Workshop
Hydrological Optics :
Measurements and Modelling

Convidado Externo – Emmanuel Boss – University of Maine

Projeto: FAPESP 2015/19653-0

Organizado pelo

Laboratório de Instrumentação de Sistemas Aquáticos (LabISA) – INPE/OBT

19 e 20 de abril de 2016

10 às 18:00 horas

Auditório do Instituto Interamericano para Pesquisas em Mudanças Globais - IAI

Auditório José Simeão de Medeiros – LabGeo

Sala 27 - Prédio Asa

Instituto Nacional de Pesquisas Espaciais - INPE

São José dos Campos - SP

Participantes

Apoio Financeiro

Workshop

Hydrological Optics: Measurements and Modelling

Characterization of bio-optical properties of reservoir waters along the cascade of Tietê River (SP): Barra Bonita and Nova Avanhandava

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April, 2016
INPE – São José dos Campos, SP - Brazil

Contextualization

Freshwater Systems

ECOLOGICAL SERVICES

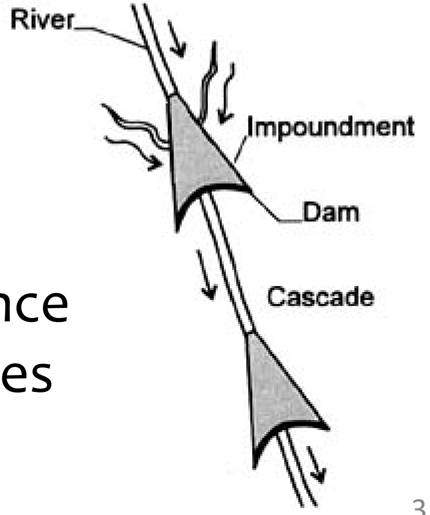
- Climate moderation
- Nutrient cycling
- Waste treatment and dilution
- Flood control
- Groundwater recharge
- Habitats for aquatic and terrestrial species
- Genetic resources and biodiversity
- Scientific information

ECONOMIC SERVICES

- Food
- Drinking water
- Irrigation water
- Hydroelectricity
- Transportation corridors
- Recreation
- Employment

- Hydrologic cycle, and its economic, social and environmental importance;
- Power generation in urban, industrial and agricultural contexts.

- Many rivers have been transformed into reservoirs and utilized in the **cascade system**



Series of reservoirs aligned in sequence along the main river and its tributaries

Thornton et al. (1996)

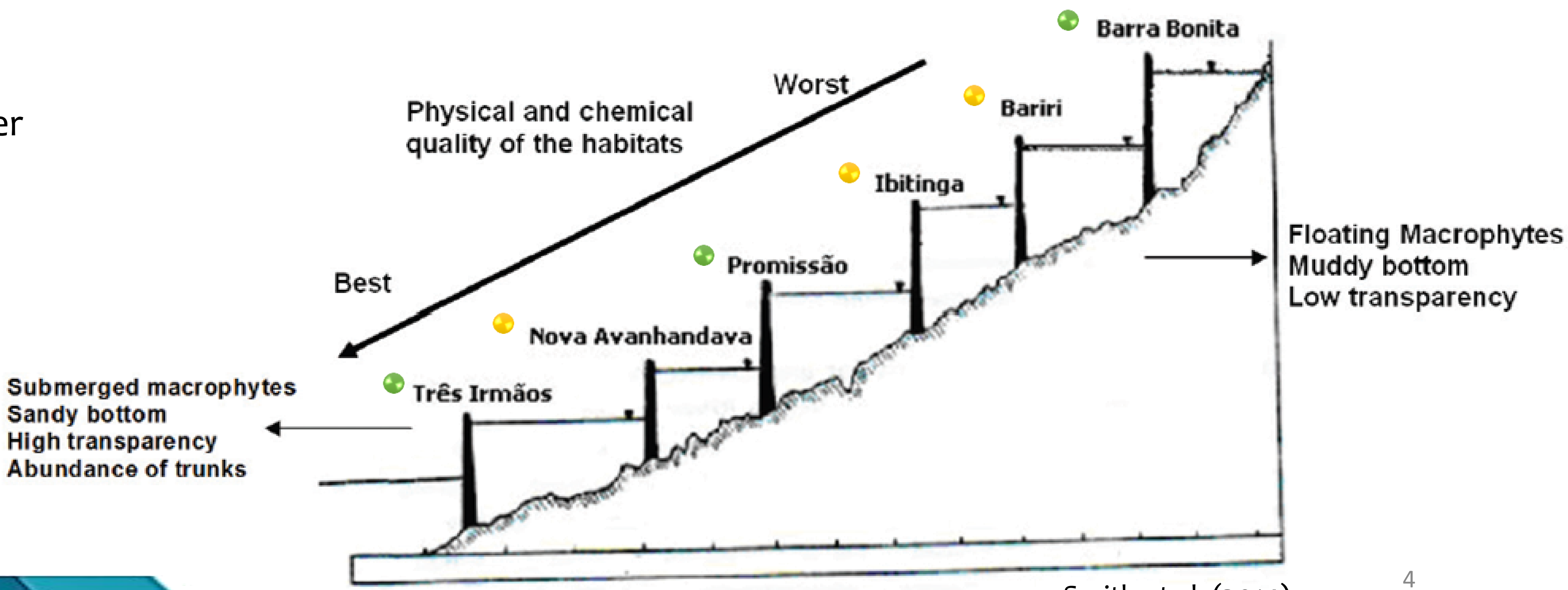
Contextualization

- Impacts
  - The interruption of continuous river gradient for reservoirs construction on this continent has caused several hydrological and structural alterations in the rivers habitat, resulting in new organization of the aquatic communities;

Storage

Run-of-river

MEDIUM AND LOW TIETÊ SYSTEM



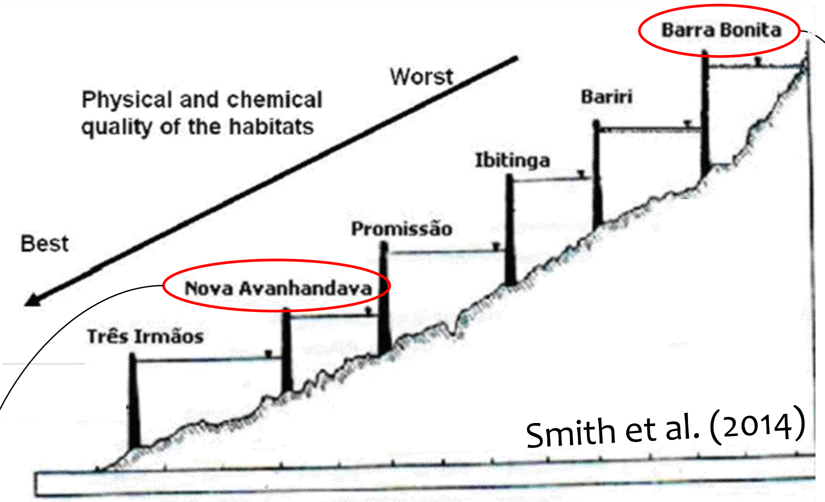
Smith et al. (2014)

Contextualization

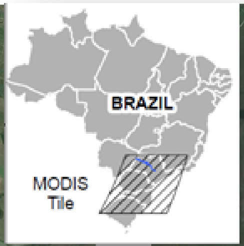
- Tietê River (~1150 km) is faced with various sources of pollution (agriculture, pasture and urban centers), damming and loss of riparian vegetation along its course.

