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EVALUATION OF *BLACK CARBON* IN THE PANTANAL BIOME

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ABSTRACT
The study evaluates black carbon (BC) in the Pantanal Biome, analyzing its concentrations and sources, such as fires and anthropogenic activities, with measurements by photometry (MAAP) and reflectance, revealing intense seasonal peaks in the dry season. Atmospheric trajectories (HYSPLIT) indicate aerosol transport, influencing the radiative balance and regional climate.

Keywords: Black Carbon. Burned.

INTRODUCTION

Black carbon is one of the main components of particulate matter and has a huge influence on air quality and climate change, and there is no agreement on a terminology that considers the definitions, specific properties, measurement methods and associated uncertainties. Petzold (2013) advocates that the term *equivalent black carbon* (EBC) should be used instead of BC for absorption measurements obtained from optical absorption methods, together with the appropriate mass absorption coefficient for the conversion of the absorption coefficient into mass concentration (MAC).

The aerosols from burning modify the radiative balance on the surface, absorbing and scattering solar radiation. Aerosols play important roles in the atmosphere, with effects on radiative balance, climate, atmospheric chemistry, cloud formation, and nutrient cycling. Studies of the chemistry of the atmosphere demonstrate a complex scenario within climate change, in which particulate matter has a potentially important impact on the climate (IPCC, 2013; 2024).

The increase of particulate matter in the atmosphere has mechanisms involved, such as anthropogenic activities, agriculture (pastures), urbanization (burning of vehicular fossil fuels), deforestation for agricultural practice (monoculture). For land use management, the cheapest practice is the burning of native biomass that may be responsible for the change in local albedo.

Aerosols are of special interest in climate studies because they can influence both directly and indirectly, that is, by scattering and absorbing solar radiation and as cloud condensation nuclei (ANDREAE et al., 2002; ANDREAE et al., 2004; KAUFMAN et al., 2005).

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The direct effects occur due to the absence of clouds, return of sunlight to space increasing the albedo, consequently the cooling of the atmosphere; absorption of sunlight that has as its main effect the reduction of convective movements, evaporation of the oceans, rainfall indices and the speed of winds during rains that has as the main cause of this phenomenon the *black carbon* which has an important role as one of the climate forcings (LIU and SMITH, 1995).

OBJECTIVE

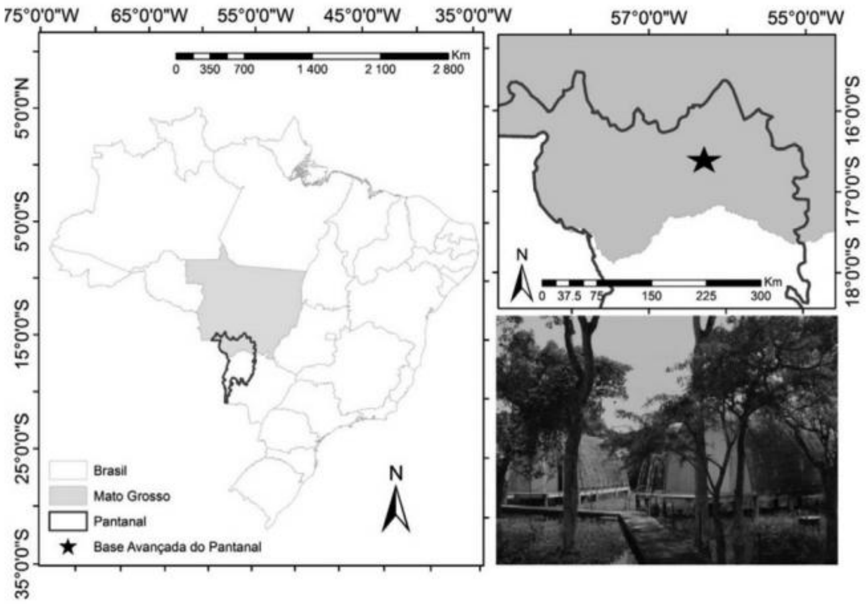
Evaluate black *carbon* in the Pantanal Biome and its characteristics.

