# 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

# In situ radiometric and bio-optical measurements at the Lower Amazon River

Aline de Matos Valerio
Milton Kampel

19-20, April 2016

# TROCAS

- This work is part of the Net Ecosystem Exchange of the Lower Amazon project (TROCAS), that seeks to unravel the sequences of processes and sources of terrestrially-derived organic matter that culminate in the immense $CO_2$ outgassing to the atmosphere.

# Summary

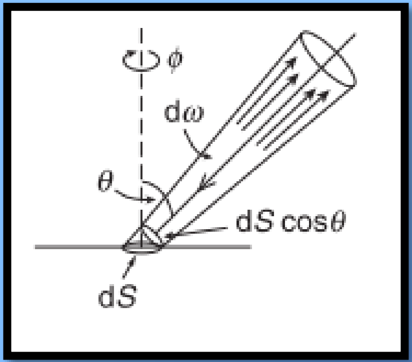
- IOP and AOP
- AOP:
  - Remote Sensing of Reflectance ($R_{rs}$)
  - Diffuse attenuation coefficient (Kd)
- IOP:
  - Absorption Coefficient
- Optical closure and the develop of an algorithm for the color of the water
- Lower Amazon River
- Preliminary results
- Discussion and ideas

# IOP and AOP

- The color of the water is determined by the scattering and absorption of incident light by the optically active constituents (OAC) as well as by the very pure water

**Optical Closure**

| **Apparent Optical Properties** | | **Inherent Optical Properties** |
|---|---|---|
| *L*<br>*R*<br>*E*<br>$K_d$ | **X**<br>**RTE** | a(λ)<br>b(λ)<br>VSF<br>c(λ) |




Kirk (2011)

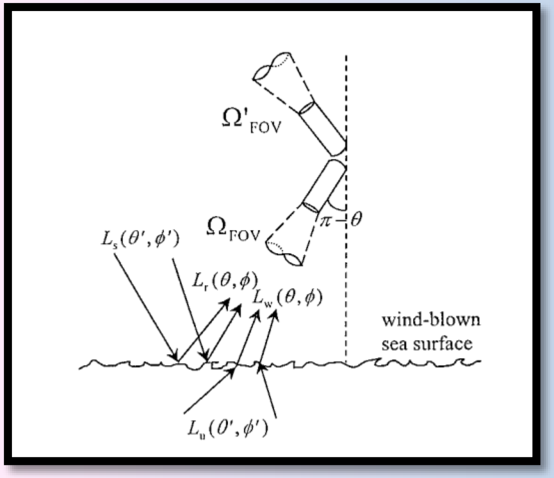
$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{cdom}(\lambda) + a_{det}(\lambda)$$

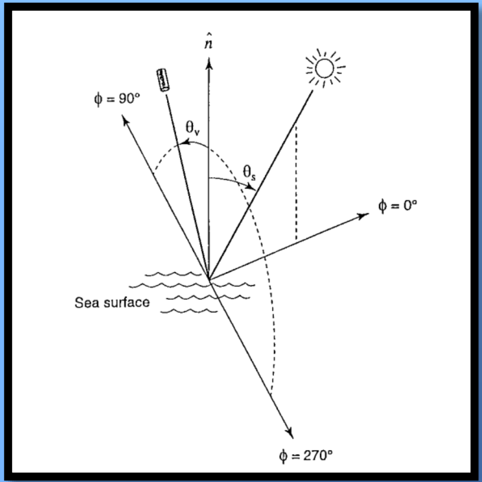
# Remote Sensing of Reflectance

- The Remote Sensing Reflectance ($R_{rs}$) it takes into account the reflected sky radiance as well the wind speed and the viewing geometry.

$$R_{rs} = \frac{L_w(0+)}{E_d(0+)} = \frac{L_u(0+) - pL_{sky}(0+)}{E_d(0+)}$$

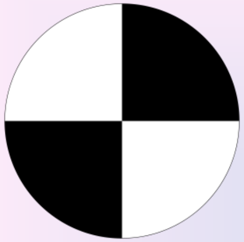
Mobley (1999)



