Sección Especial / Special Section: V Workshop on Lidar Measurements in Latin America

# Preliminary results of aerosols measurements with sun photometer at Camagüey, Cuba

# Resultados preliminares de las mediciones de aerosoles con fotómetro solar en Camagüey, Cuba

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**ABSTRACT:**

Preliminary results from sun photometer CIMEL CE-318 measurements over Camagüey, Cuba, are reported. The instrument belongs to the Iberian Network for Aerosol Measurements (RIMA). The dataset, at the 1.5 level of Aerosol Robotic Network (AERONET), covers the period between October 7th, 2008 and March 29th, 2009. Obtained results, considered as background conditions, allow characterizing the aerosols over Camagüey as Maritime Mixed. Main results showed the average value of the aerosol optical thickness: $\tau_a$(500 nm)=0.11 and its mode value at $\tau_{am}$(500 nm)=0.11 while for the Ångström exponent the average was $\alpha$=0.87 with mode value of $\alpha_m$=0.70. Relatively high values in both parameters for marine aerosols, agree with reported values by other studies for maritime environments in the Atlantic ocean. A preliminary characterization about aerosol particles size distribution over Camagüey has been conducted. Arrival of Saharan dust layers to our territory, is evident in several episodes that have taken place during the month of July 2009, with an aerosol optical thickness maximum value of $\tau_a$(500)=0.70 on July 6th.

**Key words:** CIMEL, RIMA, AERONET, Aerosols, Saharan Dust.

**RESUMEN:**

Se reportan los resultados preliminares de las mediciones con un fotómetro solar CIMEL CE-318 en Camagüey, Cuba. Este instrumento forma parte de la Red Ibérica de Medidas de Aerosoles (RIMA). Los datos empleados corresponden al nivel 1.5 de la Red Robótica de Aerosoles (AERONET) durante el período comprendido entre el 7 de Octubre de 2008 y el 29 de Marzo de 2009. Los resultados obtenidos, considerados como "condiciones de fondo", permiten caracterizar los aerosoles sobre Camagüey como Marítimos Mezclados. Los valores promedios de espesor óptico: $\tau_a$(500 nm)=0.11 con una moda de $\tau_{am}$(500 nm)=0.11 y del exponente de Ångström: $\alpha$=0.87 con una moda de $\alpha_m$=0.70, relativamente altos en ambos casos para aerosoles marinos, coinciden con los publicados en otros estudios para ambientes marítimos en el océano Atlántico. Se realiza la primera caracterización de la distribución de tamaños de los aerosoles sobre Camagüey. El arribo de masas de polvo del Sahara a nuestro territorio es evidente en varios episodios ocurridos durante el mes de Julio de 2009 con un valor máximo de espesor óptico de $\tau_a$(500)=0.70 el día 6.

**Palabras clave:** CIMEL, RIMA, AERONET, Aerosoles, Polvo Sahara.

 

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## 1. Introduction

Between 1988 and 1997, Camagüey was a site for lidar aerosols measurements [1]. The stratospheric aerosol cloud, resulting from Mt. Pinatubo eruption, was measured between 1992 and 1997 at the site [2]. Those lidar measurements have been inter-compared with others instruments, such as, coincident profiles of SAGE II satellite [3,4]. Because of the instrument characteristics only upper troposphere and lower stratosphere aerosol measurements were carried out. However, the interest to measure lower layers, as the tropospheric atmospheric aerosols, including Saharan dust, has been always present.

 

A scientific cooperation agreement between the Universidad de Valladolid (UVA), Spain, and the Instituto de Meteorología (INSMET), Cuba, was signed by the end of 2007. The main goal of that agreement was to conduct joint research on tropospheric aerosols. The research activities are conducted, jointly, by the Grupo de Óptica Atmosférica (GOA-UVA) and the Grupo de Óptica Atmosférica de Camagüey (GOAC-INSMET), formerly the Camagüey Lidar Station. For those purposes a sun photometer CIMEL CE-318 was installed at the Camagüey site (21.42° N, 77.84° W, 128 meters over sea level). The instrument is part of the Iberian Network for Aerosol Measurements (RIMA) which is federated into the Aerosol Robotic Network (AERONET) [5]. This aerosol measurement site is the first of this network in Cuba and is operative since October 7$^{th}$, 2008.

