LabISA - Instrumentation Laboratory for Aquatic Systems and Brazilian inland water bio-optical dataset

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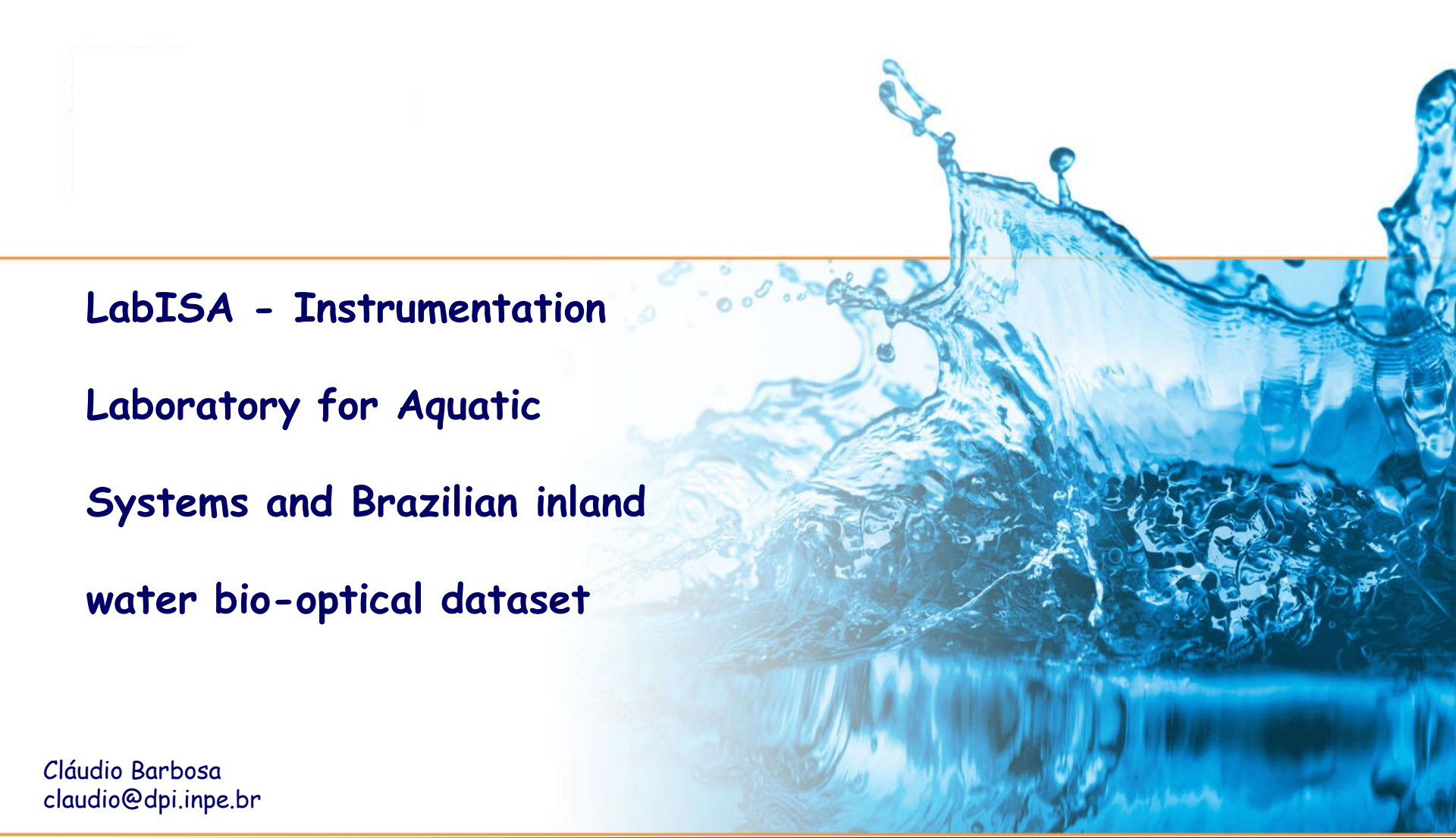


Earth Observation General Coordination - OBT

Brazilian inland water-
UMASS- September 2015

Remote Sensing of inland waters research group

The history timeline activities (two periods)

- Above water measurements & empirical algorithms (2001-2010)
  - *Focused* in the seasonal dynamics of volume and water composition in the Amazon floodplain lakes.

- Water column profiles measurements & semi analytical algorithms
  - *Focused* in bio-optics characterization and the seasonal dynamics of bio-optics properties

First period: Above water measurements (2001-2010)

In 2001, we began studies focused on the development of methodologies integrating remote sensing data, spectroradiometric data and empirical algorithms to understand the dynamics of water circulation in the Amazon floodplain lakes.

*Up to 2007 nearly 10 field campaigns measuring **above water** reflectance, limnological variables as well as bathymetry of some lakes*

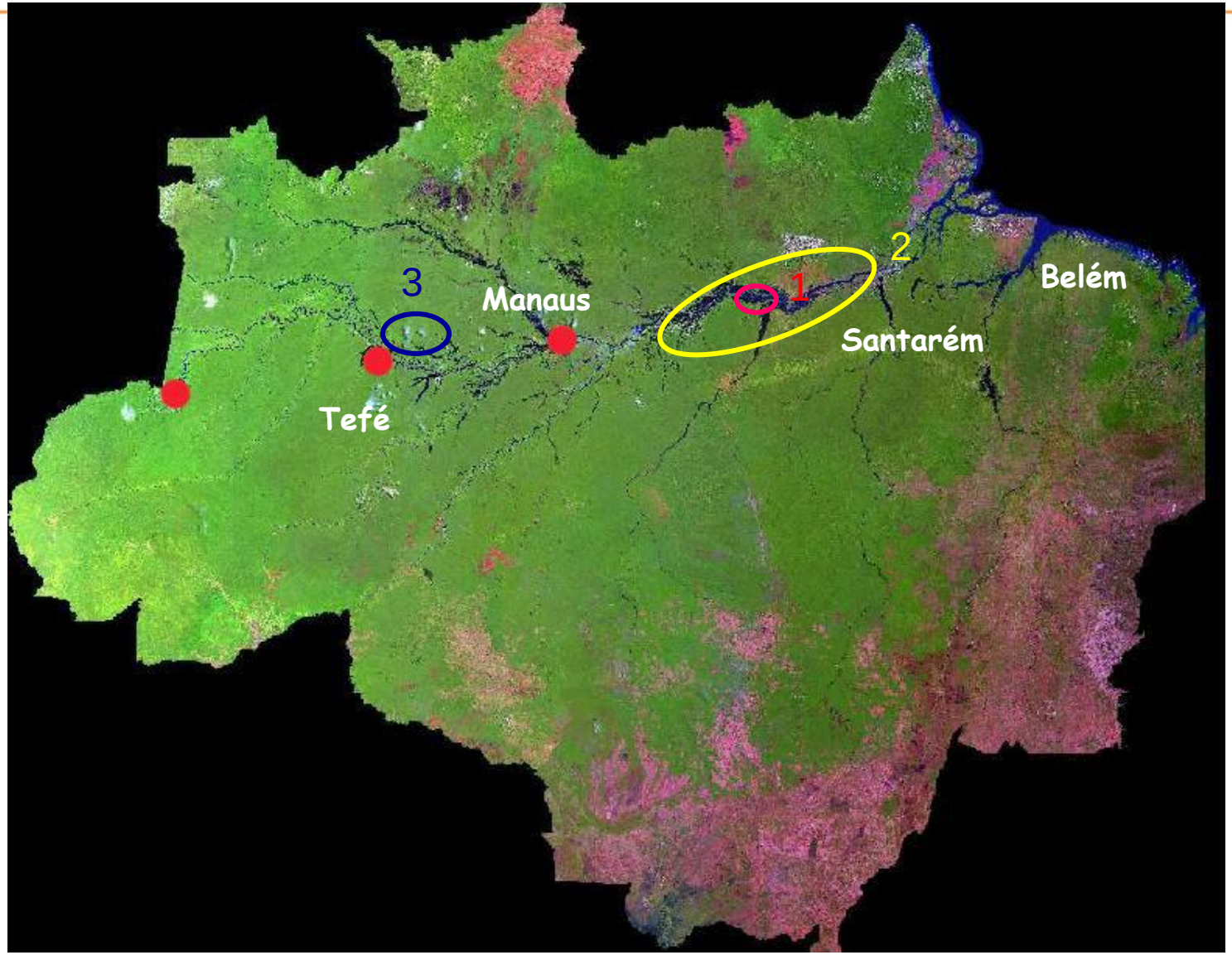
After 2007 we also started to make measurements in hydroelectric reservoirs.

Built a database integrating all available radiometric and limnological data.

2001 to 2010

Above water measurements in the amazon floodplain Lakes

Study sites in the Amazon floodplain (three sites)

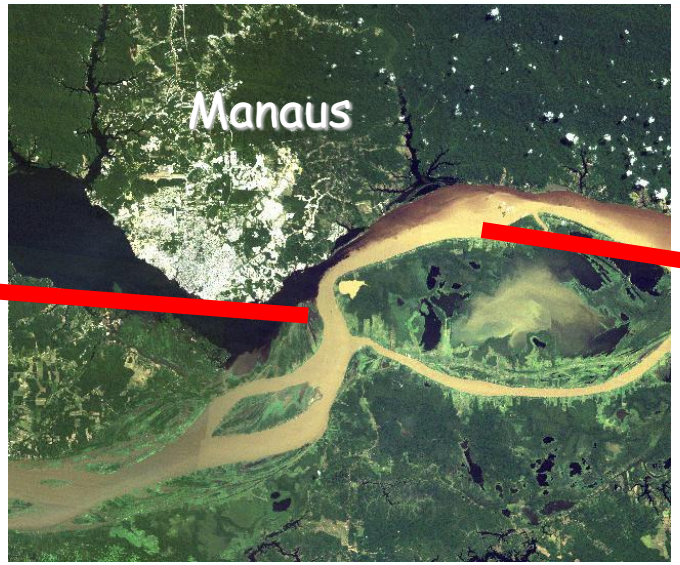


Site 1 ➔ 900 km upstream from the Amazon River mouth.

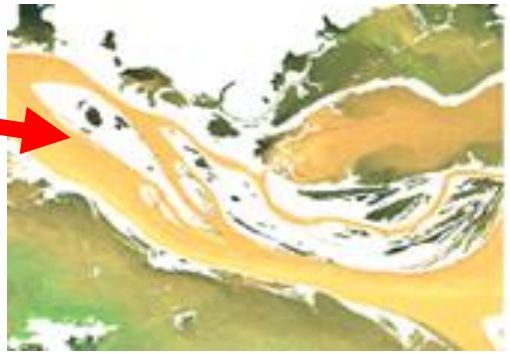
Diversity of Amazonian water types

Black water (Negro River)

Organic dissolved matter



White water (Amazon River)



High inorganic matter

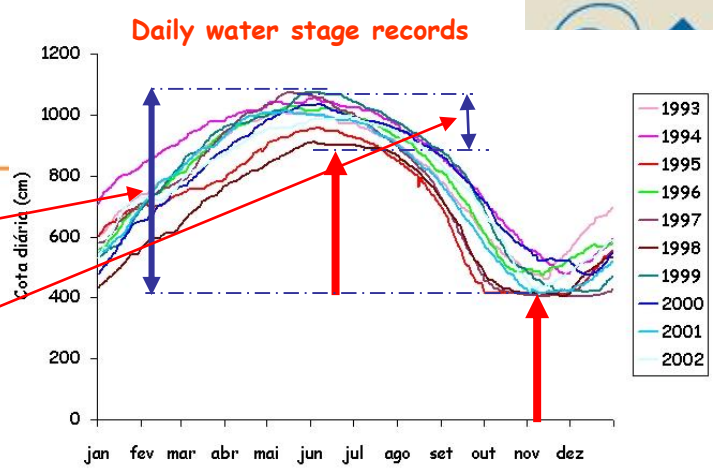
Chlorophyll concentration 500-800μg/liter

