

## MONITORING OF METHANE ON DAMS OF HYDROELECTRICS OF THE AMAZON BASIN FROM THE AQUA SATELLITE INFORMATION

Patrícia dos Santos Costa <sup>(1)</sup>, Juarez Viégas Silva <sup>(2)</sup>,  
Rodrigo Augusto Ferreira de Souza <sup>(3)</sup>, Rita Valéria Andreoli de Souza <sup>(4)</sup>,  
Naziano Pantoja Filizola Júnior <sup>(5)</sup>, Elizabeth Ferreira Cartaxo <sup>(6)</sup>

<sup>(1,2,3,4)</sup> Universidade do Estado do Amazonas, Escola Superior de Tecnologia (EST-UEA), Av. Darcy Vargas, 1200, Parque 10, 69065-020, Manaus, AM, Brasil.

<sup>(5,6)</sup> Universidade Federal do Amazonas, Laboratório de Potamologia da Amazônia (LAPA) e Núcleo Interdisciplinar de Energia, Meio Ambiente e Água (NIEMA), Av. Rodrigo Octávio Jordão, 3000, Coroado, 69077-000, Manaus, AM, Brasil.

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**Abstract:** Studies have shown that dams of hydroelectric result in emissions of greenhouse gases (GHG's) when built in forested areas in the tropics. Such emissions include methane gas released into the atmosphere in large quantities due to changes in water level, flooding and exposing large areas of land around the border. Thus, important tools for studying the concentration of GHG's in the atmosphere, especially on areas of difficult access, drillers are onboard environmental satellites. Within this context, this work aims to study the variability of methane in the atmosphere over the reservoirs Balbina, Samuel Tucuruí and, based on eight years of data (2003-2010) survey system of environmental satellite AQUA. Furthermore, it is also an additional study on the variability of precipitation and reservoir level (when available). The methodology used was based on mathematical and statistical methods that include spatial averages, anomalies, and the variance of wavelet transform technique. The results show that there is a well defined seasonal average concentration of methane and the variability of abnormality of methane (at 200 mb) on the reservoirs is similar over the years, except anomalies calculated for the level of 300 mb. In the case studies, the years 2008/2009 stood out for include two extreme events (flood and drought) that brought impacts in the areas economic, social and environmental. The application of the wavelet transform technique showed that the overall power spectrum has peaks dominate the time scale per year (0.7 to 1.2 years), however, may be noted the periods of 2005 to 2006 and 2008 to 2010 maximum values of the power spectrum of the wavelet at that time scale. The results of this study revealed that the observations made by AQUA indicate that there is a relationship between climatic conditions, reservoir level and concentration of methane in the atmosphere.

**Keyword:** Methane, Hydropower in the Amazon Basin, AQUA satellite.

### Introduction

A large preoccupation of scientific community is climate change and human consequence. The Brazil can be impacted one

time that your economy is strongly dependent of natural resources as climate, agriculture and hydroelectric generation. [Costa *et al* (2012)].

Some studies have interest of show the environment impact of construction of dam in Amazonia. These studies indicate that hydroelectric dam can result in greenhouse gas when constructed in tropical forest area [Fearnside (2008); Rosa *et al.*, (1994); Santos *et al.*, (2002)].

The greenhouse gas included carbon gas that forms above of water surface through of decomposition of tree, and methane (CH<sub>4</sub>), resultant of decomposition of vegetation subaquatic. With increase and decrease of level of water, flooding and exposing large areas of land around the edge of the water body, the dams release into the atmosphere large quantities of methane. However, this gas is considered the second most important greenhouse gas due to its concentration in the atmosphere, being recorded 21 times greater than carbon dioxide (CO<sub>2</sub>) in a setting of 100 years and its radiative forcing represents approximately 18% of the total global average (Basso, 2011).

Studies related to this problem of environmental impacts in the country are of great importance because of the existence of remote regions such as the Amazon, and the lack of continuous measurements of gas concentration on hydroelectric dams. Thus, remote surveys emerge as an alternative to complement the few existing data from individual measures on the region. So, the advancement in technology coupled with the interest of the scientific community to understand the behavior of atmospheric gases, especially in recent years, spurred the development of important tools to study the concentration of greenhouse gases in the atmosphere. Studies such as those Aumann *et al.* (2003), Susskind *et al.* (2003), and Xiong *et al.* (2008) showed the feasibility and advantage of using the sensor "Atmospheric Infrared Sounder" (AIRS) onboard the Aqua platform, to infer and monitor the concentration of gases in the atmosphere. Thus, the AQUA mission provides a great opportunity to collect data through inference of the concentration of some gases (dash and greenhouse) in the Earth's atmosphere. In addition, there is the possibility of monitoring variability of scales daily to interannual time (data available since May 2002 to the present day) the concentration of

greenhouse gases, since the AQUA satellite has global coverage with two tickets daily and spatial resolution of 1° latitude by 1° longitude.

In the context facing the management of watersheds and reservoirs, the use of remote tools for monitoring the concentration of gases, particularly methane, may facilitate adoption of policies in various areas (environmental, social and economic). To better understand the possible relationships between methane concentration, precipitation and changes in the level of hydroelectric dams in the Amazon region, knowledge of the average behavior and variability in the atmosphere, the gas under study is required since this is a gas which has a high capacity for absorption of infrared radiation when compared with carbon dioxide, and their life time in the atmosphere is at least ten years [Stuedler *et al.*, (1989)].