The main goal of this work is to characterize, by first time, the columnar aerosols properties over Camagüey, Cuba, using the currently available set of measurements. It is a first step in our goal to produce the local aerosols climatology for Camagüey, as part of the global aerosol studies strategies. Many authors addressed this topic for multiple AERONET sites (e.g. Dubovik *et al.* [6], Holben *et al.* [7], Toledano *et al.* [8]). In particular Smirnov *et al.* [9] characterized aerosol background conditions for five sites in maritime environments, three in the Pacific Ocean and two in the Atlantic Ocean. In general, these maritime sites have similar geographic conditions than Camagüey site, due to its insular characteristic. However, Camagüey site is distant about 100 km, both to the north and south coasts of the island of Cuba.

## 2. Instrumentation and datasets

### 2.1. Sun-photometer CIMEL-138

The sun-photometer CIMEL-138 is an automatic sun tracking photometer, designed for very accurate sun measurements. The main purpose of this instrument is to measure sun and sky radiance in order to derive total column water vapor, ozone and aerosols properties using a combination of spectral filters. The photometer is equipped with five filters (440, 670, 870, 936, 1020 nm) with a bandwidth of 10 nm. The sun-photometers pre and post calibration procedures are conducted in the GOA-UVA facilities under the AERONET protocols.

Two sun photometers CIMEL-138 have operated in Camagüey since October 7$^{th}$, 2008. The first of them (CIMEL #425) until March 29$^{th}$, 2009; the second one (CIMEL #353), since June 4$^{th}$, 2009, currently in operation. The Cuban specialists in charge of the instrument installation and operation, has been trained in Valladolid by the Spanish experts from the RIMA network. Both, daily verification of the instrument physical conditions and weekly maintenance, accordingly to the AERONET logistic protocol are conducted. In addition, because of the instability in the Internet connection, the transmission of the of the K7 files is routinely checked twice a day.

After 174 days of operation the first instrument was inoperative because of failure in the motorized system. The instrument operation was stopped, the photometer was dismounted and sent to RIMA for inspection, reparation and post calibration. Results of the inspection by RIMA experts showed the reason for the failure of the motorized system was mechanical problems with the filters wheel. No damage to the filters was registered. After fixing the mechanical problem the instrument has been post-calibrated and the processing of the quality level 2.0 measurements is underway by AERONET. From the total of operative days the instrument did not operated only 9 days during the entire period; 5 days by technical problems and 4 days due to the dismounting because the hurricane Paloma. In addition 15 days not reached the level 1.0 due, mainly, to meteorological situations.

### 2.2. Dataset

For the main objective of the present work, measurements of the CIMEL #425 were used, because the measurement period can be considered as background conditions. A total of 3716 raw measurements for the period October 7$^{th}$, 2008 to March 29$^{th}$, 2009 were selected, corresponding with 150 days of raw data.

The variables used in present study are the Aerosol Optical Depth (AOD) and the Ångström Exponent (AE), also named alpha parameter (α).

 

