases during GoAmazon using the synergy of the advanced instruments measurements and conventional meteorological measurements available in the different sites.

Days from September 2$^{nd}$ to 6$^{th}$ of 2014 during the GoAmazon period was selected as cirrus cloud case study. The reasons were that there almost two sites with lidar measurements and continuous measurement of cirrus clouds. Also, other reason was during these days we have a near overpass of the calypso measurements and collocated measurements were possible to compare qualitatively or quantitatively the measurements of both instruments. Figure 17 shows lidar measurements in Tiwa (upper panel) and Embrapa (lower panel) sites for the studied days. Also in the lower panel the COD values retrieves from lidar measurements are showed. The classification of cirrus clouds during these days go from the subvisual cirrus clouds through thin cirrus clouds to opaque or altostratus clouds.

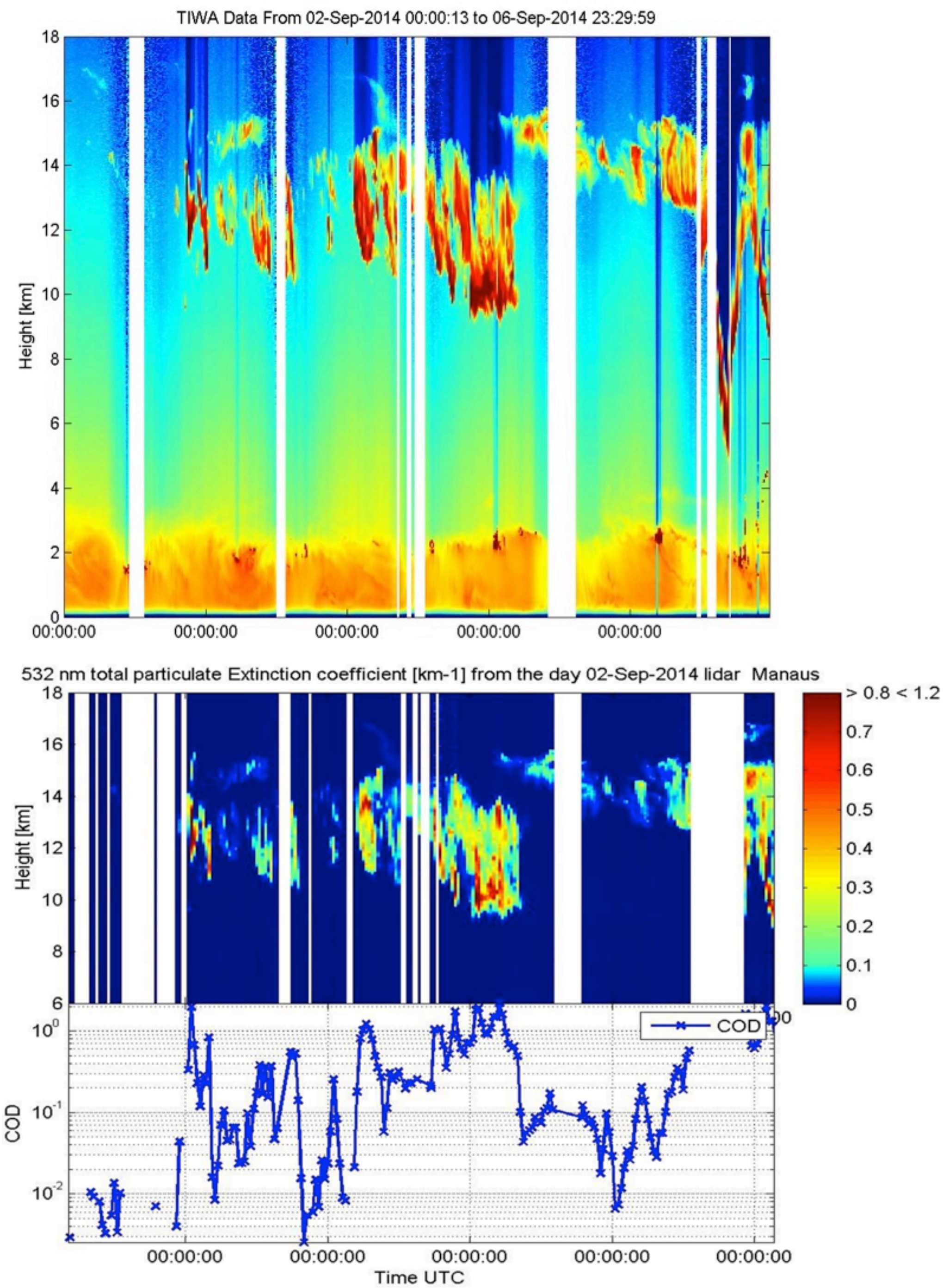


Figure 17: Lidar measurements in TIWA (upper panel) and Embrapa (lower panel) during September 2nd and 5th, 2014, throgth GoAmazon experiment. Also COD values of detected cirrus clouds are shown in the lower panel.

Figure 18 shows the measurements from caliop aboard calipso satellite during the overpass of the Embrapa and Tiwa sites in the midday of September 3rd (upper panels) and morning (middle panels) and midday (lower panels) of September 5th. The left panels show yellow rectangles with the nearest caliop measurements to the sites (inside the rectangle of 2 degrees around embrapa). The presences of cirrus clouds are evident during these overpasses of caliop around the sites at the same altitudes detected from the ground-based lidars. The left panels correspond to the blue mark in the trajectory showed in the right panels.