METHODOLOGY

LOCATION AND DESCRIPTION OF THE STUDY AREA

The site of this study is known as Baía das Pedras (Advanced Research Base of the Pantanal), a unit that belongs to the Private Natural Heritage Reserve (RPPN) of the Social Service of Commerce (SESC) - Pantanal, in the municipality of Poconé, Mato Grosso, about 160 km from Cuiabá (Figure 1) (DALMAGRO, 2012).

Figure 1 – Location of the study area, in detail the Brazilian Pantanal and the limitation of the area from which the aerosols were collected.



The research was conducted in a protected nature reserve, Private Reserve of Natural Heritage (RPPN) of the Social Service of Commerce (SESC) - Pantanal, at an altitude of 111 m (16°39' S, 56°47' W), the climate is classified as Aw-tropical humid, according to Köppen, hot and humid with rainfall in summer. In the RPPN SESC Pantanal, the annual rainfall varies between 1,000 and 1,500 mm, with a maximum in January and a minimum in August. Temperatures range from 23 °C with a temperature range of 5 °C, with average temperatures of 27-28 °C in January and 22-23 °C in July (MOREIRA and VASCONCELOS, 2011).

The soil of the region is classified as a typical Dystrophic Ta HPLIC GLEISOSOL, i.e., the soils of this class present an abrupt change in texture with a marked difference in texture from A to the immediately underlying B horizon, slow or very slow permeability, depth of 150 cm and sandy texture (MOREIRA and VASCONCELOS, 2011).

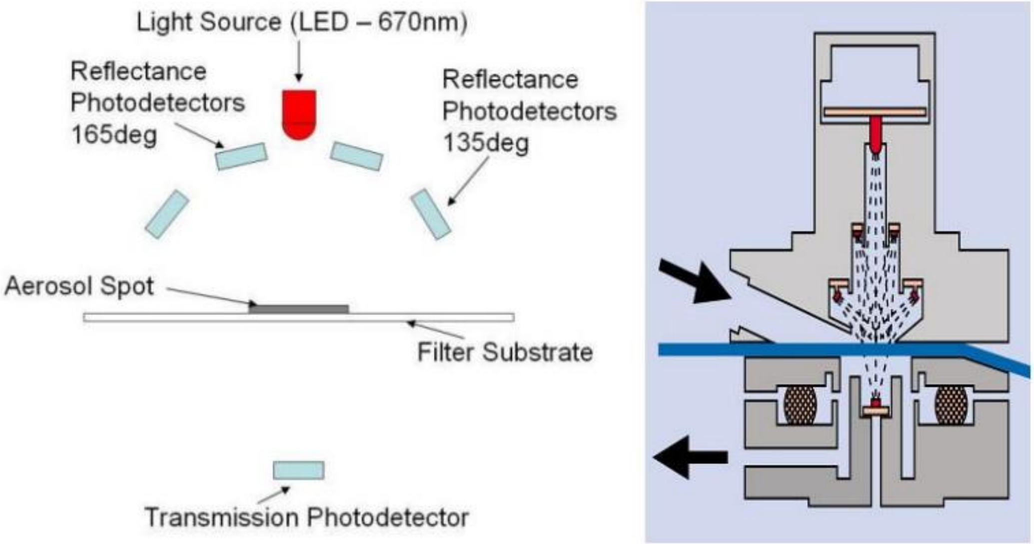
This site is characterized by a transition area of mixed vegetation between monodominant forest and natural pasture that is undergoing a process of invasion by *Vochysia Divergens Phol* (*V. divergens)* (VOURLITIS, 2011). The topography of the floodplain is predominantly flat, causing major flooding during the rainy season (DA CUNHA AND JUNK, 2000), which typically occurs between December and May, with water levels ranging between 1-2 m depth (DA CUNHA AND JUNK, 2004). During the dry period there may be no measurable precipitation and water level retreats are below the surface of the ground.

The preponderant mechanisms involved in the increase of chemical components in the atmosphere of the Pantanal are anthropogenic activities such as deforestation for agricultural practice in which the increase in CO2 concentration is involved, in agriculture (pastures), in urbanization (burning of vehicular fossil fuel and industrial emissions) and fires cause changes in the carbon and nutrient cycle (ECK et al., 2004).

