Remote sensing of the water properties of the Amazon floodplain lakes: the time delay effects between *in-situ* and satellite data acquisition on model accuracy

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Abstract – This work assesses time delay effects between the acquisition of orbital and *in situ* data on models to estimate chlorophyll concentration in the Amazon River várzea lakes. To carry out this assessment, a MERIS image, acquired concurrently with water radiometric and liminological property measurements was used. Correlations were carried out between MERIS spectral bands and MERIS simulated bands using field spectra. Correlation was evaluated for samples with time delays ranging from zero up to six days between orbital and *in situ* acquisition. With zero delay the average correlation between MERIS reflectance and MERIS simulated reflectance was 0.98. For time delays of up to 6 days after satellite overpass, the correlation ranged between 0.54 and 0.95. Regression models using ratio of spectral bands (infrared/red) to estimate the concentration of chlorophyll, resulted in determination coefficients (R^2) of 0.84 for *in situ* data against 0.64 for orbital data.

Keywords: Amazon floodplain lakes, Water quality monitoring, dynamics of water circulation, MERIS image.

1. INTRODUCTION

The aquatic environments are characterized by a high space-temporal variability when compared with terrestrial ones. This variability, associated with low revisiting rate of orbital systems, with optical sensor susceptibility to weather conditions, and with the size of Amazon basin aquatic systems (Hess et al. 2003; Junk 1997) makes it difficult to develop high accuracy models. (Rudorff, 2007; Novo et al., 2006). However, despite these limitations, remote sensing is a key tool for studying and monitoring of Amazonian lakes. Thus, it is vital to assess the effect of time delay between the acquisition of orbital data, in which the scene is registered in a few seconds and *in situ* data, whose measurements are carried out over several days, on models for estimating chlorophyll concentration (kirk, 1983).This assessment may guide the planning of new ground calibration missions by determining acceptable time delays and by informing on model´s accuracy. The objective of this work, therefore, is to assess this time delay effect. For this, an ENVISAT/MERIS image acquired concurrently to a 14 day field mission in the Amazon River floodplain lakes was used.

2. MATERIALS AND METHODS

2.1 Test site

The floodplain of Lago Grande de Curuai (LGC) was selected because its size is adequate to the MERIS 300m by 300m spatial resolution. The LGC floodplain is located in the Amazon River near Óbidos city (Brazil), 900 km upstream from the Atlantic Ocean (Fig. 1). The dynamics of flooding in LGC is related to the seasonal fluctuation of Amazon River, having an annual monomodal pattern (Junk et al., 1989) with a minimum water level, early November, and a maximum late May-early June. During the rising water stage, Amazon River water flows into the floodplain enlarging lake area from 700 km^2 to 1600 km^2 (Barbosa, 2005). The flooding dynamics in Curuai can be characterized by four stages: rising water stage, high water stage, receding water stage and low water stage. Rising and receding stages are characterized by maximum changes in water level (at rates larger 3.6 cm d^{-1}) and low and high stages are characterized by minimum changes in water level (at rates smaller than 1.2 cm d^{-1})

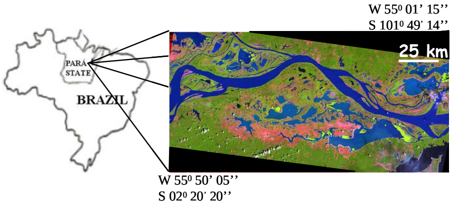

Figure 1. Test site location illustrated by a Landsat TM imagem at low water stage.

2.2 Methodology

Figure 2 summarizes the main steps adopted for this study.