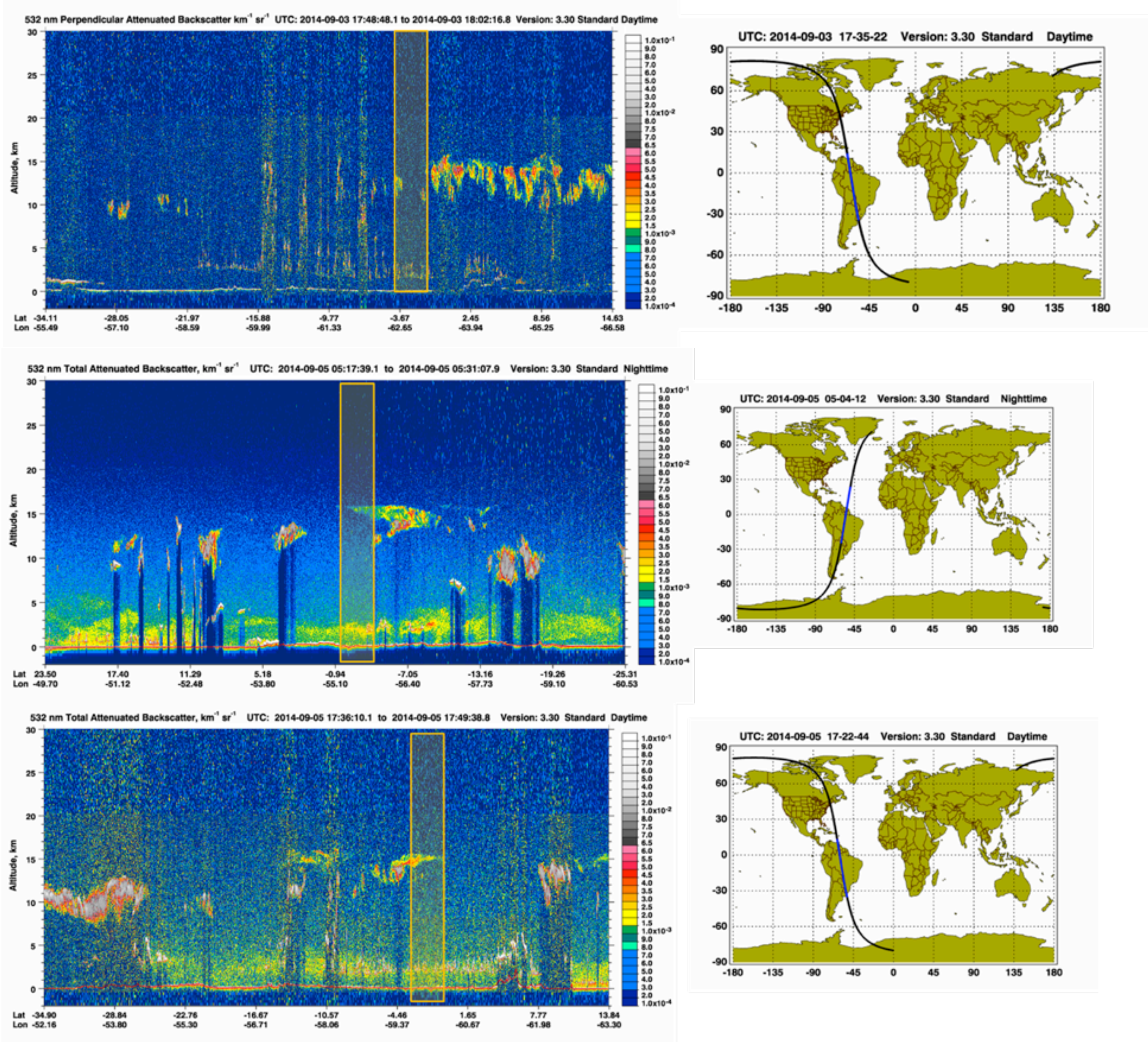


Figure 18: Caliop measurements around Embrapa and TIWA, the upper panels is the overpass of caliop around local midday of September 3rd. The caliop overpass during the September 5th in the morning (middle panel) and midday (lower panel). We can see in the left panels the signalized area with yellow rectangle showing the presence of cirrus clouds in the nearest measurement from the site.

We used two methods to obtain the radiative flux (GFDL radiative model for shortwave spectrum and libradtran to calculate the flux in shortwave and longwave spectrum) in order to evaluate the radiative effect of these clouds on radiation.