MAAP – REAL-TIME ABSORPTION MEASURES

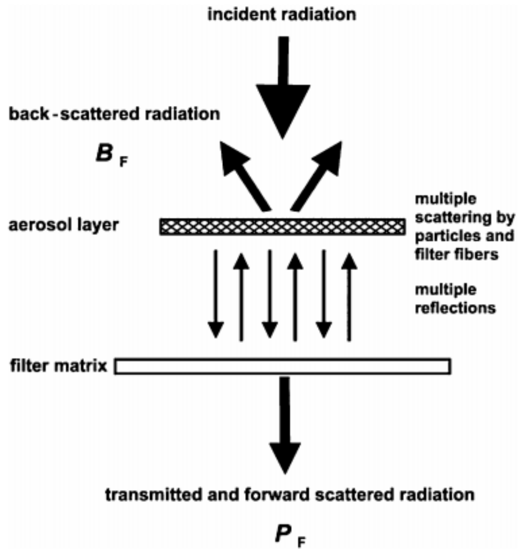
According to Petzold et al. (2005), absorption measurements were performed using the MAAP photometer (MultiAngle Absorption Photometry – Thermo Inc., Model 5012) according to Figure 2, which shows the schematic drawing.

Figure 2 – Schematic drawing of the MAAP operating principle and shows the simultaneous process of absorption measurement in a fiberglass filter and thus the optical scattering is determined and discounted by an algorithm developed for the instrument (HOLANDA, 2015; PETZOLD, 2005).



It is an instrument that reports in real time the concentration of *black carbon* at 637 nm which is converted to absorption coefficients assuming a MAC absorption mass coefficient = 6.6 m2/g and simultaneously measures the optical attenuation and the light reflection by particles deposited in a filter for various angles of detection and thus make the unique measurement of absorption. The instrument calculates the radiative transfer through the filter containing aerosols and discounts the optical scattering according to Figure 3, illustration of the operation.

Figure 3 – Schematic representation of the functioning of the radiation processes to be considered in the two-layer system constituting the aerosol considering a layer loaded in the filter with particulate matter and the particle-free filter matrix (PETZOLD, 2005).



BLACK *CARBON ANALYSIS* BY REFLECTANCE

The determination of *black carbon (*BC) concentrations was made by the optical reflectance technique before and after the collection of aerosol particles in the filters. The process is based on the incidence of light from a tungsten lamp (W) on the sample, which reflects an intensity inversely proportional to the amount of *black carbon* present. As *black carbon* particles absorb light with high efficiency, the greater the amount present, the lower the intensity of light reflected and detected by the photo sensor. The device was adjusted with white filters for 100% reflection (RIZZO, 2002).

According to Loureiro et al. (1994), the calibration curve of the light reflected by the amount of *black carbon* was empirically obtained according to Equation 1, which indicates that from the measured reflectance, the mass of *black carbon* present in the sample can be obtained for the calibration process of the equipment.

$$BC\ \left[\frac{\mu g}{m^3}\right] = \left[(30{,}90 \pm 0{,}15) - (14{,}454 \pm 0{,}007) * \log(R) * \frac{A}{V}\right]\ \ (Equação\ 1)$$

Whereas:

R = Reflectance (%);

A = Filter area (14.4 cm2);

V = Sampled volume (m3).

The equipment used was a reflectometer, brand "Diffusion Sistem Ltda" model "Smoke Stain Reflectometer – Model 43" (Figure 4).

Figure 4 – Reflectometer used for the quantification of black carbon (SANTOS, 2014).

HYSPLIT TRAJECTORY MODEL

The Hysplit model (*Hybrid Single Particle Langrangian Integrate Trajectory Model*) is a complete system for calculating simple trajectories of air parcels, as well as complex transactions, dispersion, chemical transformation, and deposition simulations. HYSPLIT continues to be one of the most widely used atmospheric transport and dispersion models in the atmospheric science community. A common application is a trajectory analysis to determine the origin of air masses and establish source-receiver relationships (DRAXLER and ROLPH, 2003).

HYSPLIT is also used in a variety of simulations that describe the atmospheric transport, dispersion, and deposition of pollutants and hazardous materials. Some examples of applications include tracking and predicting the release of radioactive material, fire smoke, windblown dust, pollutants from various stationary and mobile emission sources, allergens, and volcanic ash (DRAXLER and ROLPH, 2003).