Data collection: The *in situ* data gathering was carried out between June 06 and 19, 2004, during the high water stage with minimal change in the water level. The working hypothesis is that during high water stage the stability of the water level in the lake brings about stability in the aquatic system in such a way that water spectral reflectance becomes more connected to its composition. During this period water samples for determining the concentration of optically active components (chlorophyll, sediments in suspension and organic matter dissolved) were collected simultaneously with bidirectional reflectance spectra. Reflectance spectra were measured with Spectron SE-590. Seventy water samples for laboratory analysis of chlorophyll, total suspended sediment (TSS) were collected,.integrating the water column from surface to Secchi depth. The samples were kept at cool temperatures and filtered on the same day. TSS was determined based on Wetzel and Likens (1991) and chlorophyll analyses were based on Nush (1980).

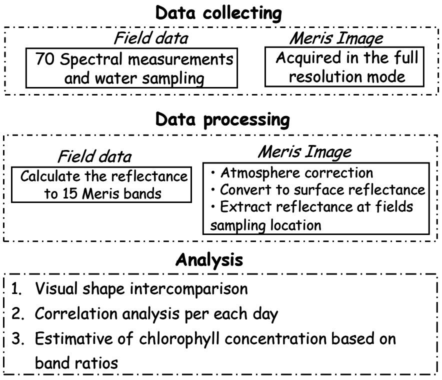

Figure 2. Summary of the methodological approach

The MERIS image with spatial resolution of 300 meters, 15 spectral bands between 400 and 900 nm and spectral resolution of 10 nm in most of the bands was acquired on June 13th, 2004. Figure 3 shows both a color composite of MERIS image and the location of the *in situ* sampling stations.

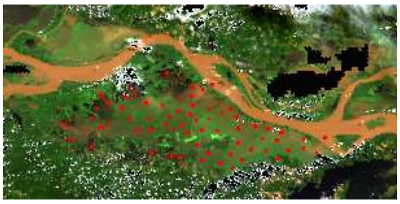

Figure 3. Color composite [Band 8 (Red), Band 5 (Green), Band 2 (blue)] of MERIS image at high water stage (2004/06/13) with red dot corresponding to *in situ* sampling stations.

MERIS image was acquired in full resolution mode (300 m) and both Level 1 and Level 2 products have been analyzed. Level 1 product contains geolocated and Top-Of-Atmosphere (TOA) calibrated radiances and information about the environmental conditions prevailing at the time and place of the acquisition provided by the European Centre for Medium-term Weather Forecast (ECMWF).

Data processing: MERIS image was atmospherically corrected using SMAC processor provided by ESA in the Basic ERS & Envisat (A) ATSR and MERIS Toolbox (BEAM). SMAC is a semi-empirical approximation of the radiative transfer in the atmosphere, which calculates surface reflectance from satellite measurements. MERIS reflectance at each *in situ* sample station was acquired for all its spectral bands. *In situ* spectra were resampled to MERIS spectral resolution to enable correlation analysis between them.

Data analysis: The first analysis consisted of comparing the shape of MERIS spectra, continuous *in situ* spectra and in-situ simulated MERIS (SimMERIS) for each sampling station, assuming that water spectral reflectance is modulated by its composition. In the second analysis the correlation between MERIS and SimMERIS reflectance spectra for each sample was computed. The correlation analysis was carried out for time delays ranging from 0 up to 6 days between ground sampling and satellite overpass. Finally, to evaluate the performance of MERIS data, regression models were generated using ratio spectral bands (infrared/red), to estimate the chlorophyll concentraion Goodin et al. 1993; Quibell, 1992; Rundquist et al., 1996).

3. RESULT AND DISCUSSION

Figure 4 shows examples of spectra in which identifiable spectral features can be observed in both MERIS and continuous *in situ* spectra. Note that apart from the intensity, both MERIS and *in situ* reflectance are very similar. Intensity difference can be explained by the uncertainty introduced by MERIS atmospheric correction and by the variability inherent to *in situ* radiometric data acquisition (Pereira Filho, 2005). The comparison of MERIS spectra and *in situ* continuous spectra highlights that MERIS band positioning matches almost perfectly the diagnostic spectral features of optically active components present in inland aquatic systems, case II water (IOCCG, 2000).