Figure 19 show the calculated profiles of shortwave cloud raditive effect through September 5th, 2014. In the upper panel the lidar measurements of cirrus clouds during the day with no measurements around the midday. The lower panel shows the profiles of shortwave cloud raditive effect, we can see the maximum with the maximum backscattered signal and also during the day around midday at the altitude near the presence of cirrus clouds. The radiative effect has negative values meaning a radiative cooling of the cirrus clouds in the atmosphere in the shortwave spectrum.

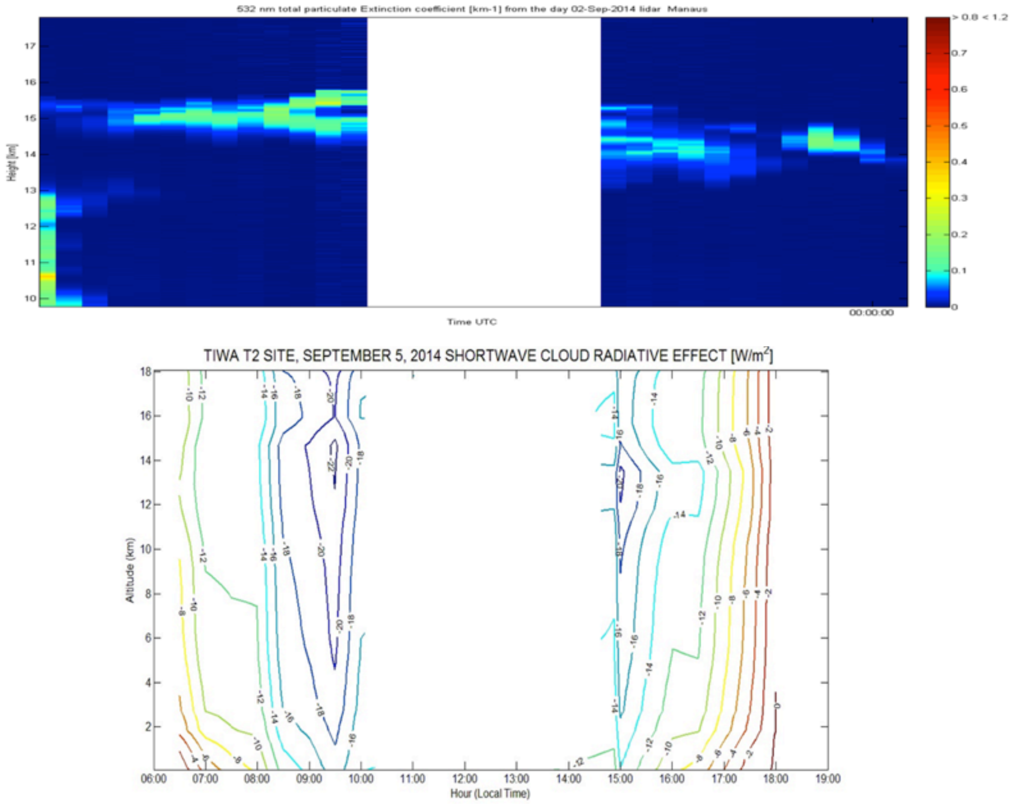


Figure 19: Upper panel lidar measurements of cirrus clouds in TIWA during September 5th, 2014. Lower panel shortwave cloud radiative effect calculated with radiative flux from GFDL radiative model.