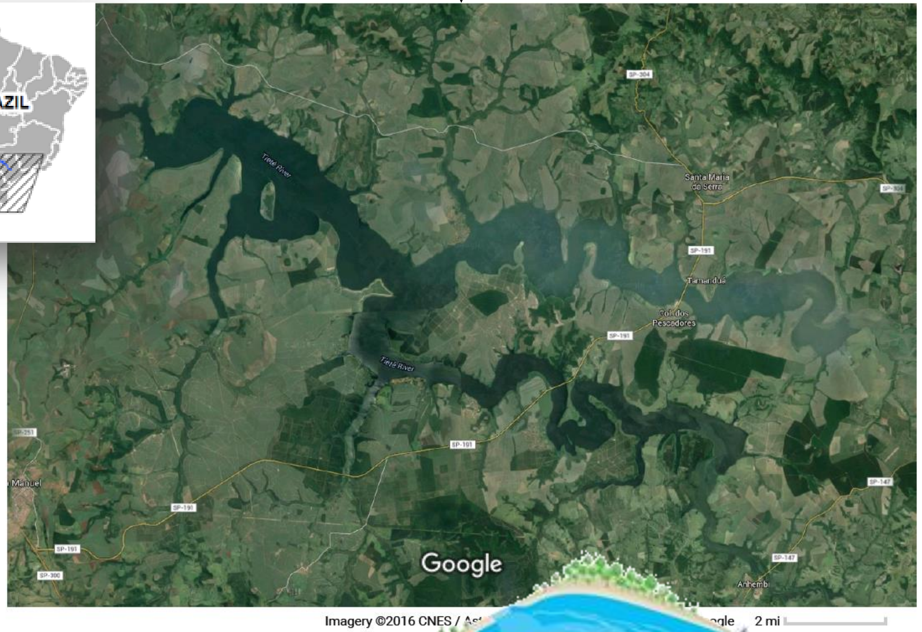
Study Area

- Oligo-mesotrophic
- Downstream
- 5th reservoir of the cascade
- Emerged Macrophytes

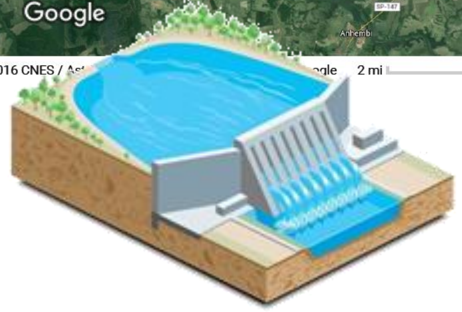


- Eutrophic
- Closed to MRSP
- 1st reservoir of the cascade
- Floating Macrophytes





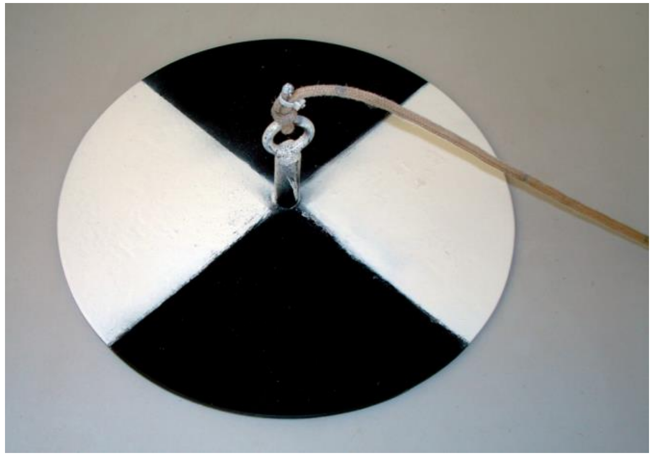
Run-of-river
Nova Avanhandava



Storage System
Barra Bonita

Contextualization

- Studies about water quality in a cascade system in Brazil.
  - Limnology Approach: physical, chemical and biological characteristics (BARBOSA *et al.*, 1999; MAIA *et al*, 2008; MOURA *et al*, 2013).



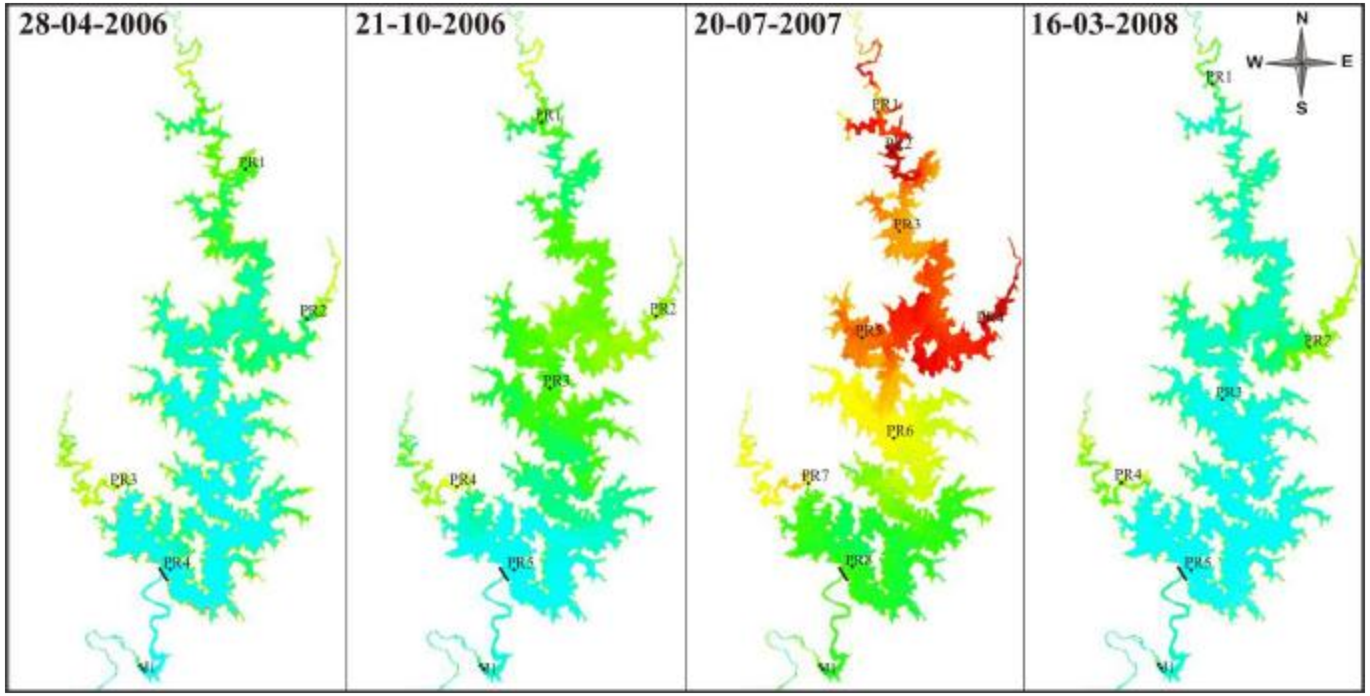
Contextualization

- Studies about water quality in a cascade system in Brazil.
  - Remote Sensing Approach: spectral Information (WACHHOLZ *et al*, 2009; PEREIRA FILHO *et al.*, 2009) .
  - Bio-optical Approach

In-Water constituents

Optical properties

Suspended solids
Dissolved organic matter
Phytoplankton (pigments)