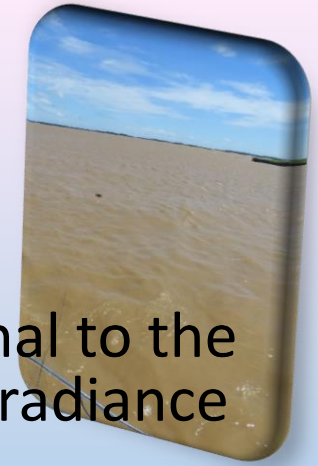



# Remote Sensing of Reflectance

- Residual glint correction
- Mobley (1999) and Ruddick (2006) suggest to do the residual glint correction.
- Garaba et al. (2013) discuss that there is no consensus of the best residual glint correction.
- Is it possible (or right) to correct in optically complex waters with highly scattering optically active materials?



# $K_d$ and Secchi Disk



- Secchi depht is approximately inversely proportional to the vertical attenuation coefficient  for downwelling irradiance ($K_d$)

$$K_d\,(PAR) = \frac{1.44}{\text{Secchi depht}}$$

Koenings and Edmundson (1991)

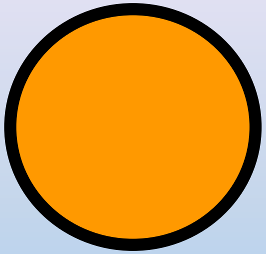
- In inland waters the relation between $K_d$ and Secchi Disk is not constant. Secchi depht is particularly sensitive to turbidity.

- For a given sun angle $K_d$ can be considered as a IOP or *quasi-IOP* Kirk (2011)

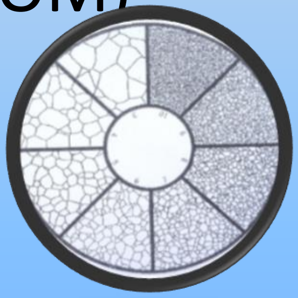
$$K_d\,(z, \lambda) = -\frac{1}{E_d(\lambda)}\frac{dE_d}{dz}$$

Mobley (1994)