Thus, this work aims to study the contribution of hydroelectric reservoirs of the Amazon, such as Balbina, Samuel and Tucuruí in methane emissions of GHGs on a regional scale and variability of this gas, as well as their average behavior in the atmosphere, based on eight years of data from the survey system aboard the environmental satellite AQUA. Also, check the possibility of using this tool in the continuous reservoir monitoring relating the concentration of CH<sub>4</sub> in the atmosphere with changes in reservoir levels in dams in the Amazon region by the cases where the data quota of shells are available. Thus, it is expected to mount a database to assess the possibility of using the AQUA satellite information as an important tool in remote monitoring of hydroelectric reservoirs in the Amazon region, contributing to the consolidation of a network of Hydrology in the region that can be used for specific purposes within the academic, research and general users.

## **Material and methods**

### **Study area**

This work utilized the hidroeletric: Balbina (A1), Tucuruí (A2) and Samuel (A3), located in the Amazon (Table 1).

Table 1 – Geographical coordinates of the study areas.

Study area	Latitude	Longitude
Balbina	1°S and 3°S	59°W and 61°W
Tucuruí	3°S and 5°S	49°W and 51°W
Samuel	7°S and 9°S	62°W and 64°W

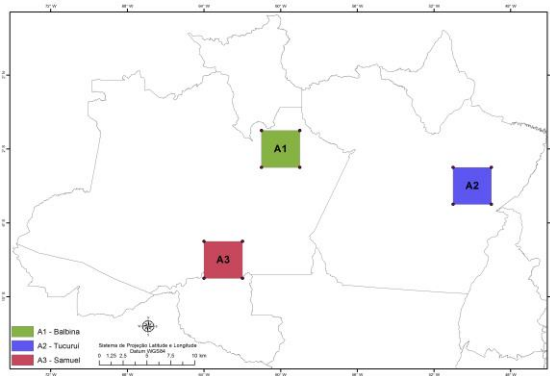


Figure 1 – Localization of the hidroelectric: Balbina/AM (A1), Tucuruí/PA (A2) and Samuel/RO (A3)

#### Data

The data used in this study derived estimates of AIRS sensor aboard the AQUA satellite, for the period 2003-2010, were the average concentrations of CH<sub>4</sub> (units ppbv) at three levels of atmospheric pressure (200, 300 and 400mb). These pressure levels are pre-set in the product "AIRS Level-3 Version 5 Standard 8-day".

These variables have a spatial resolution of 1° by 1° latitude and longitude, eight days temporal resolution and global coverage. Moreover, they used the data: average rainfall (in mm/month) and the shell (in m) of UHE Balbina level. Rainfall data belong to the "Global Precipitation Climatology Center" (GPCC) (Rudolf and Rubel, 2005) and correspond to the period 1986-2009. Spatial resolution of 1° by 1° latitude and longitude.

The in situ data are representative of the shell (in m) of the Balbina hydroelectric dam for the period 2003 to 2008 level.

#### Methodology

##### Representation of databases and statistical calculations

Initially, the average concentration of CH<sub>4</sub> over the selected regions (Figure 1) to the atmospheric pressure profiles (200, 300, and 400mb) were calculated to evaluate temporal variability over atmospheric pressure profile over the regions of study. Then monthly anomalies of these concentrations were calculated by removing the annual cycle using as a basis the weekly weather the period 2003-2010. And to the analysis of rainfall series, monthly anomalies were calculated based on 1986-2009 climatology of the information of average monthly precipitation GPCC.

##### Modulation of the annual cycle of CH<sub>4</sub> on the Balbina Reservoir by low frequency oscillations

Investigations on the modulation of the annual cycle of CH<sub>4</sub> in Balbina Reservoir by low frequency oscillations (Figure 2) was based on mathematical and statistical methods where initially we compute: Spatial Averages of CH<sub>4</sub> concentration (at 300mb) and precipitation on bounded at 1° S , 3° S , 59° W and 61° W (Figure 1), the region in order to assess the temporal variability of CH<sub>4</sub> and rainfall indices over the region of Balbina hydroelectric dam; weekly Anomalies concentration CH<sub>4</sub>, removing the annual cycle, using as a basis the weekly weather the period 2003-2009, and to examine the temporal variations of methane in the series , the methodology chosen was: the wavelet analysis.

These tests are a series of decomposition as a function of time and frequency, or represent an estimate of the spectral characteristics of the time series as a function of time. Moreover, the great advantage of using the wavelet analysis, compared with the spectral analysis using the Fast Fourier Transform (FFT), is it possible to determine the different scales of fluctuation of a geophysical field you are working in every moment. A detailed description of the

advantages of using this technique and theoretical aspects is presented by Bolzan (2006). In this study, the technique was applied to the estimated number of CH<sub>4</sub> satellite.

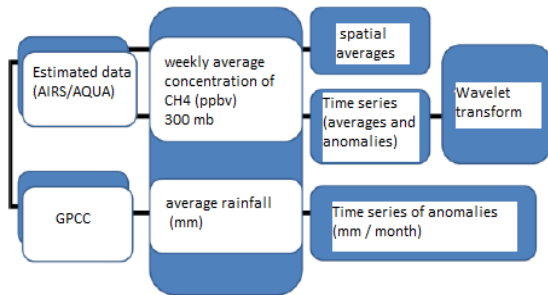


Figure 2 – Diagram of the methodology for the case study based on the techniques and use of wavelets.