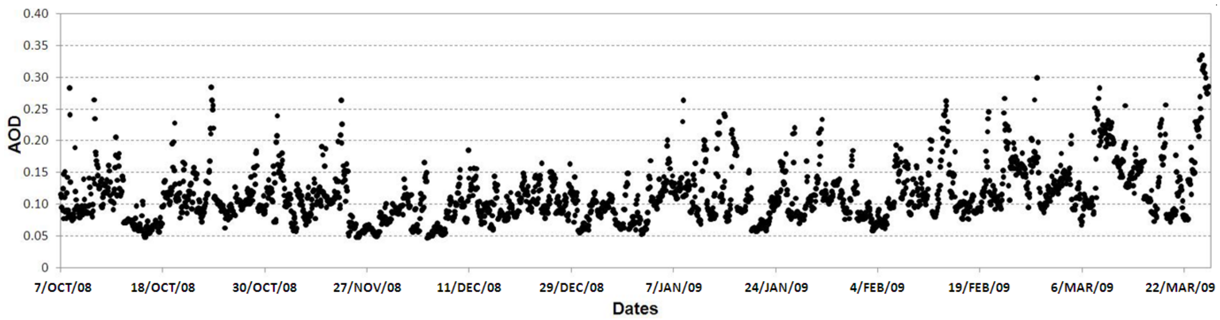


Fig. 1. Time series of Aerosol Optical Depth (AOD) at 500 nm, corresponding to 1.5 level (CIMEL #425), since October 7th, 2008 to March 29th, 2009.

Also the aerosol volume size distributions were used. All derived dataset employed in the present work correspond to the AERONET cloud screened level 1.5 [10].

The total of AOD and AE available measurements after the cloud-screened procedure was 2300, corresponding to 138 days of level 1.5 (cloud–screened data), representing 92% of all measurements. The time evolution of AOD at 500 nm measured during the period of operation of the CIMEL #425 is shown in Fig. 1. The total of 59 volume aerosols size distributions retrieved in the period of analysis was also used for the present study.

For demonstrating the presence of Saharan dust over the Caribbean and Cuban region, AOD data at 500nm from CIMEL #353 corresponding to July 2009, was selected. A backtrajectory analysis, using the HYSPLIT model [11], was conducted for determining the origin of the airmass arriving to Camagüey site.

Because the AERONET standard processing quality level 2.0 of Camagüey measurements are not yet available at the moment of this study; the obtained results in the present work have a preliminary character.

### 2.3. Site of measurements

The site of measurements is located to the northeast of Camagüey city (21.42° N, 77.84° W), distant approximately to 8 km of the city. The province of the same name is the more extensive of the country and the site of measurement is located at the center of the province in a plain territory.

This site and the country in general are dominated by two big seasons, rainy and less rainy seasons. The first period cover since June to November and is dominated by the trade winds, responsible by the arrival of Saharan dust to the Caribbean and consequently to our site. During this period the hurricanes generated in the Atlantic Ocean arrive to Caribbean Sea affecting in many cases Camagüey province. The second period take place between December and May dominated mainly by the arrival of cold air masses coming from Artict through the North American continent.

Winds from the East are the predominant over the site measurement. This pattern is mainly broken during the less rainy season, with the arrival of cold front from the North American continent when the North winds are established.

## 3. Method

According with the AERONET algorithm the AOD is derived from the direct sun measurements, after the subtraction of the Rayleigh optical thickness and ozone optical thickness. To retrieve the aerosol size distribution the sky radiance almucantar measurements at 440, 675, 870 and 1020 nm in conjunction with the direct sun measurements at the same wavelengths were used, according with the Dubovik methodology [12]. The sky almucantar measurements are made with optical airmasses of 4, 3 and 2 at morning and afternoon, and once per hour at the rest of the day.

 

The AE is derived from the fit of four wavelengths 440, 500, 675, and 870 nm when available. The information on columnar aerosol characteristics was retrieved using the measurement protocol, data processing, cloud-screening algorithm, and inversion techniques in use by AERONET [10].

## 4. Results and discussions

### 4.1. Aerosol optical depth and Ångström exponent

The monthly average and standard deviation values of the AOD and AE for the analyzed period are shown in Table I. Lower values of AOD take place in the months of November and December, with the minimum standard deviation of all cases on December. On the other hand it could be appreciate that maximum value of AOD ($\tau_a$=0.15) took place in March, where a significant increment occur during the last days for the measurement period as is shown in the extreme right side of Fig. 1.

The maximum value of AOD in March is related to several episodes of moderate turbidity, e.g. 13th-15th or 28th-29th March, with AOD (440 nm) up to 0.3. These episodes alternate with the clean background conditions. Data seem to indicate a trend of AOD increase since December. During March was also registered the maximum value of standard deviation ($\sigma^a$=0.06).