The model's calculation method is a hybrid between the Lagrangier approach, using a frame of reference for the calculations of advection and diffusion as the trajectories or parcels of air move from their initial location, and the Eulerian methodology, which uses a fixed three-dimensional grid as a frame of reference to calculate the concentrations of pollutant air (the name of the model, no longer meant as an acronym, originally reflected this hybrid computational approach) (ROLPH, 2017).

HYSPLIT has evolved over more than 30 years, from estimating simplified simple trajectories based on radiosonde observations to a system that accounted for multiple interactive pollutants transported, dispersed, and deposited at local to global scales (ROLPH, 2017).

The dispersion of a pollutant is calculated by assuming blow or particle dispersion. In the blow model, the bunches expand until they exceed the size of the cell in the weather grid (horizontally or vertically) and then divide into several new bunches, each with its share of the pollutant mass. In the particle model, a fixed number of particles are advected over the domain of the model by the mean wind field and are distributed over a turbulent component. The standard configuration of the model assumes a three-dimensional particle distribution (horizontal and vertical) (ROLPH, 2017).

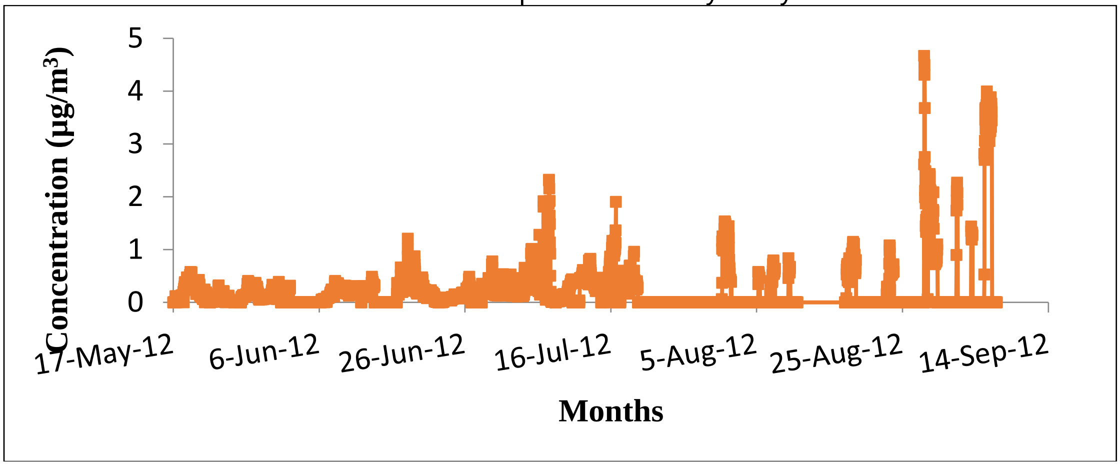
The model can be run interactively on the Web via the ARL READY system (website: *https://ready.arl.noaa.gov/HYSPLIT.php*), or the executable code and weather data can be downloaded to a Windows PC or Mac. The web version has been configured with some limitations to avoid computational saturation of the ARL web server. The registered PC version is complete with no computational restrictions, except that users must obtain their own weather data files. The unrecorded version is identical to the recorded version, except that plume concentrations cannot be calculated with forecast weather data files. The trajectory-only model has no restrictions, and prediction or archival paths can be computed with either version.

In this article, he used the model executed on the web to simulate the trajectories for atypical cases of high aerosol concentrations for specific days, such as fire peaks, or to identify a particular emission source.

DEVELOPMENT

The absorption measurement by the MAAP demonstrates the corrections that are made internally in the instrument (PETZOLD et al., 2005). The concentration of *black carbon* in the months of May to September 2012, transition from the rainy season to the dry season, are shown in Figure 5.

