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Spectral reflectance of Tucuruí reservoir waters Brazilian Amazon

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ABSTRACT

The Tucuruí reservoir was formed by damming the Tocantins river and flooding around 2430 Km² of forest land. Its average depth is 18 meters with a dendritic shoreline which is responsible for a large variety of water masses with distinctive properties. This aquatic system therefore offers an unique opportunity for collection of wide variety of spectral data representative of the conditions usually found in Amazon reservoirs. These could be used as an spectral library for interpretation of imaging spectrometric data. This paper reports an experiment performed in april 1992 in which spectrometric data were collected over the Tucuruí reservoir concurrently to water sampling at surface, at 50% light penetration depth, and at Secchi depth. Water samples were analysed to obtain chlorophyll pigment, total suspended solids concentration and yellow substance attenuation. The preliminary results shown two different types of optical waters, influenced mainly by total suspended solids concentration.

1. INTRODUCTION

Many hydroelectrics have been built in Brazil as an effort to provide energy sources for the future. Consequently, many kinds of environmental degradation have been originated. The reduction of the water flow increases the hydraulic retention and consequently modifies the horizontal and vertical distribution of the biotics and abiotics characteristics. These disturbances frequently result on the water eutrophization process.

The aquatic systems eutrophization exhibits some effects like the increasing of biomass and primary production mainly Cyanoficeas and the reduction of species diversity, soluble oxygen and water transparency¹. In order to understand these processes it is necessary to quantify the water properties like limnological and optical parameters.

These studies are very difficult in the Amazon region in terms of acces to the study areas. Therefore, the ideal approach to the water quality monitoring in these regions are the LANDSAT and SPOT satellite data which are received in Brazil. In the case of the Tucuruí reservoir many studies have been done using the TM data to estimate macrophytes density², total suspended solids and Chlorophyll concentration^{3,4,5,6,7}.

The efficient use of remote sensing data depends on our capability to understand and quantify the interactions between the solar radiation and the components of the water body. Pure water has a high absorption in the red and infrared bands of the eletromagnetic spectrum. Common water bodies, by the other side, have their spectral signature shaped by their optically active components such as pigments, inorganic matter, and organic dissolved substances⁸.

Suspended inorganic matter is the main light scatter within the aquatic environment. Its particle size, shape and concentration are the main factors to explain the amount of upwelling scattered light⁹ on the long wavelengths. On the other hand the yellow substance is the main component to absorb in the short wavelengths; its presence difficulties the determination of chlorophyll concentration¹⁰. The photosynthetically active pigments have different spectral characteristics and its presence determines the water body spectral signature. The photosynthetically active pigment is the Chlorophyll a that absorbs at 435 nm and 675nm.⁸

The apparent water radiance, as detected by sensors, is composed by: 1. scattered upward radiance; 2. surface reflected sky radiance; 3. glitter solar radiance, 4. atmosphere radiance and transmittance effects.¹¹

To understand the very complex processes which are occurring in the Tucuruí reservoir, a large quantity and variety of limnological data has been collected by the ELETRONORTE technical team. In order to complement and use this kind of information for remote sensing purposes a field data collection experiment, that included the measurement of spectral data, was performed by INPE during the 1992 SAREX campaign.

2. STUDY AREA

The Tucuruí reservoir (S03°43'/W050°00' and S05°15'/W049°12') (Fig. 1) was formed by damming the Tocantins river and has 45 billion m³ volume. Flooding an area around 2430 Km² of forest land, its average and maximum depth are estimated in 18 and 72 meters respectively. The dendritic shoreline, the high hydraulic retention time between 20 and 500 days and the Tocantins flow seasonal variation induces macrophyte infestation over a reservoir large and are responsible for very different water masses.⁴

3. METHODOLOGY

3.1. Water data acquisition and analysis

Water samples and radiometric measurements were collected at 11 sites in the central of Tocantins channel and in the Tucuruí channel (Fig.1). All the samples location (latitude and longitude) were determined by a portable Trimble GPS.