## Results and discussion

The temporal variability of methane

The average concentrations of methane 8 days for three different levels of atmospheric pressure are shown in Figure 3. It is observed from this figure that there is a well-defined seasonality for all pressure levels, with maximum values occurring in the dry season (July to September) and minimum values predominating in the rainy season (January to April). The seasonal pattern is similar in all pressure levels, with the highest concentrations observed in the level of 400mb.

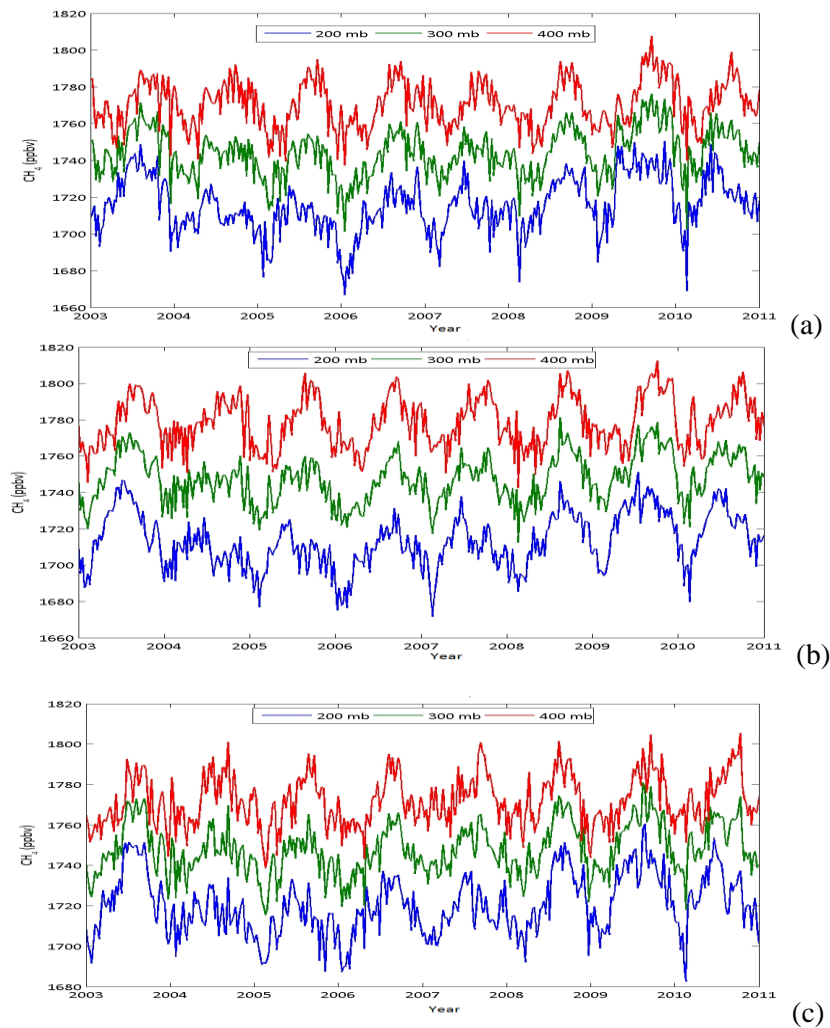


Figure 3 – Time series of the average concentration of CH<sub>4</sub> over the reservoir Balbina (a) Tucuruí (b) and Samuel (c), three different levels of air pressure.

Figure 4 and 5 shown anomalies of CH<sub>4</sub> concentration for three levels atmospheric pressure on the areas of study for the 200mb, 300mb and 400mb. In general, it is observed in these figures the predominance of negative anomalies between the years of 2004 until mid-2008. Moreover, positive anomalies occurred in the years 2003 and second half 2008 to 2010, which was more pronounced in

2009. Note is the variability of the anomaly on the methane reservoirs Balbina Tucuquí and Samuel is similar over the years, with a maximum (minimum) around anomalies 30 (-30) ppbv, except anomalies shown for the level of 300mb (Figure 5), maximum (minimum) anomalies occurring around 25 (-25) ppbv.