For the whole period the average AOD value at 500 nm was 0.11 below average AOD value between 0.13 and 0.14 at two AERONET Atlantic sites, Bermuda and Ascencion, reported by Smirnov [9]. The standard deviation for the whole period was 0.05 also below the values of 0.09 and 0.07 for the mentioned sites. Those differences may be associated to the short period of observations used in the present work. However, both AOD and its standard deviation are in the same order of magnitude and near the ones reported by Smirnov for Atlantic sites [9].

The distribution of the frequency of occurrence of AOD at 500 nm is presented in Fig. 2. The mode value is $\tau_{am}$(500 nm)=0.11 with a 32% of occurrence, as it can be appreciated in

TABLE I

Monthly averages and standard deviations of the aerosol optical depth and the Ångstrom Exponent.

| Month | $N$ | $\tau_a$ | $\sigma^a$ | $AP$ | $\sigma^b$ |
|---|---|---|---|---|---|
| Oct/2008 | 416 | 0.11 | 0.04 | 0.77 | 0.25 |
| Nov/2008 | 295 | 0.10 | 0.04 | 0.91 | 0.37 |
| Dec/2008 | 366 | 0.10 | 0.03 | 0.64 | 0.35 |
| Jan/2009 | 469 | 0.11 | 0.04 | 1.12 | 0.32 |
| Feb/2009 | 410 | 0.12 | 0.04 | 0.88 | 0.30 |
| Mar/2009 | 340 | 0.15 | 0.06 | 0.89 | 0.31 |

$N$ = Number cases of analyzed measurements.
$\tau_a$ = AOD mean at wavelength 500 nm.
$\sigma^a$ = Standard deviation of the AOD.
$\sigma^b$ = Standard deviation of the AE.

this frequency histogram. The highest percents of AOD values are around 0.1 and the data show a log-normal distribution.

The monthly averages of the AE, in Table I, show higher variability than the AOD monthly averages, ranging from 0.64 to 1.12, with differences in one order of magnitude. Monthly standard deviations remain around 0.30 in the same order of magnitude. The maximum value of the AE (α=1.12), take place in January 2009. During this month three cold fronts arrived to the measurement site at Camagüey. Although the cold fronts were classified as weak, they may have transported polluted air masses from the south region of North America to the site of measurements. This month registered also the maximum number of available measurements.

The average value of the AE (α=0.87) for the whole period is between the two average values for Bermuda and Ascencion, 0.09 and 0.07 respectively, reported by Smirnov [9]. In particular the AE average value for Camagüey is closer to the Bermudas site AE average value. This fact can be related to the vicinity of both sites to North America, a common source of pollution for them.

The frequency histogram of AE is plotted in Fig. 3, showing a normal distribution and a mode value centered at $\alpha_m$=0.70. The highest percents (67%) of the frequencies are lower than α=1, demonstrating the dominant presence of maritime aerosols and their influence over Camagüey. A minor influence, but not less important, of continental or urban-polluted aerosols is evident from the 33% of occurrence frequencies larger than one.

 

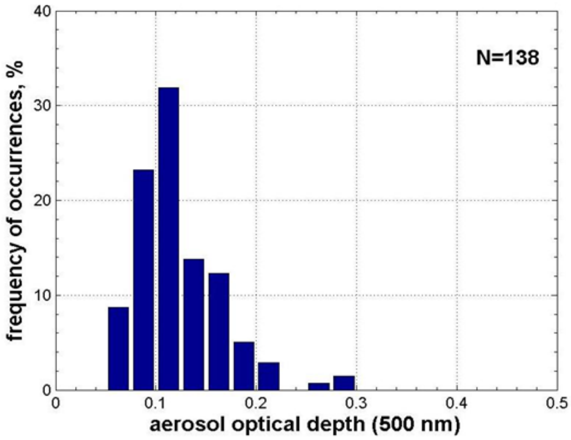


Fig. 2. Frequency of occurrence of AOD at 500 nm.