# Bio-optical properties

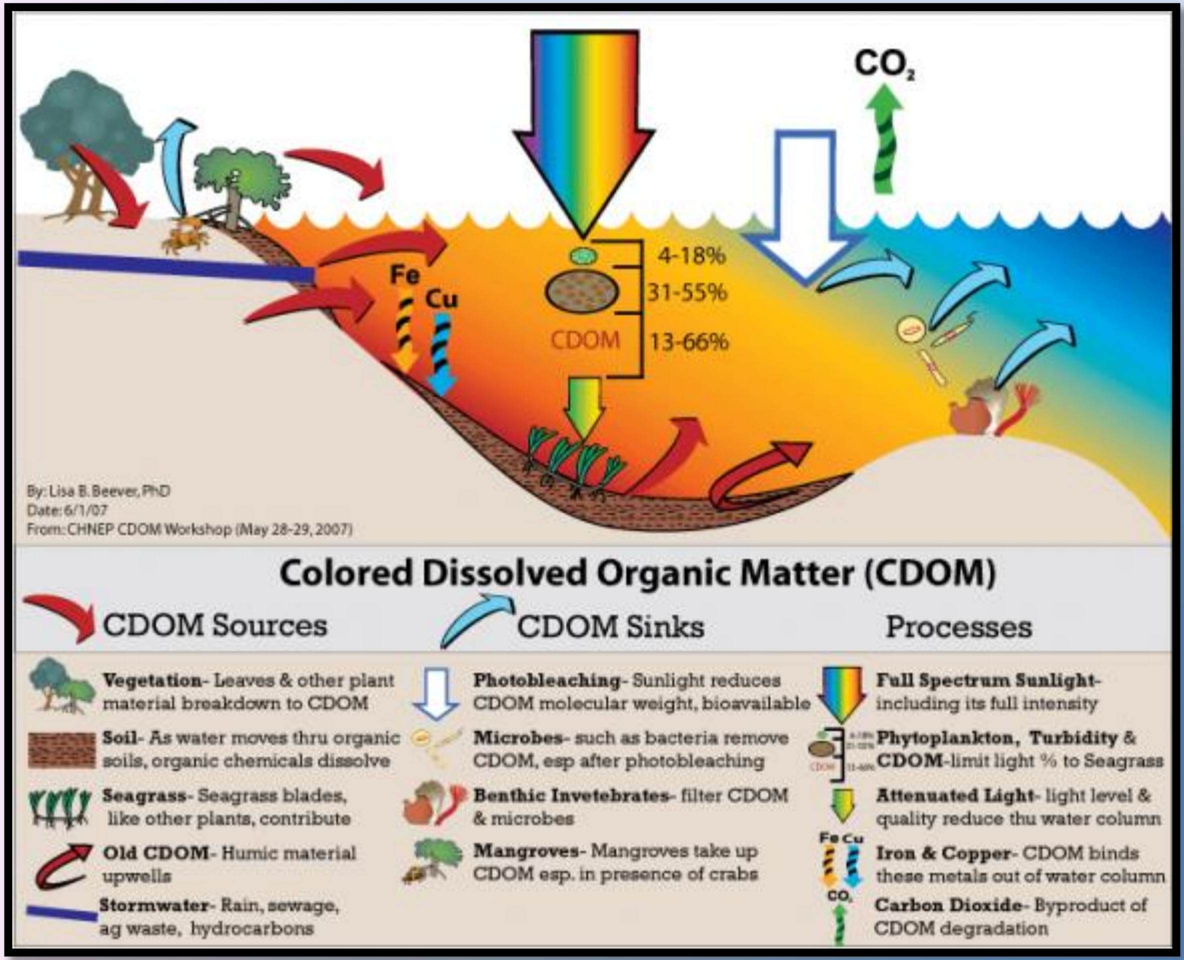


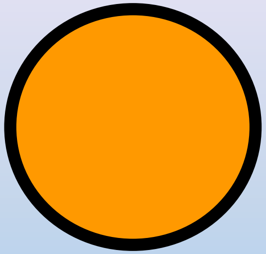
- Absorption coeficiente of:
  - Chromophoric Dissolved Organic Matter (CDOM)
    - Spectral parameter: Slope of de CDOM
  - Suspended particulate matter
    - NAP
    - Phytoplankton

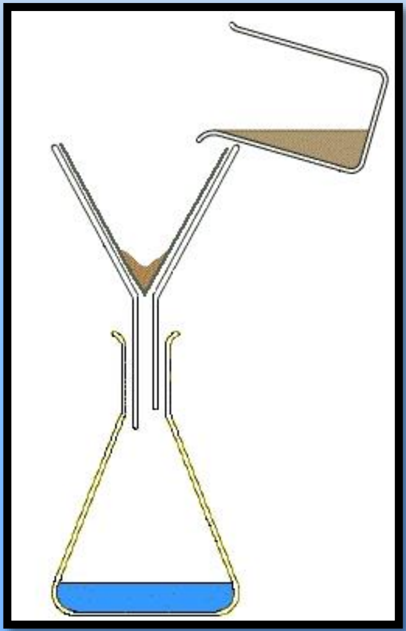


- Chlorophyll-*a* concentration (chl-*a*)