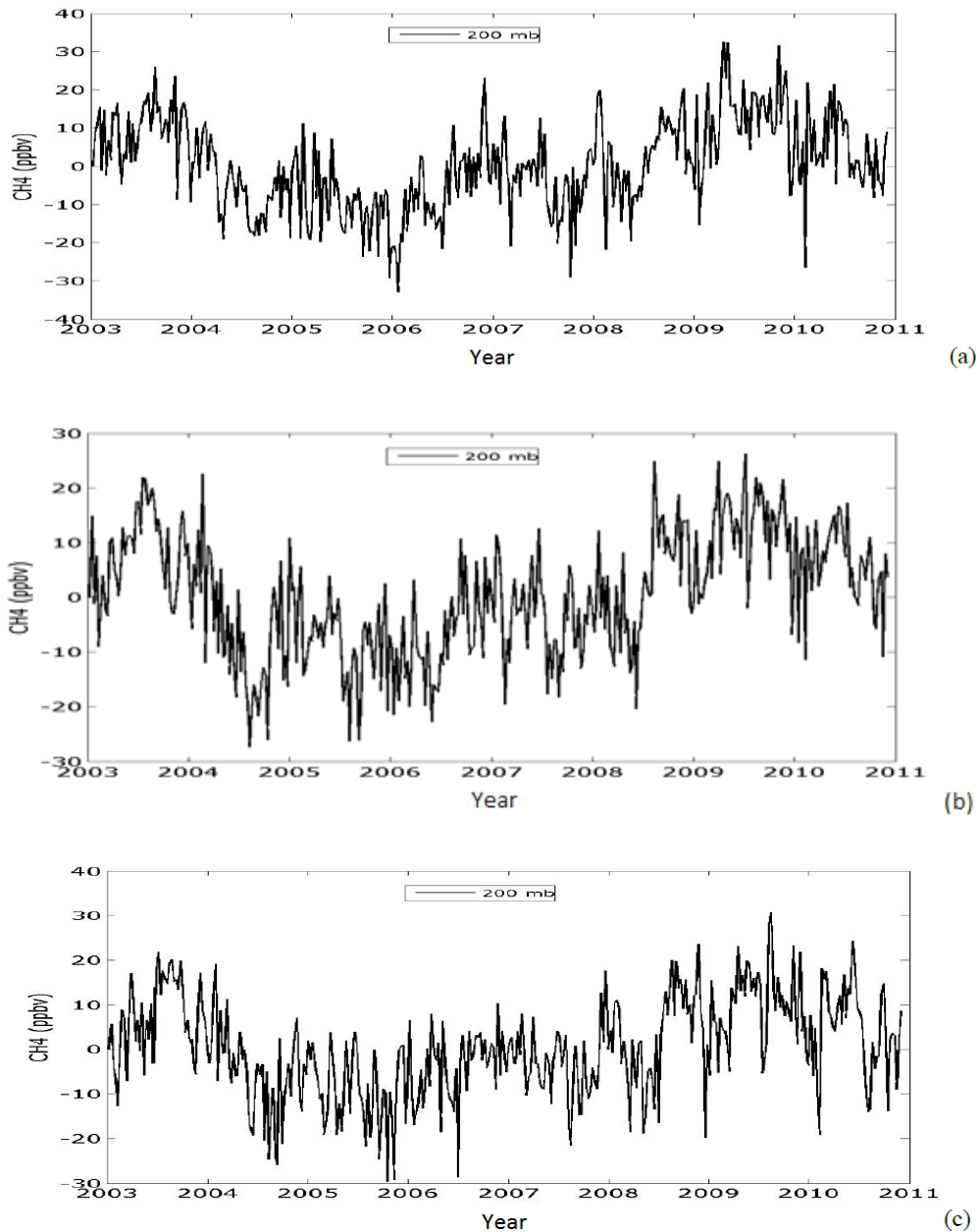


Figure 4 – Anomalies of CH<sub>4</sub> concentration for 200mb level of atmospheric pressure in Balbina (a), Tucuquí (b) and Samuel (c).