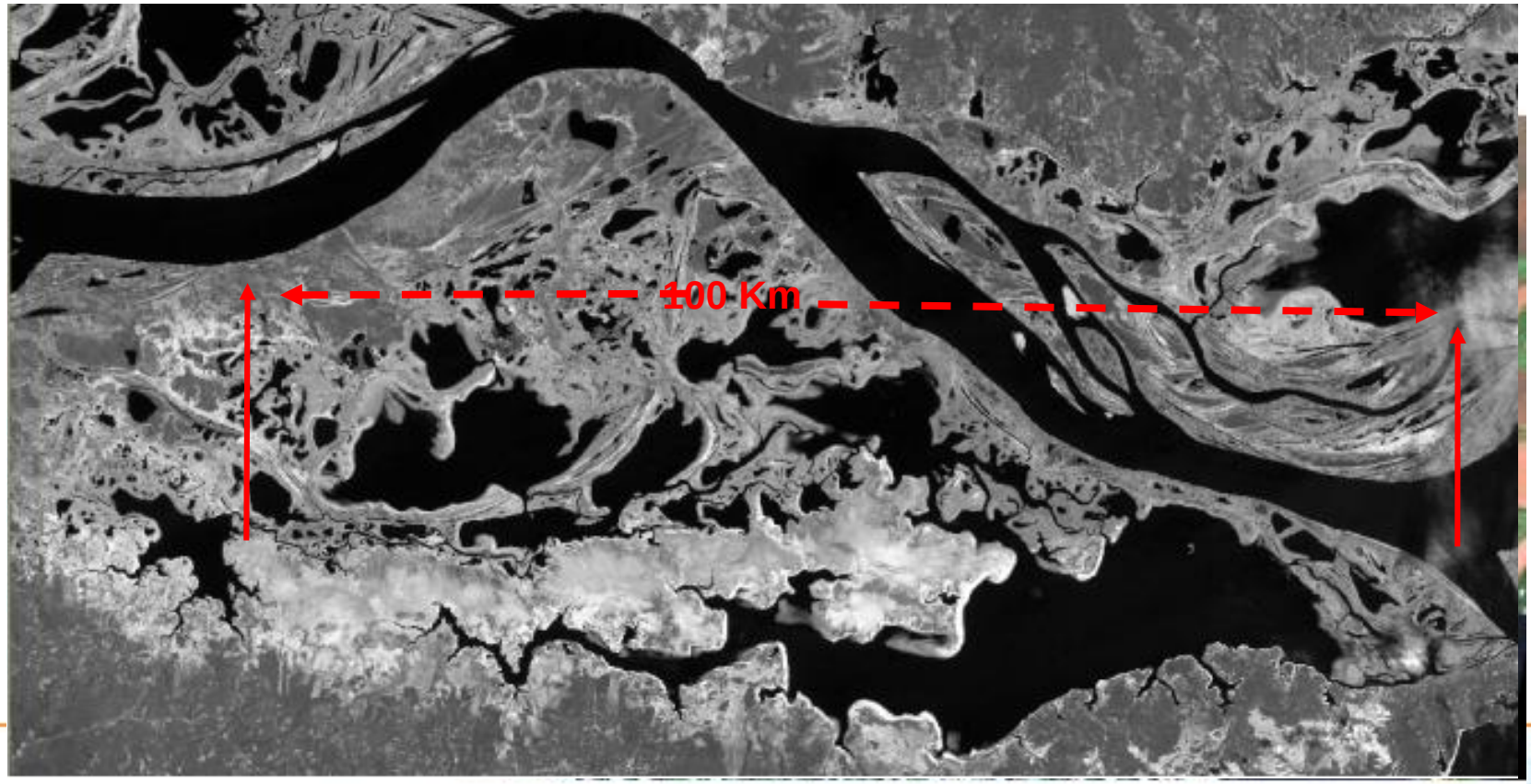
Clear Water (Tapajós River)

Dynamics of flooding in terms of water level fluctuation

Annual flooding amplitude : 7 meters

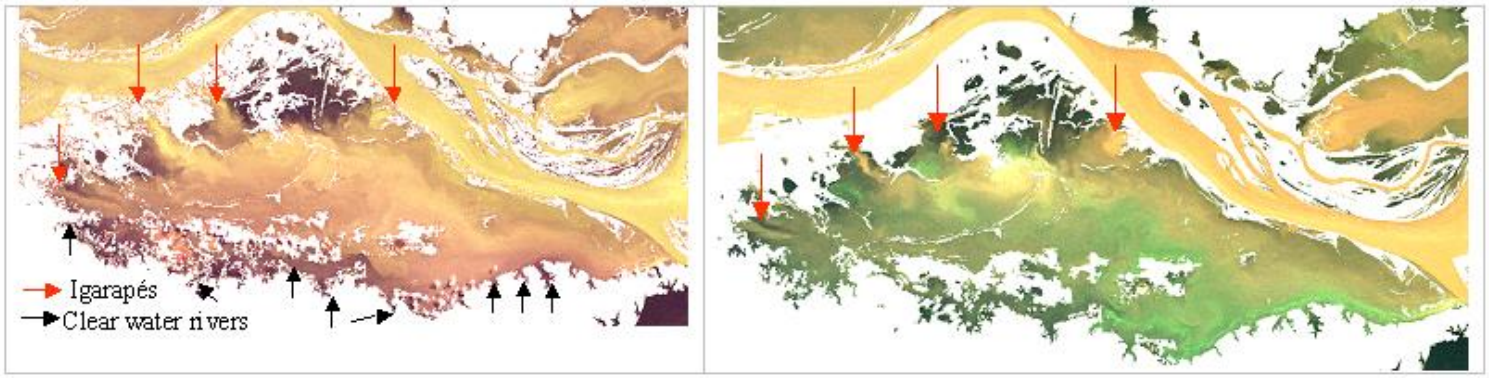
Inter-annual fluctuations : 2 meters



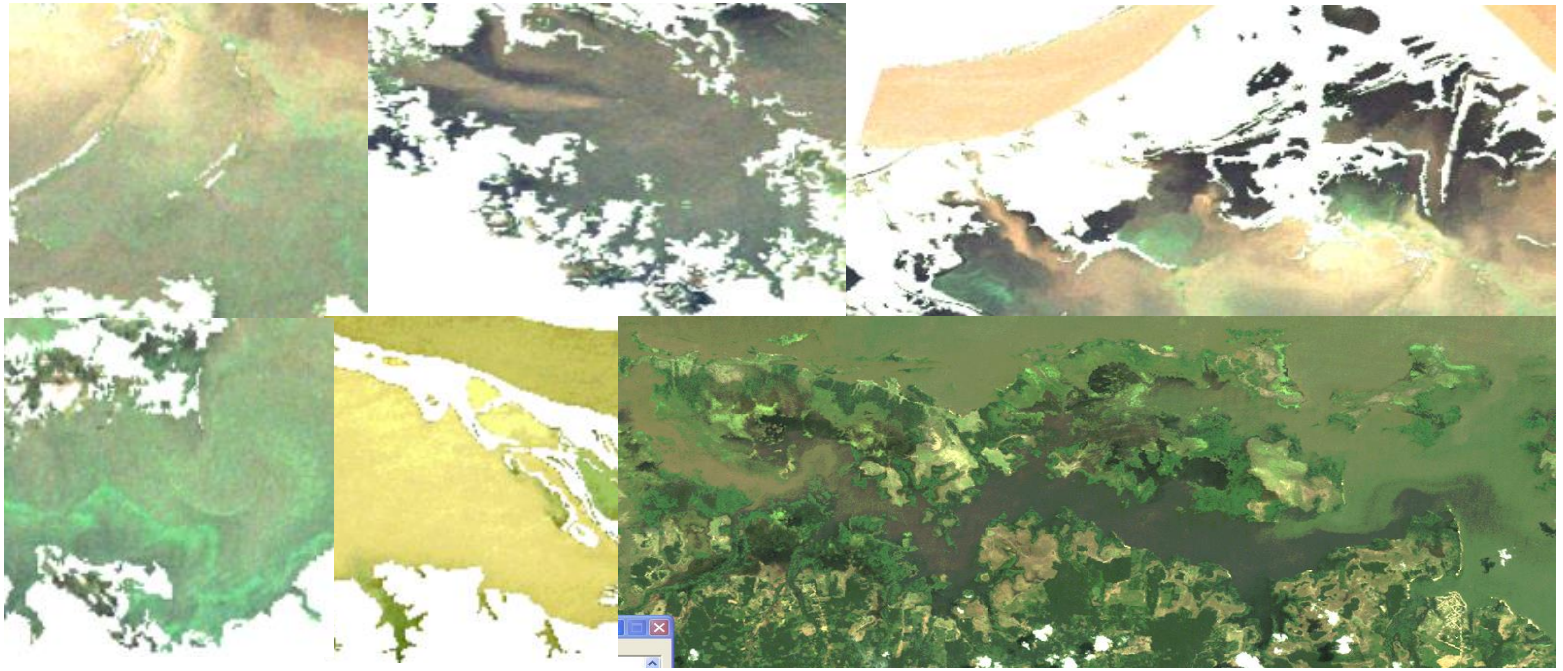


The flood pulse leads to a complex mixture of water composition seasonally

1999



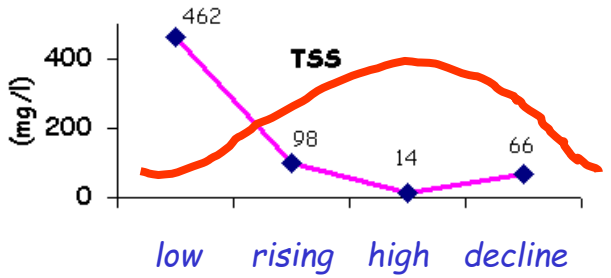
2002

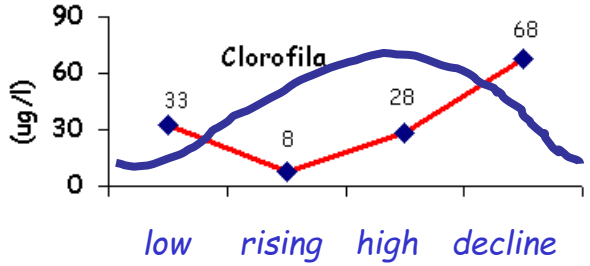


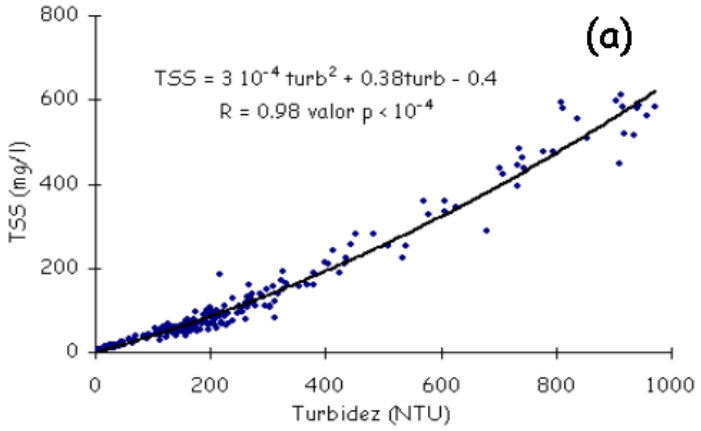
Effect of food pulse on the water composition

Mean concentration values

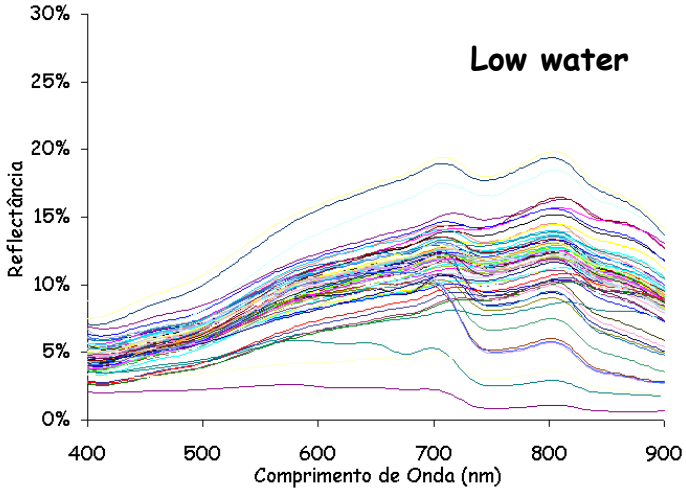
Variável		Média	Rio Amaz.	Mínimo	Máximo
pH	*rising*	7,72	6,5	6,10	9,30
	low	6,75	6,5	4,70	7,50
	decline	7,27	6,6	5,90	8,00
	high	7,53	6,6	6,01	9,4
Turbidez (NTU)		160,79	62	12,00	375,00
		769	183	39,00	1645,00
		236,78	354	101,00	569,00
		29,93	124	5,00	90,00
TSS (mg/l)	*rising*	66,13	27,5	5,46	200
	low	462,71	60	12,74	1137,75
	decline	98,7	161	36,75	359,42
	high	14,51	58	5,68	34,90
Clorof. (µg/l)		68,78	4,15	5,61	350
		33,4	2	0,80	87,86
		8,2	2,3	0,21	25,79
		28,85	0,7	1,16	131,28
COD (ppm)	*rising*	8.37	5.11	4.20	31.52
	low	6.04	4.83	1.03	11.38
	decline	5.56	4.47	2.81	11.25
	high	6.73	8.32	4.38	15.29





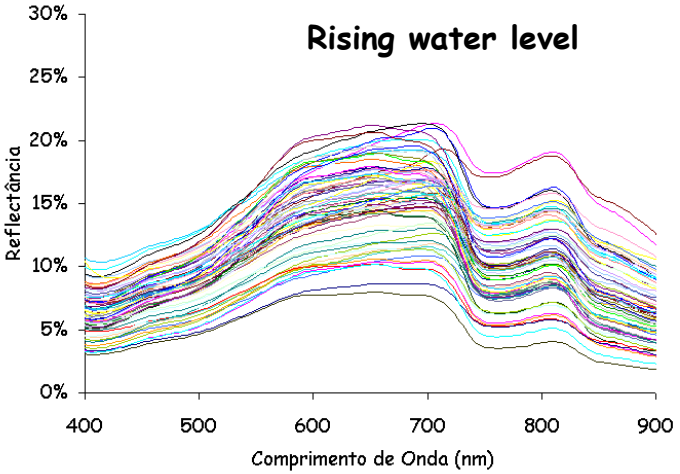


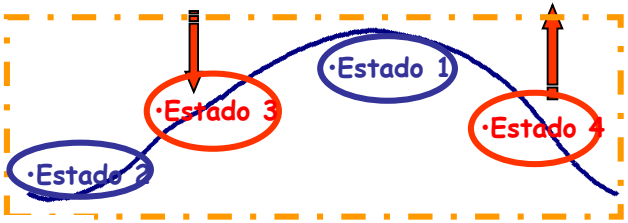
Effect of food pulse on the water spectral response