# Chromophoric Dissolved Organic Matter



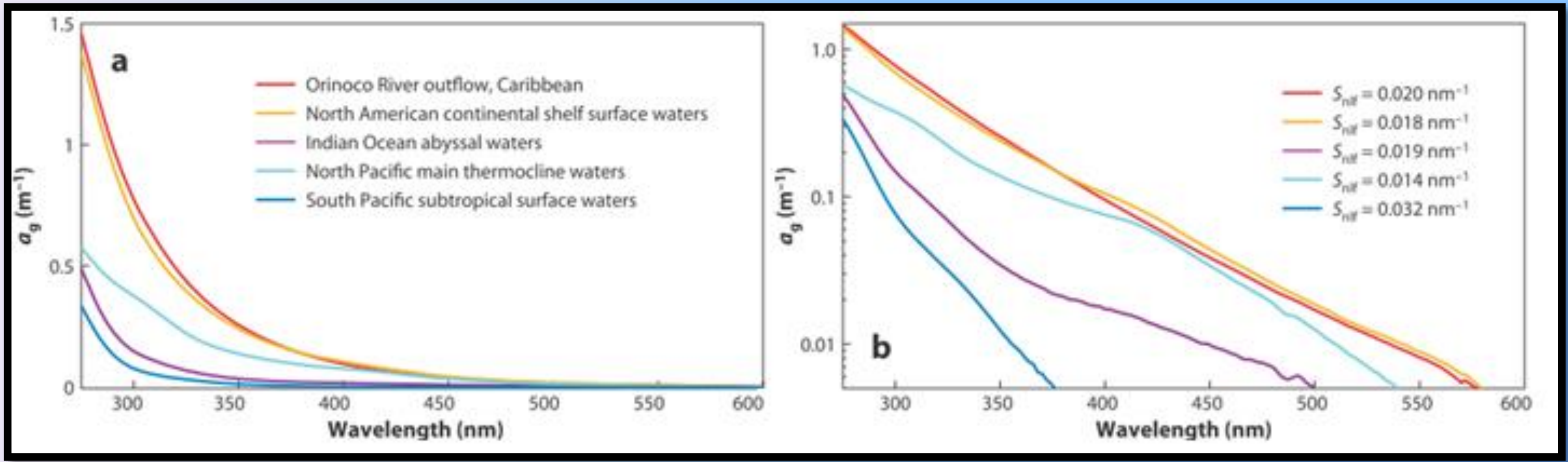





Filter 0.2 µm

# Chromophoric Dissolved Organic Matter

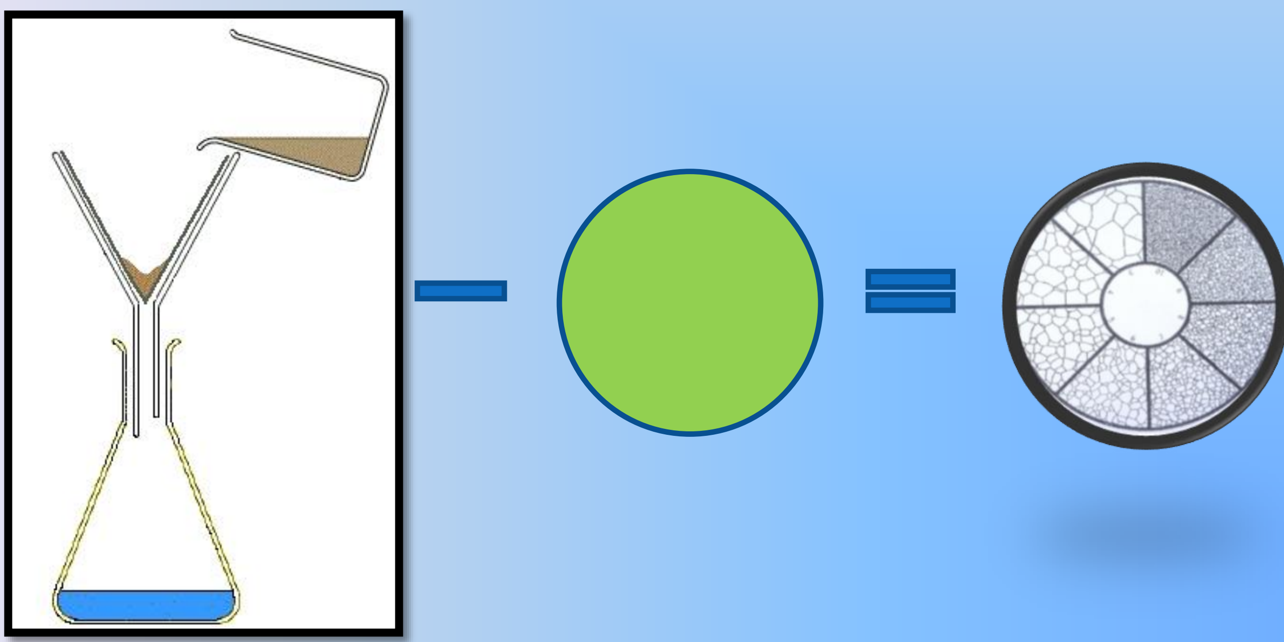
- Slope of the CDOM
  - The absorption of the CDOM is typically modeled as an exponential function in which a spectral slope parameter (*S*) describes de rate of decrease in absorption with increase of wavelength.