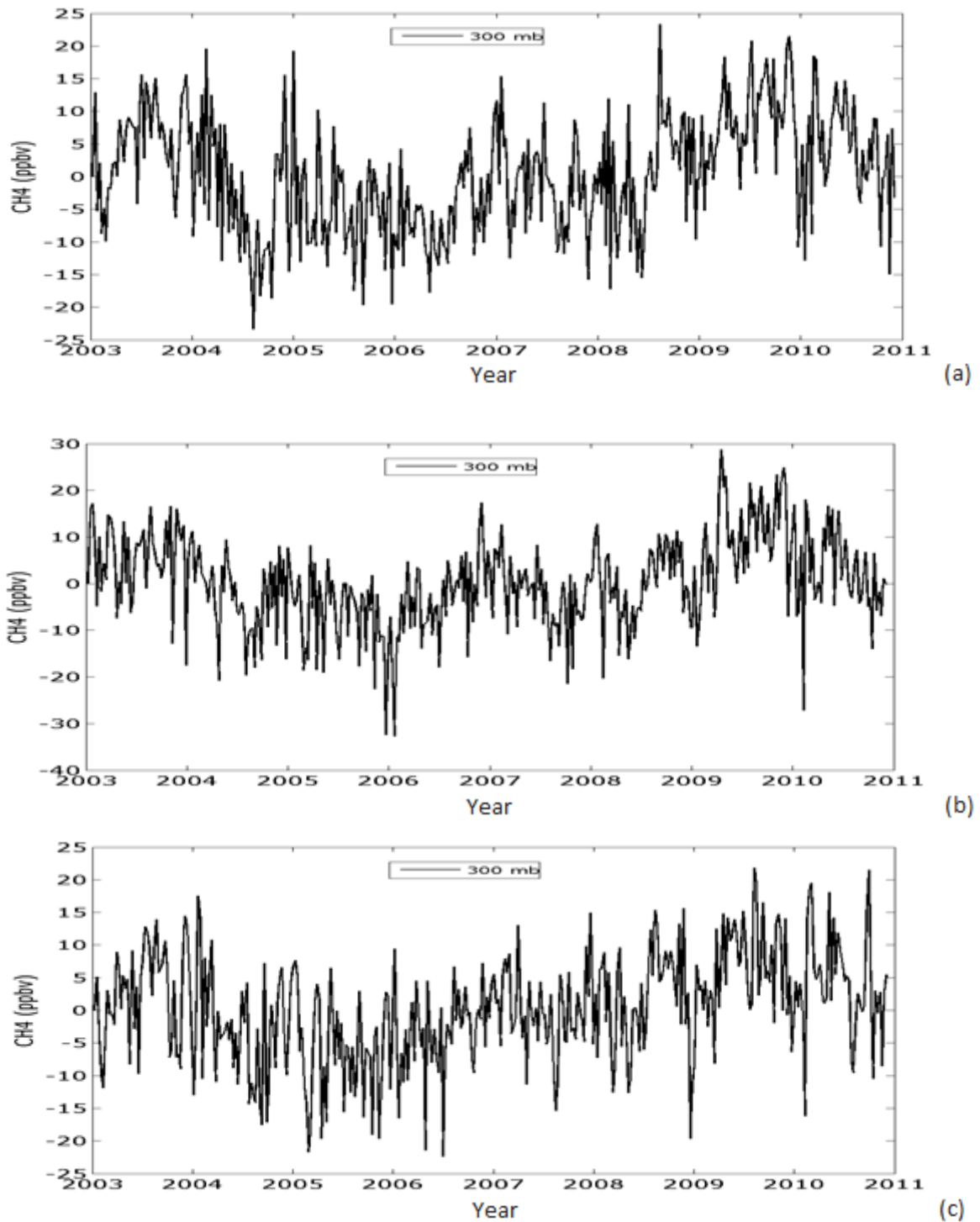


Figure 5 – Anomalies of CH<sub>4</sub> concentration for 300mb level of atmospheric pressure in Balbina (a), Tucuruí (b) and Samuel (c).

The closer to the surface (400mb) level atmospheric pressure can be seen in Figure 6. Overall, we note that seasonality along the climatological anomaly series of

CH<sub>4</sub> is less clear whether compared to other levels of atmospheric pressure. The magnitudes of the anomalies of methane varied with maximum (minimum) of 20 to 25 ppbv (-20 to -30), on the reservoirs.

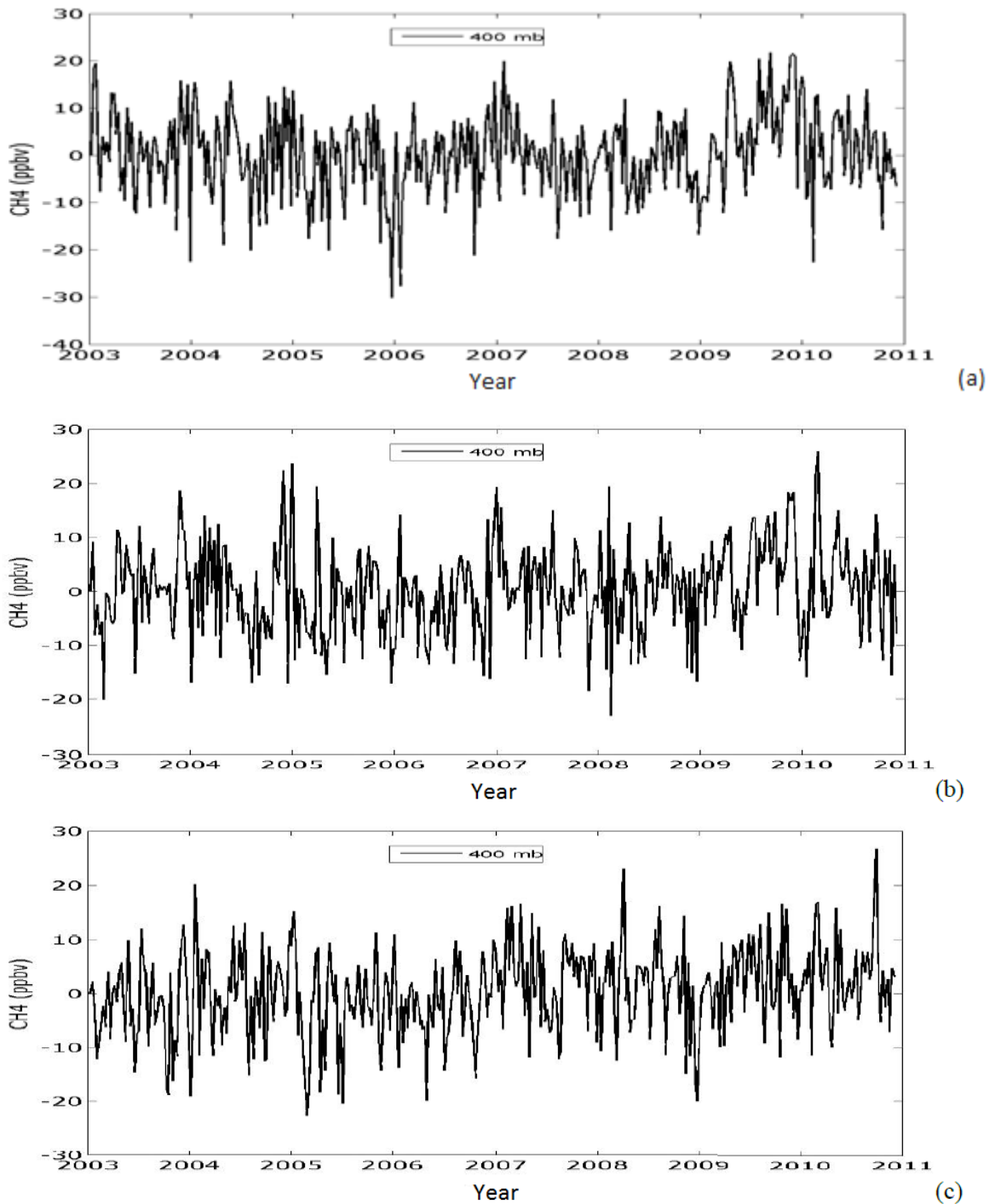


Figure 6 – Anomalies of CH<sub>4</sub> concentration for 400mb level of atmospheric pressure in Balbina (a), Tucuruí (b) and Samuel (c).