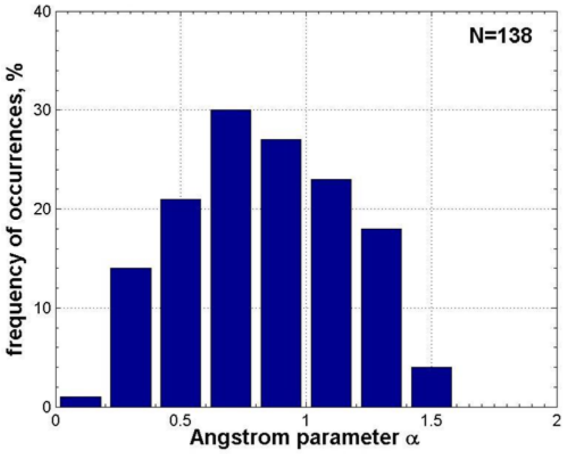


Fig. 3. Frequency of occurrence for Ångström alpha parameter α (440 – 870nm).

The scattergram of AOD (at 500 nm) vs. AE in Fig. 4, reinforce the hypothesis characterizing the Camagüey site, as a maritime mixed environment, due to the presence of maritime and continental or urban-polluted aerosols. Maritime aerosols should be located in the region with $\tau_a$ (500) below to 0.15 and AE below 1. All points with AE values higher than 1 are considered to represent the influence of continental or urban-polluted aerosols.

In addition to the possible arrival of aerosols from the continent, there are some probable sources of industrial aerosols from an area to the east northeast of the site, distant around ~70 km. Furthermore, it is possible also, the influence of urban aerosols coming from the Camagüey city, distant around 8 km to the southwest. Nevertheless the sources of continental or urban-polluted aerosols have not been determined yet for Camagüey site but will be studied in the near future.

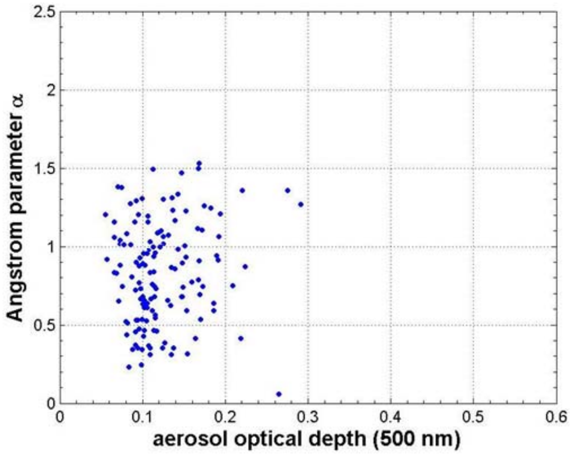


Fig. 4. Scattergrams of Ångström exponent (440-870) versus Aerosol Optical Depth (500nm) daily means for Camagüey.

### 4.2. Particle size distribution

The average aerosol volume size distribution ($dV/d\ln R$) for Camagüey site during the analyzed period is illustrated in Fig. 5. A clearly defined bimodal distribution can be observed, with the fine mode with radii 0.05<$r$<0.4 μm and the coarse mode with radii 0.4<$r$<15 μm. The bimodal character of the aerosol volume size distribution and the ranges of the fine and coarse modes at Camagüey site agrees with the same features reported for Bermuda [9]. However, in the present study, the coarse mode prevails over the fine mode while in Bermuda both modes are practically equal. In the Camagüey site fine mode maximum is located at 0.15 μm with a magnitude of 0.013 μm$^3$/μm$^2$ and the coarse mode is at 3.86 μm with 0.025 μm$^3$/μm$^2$ volume concentrations. The larger values of the coarse mode concentration are in agreement with the marine aerosol properties.