To identify the vertical profile of the water components, the water samples were collected in standard hydrographic depths: 100%, 50% of light penetration and Secchi depth (Zse). The water samples were preserved at low temperature¹² and their Chlorophyll concentration (Chl) was determined by a standard spectrophotometric technique¹³. The total suspended solids (TSS) were determined by a conventional gravimetric method and the yellow substance concentration (YS) measured through its absorption coefficients at 440nm (g₄₄₀)¹⁴.

Fig. 1. Study area

3.2. Radiometric measurements

Normalized radiance or reflectance factor spectra of water bodies have important information concerning its quality and could be acquired through spectroradiometric systems installed on boats or aircrafts.¹¹

For the measurement of the different water masses spectral reflectance factors, a radiometric system was set up on the stem of a 5 meter aluminium boat. As shown in Fig. 2, two optical units of the SE-590, with a 6 degree field of view, were attached to a metallic plate at a sturdy tripod top. One of the optical units (#1) has its field of view aimed to a small plate sprayed with Barium Sulfate and calibrated to a laboratory reflectance standard. The other unit (#2), views the water sample under a 45 degrees zenith angle and a 90 degrees azimuth relative to the Sun direction in order to avoid the wind glitter effects and the shadowing of the sample by the boat and tripod structure. To decrease the skylight radiance reflected into the field of view, this unit was equipped with a polarizing filter.

The SE-590 is a 256 channel radiometer for the 350nm-1150nm spectral range with 8nm effective spectral resolution. Its data-logger unit can be set for different acquisition modes. In this field work case it was prepared to measure groups of 4 spectra in each optical unit which were averaged before storage on the tape. Under solar illumination the integration time of the system is less than one second; this short time yields for very close measurements of the water sample and reference.

The system was previously calibrated by measuring the reference plate spectral radiance with the two optical units under the same illumination. This measurements ratio (K_λ) is the spectral correction factor that needs to be applied to the spectral reflectance factors to correct them for the optical units different sensitivities. In this case, the spectral reflectance factors R_λ of the water samples are given by:

$$R_\lambda = L_{s,\lambda} / L_{r,\lambda} \cdot K_\lambda J_\lambda$$

where $L_{s,\lambda}$ and $L_{r,\lambda}$ are the spectral radiances of the water and of the reference plate respectively and J_λ is the reference plate spectral calibration factor.

Fig. 2. Experiment design

The spectral data of two water samples were measured at each of the 11 stations on the Tocantins and Pucurui channels (Fig. 1). The 44 spectra were transferred from the digital tape of the data-logger to a computer file by means of the software ESPECTRO. This is a computer program developed at the Laboratory for Radiometry of INPE and specially developed for the SE-590 data processing.²³ The main steps of the data reduction were:

1. to transfer the 44 spectra to a DOS file.
2. to ratio each sample and reference spectra.
3. to average the same station spectra.
4. to apply the intercalibration factors.

4. RESULTS AND COMMENTS

4.1. Water parameters analysis

Water quality data are summarized on Table 1. The highest CHI concentration was observed at Pucurui channel central part where large Microcystes colonies were found. The vertical profile showed a subsurface maximum CHI concentration. The CHI distribution is related to the nutrient distribution and also to the hydrological cycle in this region.