**Temporal variability of precipitation**

The precipitation anomalies on HPP's (Figure 7) are presented for the period 2003 to 2009. Was observed on the Balbina Reservoir

a predominance of negative anomalies in the first four years of the series, with a change of signal from the first half of 2007, positive anomalies persist for the entire year of 2008 with signal inversion during most of 2009 and

2010, behavior of the series of precipitation for the years 2008 and 2009 may be associated with year "La Niña", which may consequently have driven the full record of 2009. According Sales *et al* (2010), the hydrological year 2008/2009 amounted to 244 days of flooding, which equates to approximately 67% of the calendar year since 1903 with 107 year return in 2009, on the other reservoirs this behavior is not well defined. Have to Tucuquí reservoir highlights the year 2006 with maximum values of precipitation (280 mm/month) and then in

2010, with a peak occurring at 220 mm/month. The minimum was near the climatological average, except for the years 2003 and 2007 (-120 and -160 mm/month, respectively). Analyzing precipitation over the Samuel reservoir is noted that since the last few months of 2005 to the first three months of 2006 the predominance of positive anomalies, ranging from 25 to 50 mm/month rainfall. The years 2004 and 2007 showed anomalies of approximately 150 mm/month below the climatological average.

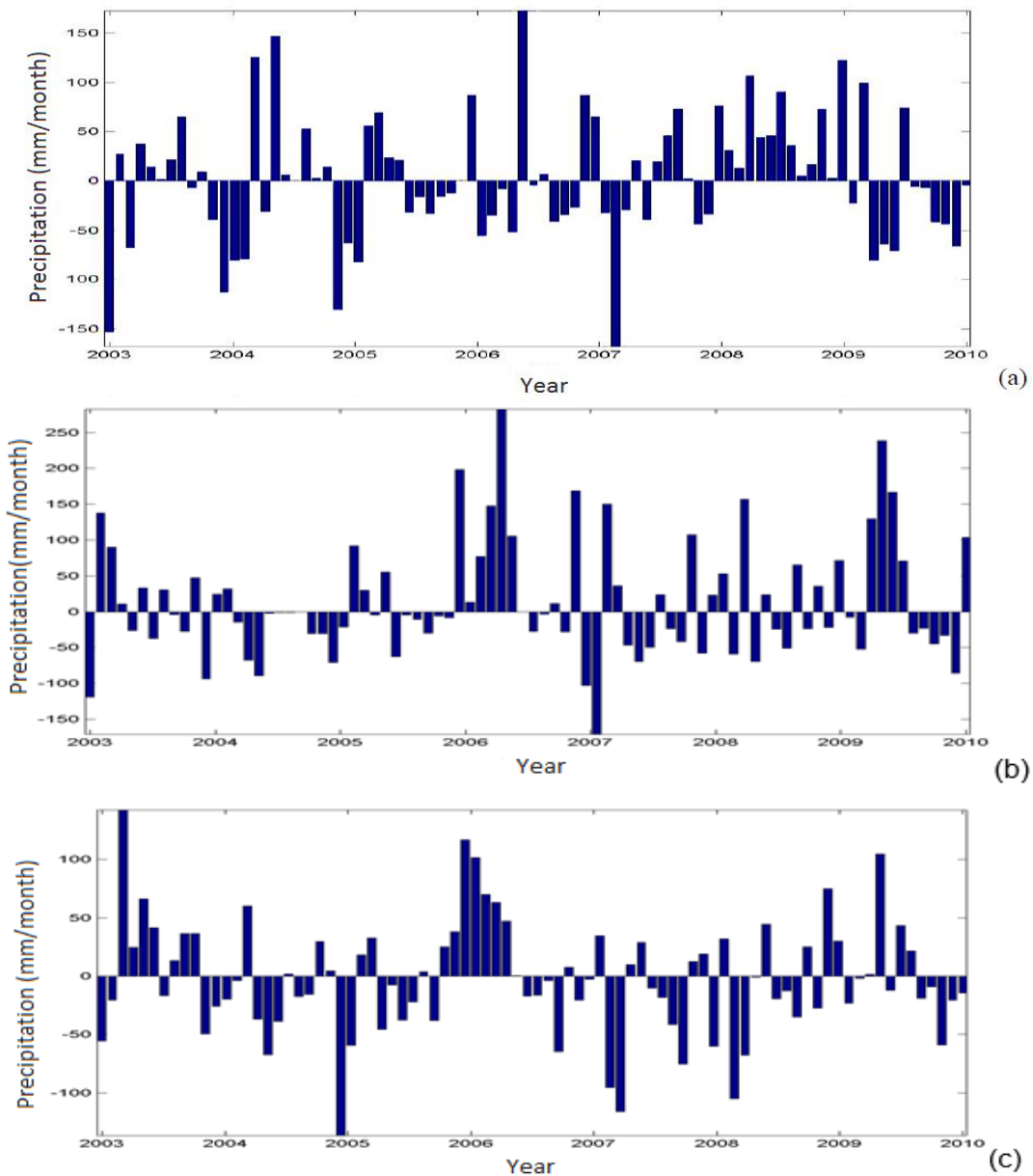


Figure 7 - Anomalies of average precipitation for the period 2003-2009, on the reservoirs Balbina (a), Tucuquí (b) and Samuel (c).