Landsat 5/TM

WACHHOLZ *et al*, 2009

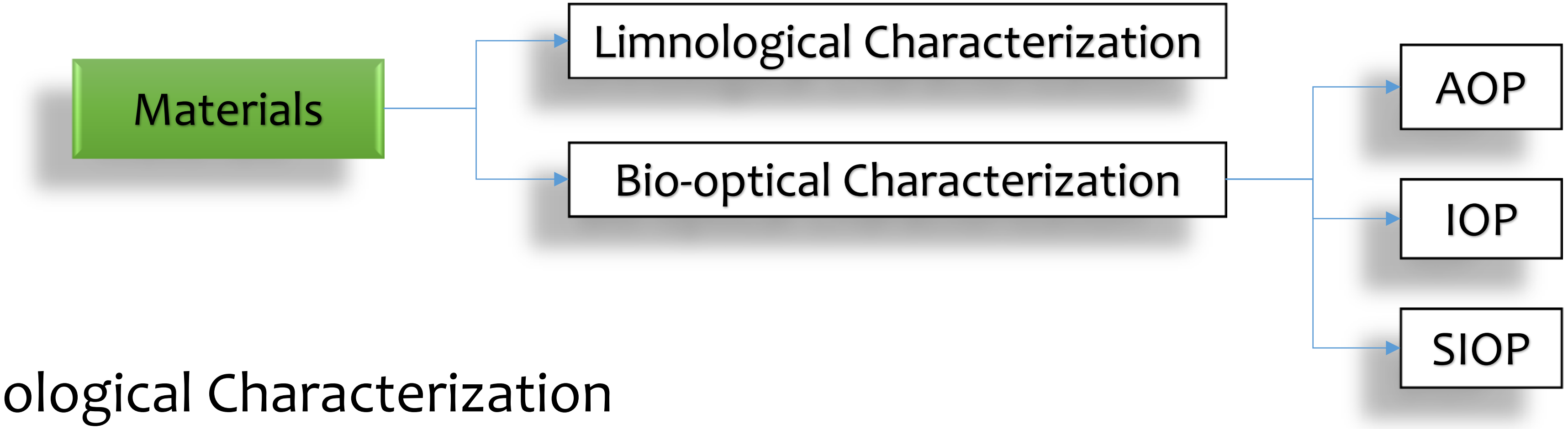
Questions

- Do the Optical Properties change along the cascade system? Based on this, can we use a single bio-optical model to estimate the OACs in both reservoirs ?

Objectives

- To characterize two reservoirs located at the Tietê river cascade system, emphasizing differences in the optical properties by means of *in situ* measurements. For this, the following specific objectives are:
  - To compare the bio-optical characteristics of both reservoirs.;
  - To analyze the performance of a single approach to estimate TSS concentration in both reservoir.

Materials

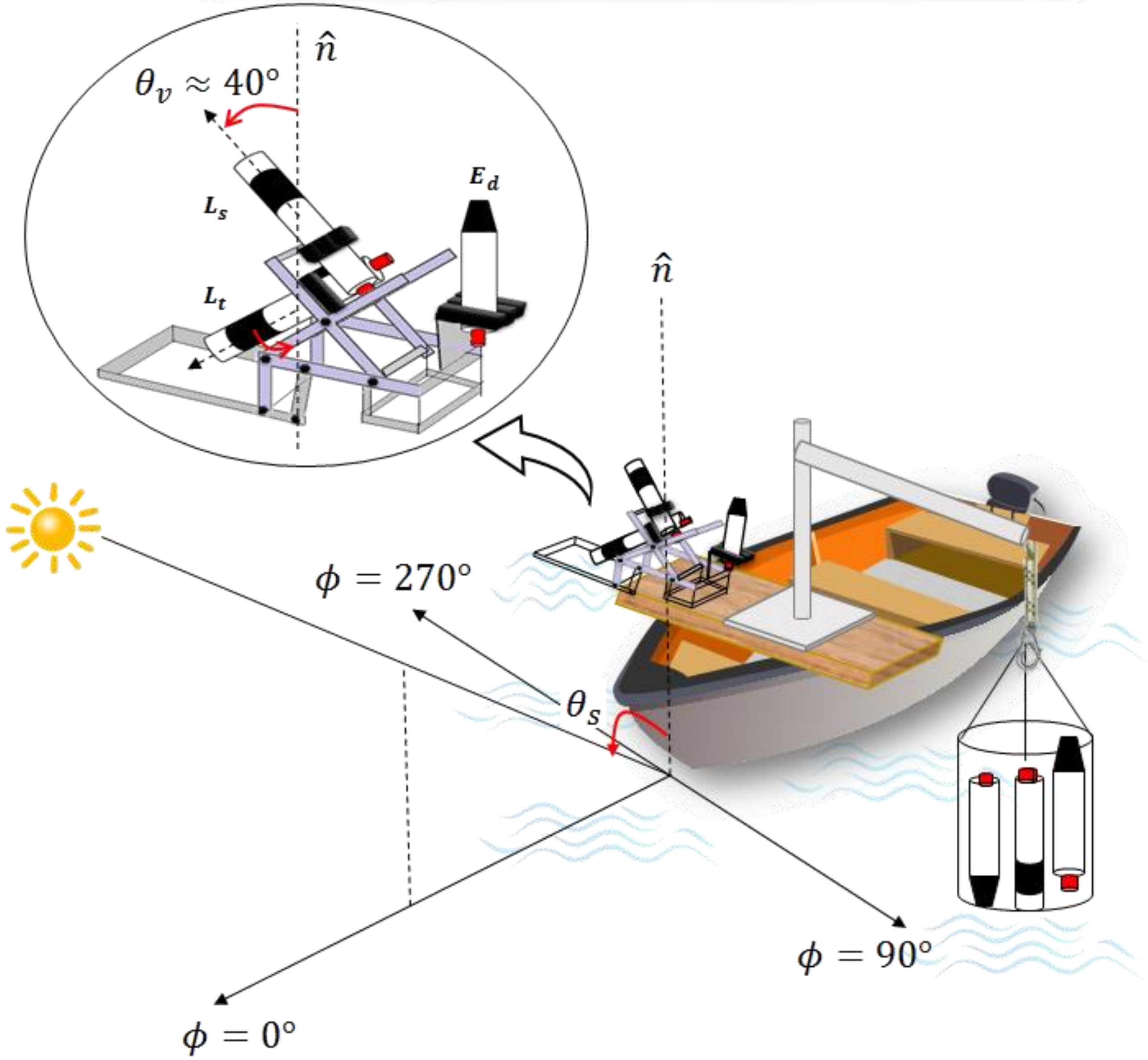


- Limnological Characterization
  - Transparency → Sechhi Depth
  - Turbidity by a portable turbidimeter (Model Hanna HI 93414)
  - Dissolved Oxygen by a portable meter (Model Hanna HI 9146-04)
  - Water samples (stored and refrigerated for laboratory analysis)

[DOC]
[Chl-*a*]
[TSM]
[N, P]

Materials

- Bio-optical Characterization
  - AOP → RAMSES-ARC (radiance sensors) and RAMSES-ACC (irradiance sensors) spectroradiometers manufactured by TriOS, with 320-950 nm spectral range.



Surface

Materials

- Bio-optical Characterization
  - IOP → The specific inherent optical properties were measured by the Shimadzu UV-VIS 2600 double beam.