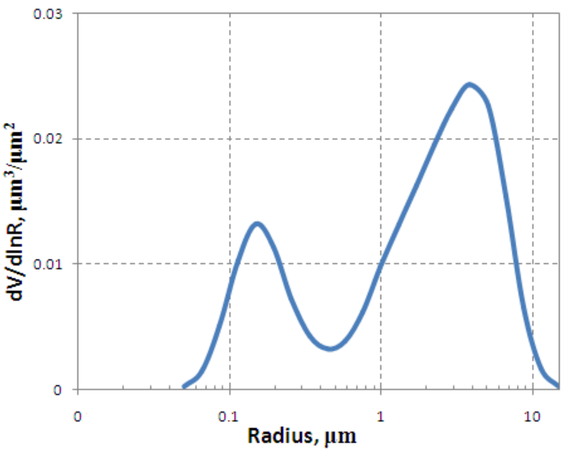


Fig. 5. Average volume particle size distribution.

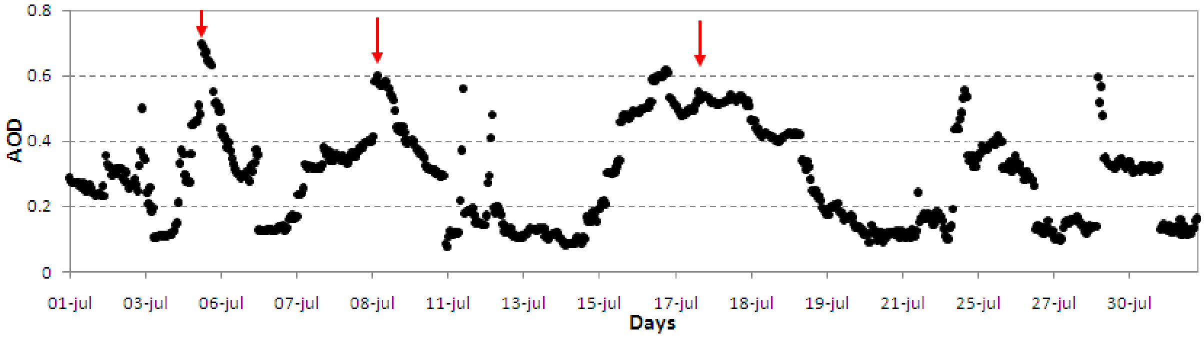


Fig. 6. AOD time evolution at 500 nm, corresponding to Level 1.5 (CIMEL #353) for July 2009. Arrows indicate principal Saharan dust events.

However, for Camagüey, there are certain amounts of cases (17%) where the atmospheric conditions change the shape of the size distribution, prevailing the fine mode over the coarse. As general rule this happens in the early morning hours. On the other hand, in the 24 % of cases, the fine mode is significantly minor than the coarse mode, about 7 times, the magnitude of coarse mode.

### 4.3. Saharan dust events

During the summer season in the northern hemisphere, air masses containing dust and other materials, move from Africa westward over the tropical Atlantic Ocean above the Trade Winds moist layer. The dust originated in the Saharan desert reach the Atlantic Ocean, in general, and Caribbean Sea, in particular, in about 5-7 days. Mechanisms that explain the origin of these events and their propagation through Atlantic are discussed by Carlson and Prospero [13].

Arrivals of Saharan dust to various sites of the Caribbean have been documented by many authors employing different techniques [e.g. 14,15]. The presence of theses events over Cuba has been discussed by Mojena [16], making use of satellite data.

Following we show the first Saharan dust events registered with ground–based measurements employing a CIMEL sun photometer in Cuba. Successive episodes occurred during July 2009, as can be seen in Fig. 6. It shows all AOD measurement points (500 nm) for the referenced month, measured with CIMEL #353. Arrows indicate the most important events, which took place during this month.

The three most important events have different magnitudes and durations. The first one of them was the most intense with a maximum AOD (500nm) of $\tau_a$=0.7, between days 5th and 6th of July. Images of the aerosols index measured by OMI (not shown), reveal a great air mass of dust leaving the west coast of Africa in direction to the Caribbean by the 29th and 30th of June 2009.