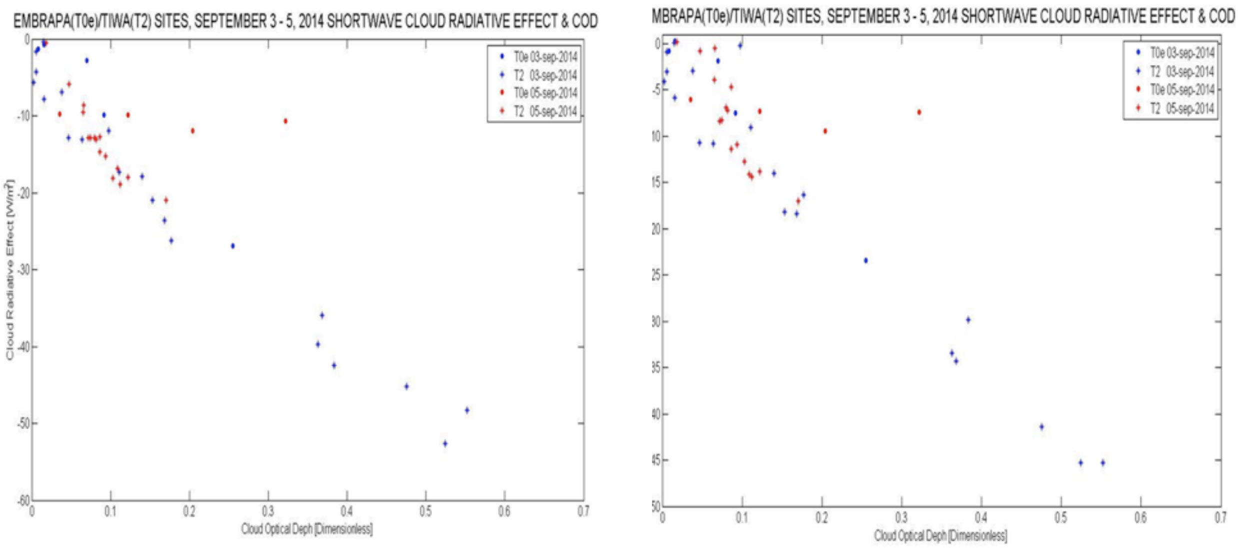


Figure 20: Cloud radiative effect calculated with radiative flux from GFDL radiative model in September 3rd (blue) and 5th (red), 2014, at above both sites Embrapa (dot mark) and TIWA (cross mark) for the top of atmosphere (left panel) and surface (right panel).

Figure 20 shows cloud radiative effect calculated with radiative flux from GFDL radiative model in September 3rd (blue color) and 5th (red color), 2014, at above both sites Embrapa (dot mark) and TIWA (cross mark) for the top of atmosphere (left panel) and surface (right panel). We can see the negative values meaning radiative cooling of the atmosphere at TOA and surface in both sites. The effect is slightly higher in the TOA than surface.

Other cirrus clouds case study was selected September 21th, 2014 during GoAmazon. Figure 21 shows the lidar backscattering signal and the cloud optical depth. Cirrus clouds were present during whole day; we can assume that during the midday this cloud was present. A principal cloud was present between 12 km and 17 km almost during all day. During first hours of the day some lower cirrus clouds were present below 12 km but above 10 km, almost all the time the cloud was classified as thin cloud with COD between 0.3 and 0.03, values marked with the broken black line.