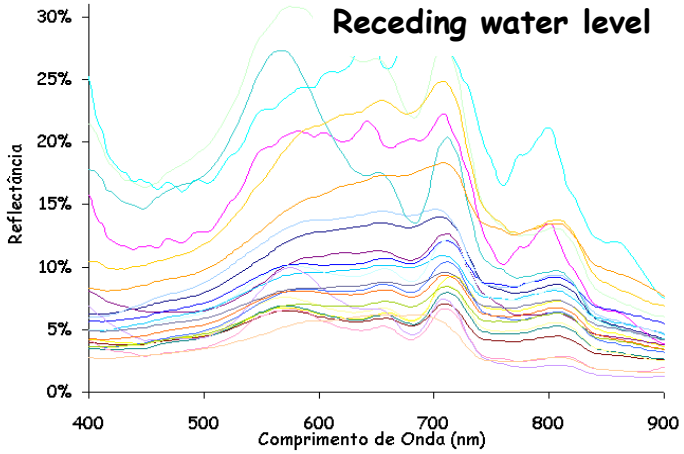


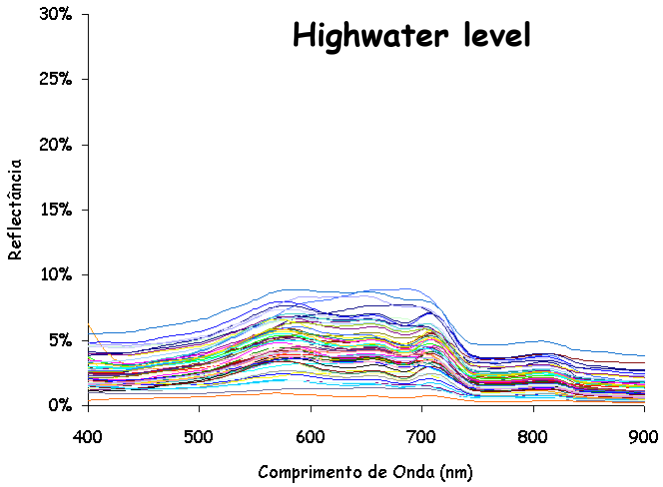
How changes on water composition affect both:

Amplitude and Shape of the spectra







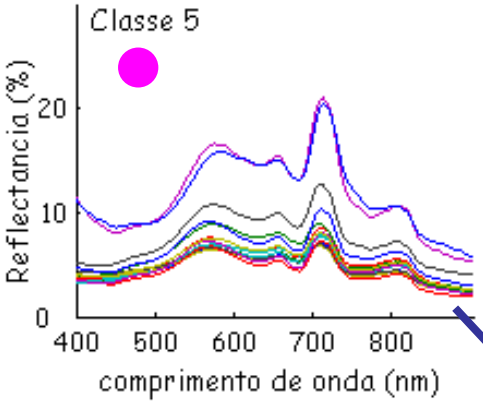


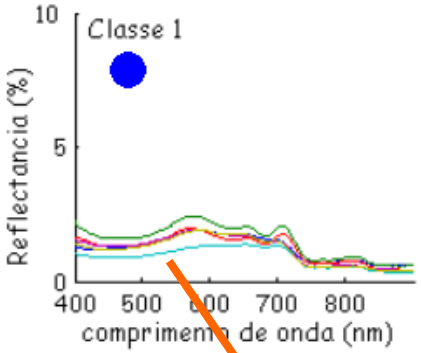
Spectra shaped by water composition

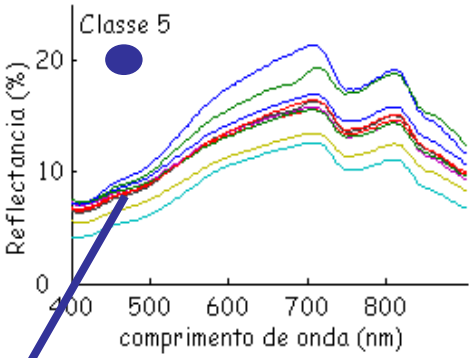
Dissolved organic matter

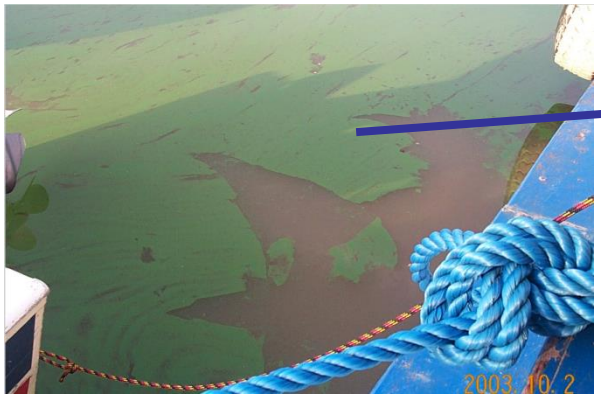
High chlorophyll concentration

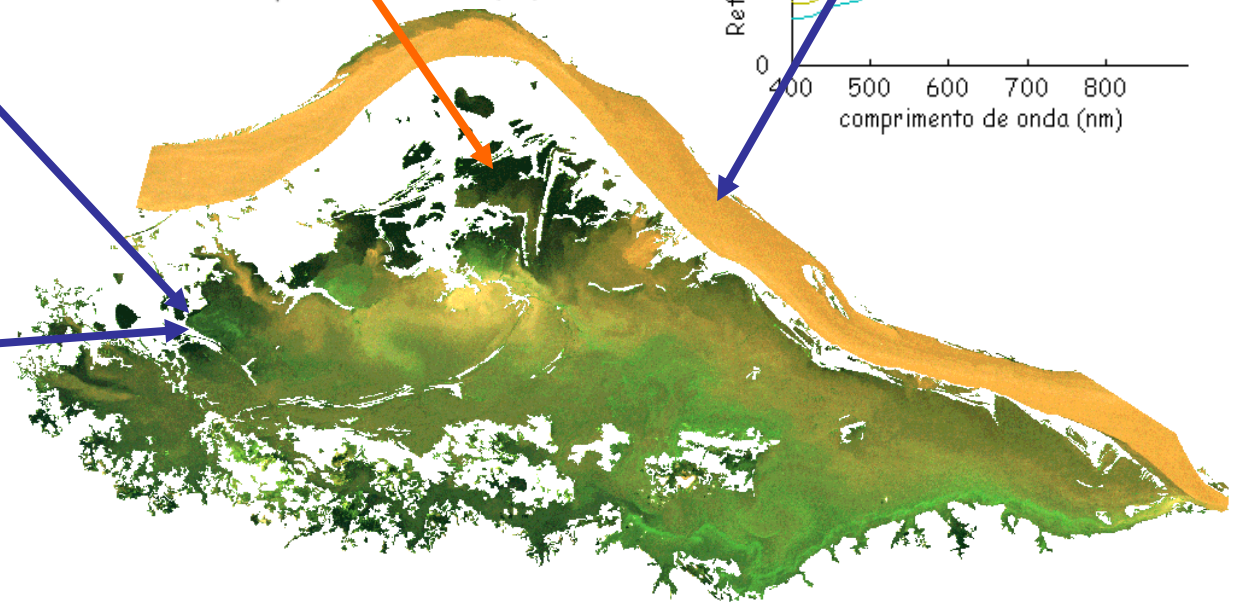
High inorganic suspended solid concentration



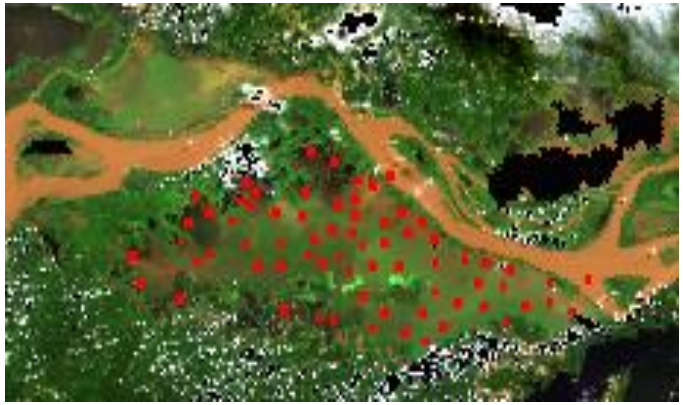








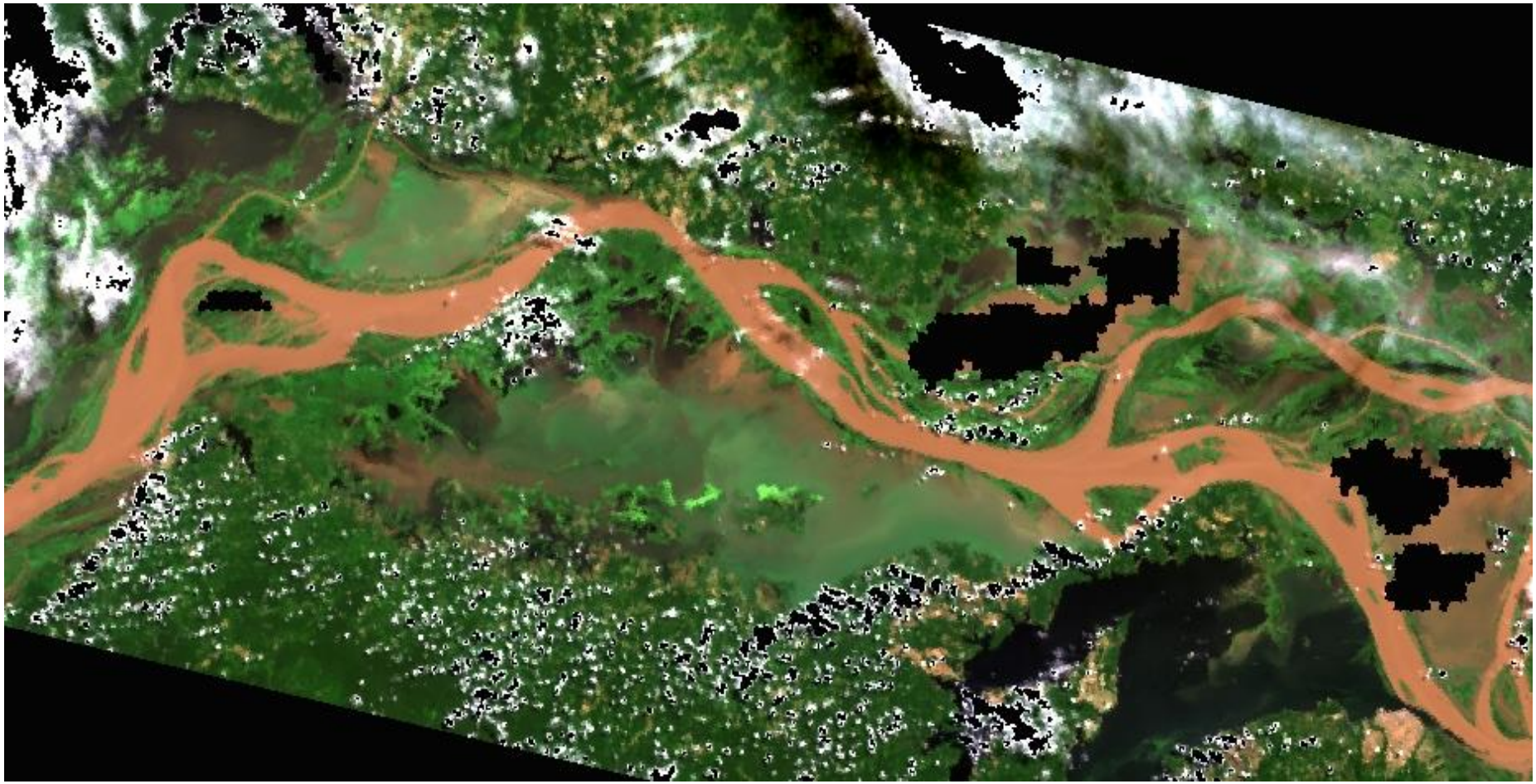
Intensive sampling in different water level stage (2003-2010)



Field infrastructure

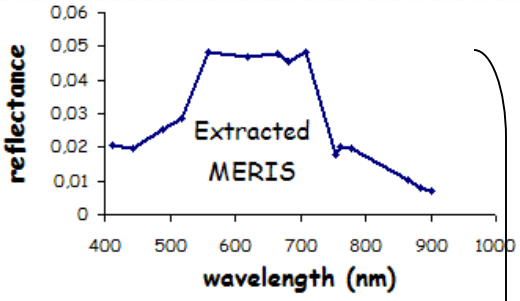
Field infrastructure

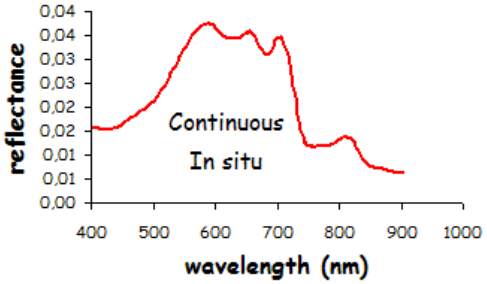
MERIS Image

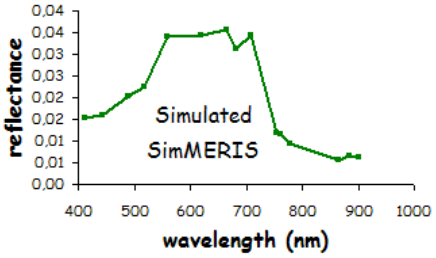


Visual intercomparison of spectral shape

Spectron SE590 & Hand Held ASD



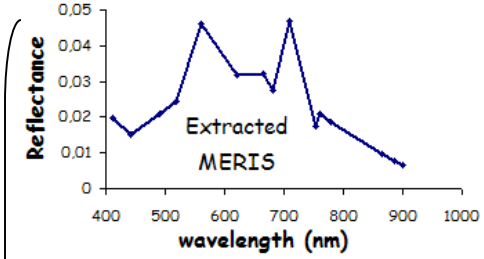


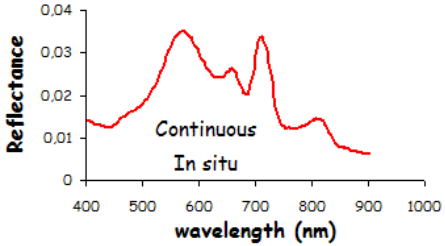


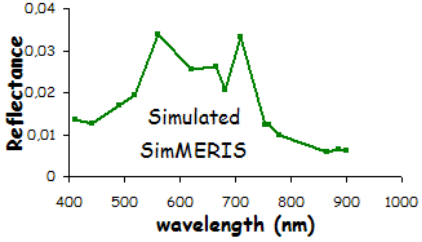
Chlorophyll = 26 ug/l

Reflectance at each in situ sample station was extracted from MERIS image for all MERIS spectral bands