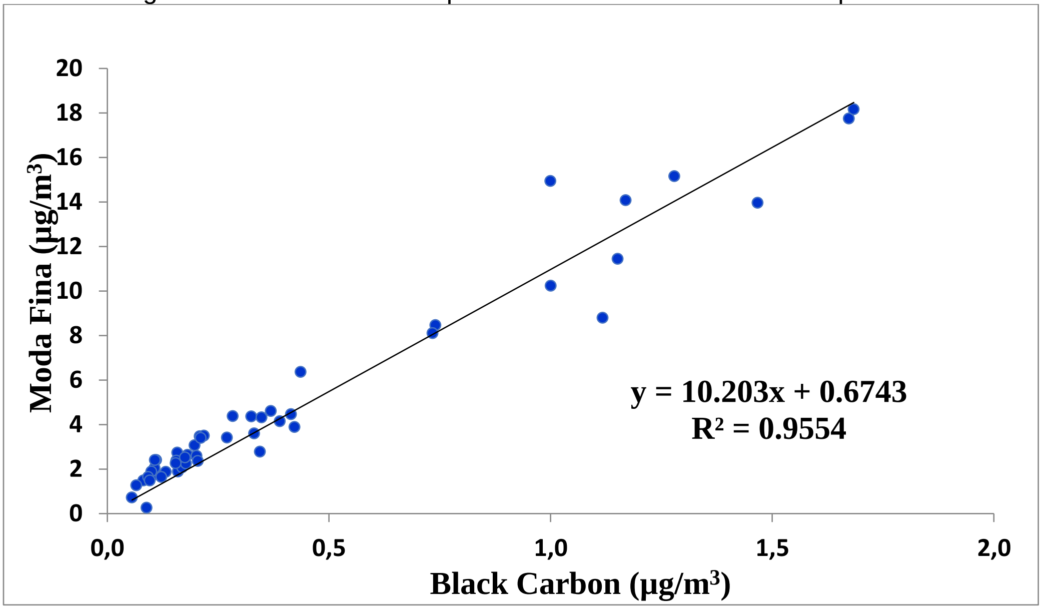
Figure 5 – Black *carbon concentration*, instantaneous measurements every 30 minutes from May to September 2012 in fine fashion at the Pantanal station. Transition period from rainy to dry.



The concentration of *black carbon* had a very pronounced seasonal variation with high concentrations of the fine fraction observed on September 12, 2012 due to the burning period that exists in this region (SANTOS, 2014).

The regression in Figure 6 shows the values measured by MAAP showed an angular coefficient of 10.203 and showed a high coefficient of determination, fine particulate matter – (PM2.5 (R2= 0.9554)).

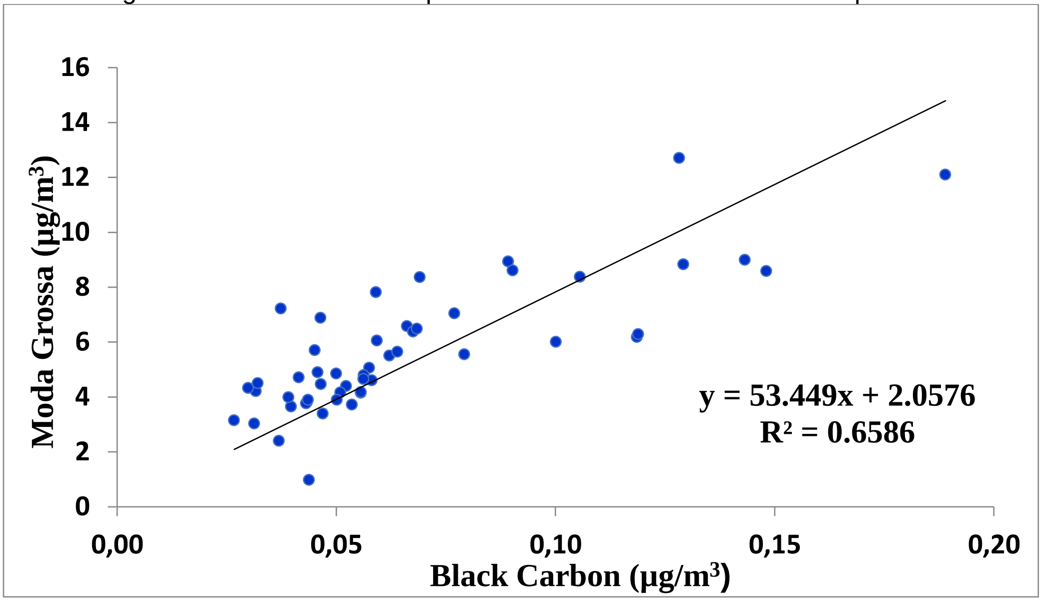
Figure 6 – Linear regression of the relationship between black carbon and fine particulate matter (MPF).