## CASE STUDY

Modulation of the annual cycle of CH<sub>4</sub> on the Balbina Reservoir by low frequency oscillations

Figure 8 shows the wavelet analysis for the time series of CH<sub>4</sub> for the period 2003-2010. In panel (a) the local power spectrum of the continuous wavelet transform and is shown in Figure 8b, the specter of global power (EPG). As expected, the annual cycle contains most of the variance, although other variability (for example, patterns) is also present, but no statistical significance (to make it meaningful, it is necessary to remove the annual cycle, Figure 9). The overall power spectrum domain shows no significant range of 2 to 4 years and above the annual dominant peak

level (0.7 to 1.2 years) and two secondary peaks (Figure 8 b). The annual peak results from strong variability 0.7 to 1.2 (scale of the annual cycle) occurring throughout the period of data. However, it can be noted in the periods 2005-2006 and 2008-2010 values EPO (Power Spectrum of the Wavelet) maxima and significant (Figure 8, a), suggesting a modulation of the annual cycle variability for lower frequency.

As mentioned previously, for the series of anomalies of CH<sub>4</sub>, the global power spectrum of the field shows two dominant peaks at interannual time scale (2-4 years and above 4 years). The peaks inter 2 to 4 years (Figure 9) results in a significant variability in this time scale occurring throughout the data period.

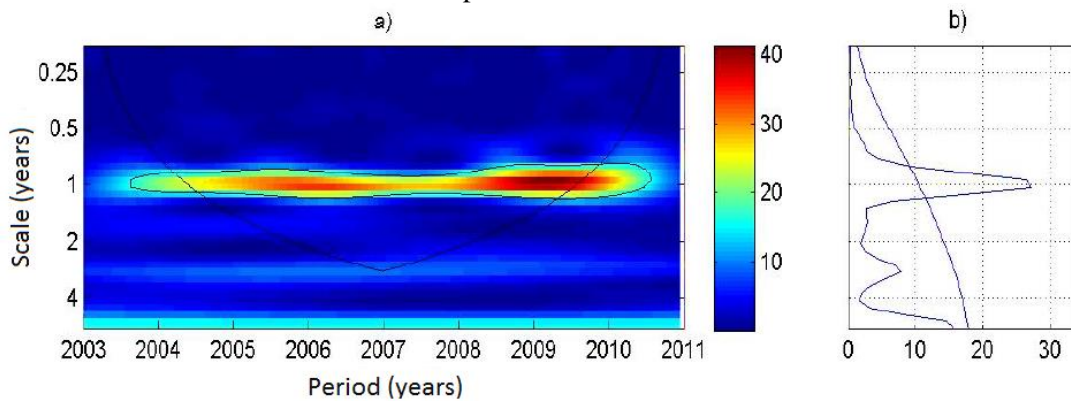


Figure 8 - a) Power Spectrum for the location of the wavelet series of CH<sub>4</sub>; normalized by  $\sigma = 12.38$ . The U-shaped curve represents the cone of influence. b) Power of Global wavelet. The closed contour indicates areas where the spectrum of the wavelet power is significant at a confidence level of 95%.

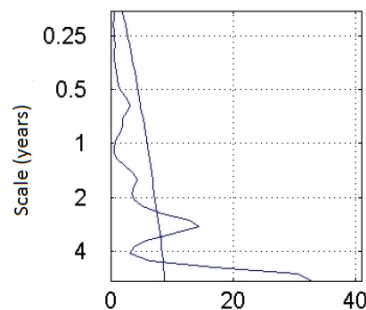


Figure 9 – Spectrum of the wavelet global power normalized by the number of standard deviation anomaly of CH<sub>4</sub>, with the corresponding curve of statistical significance at the 95% confidence.

Modulation of EPO manifests as follows: for the years of highest amplitude of

the annual cycle, we obtain the maximum average power spectrum of the wavelet

(MEPO, Figure 10). The MEPO to scale from 0.7 to 1.2 years provided shows local maximum and minimum over the years. Thus, for CH<sub>4</sub>, the annual cycle appears to be more

intense in the years 2005-2006 and 2008-2010. The time interval between consecutive maximum MEPO is 2-4 years, this suggests that CH<sub>4</sub> has an interannual modulation.

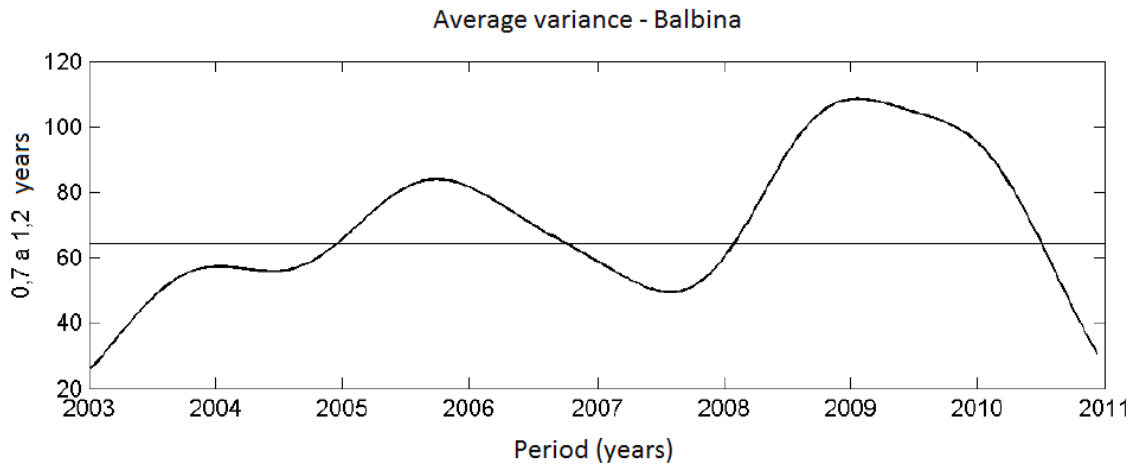


Figure 10 - MEPO in the band 0.7 - 1.2 years, where the line is the confidence level of 95%.