In situ spectra were resampled to MERIS spectral resolution bands (SimMERIS)

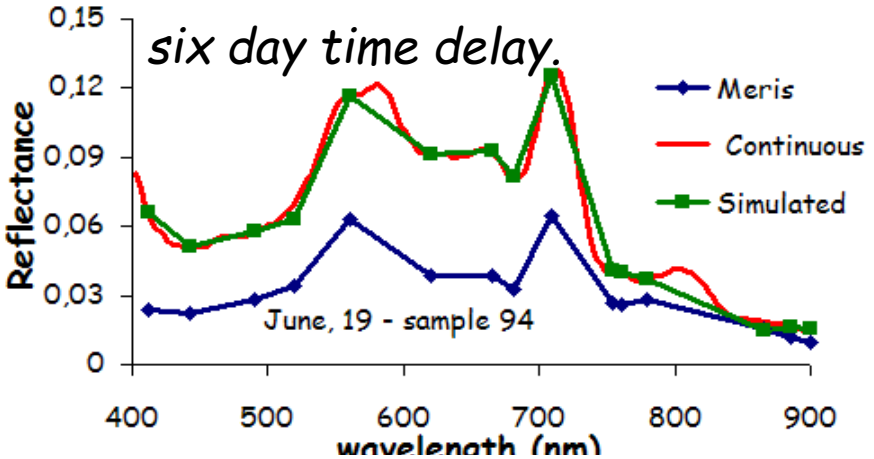


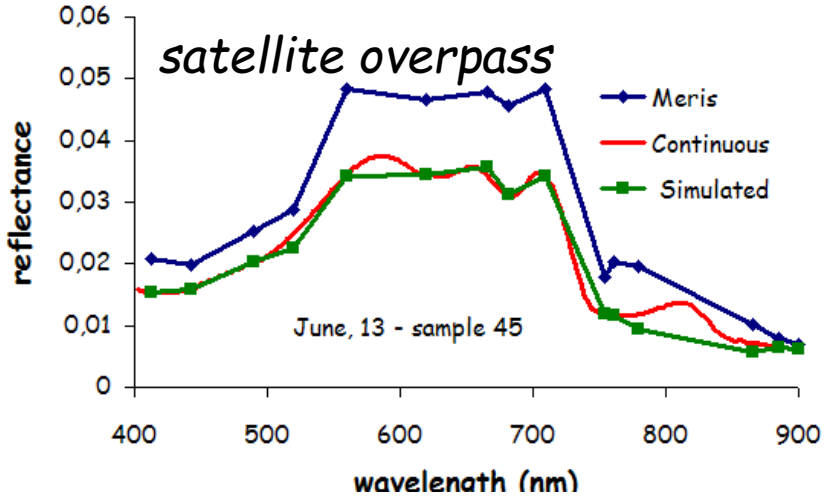


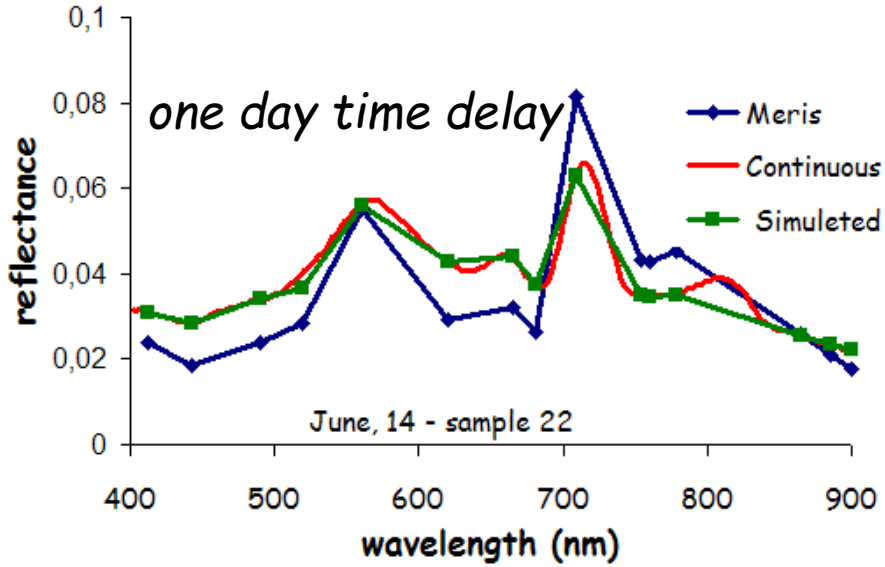


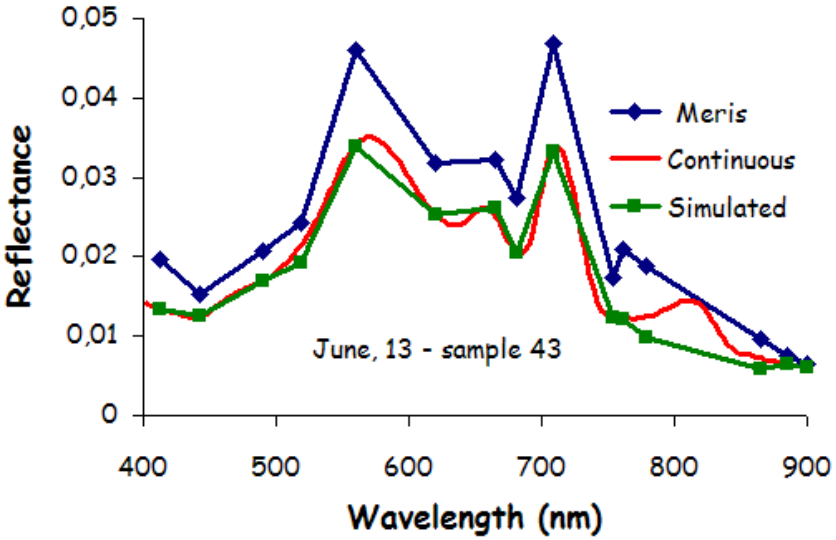
Chlorophyll = 61 ug/l

Visual intercomparison of spectral shape

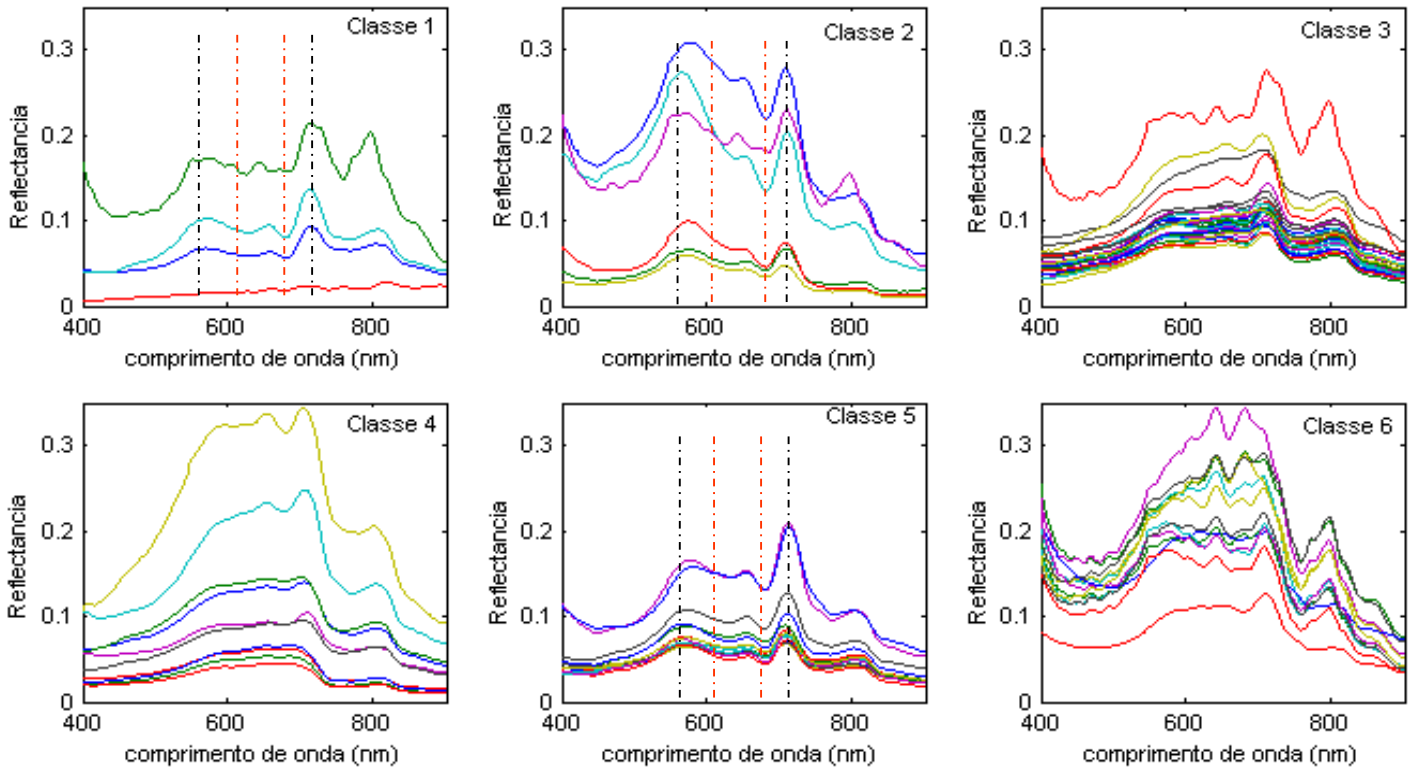






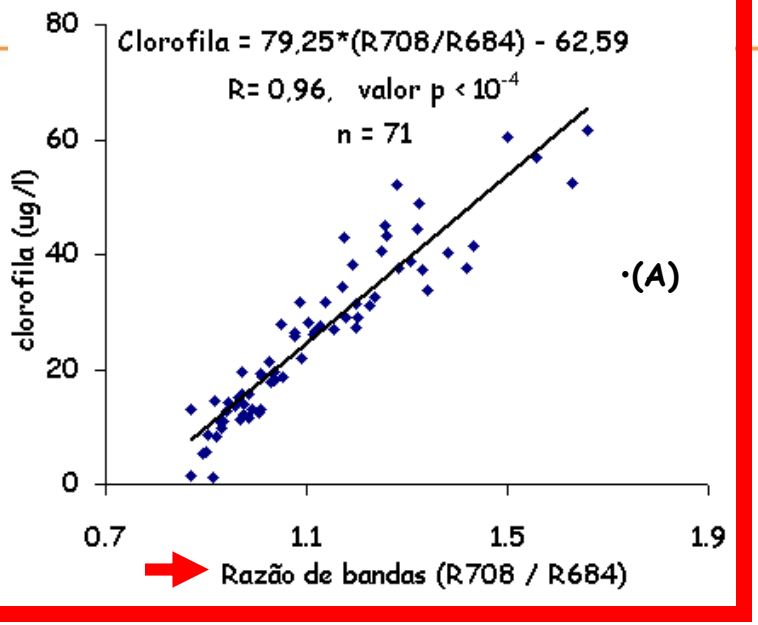


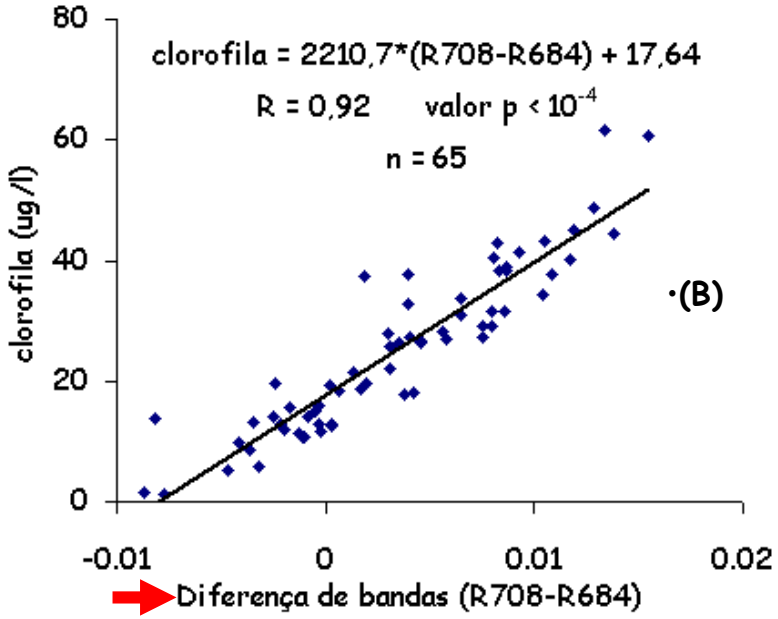
Water masses characterization (decline water)
Clustering based on (SAM)