The result of this regression is determined by the highest absorption values that occur in the month of April to May, when the site started to receive aerosols from fires transported over long distances. In order to observe the effect of absorption by biogenic particles, it is necessary to study this regression to low absorption values, characteristic of the effects of biogenic aerosol. Based on this procedure, these linear regressions were redone by applying an upper limit to the absorption values. The limits of each regression were reduced to analyze the impact of aerosol sources for decreasing absorption values and thus to observe with the grouping of chemical elements what are the respective sources for each period studied.

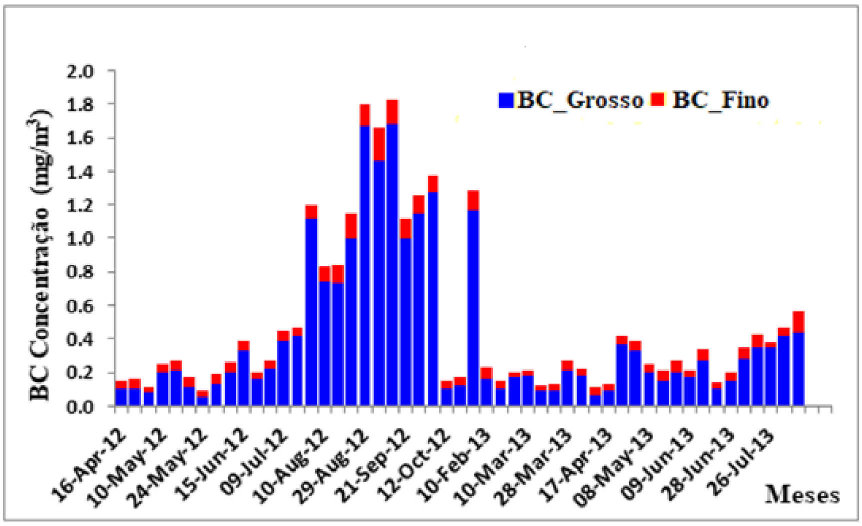
The regression in Figure 7 showed the values measured by MAAP and presented an angular coefficient of 53.449 and showed a good coefficient of determination, coarse particulate matter – (PM10 (R2= 0.6586)).

Figure 7 – Linear regression of the relationship between black carbon and coarse particulate matter (MPG).



For the analysis carried out in relation to the filters in relation to *black carbon* , Figure 8 is used, which shows the time series of BC concentration in the fine and coarse modas of the aerosols. According to Santos (2014), it is observed that there is a higher concentration of BC in the fine fraction of the aerosol and the reduction in the average concentration of BC in the thick fashion in the rainy season is due to the rains that are frequent in this period.

Figure 8 – Concentration of black carbon in fine and thick fashion.



When comparing Figure 5 with Figure 8, the relationship for the BC_fino is observed, as they correspond to values close to what was measured by the MAAP equipment in the Pantanal. It is verified that the highest concentrations of fine and coarse BC were 1.7 and 1.6 µg/m3 during the dry and rainy period in the Pantanal and it is observed the transition from the rainy to the dry season in which there was an intense peak on September 12, 2012 and these higher concentrations are characterized by the low precipitation rate and the decrease in the efficiency of the removal processes (dry period) with many fires in this period.

The Amazon Rainforest contributes significantly to the inventory of emissions of particulate matter and trace gases into the atmosphere with a significant contribution of the biogenic and pyrogenic components, deforestation and fires are the main causes of changes in the composition of the atmosphere (ARTAXO et al., 2001).