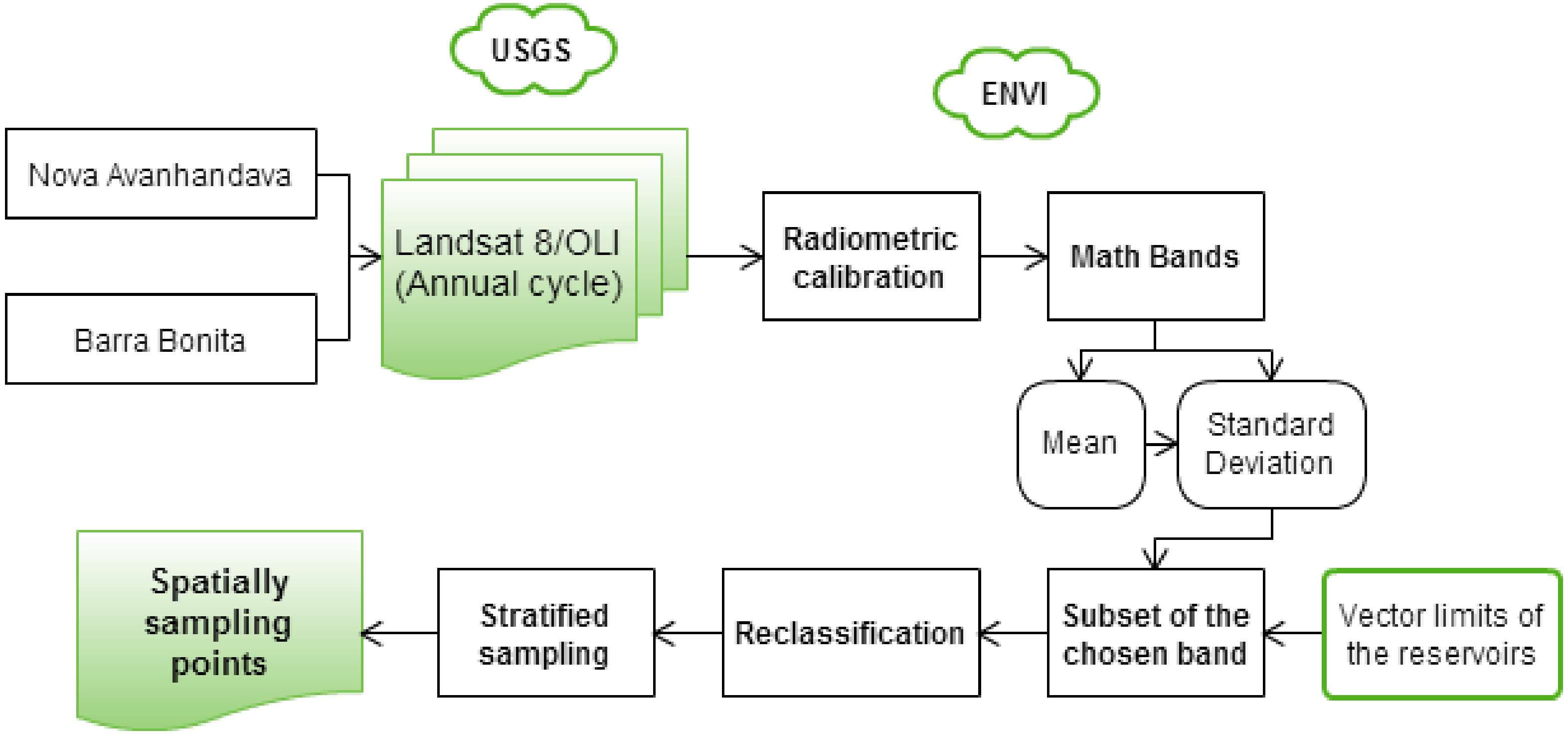
Methods

- Planning field campaigns
  - Fieldwork occurred in two periods of the year, the first coinciding with the beginning of the dry season (April and May 2014) and the other in the end of the dry season (October 2014 and September 2015).
  - A new field campaign will be carried out in May 2016.

Methods

- Sampling design

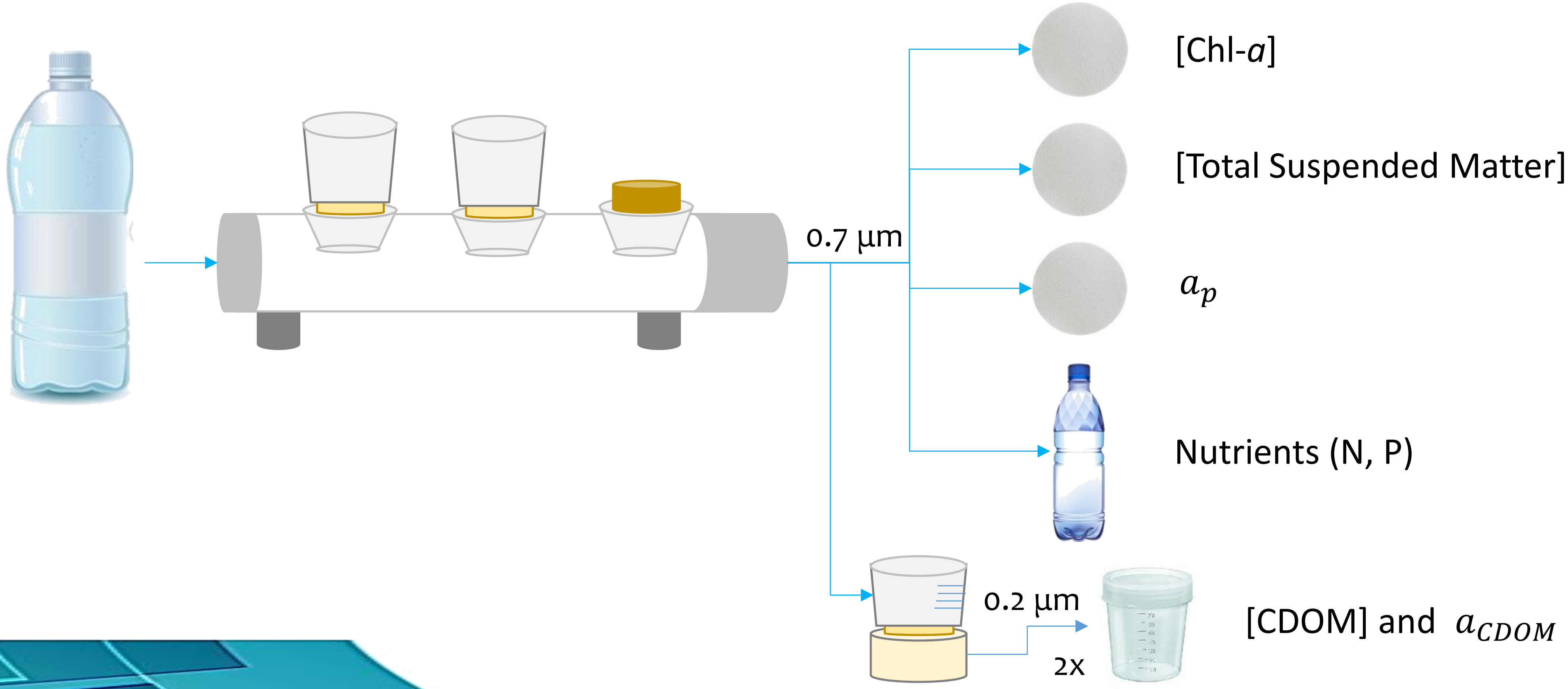
- As a result, regions with similar statistical and spectral characteristics were defined and, using Hawth's Tools compatible with ArcGIS Software 10.x, field samples were chosen.



Methodological scheme for defining the sample points

Methods

- Data acquisition
  - Limnological characterization
    - Based on the exploratory knowledge of the study areas, it was necessary to collect 5L of water to Nova Avanhandava and 1L to Barra Bonita.



Methods

- Data acquisition
  - Bio-optical characterization
  - AOP
    - The radiometric data collected with spectroradiometers followed the protocols established by Mueller (2000) and Mobley (1999).
    - For each sample spot, measures were taken at the surface, subsurface and at depth.
    - The time for each sample was calculated according to the number of measurements to be obtained.
  - IOP
    - Waters samples were collected in the field and then analyzed in laboratory to retrieve the IOPs.