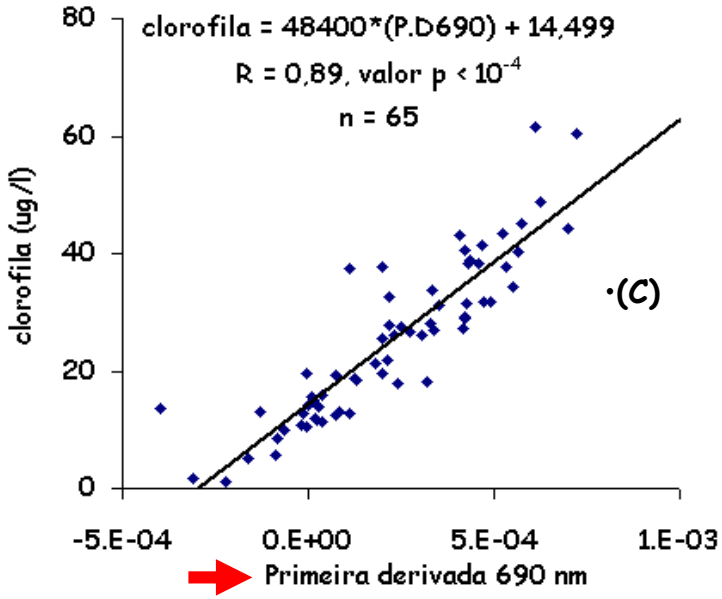


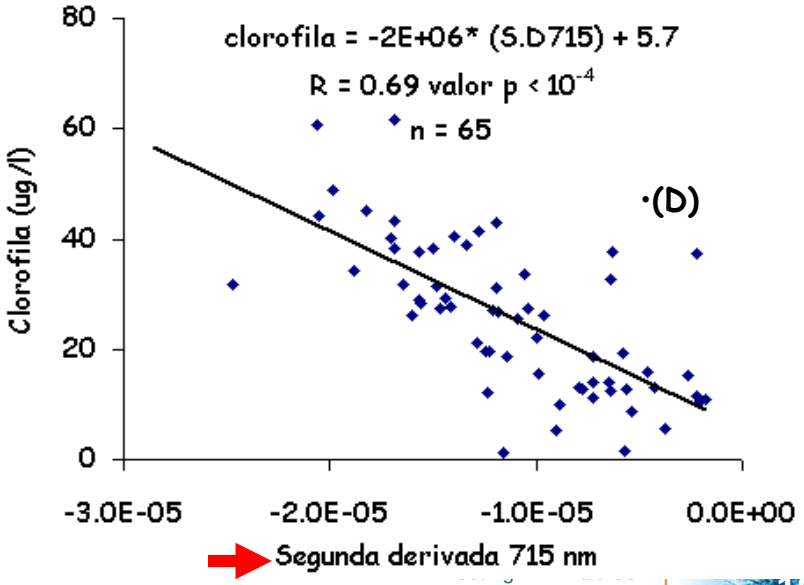
	TURB	TSS	TSI	TSO	TSO/TSS	TSO/TSI	CLORO	cloro/TSS	CID	COD
C1	202	87.52	56.69	30.84	0.35	0.54	204.30	2.33E-03	15.04	6.56
C2	87	39.30	23.82	15.48	0.39	0.65	89.75	2.28E-03	10.29	4.74
C3	205	95.08	76.81	18.27	0.19	0.24	63.31	6.66E-04	11.46	6.04
C4	161	65.17	54.38	10.79	0.17	0.20	25.57	3.92E-04	12.18	5.25
C5	124	52.69	35.59	17.10	0.32	0.48	91.86	1.74E-03	10.75	4.75
C6	151	55.08	40.41	14.66	0.27	0.36	61.62	1.12E-03	8.33	5.20

Chlorophyll concentration (empirical models)