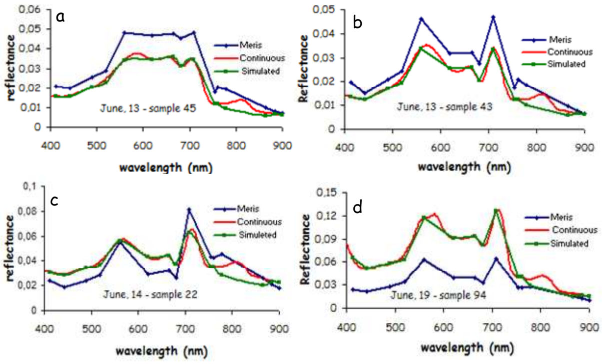

Figure 4. Examples of spectra. (a,b)satellite overpass (c) one day time delay (d) six day time delay.

Figure 5 summarizes the correlation analyses between MERIS and SimMERIS spectra for each sample. Ten sampling points were used for each day. The average correlation for zero delay (Table 1) was 0.98, with a maximum of 0.99 and a minimum of 0.97. The average correlation between MERIS and SimMERIS for time delays ranging from 1 to 6 days after the satellite overpass varied from 0.54 to 0.95.

As shown on table 1, low average correlation for 1 day time delay is explained by the occurrence of negative correlation. The data analysis shows, however, that only 2 out of 10 samples had negative values, and only 3 presented low correlation coefficient. The remaining samples showed correlation coefficients ranging from 0.70 and 0.96, with an average of 0.82. By examining the geographic position of samples displaying negative correlation, it was observed that they were located at the lake boundary, in regions of transition between open water, aquatic macrophyte stands and flooded forest. As such targets tend to present high infrared reflectance even when in sub-pixel dimensions they might have contributed to modify the spectral response of water in MERIS image. On average, for a period between 3 days before and 6 days after the satellite overpass, average correlation ranged between 0.54 and 0.95. Figure 5 shows the correlation coefficient dispersion as a function of time delay. Its analysis shows that the correlations tend to be high very close to 1, with averages exceeding 0.8.

Low correlation values represent exceptions explained by the position of the sample in regions of transition between land and open water, which contaminates the reflectance due to normal mixtures of targets in 300 meter pixels. The correlations for time delay larger than 3 days before the satellite overpass showed less consistency, with values ranging from high negative correlations and high positive correlations what indicates a probable change in lake limnological conditions.

Tabela 1. Correlation coefficient values.

day	Maximo	Mínimo	Média
-3	0.98	0.59	0.84
-2	0.99	0.88	0.95
-1	0.99	0.51	0.88
0	0.99	0.95	0.97
1	0.96	-0.30	0.54
3	0.98	0.88	0.94
6	0.99	0.87	0.95

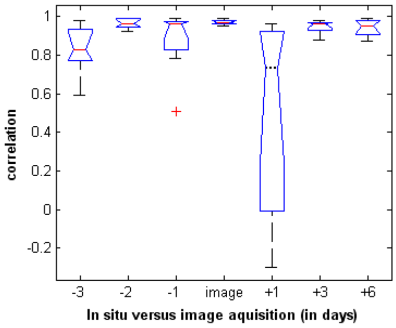

Figure 5. Box plot of correlation between MERIS and SimMERIS.