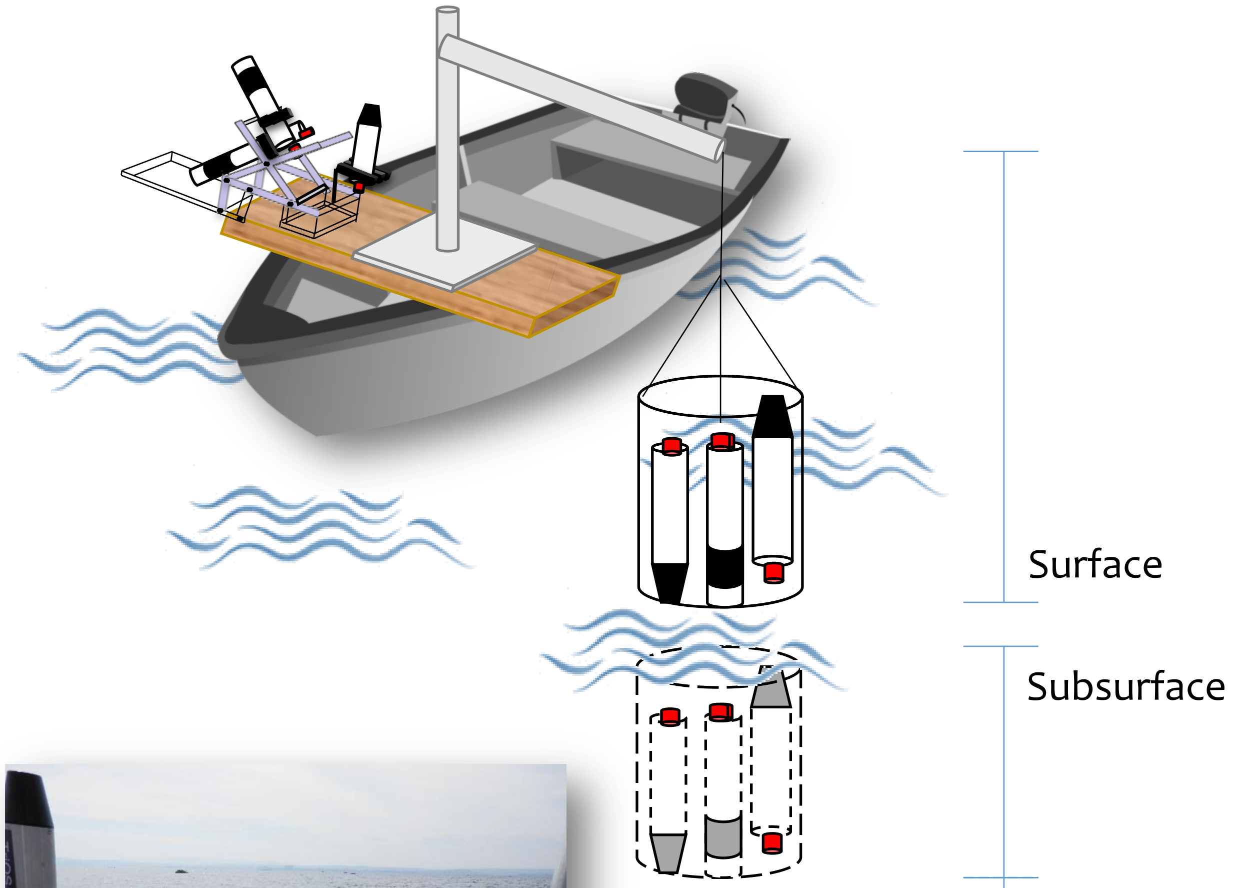
Methods

- Data Processing
  - Limnological characterization

Chl-*a* *(filter)* →	Spectrophotometry (663 and 750 nm)	Golterman et al. (1978) 90% acetone
TSM *(filter)* →	Drying and weighing	APHA (1998)
CDOM *(water)* →	Chemical Analysis (Analytical Method)	Analytical quantification method based on the working principle of the Shimadzu 5000 TOC analyzer.

Methods

- Data Processing
  - Bio-optical characterization
  - AOP
    - 15 measures for each depth;
    - The representative curve is based on the median curve (FERREIRA, 2014).
    - The radiance and irradiance sensors have different intervals, so the measures were interpolated with 1nm between 350 – 950 nm.
    - Normalization of below-surface measures by surface irradiance.
    - Estimation of R_{rs}.

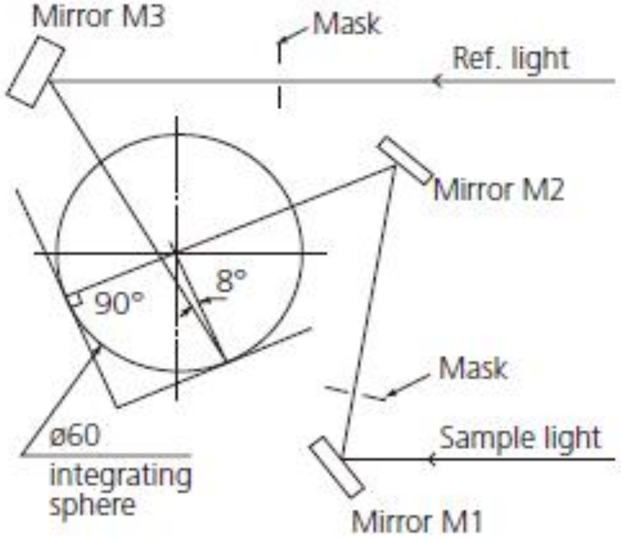


Methods

- Data Processing
  - Bio-optical characterization
  - IOP

$$a(\lambda) = a_{TR}(\lambda) + a_{\phi}(\lambda) + a_{CDOM}(\lambda) + a_w(\lambda)$$

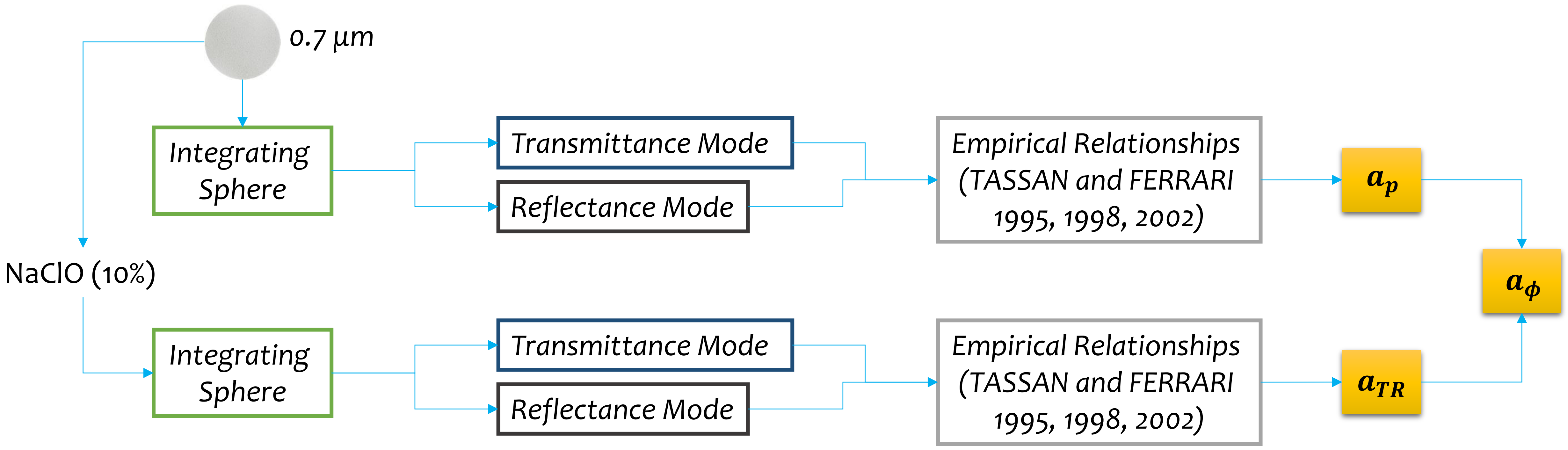
- The determination of the total particulate absorption coefficient ($a_p(\lambda) = a_{TR}(\lambda) + a_{\phi}(\lambda)$) was determined using an integrating sphere.