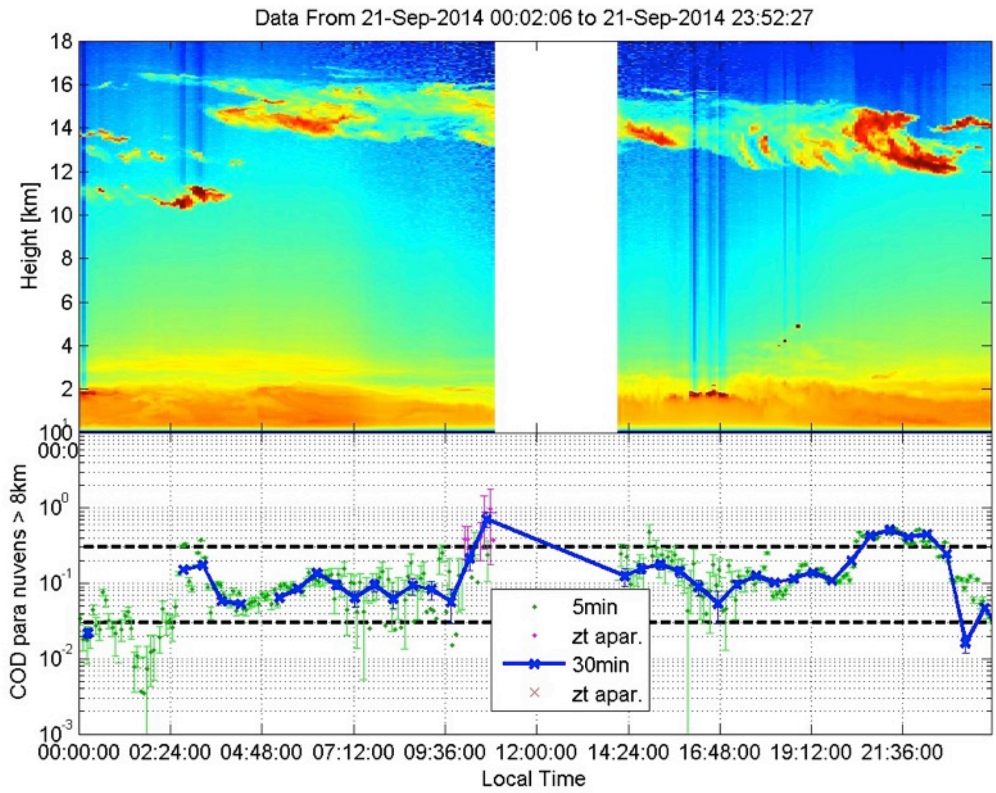


Figure 21: Lidar measurements in Embrapa (upper panel) during September 21st. Also COD values of detected cirrus clouds are shown in the lower panel.

We used this results showed in previous Figure 21 (Vertical Extinction profile (250m) and 30 min time step.) to introduce to libradtran model in order to calculate the radiative effect of cirrus clouds during September 21st. Also other values were used the standard ice parameterization from Fu 1996 e 1998. We consider shortwave (0.3 - 3µm) and longwave (3 - 100µm) spectrums and two values of effective radius of ice particles are used 20 µm and 50µm. These characteristics and values were used to calculate the instantaneous cloud radiative effect in both radiation intervals.