In the Pantanal, the sources of aerosols from fires in the dry season are observed, as well as the sources of soil resuspension and biogenic action with a contribution in the rainy season (SANTOS et al., 2016), in the Amazon basin there is a contribution from forest emissions, fires and soil particles resulting from the interaction between winds and surfaces. Anthropogenic particles are generated in a large concentration of mass and number through fires after deforestation and maintenance of pastures in the Amazon Basin mainly at the end of the dry season (ARTAXO et al., 1990) and can be compared with the Pantanal that the process of maintenance of pastures occurs and has anthropogenic sources.

According to Artaxo et al. (2000) and Maenhaut et al. (2002), values above 7.0 μg/m3 were observed in regions where intense biomass burns occur in the dry season.

In the work of Arana (2014), he found average values for BC in fine and coarse fashions with values of 0.574 and 0.051 μg/m3, respectively, for the region of Rebio Cuieiras during the dry season and 0.154 and 0.066 μg/m3 for the rainy season (ARANA, 2014).

For the Porto Velho region, it found average values for BC in the fine and coarse fashions with values of 2.695 and 0.221 μg/m3 for the dry period and 0.258 and 0.0913 μg/m3 for the rainy season. The effect of the period of droughts and emissions from fires in the Amazon region and the consequent changes suffered in the optical properties of the atmospheric aerosol in this impacted region are noted. For the years 2009, 2010 and 2012, the impact of the dry period was less intense than in 2010, with concentrations in fine fashion around 1 to 4 μg/m3 (ARANA, 2014).

For Yamasoe (2000) and Echalar et al. (1998), studies on the elemental composition of particulate matter have shown that the emission of *black carbon*, which is known to be mostly soot from combustion and is associated with trace elements of emissions from fires, such as: S, K, Cl, Ca and Zn in the fine fraction of particulate matter, and can be compared with the Pantanal, which presents trace elements such as: Br, Mg, Al, Si, P, S, K, Ca, Ti, Fe and Zn from the burning of biomass, soil and biogenic emission in the Pantanal (SANTOS et al., 2016).

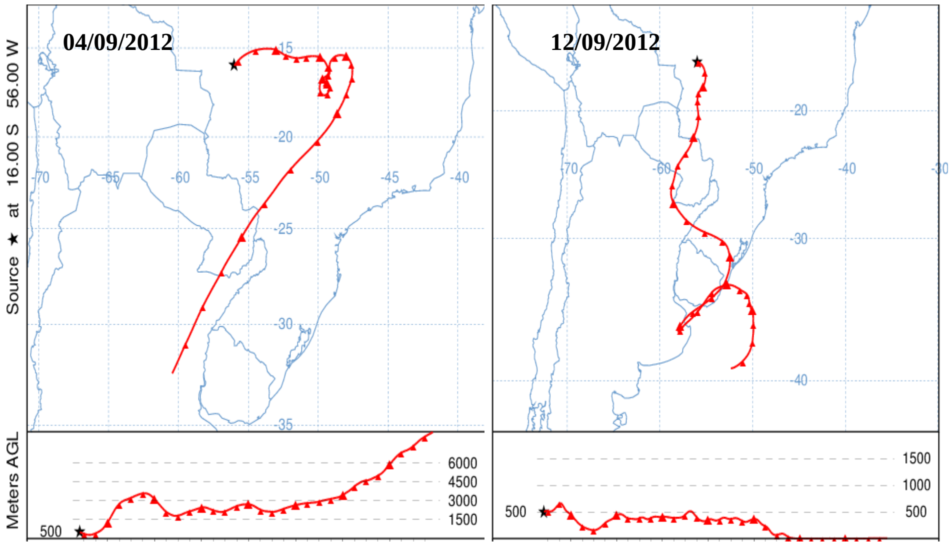
The average diameter interval where there is the highest concentration of *black carbon* is coincident with the wavelength interval of visible radiation and contributes to the BC particles having a high shock section in the absorption of solar radiation (CASTANHO, 1999).

Consequently, this property makes BC a pollutant of high influence on the radiative balance of the atmosphere on a regional scale and the concentration of *black carbon* in the coarse fashion remains constant throughout the year, indicating sources of a more local character and constant emission (CASTANHO, 1999).