280 nm to 800 nm and spectral sampling of 1 nm

Top view of the integrating sphere model ISR-2600 Shimadzu.

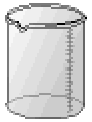
Methods



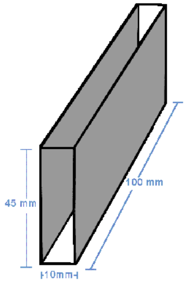
Buiteveld (1995) $\rightarrow C_{tripton} = C_{TSM} - 0.07 \times C_{Chla}$

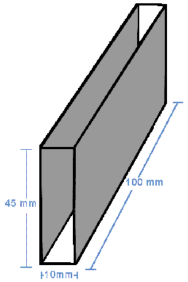
- The fit of the model is performed between 380 and 730 nm, excluding the interval between 400-480 nm and 620-710 nm, in order to avoid any waste related to absorption by some type of pigment that may have remained after depigmentation by hypochlorite (BABIN et al., 2003).

Methods



0.2 µm





Quartz cuvettes
(r = 100 mm)

Long-Path Rectangular Cell Holder

Absorbance Mode
$DO_{sample}, DO_{reference}$

$\boldsymbol{a_{CDOM}}$

$$a_{CDOM}(\lambda) = 2.303\frac{DO_{sample}}{r} = 2.303\frac{DO_{sample}}{0.1}(m^{-1})$$

- The CDOM specific absorption spectrum (a^*_{CDOM}) was adjusted by the model presented by Bricaud et al. (1981).

$$a_{CDOM}(\lambda) = \hat{a}_{CDOM}(\lambda_0)e^{(-S_{CDOM}(\lambda-\lambda_0))}$$

Tilstone et al. (2002)

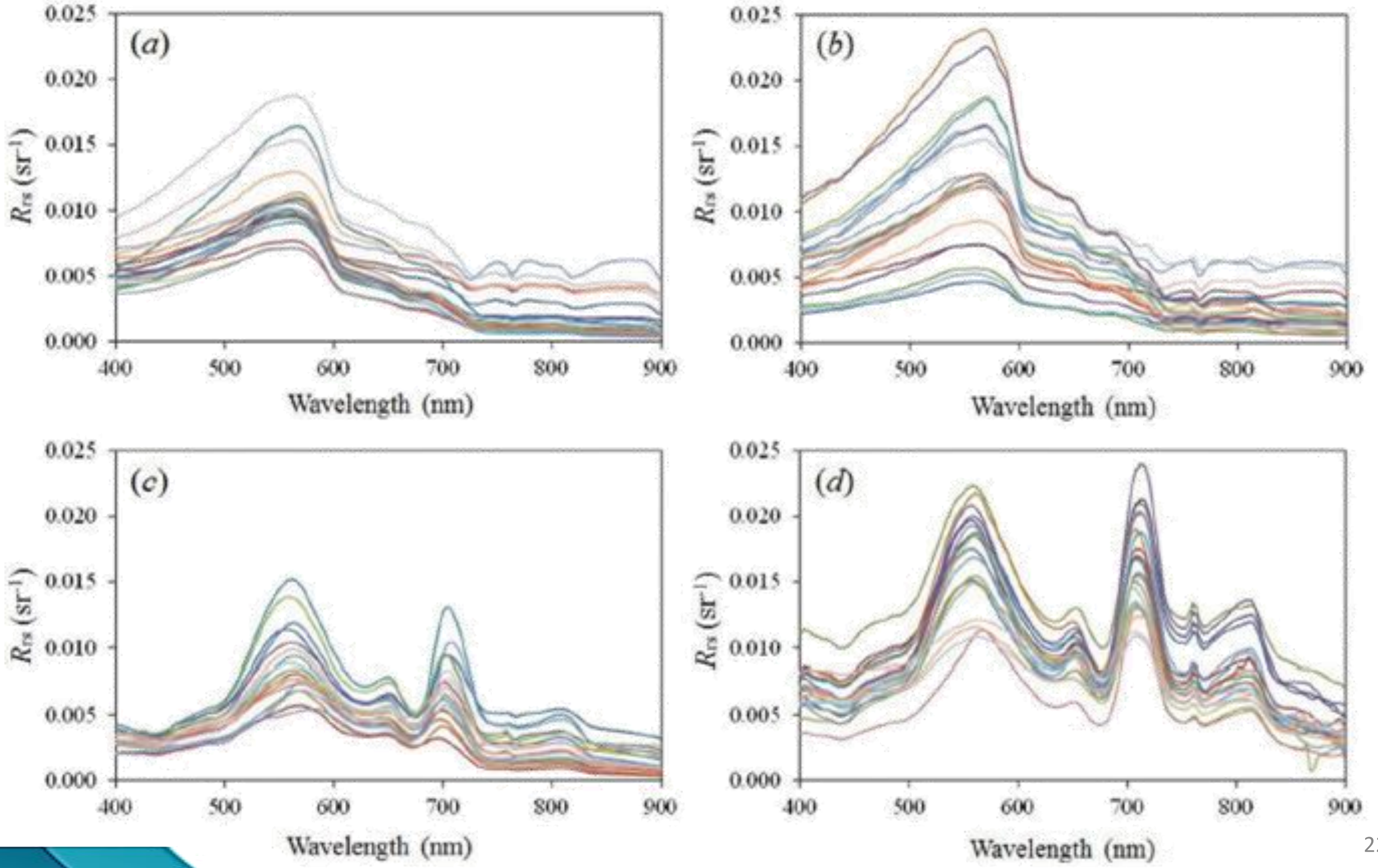
Results (1st Goal)