The effect of time delay between MERIS and *in situ* data was also evaluated by using empirical models to estimate the chlorophyll concentration in the water. That was carried out by selecting band ratio suggested in the literature (Goodin et al. 1993; Quibell, 1992; Rundquist et al., 1996). The band ratio (708/681) was determined for both data sets and used as input in linear regression models according two experiments: 1- for all collected data (radiometric and chlorophyll concentration); 2- for the data collected on the day of the satellite overpass. The results in Figure 6 show that in experiment 1 there is a decrease of the in R^2 from the SimMERIS ($R^2 = 0.84$) to MERIS data ($R^2 = 0.64$). These results were already expected because of the poor correlation between MERIS data and SimMERIS measured 3 days before the satellite overpass, which indicates a change in the aquatic system optical properties probably induced by winds. This optical change, however, did not interfere in the SimMERIS model accuracy because *in situ* reflectance measurements were carried out simultaneously with water sampling for chlorophyll determination. In the experiment 2 R^2 was 0.95 against 0.74. This improvement of both models is explained by the larger optical homogeneity of water masses sampled in a single day. The lower R^2 displayed by MERIS model can be explained, among other factors, by sub-pixel cloud cover and sub-pixel target mixture of macrophyte floating stands dragged by the wind, which are very common during this season.

Another factor that may explain this difference is the chlorophyll quantification method, which is based in water samples integrated from surface up to Secchi depth. *In situ* water samples are collected at the same 0.05 m^2 spectrometer foot print from which *in situ* reflectance are measured. Because of that, these chlorophyll values do not represent the phytoplankton patchiness of a pixel integrating an area of 90 x 10^3 m^2, such as MERIS. These results demonstrate that MERIS image is better than the assessed accuracy because of *in situ* data was not fit to represent within pixel variability. Therefore MERIS image is suitable for mapping the spatial chlorophyll distribution even using field data lagged of up to 9 days, provided that aquatic system optical properties remain constant.

In order to have a better assessment of MERIS accuracy new *in situ* data collection are being planned.

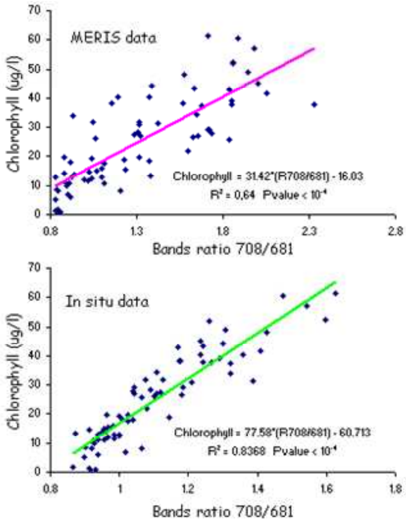

Figure 6. Relationship between chlorophyll and band ratio for all MERIS and *in situ* collected data.

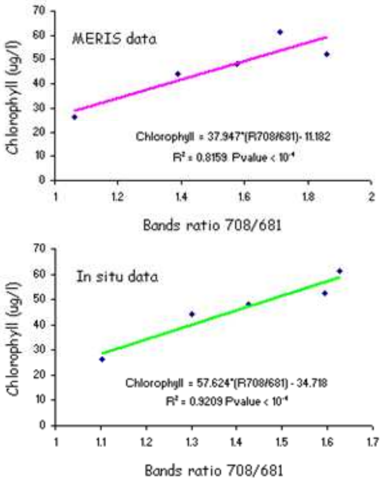

Figure 3. Relationship between chlorophyll and band ratio for data collected on the satellite overpass day.

4. CONCLUSIONS

The results show that in spite of the 300 by 300 m resolution, MERIS sensor can be efficiently applied to estimate chlorophyll concentration in Amazon floodplain lakes, case II waters. MERIS model accuracy, however, is not as high as SimMERIS not only because of the time delay but also *in situ* reflectance failed to represent phytoplankton patchiness. There is an excellent match between MERIS spectra and both *in situ* continuous spectra and SimMERIS spectra in spite of the intensity difference. These intensity differences might have affected model accuracy assessment and can be overcome by using spectral angle mapping approaches such as SAM (Spectral Angles Mapper), which is not sensitive to it.