Table 1- Results of water parameters measurements

Site	lat/long	Zse	TSS1	TSS2	TSS3	CHI1	CHI2	CHI3	YS1	YS2	YS3
1	S4°14'34''/W49°33'46''	0.8	6.00	5.40	5.50	2.86	2.86	2.62	1.9	2.1	2.1
2	S4°13'11''/W49°34'48''	1.0	5.60	5.30	5.50	2.98	3.09	2.98	2.2	1.8	2.3
3	S4°10'15''/W49°36'52''	1.3	3.60	4.00	3.90	4.28	4.40	4.52	0.9	1.7	2.0
4	S4°13'43''/W49°41'59''	3.0	1.20	1.30	1.30	4.28	3.57	3.57	0.3	0.2	0.5
5	S4°15'37''/W49°43'18''	3.0	1.60	1.50	1.50	4.64	4.17	4.40	0.6	0.7	0.6
6	S4°17'12''/W49°42'23''	2.9	1.50	1.70	1.50	3.93	3.93	4.28	0.5	0.5	0.3
7	S4°18'59''/W49°42'31''	2.6	2.20	2.00	1.40	4.17	4.17	4.40	0.1	0.8	0.8
8	S4°19'29''/W49°43'58''	3.0	1.40	1.80	1.40	3.57	4.17	2.38	0.7	1.0	1.0
9	S4°20'27''/W49°44'57''	2.5	1.10	1.30	1.30	3.93	2.38	2.50	0.7	1.0	1.0
10	S4°21'18''/W49°45'56''	2.3	1.30	1.60	1.80	2.74	3.45	4.17	1.4	1.7	1.5
11	S4°21'40''/W49°46'24''	2.0	1.10	1.30	1.40	1.79	2.26	3.09	2.0	2.0	1.8

Where: Zse-Secchi depth in meters

TSS-Total suspended solids in mg/l at 100%, 50% of light penetration and at Secchi depth, 1, 2 and 3 respectively

CHI-Chlorophyll concentration in $\mu\text{g/l}$ at 100%, 50% of light penetration and at Secchi depth, 1, 2 and 3 respectively

YS-Yellow Substance in m^{-1} at 100%, 50% of light penetration and at Secchi depth, 1, 2 and 3 respectively

The table shows that the TSS concentration is higher at the Tocantins channel due to its more dynamic circulation.

In general the yellow substance concentration (absorbance at 440nm) is high as it is expected for this natural inland water⁸. Its mean value of 1.02 m^{-1} and its highest values are found on the Tocantins channel and close to the macrophytes area. These values were expected because in these areas the biodegradation processes are intensified by the presence of dead trees, macrophytes and forest contribution.

4.2. Spectral data analysis

The reflectance factors spectra preliminary analysis shown in Fig. 3 for the Tocantins channel and in Fig. 4 for the Pucurui channel was performed and some features could be noticed from the curves:

Fig. 3. Tocantins channel curves

The first group (Fig.3) exhibits a higher amplitude owing to the Tocantins higher TSS concentration. It is important to notice that the TSS measures the concentration of inorganic and organic matter. The first one contributes to the backscattering and the second to the absorption (as in the case of Chlorophyll). Therefore a TSS decrease results in a Secchi depth increase and consequently the backscattering reduction.

The low reflectance factor in the 400-500nm band could be related to the high specific absorption by the yellow substance and chlorophyll pigments.

Fig. 4. Pucurui channel curves

The increased spectral reflectance factor near 445nm in curves 1, 2, 3, 8, 9, 10 and 11 are not so evident in the remaining curves which are related to the highest CHI concentration. Probably this could be explained by the chlorophyll absorption centered at 445nm.

The range between 500 and 700nm corresponds to the highest values for all curves and its decreasing amplitude could be related to the decreasing water TSS concentration according to many authors.^{16,17,18,19,20,21}

The concavity near 604nm perhaps corresponds to the fifth harmonic of the OH stretch vibration of liquid water⁸.

At 620nm there is a peak in the curves of Fig. 3. This peak is not so evident in the other curves and this could be explained by the high diversity of Cyanophynea, mainly large colonies of *Microcystes* that have phycocyanine pigment with absorption peak at 620nm. Absence of these peaks in the curves of the sites located in the Pucurui channel is probably associated with the increase of *Microcystes*. The same effect, due to the phycocyanine absorption, was observed in radiometric measurements in eutrophic lakes.¹⁵

The low reflectance observed at 670nm, probably is related to the Chlorophyll a absorption as it was previously observed by many authors. 13,21

Above 700 nm the water infrared absorption dominates and decreases the spectral amplitudes to its minimum.

This preliminary analysis showed two different types of optical water bodies as they are mainly influenced by the TSS concentration. The Tocantins channel water with the highest TSS concentration exhibited the highest spectral reflectance factor as it was expected. Some important facts could be observed from the spectral curves and they seem to be a powerful data basis for water quality studies at the reservoir.

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