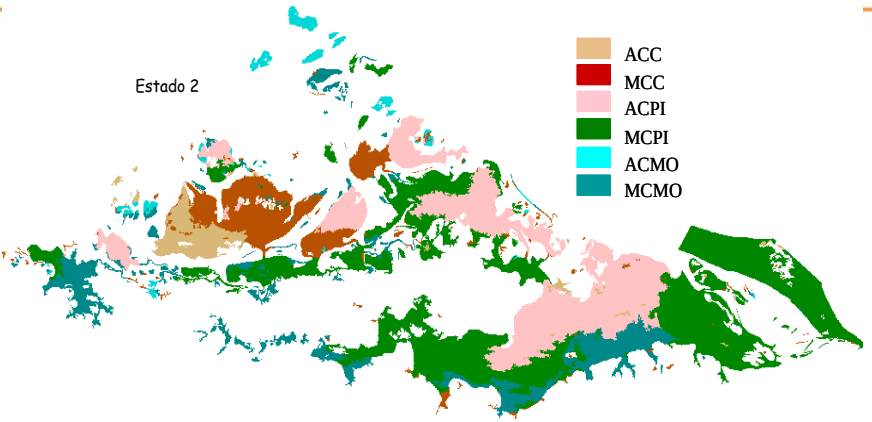


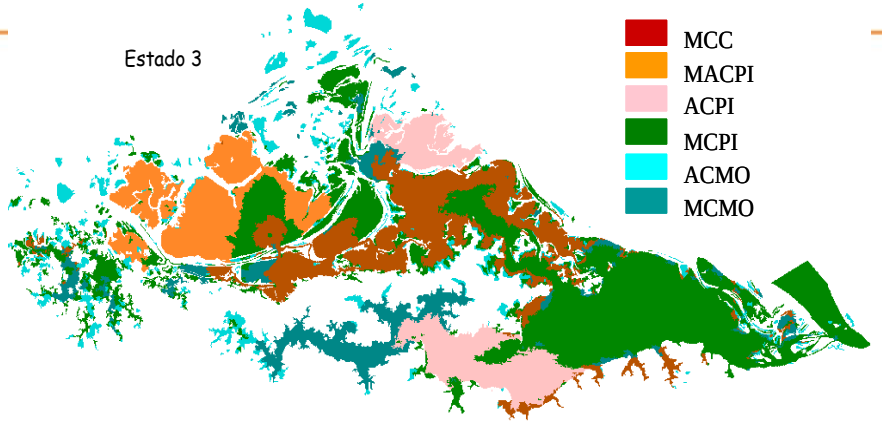


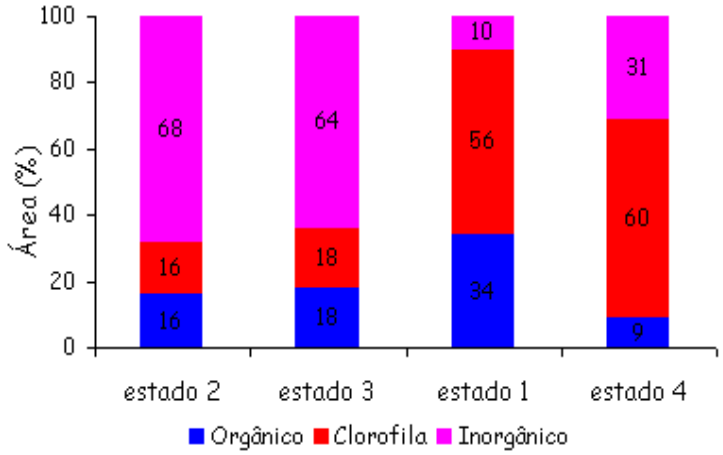




mapping water masses

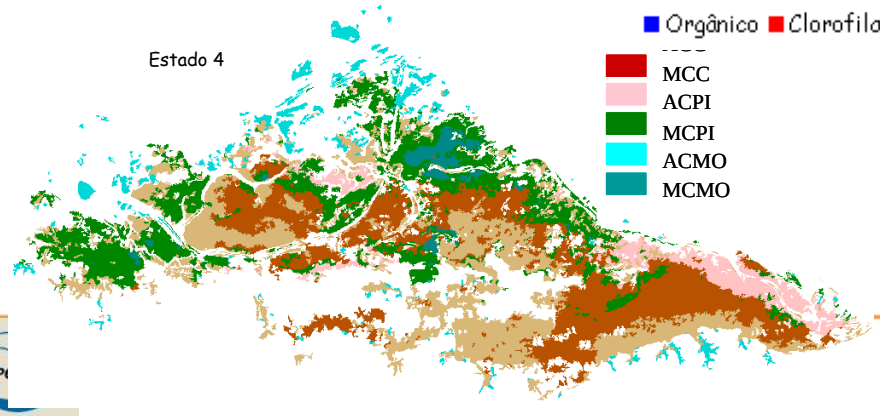


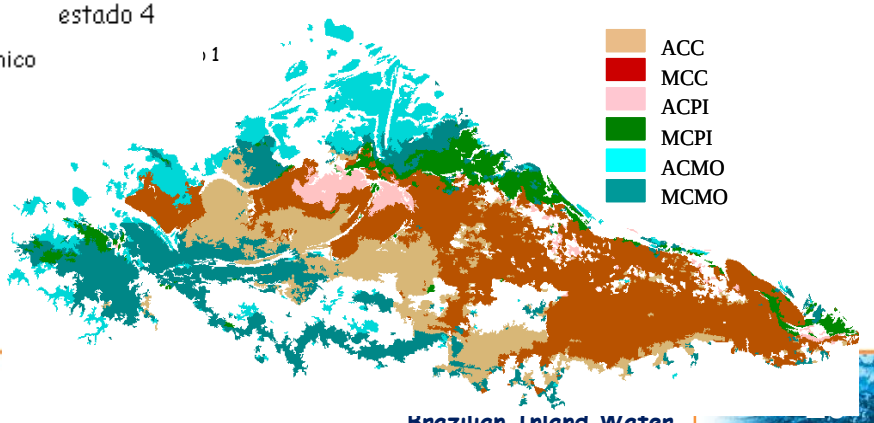




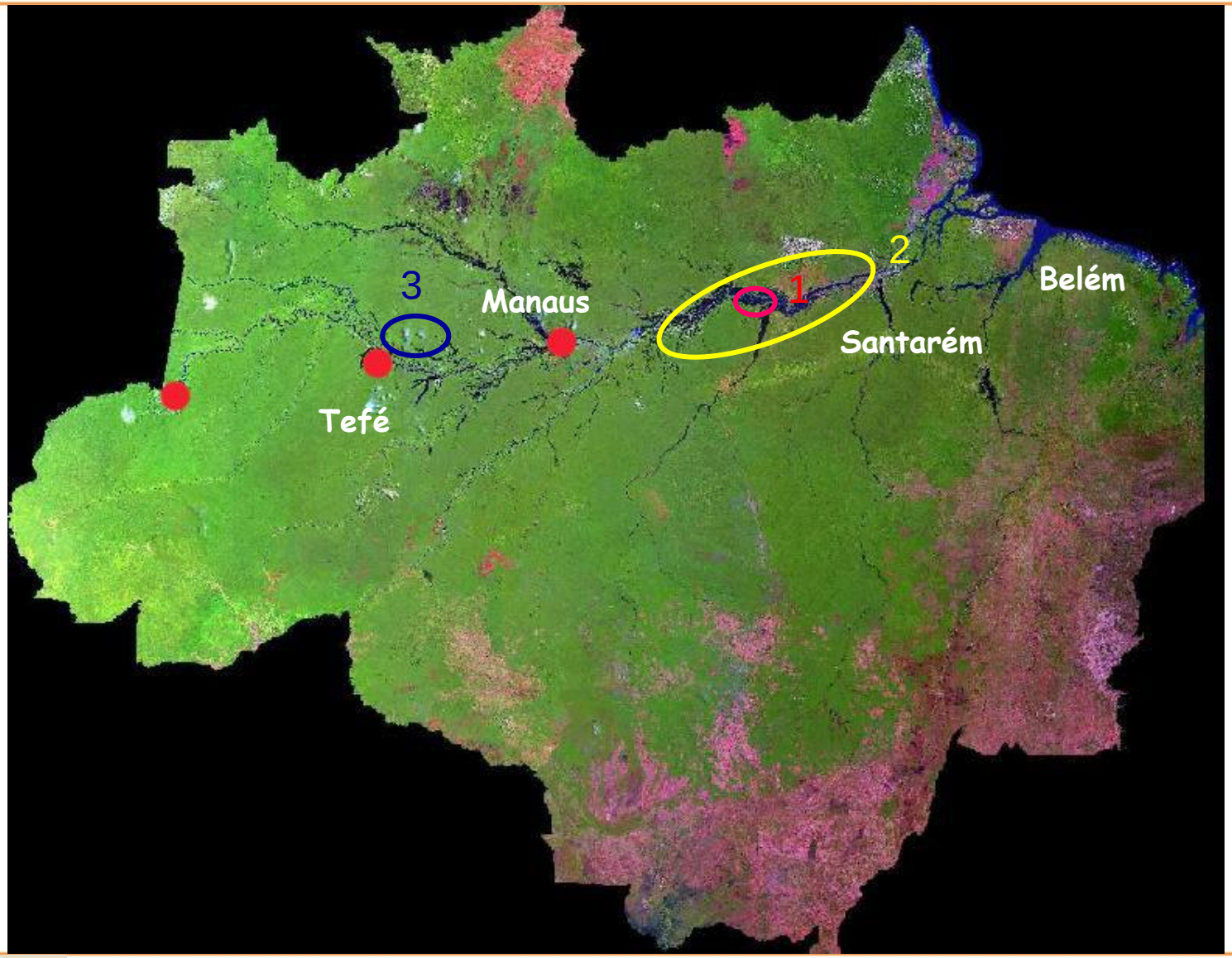
State 2 = low *state 3 rising*

State 1 = high *state 4 decline*

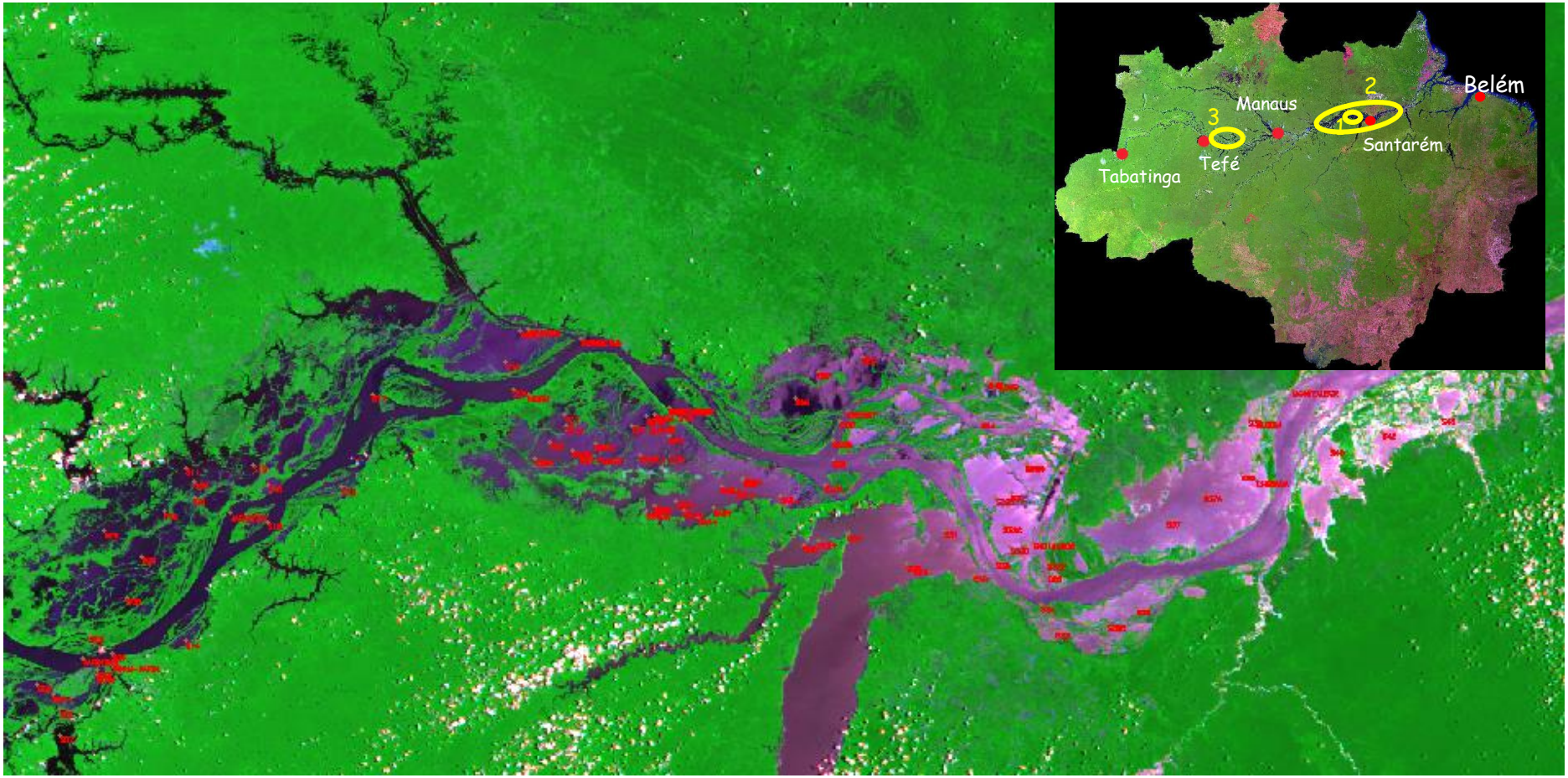




Site 2 An extension of site 1 - nearly 1000 km



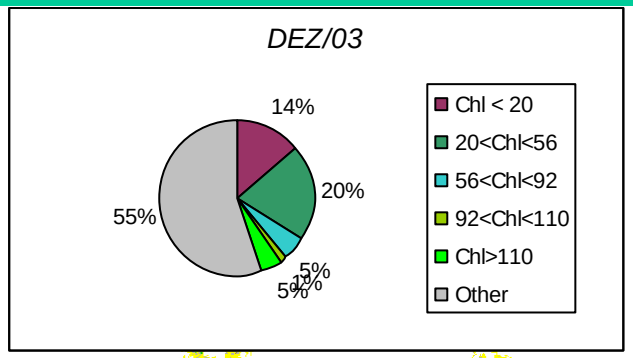
Site 2 An extension of site 1 - nearly 1000 km

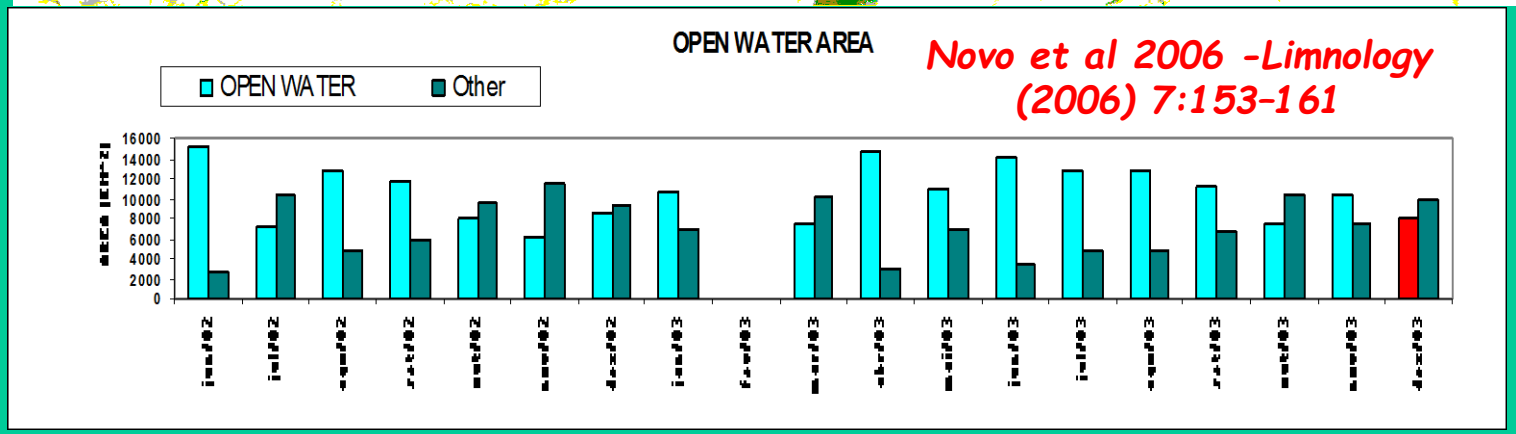


Seasonal changes in chlorophyll distributions in Amazon floodplain lakes derived from MODIS images (Novo et all, 2006 Limnology (2006) 7:153–161)

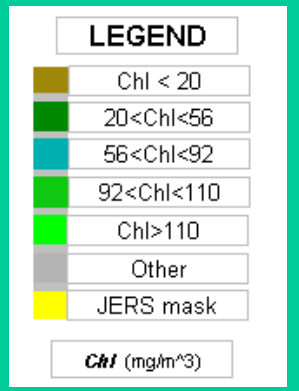
Chl (Images MODIS, empirical model)

Seasonal changes :2002 & 2003





Novo et al 2006 -Limnology (2006) 7:153-161



Some master dissertation and PhD Thesis

- *Remote Sensing of water circulation dynamics in the Curuai floodplain/Amazon River*
- *Spectral Library: References for water types classification in Amazon wetlands*
- *Fluorometric and Spectral data applied to estimate chlorophyll concentration in freshwater environments*
- *Empirical models for suspended sediments concentration estimative in white water amazon rivers from LANDSAT 5 images*

Some master dissertation and PhD Thesis

- *Integration between MODIS images and census data to assessment of livestock impact in aquatic systems on the lower amazon*

- *Mapping the Amazon river floodplain using object based classification with SRTM-DEM and HAND-DEM Data*

- *Occurrence and removal of sunglint effects in hyperspectral and high spatial resolution images from the Spectrir sensor*

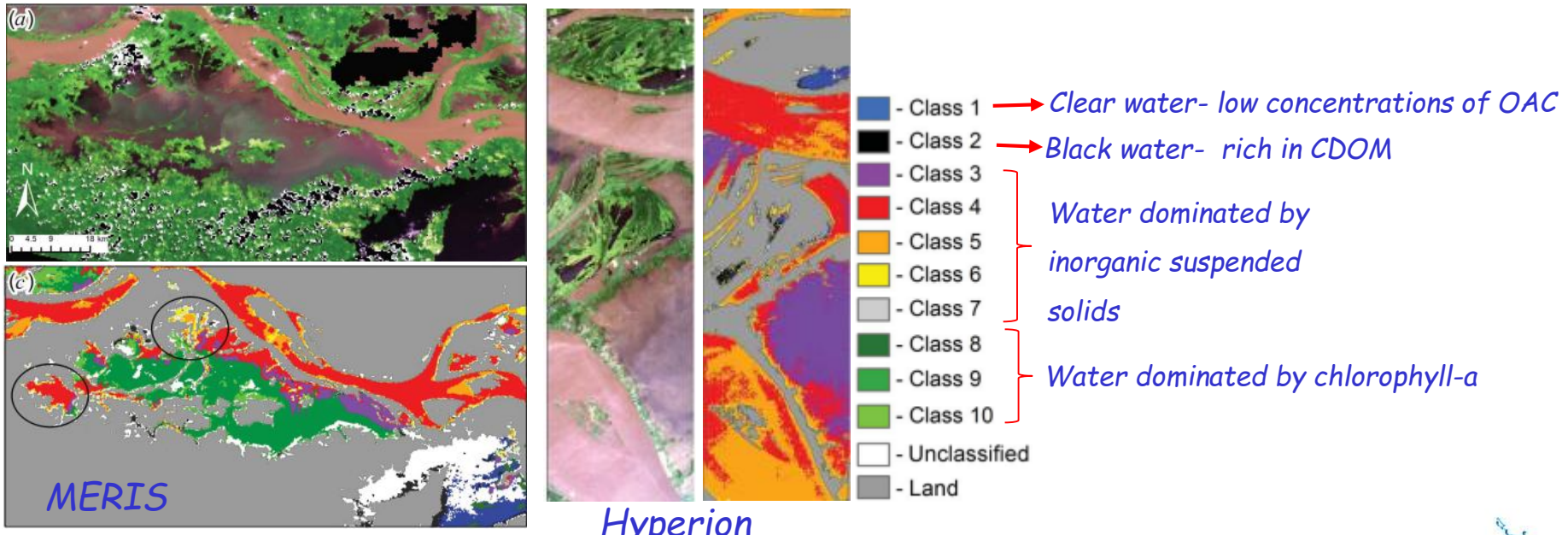
Reference spectra to classify Amazon water types

Lobo at all 2012 - IJRS Vol. 33, No. 11

A spectral database (392 spectra) were compiled into spectral library

➔ resulting in 10 reference spectra, that describe four limnological characteristics

Result of SAM algorithms: overall accuracy of 86%



Mapping potential cyanobacterial bloom using Hyperion data in Patos Lagoon estuary -Brazil

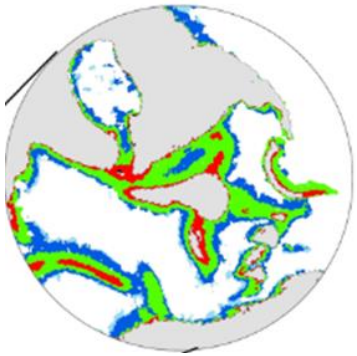
Spectral angle mapping using two spectral library :

➔ analytical (Kutser, 2004)

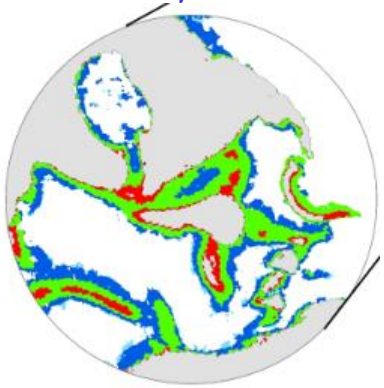
➔empirical

Hyperion image

Empirical



analytical



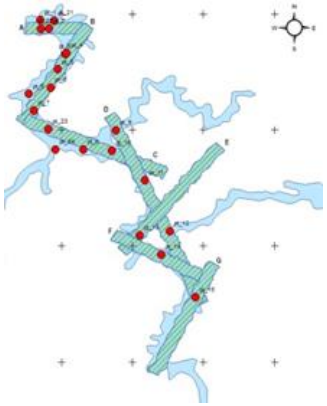
88% of similarity

Lobo at al 2009

Acta Limnol. Bras

vol. 21, no. 3

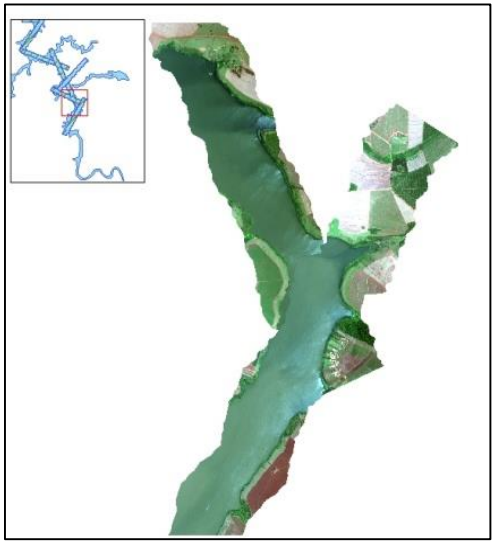
Project: Spatio-temporal evaluation of inland aquatic system's eutrophication in response to sugarcane expansion

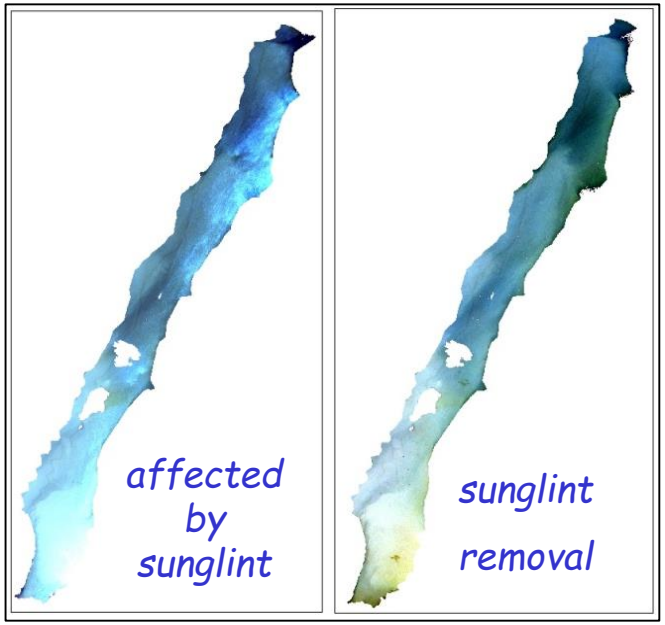


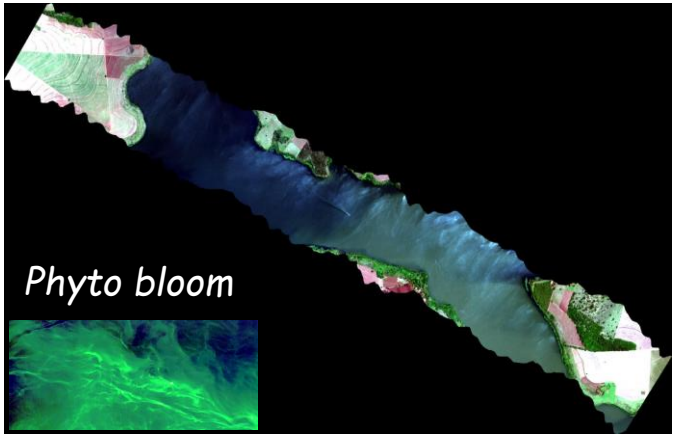
Airborne Hyperspectral Imaging

SpecTIR V-S: Flight lines

357 spectral bands







First period: Above water measurements (2001-2010)

- Allowed characterizing patterns of spatio-temporal dynamics of water masses composition without however characterizing the spectral composition of the underwater light field.