Model accuracy is also affected by aquatic system optical property stability during *in situ* data acquisition. Provided that optical conditions did not change, time delay between *in situ* sampling and satellite overpass is not a critical constraint to model development. That is an important aspect in acquiring samples to calibrate images for large aquatic systems where the entire variability of the area cannot be precisely represented by samples collected in a single day.

REFERENCES

References from Journals

Goodin, D. G.; Han, L.; Fraser, R. N.; Rundquist, C.; Stebbins, W. A.; Schalles, J. F. Analysis of suspended solids in water using remotely sensed high resolution derivative spectra photogram. Eng. Remote Sensing, v. 59, n.4, p. 505-510, 1993.

Hess, L. L., Melack, J. M., Novo, E. M. L. M., Barbosa, C. C. F., & Gastil, M. Dual-season mapping of wetland inundation and vegetation for the central Amazon basin. Remote Sensing of Environment, 87, 404−428. 2003.

Junk WJ, Bayley PB, Sparks RE The flood-pulse concept in river – floodplain systems, in Proceedings of the International Large River Symposium, edited by D. P. Dodge, pp. 110-127, Can. Spec. Publ. Fish. Aquat. Sci. 106, National Research Council of Canada, Ottawa, Ontario. (1989)

Junk WJ, ed. (1997) The Central Amazon Floodplain. Springer, Berlin.

Kirk, J.T.O Light & Photosynthesis in Aquatic Ecosystems, London, Cambridge University Press,1983

Mobley, C. D. Light and Water: Radiative Transfer in Natural Waters. San Diego. Academic Press. 1994

Novo, E.M.L.M.; Barbosa, C.C.F.; Freitas, R.M.; Shimabukuro, Y.E.; Melack, J.M.; Pereira Filho, W. 2006. Seasonal changes in chlorophyll distribution in Amazon floodplain lakes derived from MODIS images. Limnology, 7(3): 153-161.

Nush EA Comparison of different methods for chlorophyll and phaeopigment determination. Arch. Hydrobiol. Beih. Stuttgart, pp 14-39 (1980)

Quibell, G. Estimating chlorophyll concentrations using upwelling radiance from different freshwater algal genera. International Journal of Remote Sensing, v.13, n.14, p. 2611-2621, 1992.

Rundquist, D. C.; Han, L.; Schalles, J. F.; Peake, J. S. Remote measurement of algal chlorophyll in surface waters: the case for the first derivative of reflectance near 690 nm. Photogrammetric Engineering and Remote Sensing, v.62, n.2, p.195-200, 1996.

Rudorff, C. M., Novo, E. L.. M., Galvão, L.. S., Pereira Filho, W. Análise derivativa de dados hiperespectrais medidos em nível de campo e orbital para caracterizar a composição de águas opticamente complexas na Amazônia. Acta Amazonica. Vol. 37, 2, pp. 269-280, 2007.

IOCCG (2000). Remote Sensing of Ocean Colour in Coastal, and Other Optically-Complex Waters. Reports of the International Ocean Colour Coordinating Group, Sathyendranath, S. (ed.), No. 3, IOCCG, Dartmouth, Canada.

Wetzel RG, Likens GE Limnological Analyses, 2nd Ed., Springer-Verlag, New York (1991)

References from Websites

Barbosa CCF (2005) Sensoriamento remoto da dinâmica de circulação da água do sistema planície de Curuaí/Rio Amazonas. PhD Thesis, National Institute for Space Research (INPE), São José dos Campos, Brazil (http://mtc-m18.sid.inpe.br/col/sid.inpe.br/MTC-m13@80/2006/02.22.15.03/doc/publicacao.pdf).

Pereira Filho, W. ; Barbosa, C. C. F.; Novo, E.M.L.M. Influência das condições do tempo em espectros de refletância da água. In: Simpósio Brasileiro de Sensoriamento Remoto,12, Goiânia. http://marte.dpi.inpe.br/col/ltid.inpe.br/sbsr/2004/11.21.20.51/doc/415.pdf (2005)

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