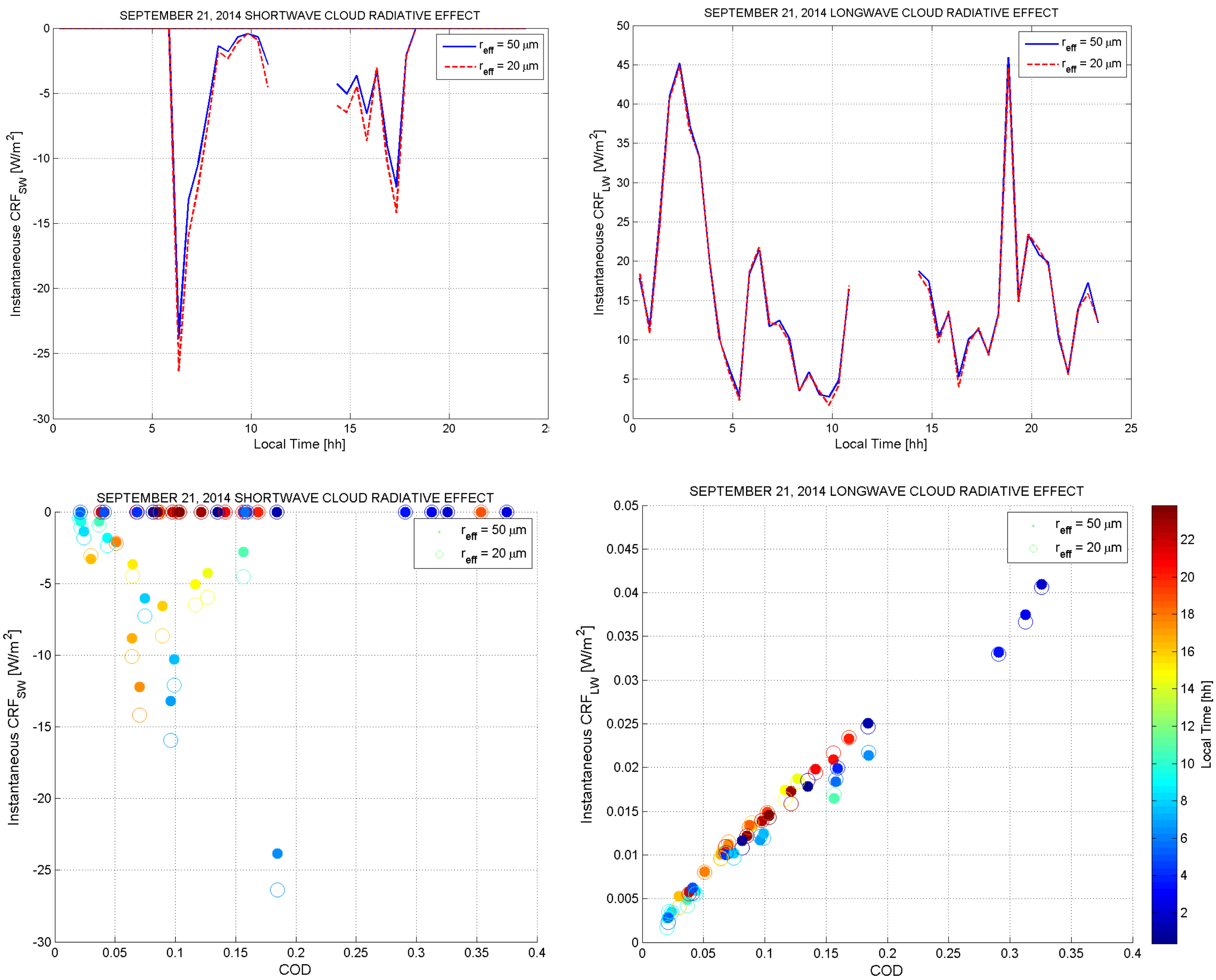


Figure 22: Cloud radiative effect in surface calculated with libradtran radiative model in September 21st with effective radius of ice particles 50 µm (blue solid line) and 20 µm (red broken line) at shortwave (left panel) and longwave (right panel). The lower panels show the relation of cloud radiative effect with cloud optical depths and color bar with local time of the day.

Figure 22 show the cloud radiative effect calculated with libradtran radiative model in September 21st with effective radius of ice particles 50 µm (blue solid line) and 20 µm (red broken line) at shortwave (left panel) and longwave (right panel). The lower panels show the relation of cloud radiative effect with cloud optical depths and color bar with local time of the day. In the upper panels we can see at the left upper panel that values of shortwave CRE have negative sign meaning radiative cooling and the right upper panel show longwave CRE have positive value meaning a radiative heating. The heating values are higher in module than the cooling values so the heating effect of the cirrus clouds dominant over the cooling effect. The differences between these two assumed values of ice crystal size were not high, with lower differences in the longwave case.

The lower panels show the dependence of the CRE with COD and hour of the day. In the shortwave case there is not direct dependence with COD, and the maximums are in the hours near the midday. But in the case of longwave there is a clear dependence with the COD.

# IV. PUBLICATIONS AND PARTICIPATION IN EVENTS

## IV.1. LIST ALL SCIENTIFIC EVENTS

Barbosa, H. M. J. ; Barja, B. ; Pauliquevis, T.M. ; Gouveia, D. A. ; Artaxo, P. ; Cirino, G. G. ; Santos, R. M. N.; Oliveira, A. B.: Ground based lidar observations of aerossol and cirrus clouds optical properties in central Amazon during the dry season. In: 4th iLEAPS Science Conference, 2014, Nanjing.

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