➔ key information to support primary productivity studies.

Second period: Water column measurements (2011-2016)

In 2010, we moved towards to measure the ***Inherent and Apparent Optical Properties*** *in water column in order to do:*

- *the* ***spectral characterization*** *of the underwater light field,*
- ***the bio-optical characterization*** *of lakes and reservoirs*
- *Use* ***semi analytical algorithms*** *to retrieve constituents.*

Why? ➔ ***semi analytical algorithms have time frame coverage***

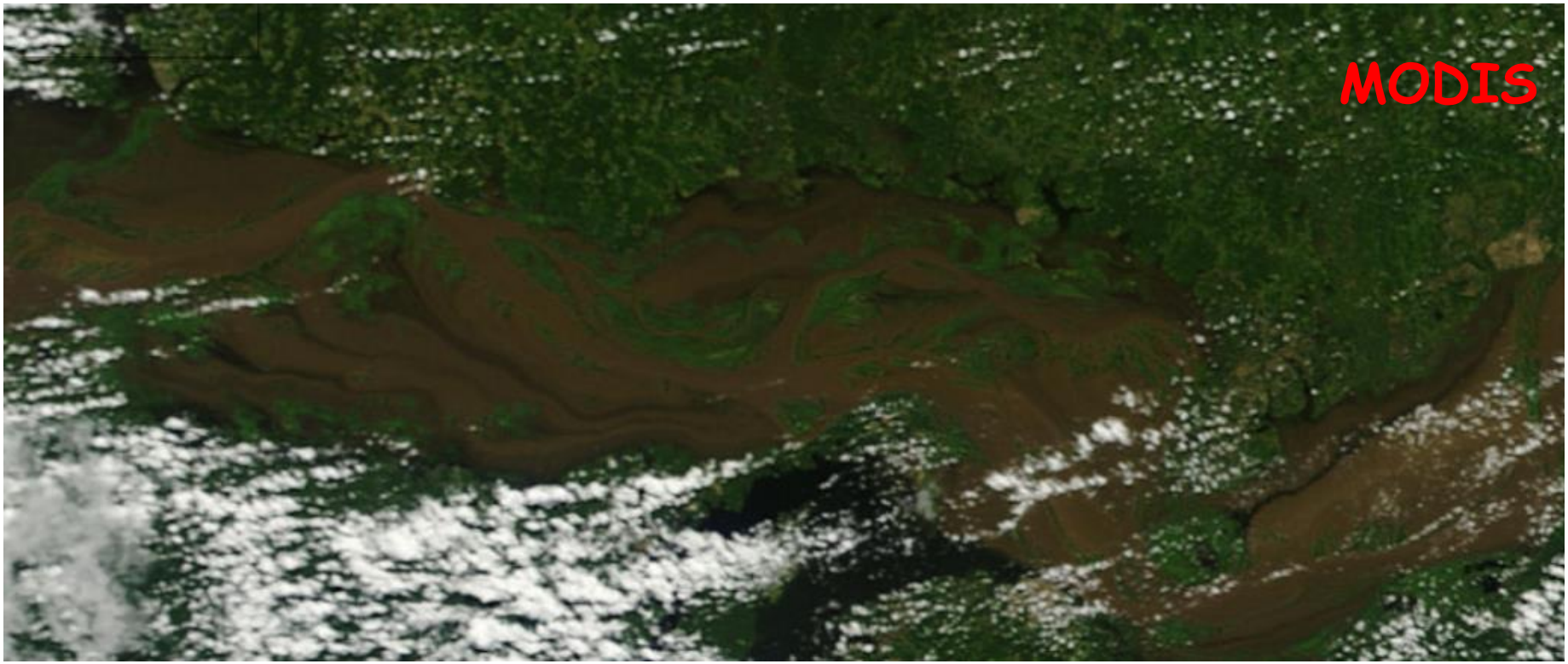
Second period: Water column measurements (2011-2016)

The history timeline (two periods)

- Above water measurements & empirical algorithms (2001-2010)
  - Focused in the seasonal dynamics of volume and water composition in the Amazon floodplain lakes.

- **Water column profiles measurements & semi analytical algorithms**
  - **Focused in bio-optics characterization and the seasonal dynamics of bio-optics properties**

Motivation



Motivation

Second period: Water column measurements (2011-2016)

It took us nearly three years and be involved in six projects to acquire the whole set of instruments

- *ANEEL*
- *Three FAPESP Projects*
- *FUNDO AMAZONAS*
- *CNPq UFC*
- *FAPESP - mamiraua*

Some of the Projects that funded instruments

- Modeling human impacts on ecological properties of wetland and aquatic ecosystems of central Amazon floodplain.

- Spatio-temporal evaluation of inland aquatic system's eutrophication in response to sugarcane expansion using remote sensing images

- Emissions of Greenhouse Gases in Hydroelectric Reservoirs

Instrumentation Laboratory for Aquatic Systems (LabISA)

Two AC-S (10 and 25 cm)

LISST-Portable

UV-VIS-2600 Shimadzu

CTD

HydroScat-6P

10AU Field and Laboratory Fluorometer

ECO BB9

http://www.dpi.inpe.br/labisa/index_en.html

Six RAMSES radiometer

ASD HandHeld 2: VNIR

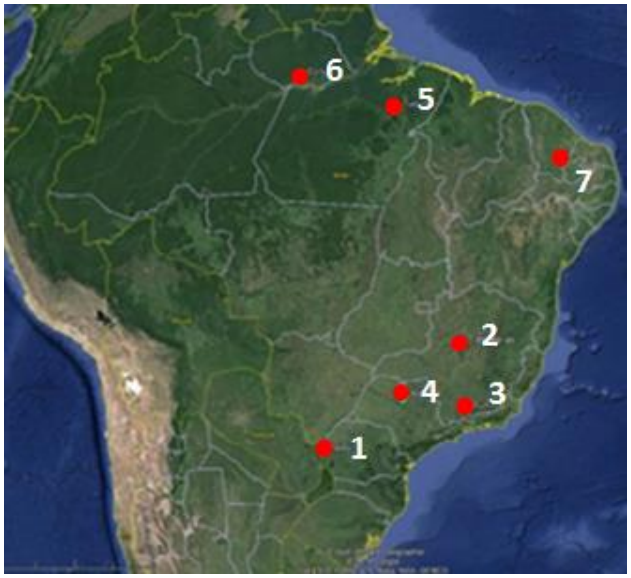
ADP- Acoustic Doppler Profiler

Course "Radiative Transfer Theory, Optical Oceanography, and Hydrolight" (Curtis Mobley, INPE, 2013)

Examples of recent results
(2012 – 2015)

Sampled sites (six reservoirs and lakes at Amazonian floodplain)

Selected for accomplishing the goals of the projects that funded the instruments.



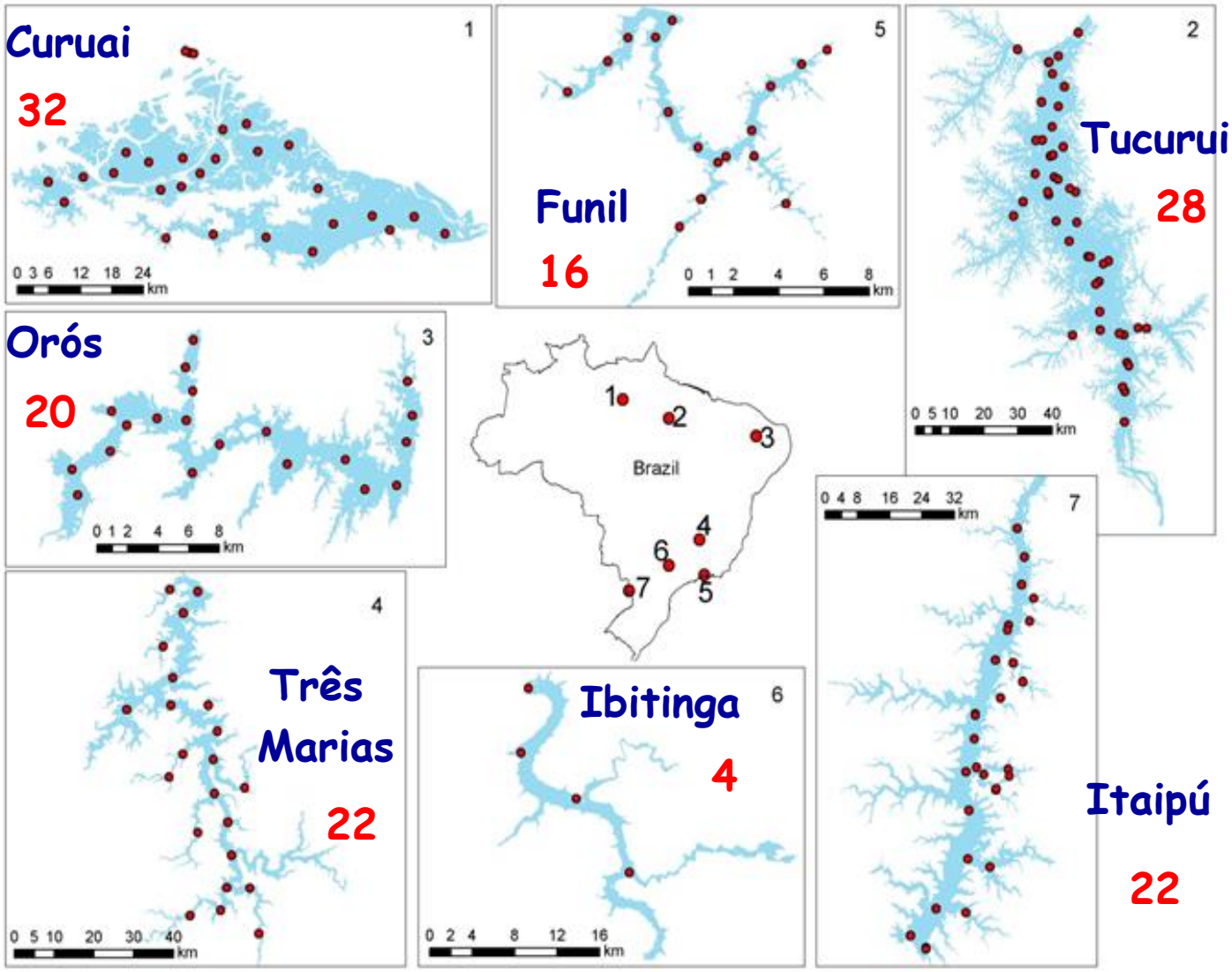
***Goals**: providing support for*

- **Effects of climate change in the Amazon region**
- **Environmental impacts and the net carbon budget in Brazilian reservoirs.**

Sampled sites

	Site	Area (Km^2)	Biome
1	Itaipu	1.350	Atlantic Tropical Forest
2	Três Marias	1.040	Brazilian Savana (Cerrado)
3	Funil	40	Atlantic Tropical Forest
4	Ibitinga	114	Atlantic Tropical Forest
5	Tucuruí	2.430	Amazon
6	Curuai	2000	Amazon
7	Açude Orós	190	Semi-arid Caatinga

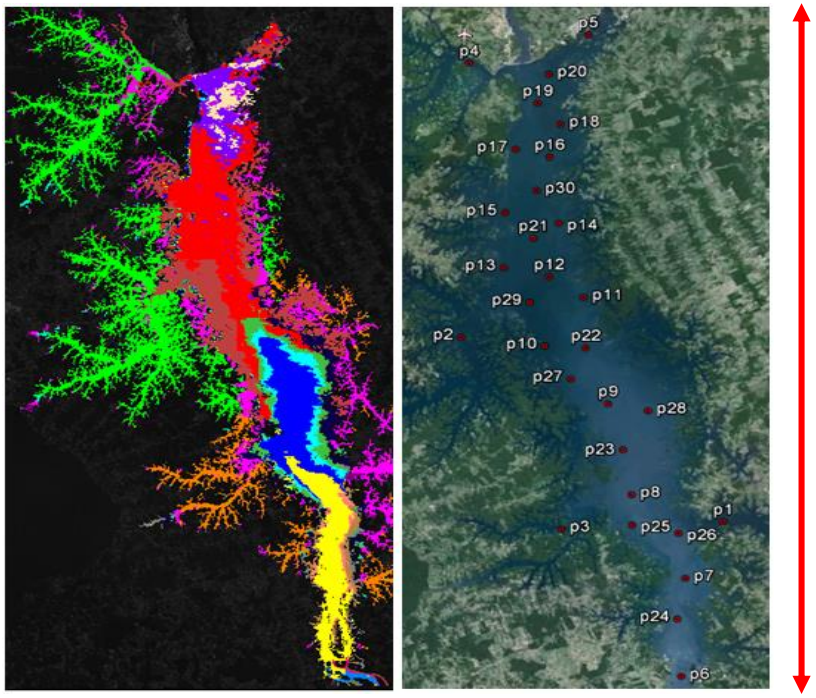
Optical and limnological data were gathered along 13 field campaigns Between 2012 and 2015