Figure 7 shows the back-trajectory analysis at 12 UTC for the 5th of July and 168 hours back (7 days) using the HYSPLIT model. Both levels, 500 and 1500 meters, show the origin in the middle Atlantic at ~2500 and ~2000 meters of altitude, respectively. The 3000 m level shows clearly the origin of the airmasses on the west coast of Africa.

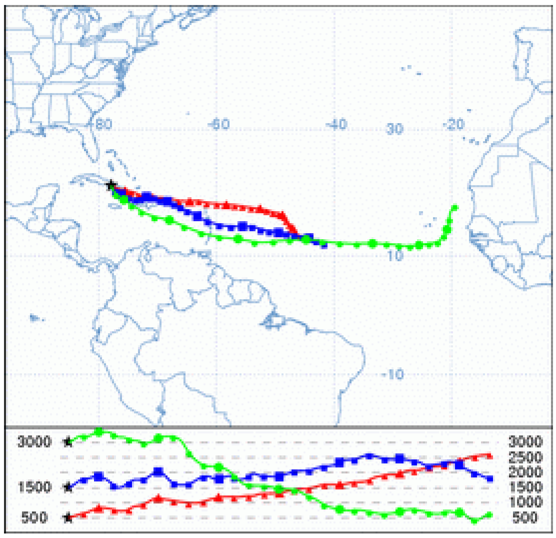


Fig. 7. Backtrajectory analysis for 5th July 12 UTC (168 hours back), by the HYSPLIT (NOAA) model.

 

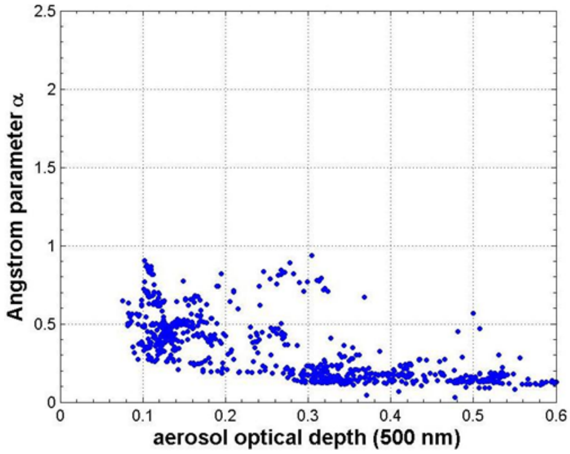


Fig. 8. Scattergrams of Ångström exponent (440-870) versus AOD (500nm) daily means for Camagüey at July 2009, during various Saharan dust events.

The second most important event was the long lasting of all, with 7 days of duration from 14th to 20th of July, 2009. The maximum AOD value for this episode was $\tau_a$=0.62 the 17th around 12:00 UTC. The third event took place between 7th and 10th July (3 days) and the maximum AOD value was $\tau_a$=0.6. Other events, but less intense, could be appreciate between days 23rd and 27th and between days 28th and 31st with 5 and 4 days of duration respectively, during the same month.

The scattergram shown in Fig. 8 represent all measurement points during July, 2009. The strong presence of Saharan dust during this month is demonstrated in the figure, where the high values of AOD (500 nm) versus the small AE values, evidence the existence of large particles which is consistent with this type of phenomenon. The presence of maritime aerosol is also clearly appreciated in the region bellow $\tau_a$ (500nm)<0.15 and α (440-870) minor than one.

## 5. Conclusions

Preliminary results of the aerosol characterization at Camagüey site (first AERONET site in Cuba) show a maritime mixed environment. Aerosol Optical Depth and Ångström Exponent values agree with other studies for similar sites in the Atlantic Ocean, despite of the small period analyzed. The mean AOD (500 nm) value was 0.11, with a maximum of 0.7 during various Saharan dust events, on July 2009. The Arrival of Saharan dust to Camagüey, Cuba, has been demonstrated during multiples events on July, 2009. This phenomenon has been assessed by back-trajectory analysis using HYSPLIT model.

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