LONG-DISTANCE TRANSPORTATION

The removal processes suffer direct interference in the local climatic characterization, since the characterization of the dry and rainy periods can be related to the concentrations in the particulate matter samples. When referring to the Pantanal, which has two well-defined periods, one dry and the other rainy, it is important to know which systems interact, providing such characteristics, according to Figure 9, in which the trajectories calculated for the Pantanal of Mato Grosso will be evaluated on the days of intense peaks due to the period of fires in the region (September 4 and 9, 2012).

Figure 9 - Trajectories calculated by the NOA HYSPLIT MODEL, Backward trajectories, for the Advanced Research base in the Pantanal of Mato Grosso on the days of intense peak aerosols (September 4 and 12, 2012) and integrations were made for the calculation of each trajectory was 24 hours.



The wind passes through the Pantanal, Paraguay and has a great influence on cold fronts. The wind coming from the South with lower humidity will increase the emission of particulate matter as seen in the peak of OC/EC, of *black carbon* on September 4 and 12, 2012, which is observed in the trajectory in Figure 9 and with this there is an increase in the sources of fires, soil resuspension as observed in the elemental characterization of the trace elements present in the dry period.

For Marengo et al. (2009), it can present intensified action when cold fronts advance in a northerly direction during the summer to their climatological position. Another important factor is the occurrence of low-level jets (JBN) which are wind currents with maximum speeds close to 2 km of altitude east of the Andes mountain range, whose direction channels the winds and collaborates in the transport of moisture from the Amazon to the South and Southeast. These characteristics indicate aspects of atmospheric instability, with vertical turbulence and air mixing, favoring the dispersion of pollutants and these cold masses are observed in the study region of the Pantanal with "cold" days, but with a strong presence of fires.

For Cavalcanti and Kousky (2009), this system is formed at high latitudes that are the result of the contact area between two air masses with different characteristics that generates a discontinuity surface, whether anemometric, barometric, thermal, among others.

During the dry period and in relation to the physical characteristics of the systems that are acting, there is a period of atmospheric stability that presents little vertical turbulence and constant thermal inversions, factors that hinder the mixing of air and the dispersion of pollutants, but it is very characteristic for the Pantanal, the sources of emissions from fires, biogenic and soil resuspension with the fine fashion of aerosols.

There was an increase in fire outbreaks in the Midwest and Northeast regions, compared to last August last year. There was also a 22% increase in hot spots compared to the same period in 2011 and peaks of *black carbon* accentuated in September as shown in Figure 5 and long-distance transport can be observed in Figure 9.

Despite the rainfall deficiency, especially during the first half of September, the performance of the fourth and sixth frontal systems contributed to the accumulated rainfall in the Midwest Region. Even so, the positive precipitation anomalies occurred in an isolated way in the east and center of Mato Grosso do Sul, south of Goiás and north of Mato Grosso, according to data from INMET.

About 62,100 fire outbreaks were detected in the images of the AQUA_MT satellite, the current reference satellite for temporal comparisons, during the month of September.

This value corresponded to an increase of 35% compared to August last year, following the trend of greater use of fire in vegetation as the drought continues in the central part of the country and in the Northeast Region. There was also an increase of 22% in hot spots compared to the same period in 2011, consistent with the negative precipitation and positive maximum temperature anomalies, which are observed due to the peaks represented in Figure 9, the days most affected by fires, which were September 4 and 12, 2012.

FINAL CONSIDERATIONS

For the MAAP equipment, it presents a higher concentration of *black carbon* in fine fashion during the burning period on September 4 and 9, 2012 and can be compared with the trajectories by the Hysplit model, and a reduction in the concentration of *black carbon* in thick fashion is observed due to the rainy season, which measures black carbon concentrations in real time.

Thus, it is possible to evaluate the origin of the trajectories calculated with the Hysplit program for the Advanced Research base of the Pantanal of Mato Grosso on days of intense peak of particulate matter, in which the wind coming from the South with lower humidity will increase the emission of aerosols as observed on September 4 and 9, 2012, an intense peak for the ratio between organic carbon/elemental carbon. There is an increase in fires, other sources related to the Advanced Research base of the Pantanal of Mato Grosso such as soil resuspension, biogenic as observed in the elemental characterization present in the dry season.

With this, the evaluation of *black carbon* in the Pantanal of Mato Grosso and its possible sources of particulate matter was observed.

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