	Area (Km²)
1	2000
2	2.430
3	190
4	1.040
5	40
6	114
7	1.350

Measured variables:

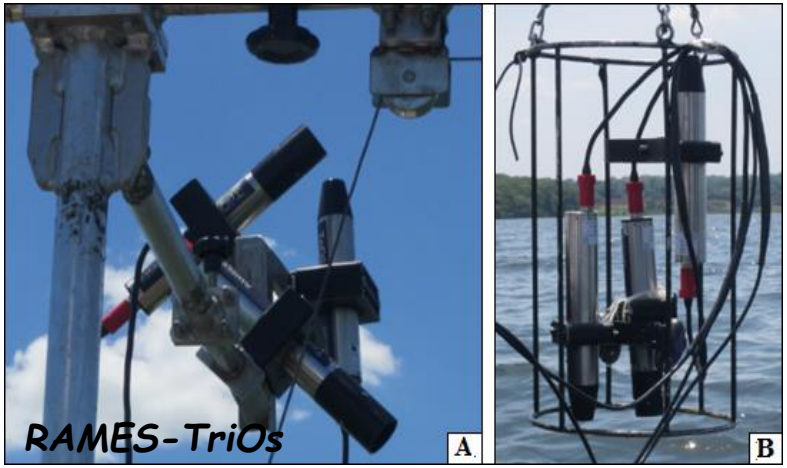
Defined taking as reference the ones listed on NASA document that describes key *in situ variables* to be measured for satellite ocean color sensor validation, algorithm development and algorithm validation



Sampling station were defined based on homogeneous spectral response mapped from an unsupervised classification

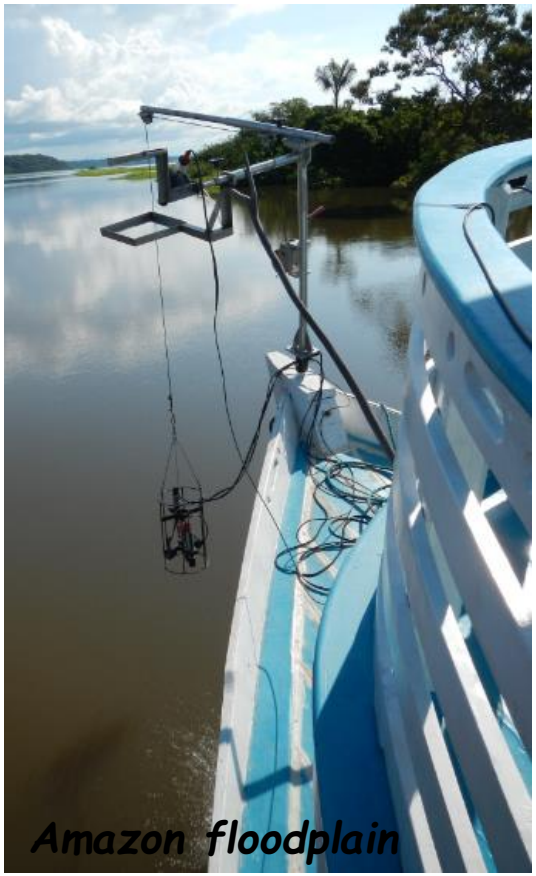
Measured variables:
Profiles of Apparent Optical Properties (AOP)

Six inter-calibrated spectroradiometers



Downward & Upward irradiances /radiances

E_s, E_d, L_w, L_u, E_u, E_{sky} (320 to 950nm)



Measured variables:

Profiles of Inherent Optical Properties (IOP) & Probe

Attenuation & Absorption & Backscattering

4 Hz sampling rate

Probe (Tu,Te,Co,pH,DO)

Specific coefficients (a_{ph}^*, a_{NAP}^*, a_{TP}^*)

OAC (Chl-a, TSS,TSI,TSO,DOC,DIC,CDOM)

Due to remoteness during Amazonian campaigns , the team stay all time onboard.

Pre-processing

Some data has to be submitted to correction protocols

- ✓ Absorption measurements ➔ be corrected for scatter absorption tube
- ✓ Backscattering ➔ have be corrected for attenuation in optical path
- ✓ AOP measurements ➔ have be normalized for sunlight changes

Algorithms were developed and tested for case I waters

- ✓ Have to be assessed since efficiency is related to water composition
- ✓ Assessments were made for Amazonian lakes water.

(Carvalho et al, 2015 special edition on inland waters of RSE).

Descriptive statistics of some bio-optical properties of Brazilian inland aquatic systems

	Statistic	Tucuruí	Itaipú	Três Marias	Curuai	Ibitinga	Funil	Orós
Z_{eu} (1%) [m]	Mean/Median	4.84/6.87	3.17/3.26	6.57/7.54	1.18/1.38	5.61/7.42	2.45/3.11	-
	Min/Max	1.14/9,39	1.89/4.18	2.19/13.14	0.35/2.72	2.66/9.20	1.02/4.51	-
K_d (PAR) [m^{-1}]	Mean/Median	0.95/0.67	1.45/1.41	0.70/0.61	3.90/3.33	0.82/0.62	1.88/1.48	-
	Min/Max	0.49/4.03	1.10/2.44	0.35/2.10	1.69/13.30	0.50/1.73	1.02/4.50	-
	Std. deviation	0.75	0.31	0.37	1.72	0.36	1.00	-
$c_{(450)}$ [m^{-1}]	Mean/Median	4.51/2.89	-	3.66/2.72	20.08/19.44	4.75/4.39	6.44/5.62	-
	Min/Max	1.47/16.04	-	1.40/15.35	12.47/37.95	2.49/8.10	3.26/12.80	-
	Std. deviation	4.11	-	2.99	-	1.84	3.13	-
$a_{CDOM(440)}$ [m^{-1}]	Mean/Median			0.66/0.41	2.16/2.13	0.88/0.90	0.56/0.56	
	Min/Max			0.19/4.3	1.70/2.66	0.78/0.99	0.36/0.67	
	Std. deviation			0.81	0.23	0.09	0.1	
Turbidity (NTU)	Mean/Median	3.12/1.45	7.86/8.50	2.87/0.90	20.88/21.70	10.52/7.20	8.77/6.10	11.23/6.00
	Min/Max	0.10/17.0	3.60/10.70	0.10/24.10	8.10/33.20	1.00/45.40	3.60/33.80	1.12/99.00
	Std. deviation	4.41	2.09	5.28	5.72	10.52	7.63	13.18
Chl-*a* (µg/L)	Mean/Median	7.19/5.01	1.61/1.12	5.47/4.67	18.41/11.74	41.9/20.65	38.00/13.08	22.33/19.44
	Min/Max	2.75/39.53	0.59/04.81	1.17/13.22	0.90/92.06	3.72/180.40	1.39/242.86	0.50/80.67
	Std. deviation	7.10	1.21	3.33	18,82	53.90	64.15	16.23
TSS (mg/L)	Mean/Median	3.43/1.92	1.77/1.61	4.34/3.33	32.37/15.72	7.02/5.20	5.67/5.00	13.26/9.00
	Min/Max	0.26/20.41	0.63/3.77	1.33/11.93	0.53/161.85	0.80/30.80	0.87/18.60	1.00/100.00
	Std. deviation	4.26	0.74	2.54	34.93	7.35	4.50	15.25
DOC (mg/L)	Mean/Median	2.32/1.98	2.17/2.06	1.95/1.90	2.11/7.74	3.63/3.44	3.41/3.32	9.26/8.61
	Min/Max	1.45/7.03	1.73/4.09	0.93/2.71	4.14/7.74	2.72/4.91	2.80/5.22	5.27/14.48
	Std. deviation	1.12	0.62	0.37	1.05	0.63	0.62	1.85

Range of values

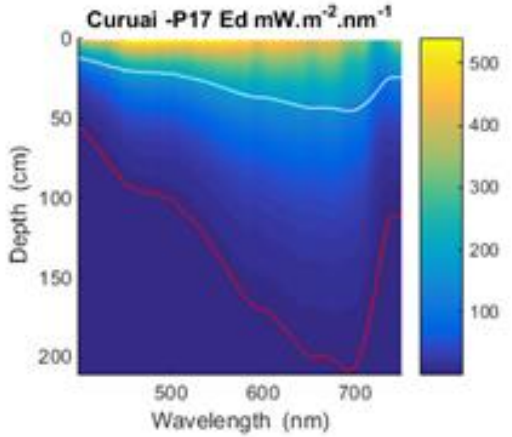
- ✓ In reservoirs, the chlorophyll-a ranged from 0.6 to 243µg/L while in Amazonian lakes ranged from 0.90 to 92 µg/L.

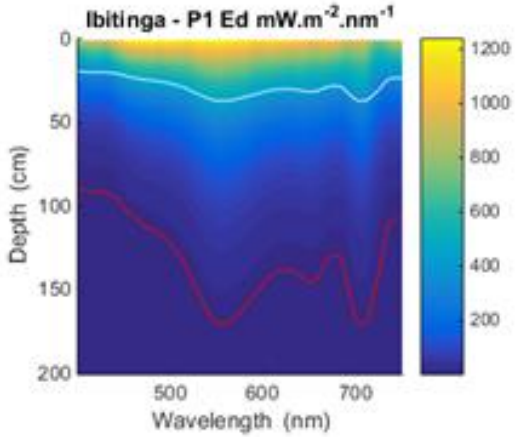
- ✓ In reservoirs the highest Total Suspended Solids (TSS) was 30 mg/L while at the Amazonian lakes was as high as 160 mg/L.

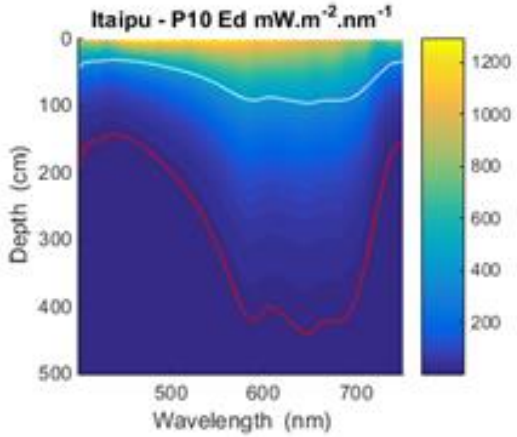
- ✓ The median value of beam attenuation coefficient (450 nm) reaches 5 m^{-1} in reservoirs and 19 m^{-1} at the Amazonian lakes.

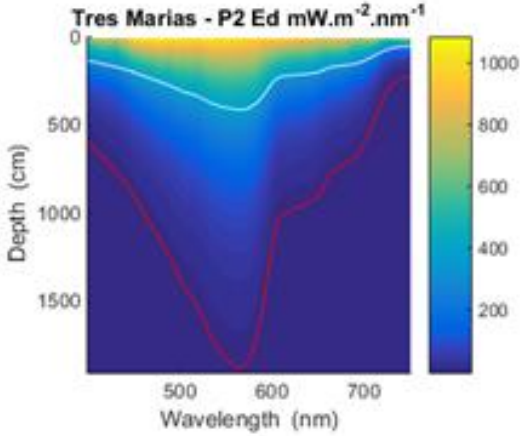
- ✓ The Kd (PAR)** reaches 1.5 m^{-1} in reservoirs and 3.3 at the Amazonian lakes

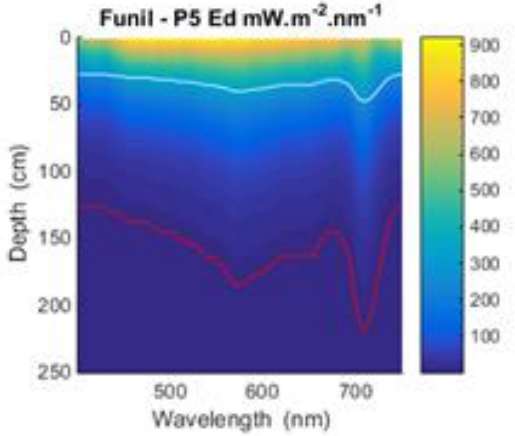
Spectral composition of normalized downwelling irradiance relative to surface incoming light (incident irradiance Es(λ)











Underwater light field:

Red curves are the depth of euphotic zone, and white curves are the attenuation depth (the thickness of the layer from which 90% of the signal recorded by satellite sensor originates).

Conclusion

Main difficulty faced ➔ The huge amount of data of each campaign

- ✓ Developing an interactive toolbox for processing and analyzing

- ➢ We are building a dataset which is the first and most comprehensive bio-optical information available for the Brazilian inland waters.

Some master dissertation and PhD Thesis

- OPTICAL MODELS AND IN SITU DATA COLLECTED IN FUNIL (RJ) RESERVOIR USED TO AID RESEARCHES ON REMOTE SENSING OF CONTINENTAL WATERS

- OPTICAL AND DISSOLVED ORGANIC CARBON CHARACTERIZATION IN TRÊS MARIAS/MG RESERVOIR

- TEMPORAL CHARACTERIZATION OF THE BIO-OPTICAL PROPERTIES OF THE IBITINGA/SP RESERVOIR

- BIO-OPTICAL MODELS TO SUPPORT THE RETRIEVAL OF OPTICALLY ACTIVE CONSTITUENTS IN AMAZON FLOODPLAIN LAKES

Obrigado