To better evaluate the modulation of the annual cycle of the low frequency variability, the range of variation of the rate of CH<sub>4</sub> mediated to 2 to 4 years scale obtained by wavelet analysis and reconstructed precipitation rate for this scale of time (2 to 4 years) are arranged on the same graph (Figure 11). It is remarkable consistency of the maximum of the two series with maximum MEPO the annual cycle, which shows that the annual variability of CH<sub>4</sub> is modulated by interannual variability of CH<sub>4</sub> which in turn is associated with precipitation variability in the region. Thus, the predominance of positive anomalies of methane from the second half of 2008 is associated with a significant increase in precipitation in the region. This fact is related to the increase in flooded areas during extreme events, providing a larger (smaller) amount of decomposing biomass and, consequently, with the arrival of the period of

ebb tides, with higher (lower) CH<sub>4</sub> emission to the atmosphere. Therefore, for CH<sub>4</sub>, the interannual modulation of the annual EPO appears to be associated with the interannual variability of rainfall.

Marengo *et al* (2011) suggest that the combination of several meteorological factors such as: the greater moisture transport from the tropical North Atlantic along the coast of Venezuela - Guyana towards the western part of the Amazon and the expansion of the downtown Chaco during summer of 2008-2009 and migration to the south of the Intertropical Convergence Zone during May - June 2009, due to the warming of surface waters in the tropical South Atlantic were responsible for the increase in precipitation in the region. As a result of these factors the beginning of the rainy season in the region was anticipated, contributing to the occurrence of an intense full in rivers.

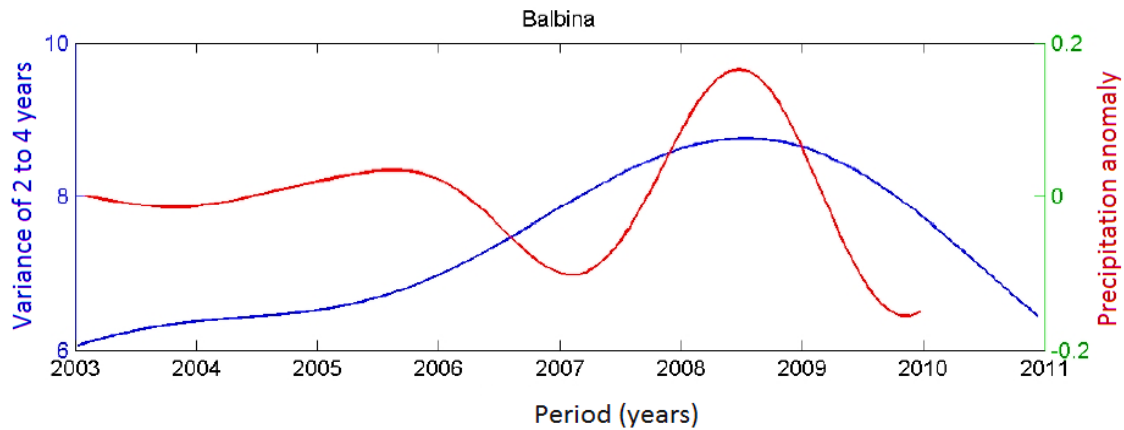


Figure 11 - Series of variance index mediated CH<sub>4</sub> to scale 2 to 4 years (blue) and normalized reconstructed precipitation rate to the range of 2 to 4 years (red).

## Conclusion

The observations made by probing AQUA system, based on historical series (2003-2010) of the concentration of CH<sub>4</sub> in the atmosphere, indicate that there is a relationship between climate conditions (precipitation), the reservoir level and concentration of methane in the atmosphere. The seasonal pattern in methane concentration is consistent with the pattern of rain and, therefore, reservoir levels, so that larger (smaller) CH<sub>4</sub> concentrations occur in the dry (wet). The annual variability and its modulation frequencies on the lower region of the hydro Balbina as the methodology which uses wavelet analysis techniques to time-frequency analysis shows, as expected, the EPG presenting dominant peaks in the range of annual time (0.7 to 1.2 years), however, can be noted in the periods 2005-2006 and 2008-2010 maxima of EPO that timescale. Therefore, these maximum values are associated with modulation of the annual cycle of interannual variability that is also related to the increase in flooded areas during extreme events, providing a larger (smaller) amount of biomass decomposition and, consequently, with the arrival of the period of ebb, with higher (lower) CH<sub>4</sub> emission to the atmosphere. Therefore, for CH<sub>4</sub>, the interannual modulation of the annual EPO appears to be associated with the interannual variability of rainfall.

Finally, these preliminary analyzes suggest the possibility of using remote monitoring information on the variability of methane concentration on large wetlands as a way of monitoring this greenhouse gas. Likewise, it is recommended that similar analyzes are performed for HPP's Tucuruí and Samuel. Such information may support the adoption of public policies that help the management of the watershed and the reservoirs of hydroelectric power plants in this basin environmental, social and economic spheres.

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