1st Field Campaign

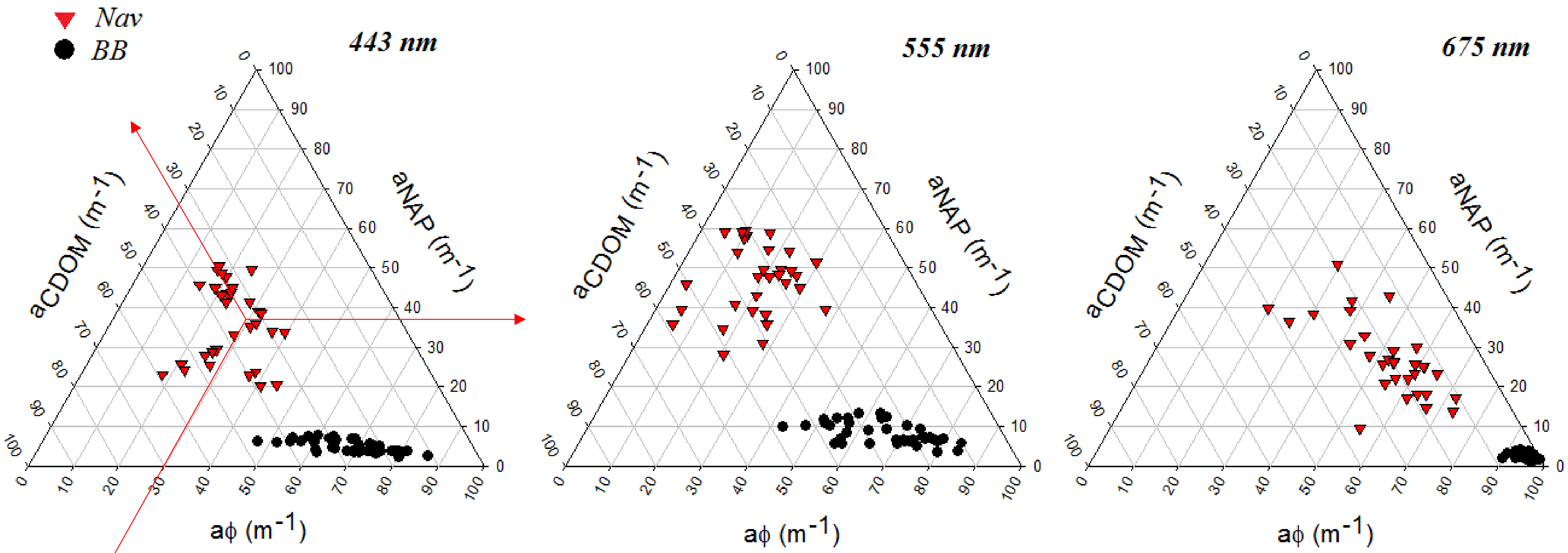
2nd Field Campaign

NAV

BB



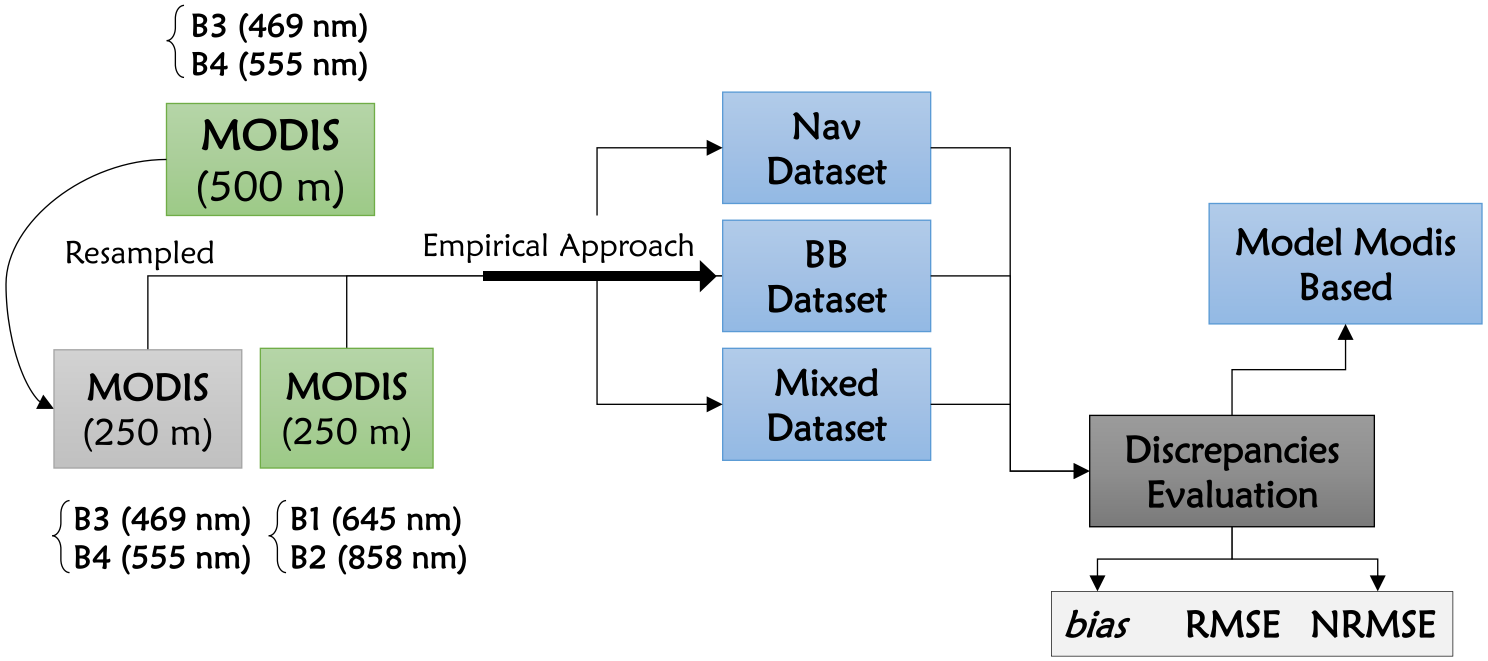
Results (1st Goal)



Nav	$a_{CDOM} \rightarrow$ 37.36 %	$a_{NAP} \rightarrow$ 46.78 %	$a_{\phi} \rightarrow$ 52.08 %
BB	$a_{\phi} \rightarrow$ 68.19 %	$a_{\phi} \rightarrow$ 66.76 %	$a_{\phi} \rightarrow$ 95.37 %

Methods

- 2nd Goal



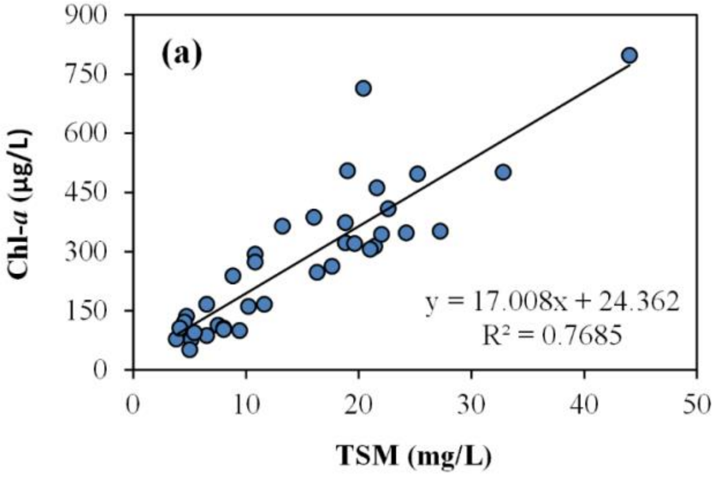
Data Collected → 1FC (Autumn) (20 samples); 2FC (Spring) (20 samples)

- Limnological variables (TSM, Chl-*a*)
- Radiometric measures (Spectroradiometers from TriOS)
- MODIS images (MOD09Q1 – 8days composite)

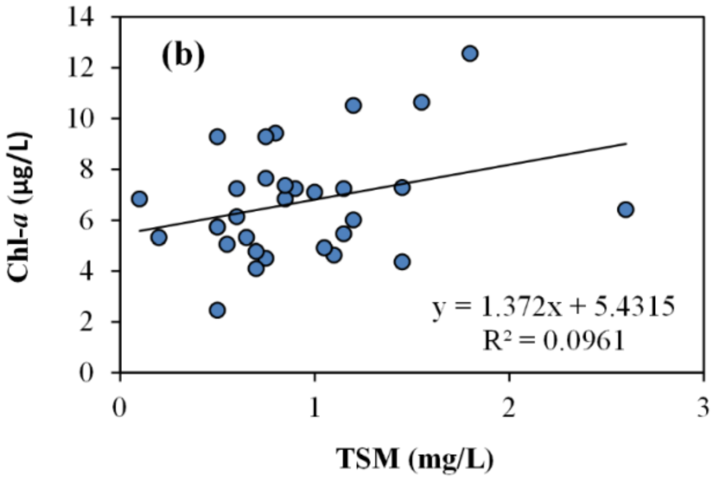
Results

		Nav (1FC)	Nav (2FC)	BB (1FC)	BB (2FC)
Chl-*a* (µg l^{-1})	Min - Max	2.46 – 12.56	4.51 – 9.42	51.33 – 293.24	263.2 – 797.8
	Mean	6.48	6.94	133.96	413.2
	SD	2.52	1.59	62.65	138.01
TSM (mg l^{-1})	Min - Max	0.10 – 2.60	0.50 – 1.20	3.80 – 16.30	10.80 – 44.00
	Mean	1.01	0.81	7.40	21.91
	SD	0.62	0.20	3.15	7.04
Chl-*a*:TSM (µg/mg)	Min - Max	2.47 - 68.26	4.75 - 18.57	10.27 - 28.81	12.93 - 34.99
	Mean	11.49	9.18	18.84	19.56
	SD	15.63	3.66	6.18	5.65

BB



Nav



Nav
(Autumn 2014)

BB
(Autumn 2014)

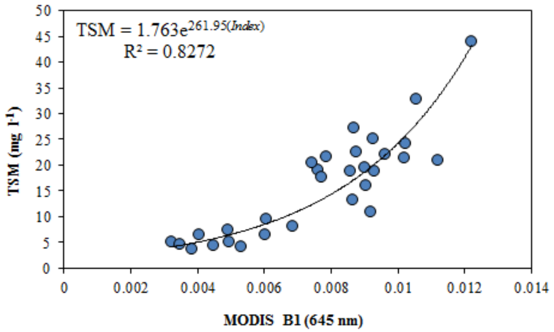
Results

TSM algorithm calibration

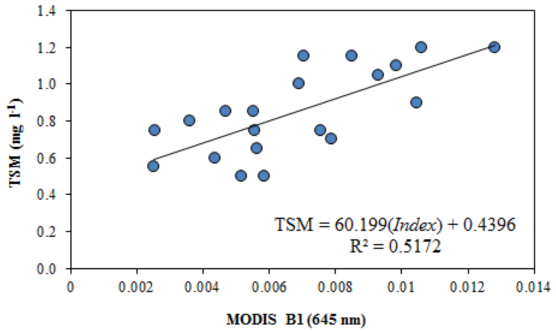
Study Site	Model (χ)	Model Fit	R^2	*p*-value*	*n*
BB	B1	y = 1.763 * exp(261.95 * b1)	0.83	<0.0001	30
		y = 68056 * b1 ^ 1.735	0.82	<0.0001	
		y = 264559x2 - 423.54x + 2.3818	0.78	<0.0001	
		y = 3445.6x - 10.196	0.75	<0.0001	
Nav	B1	y = 60.199x + 0.4396	0.51	0.0004	20
		y = 1952.8x2 + 31.708x + 0.5285	0.52	0.002	
Mixed Data	B1/B3	Log10[TSS] = -4.4239x2 + 11.176x - 5.9308	0.76	<0.0001	50
		Log10[TSS] = 1.9701ln(x) + 0.5732	0.69	<0.0001	
		Log10[TSS] = 1.8876x - 1.3814	0.64	<0.0001	

*A significance level of 5%.

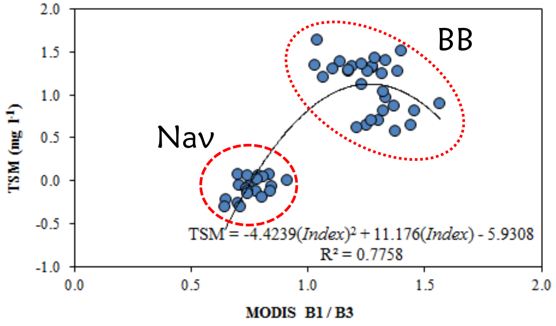
BB



Nav



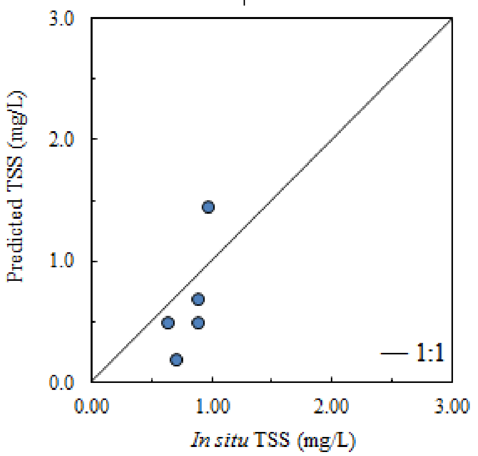
Mixed Data

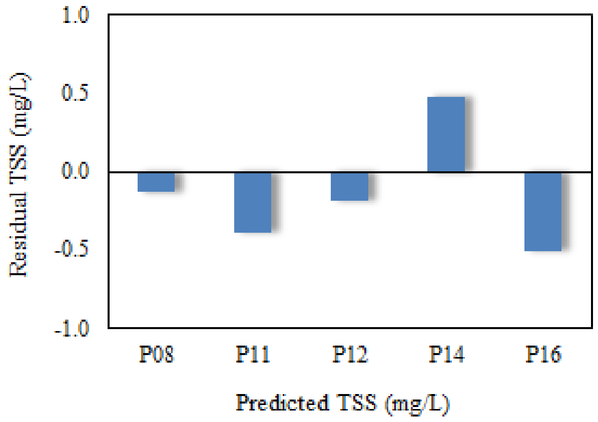


Results

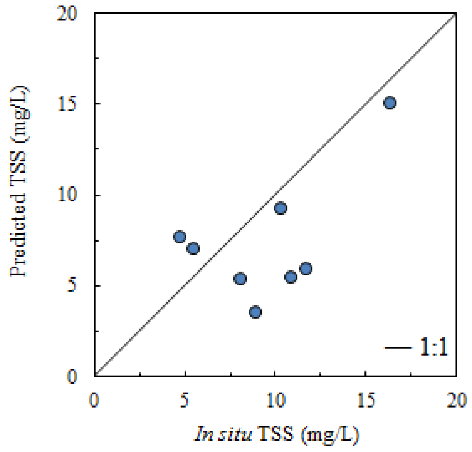
TSM algorithm validation

Study Site	Model (χ)	RMSE (mg/L)	NRMSE (%)	Bias (mg/L)	*n*
BB	B1 Exponential	3.66	31.54	-1.98	8
	B1 Power	3.98	34.28	-1.64	
	B1 Quadratic	3.77	32.53	-1.52	
	B1 Linear	5.08	43.81	-1.74	
Nav	B1 Linear	0.37	29.43	0.14	5
	B1 Quadratic	0.37	29.48	0.14	
Mixed Data	B1/B3 Quadratic	6.46	40.14	1.45	13
	B1/B3 Log	5.48	34.04	1.81	
	B1/B3 Linear	64.70	401.89	15.77	

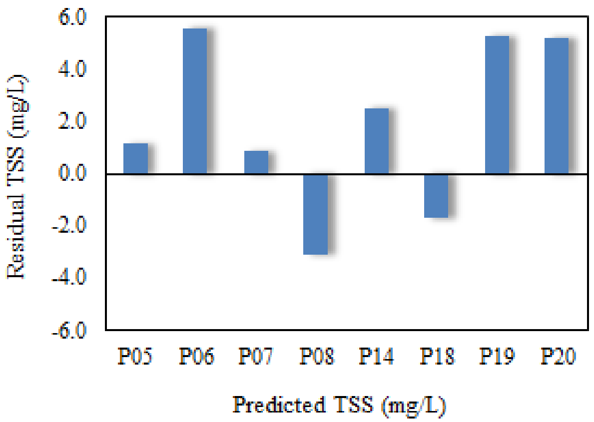




Nav



BB



Final considerations

- The optical properties from both reservoirs showed to be different leading to the inefficiency of one single model using mixed data from both reservoirs to retrieve TSM concentration.

- Semi-analytical approaches must be carried out in order to test the suitability of one single model to study optically different environments.

- Highlight and correlate the driving forces that are leading to the bio-optical differences between both reservoirs.

Acknowledgment

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Científico e Tecnológico

FAPESP