Nelson & Siegel, 2013

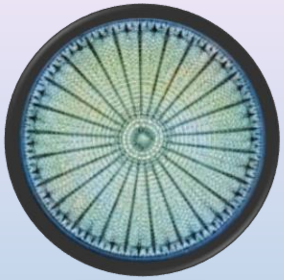
# Suspended particulate matter

A collective name for solid particles in the water which is trapped on a 0.7 µm filter.



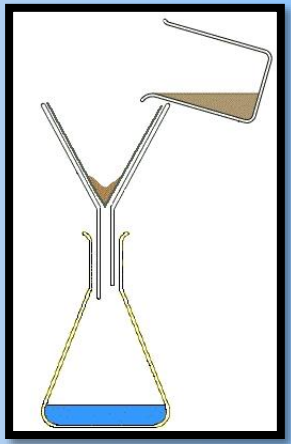
ap(total) aphy aNAP

# Chlorophyll-*a* concentration



•Chlorophyll is a key biochemical component that is responsible for photosynthesis.

•Chlorophyll is essential to the existence of phytoplankton. Phytoplankton can be used as an indicator organism for the health of a particular body of water.



Filter 0.7 µm

# Algorithm for complex freshwater environments

- There are several studies that estimate and monitor the bio-optical properties by remote sensing in waters dominated by phytoplankton, as the oceans. However, the use of remote sensing to study the bio-optical properties of optically complex waters such as rivers, faces some challenges that must be overcome.
- From an optical point of view, the lack of a direct relationship between the NAP absorption and the phytoplankton makes difficult the general parameterization of the optical properties. Thus, bio-optical algorithms develop for ocean applications can peform poorly when applied in inland waters.
- Thus, it is necessary to develop or adjust algorithms proper to inland waters and estimate the COA individually. The difficult of estimating individually COA comes from the similarity of the spectral curve of NAP and CDOM absorption. Therefore, new algorithms are based on diferences in their backscattering curves in the visible region near 555 nm (Matsuoka et al., 2013; Zhu, Yu, 2013) or the relationship between the ratio of Kd and aCDOM (Loisel et al., 2014).

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# Algorithm for complex freshwater environments

- Empirical (band ratios)

Band ratio
Regression
Less knowledge about IOP X AOP
Limited to similar Waters

- Semi-analytical
- Matrix inversion methods

# Algorithm for complex freshwater environments

- Empirical (band ratios)
- Semi-analytical
  - RTE
  - IOP X AOP
  - Different types of water
  - Needs empirical relationships
- Matrix inversion methods

# Algorithm for complex freshwater environments

- Empirical (band ratios)
- Semi-analytical
- Matrix inversion methods

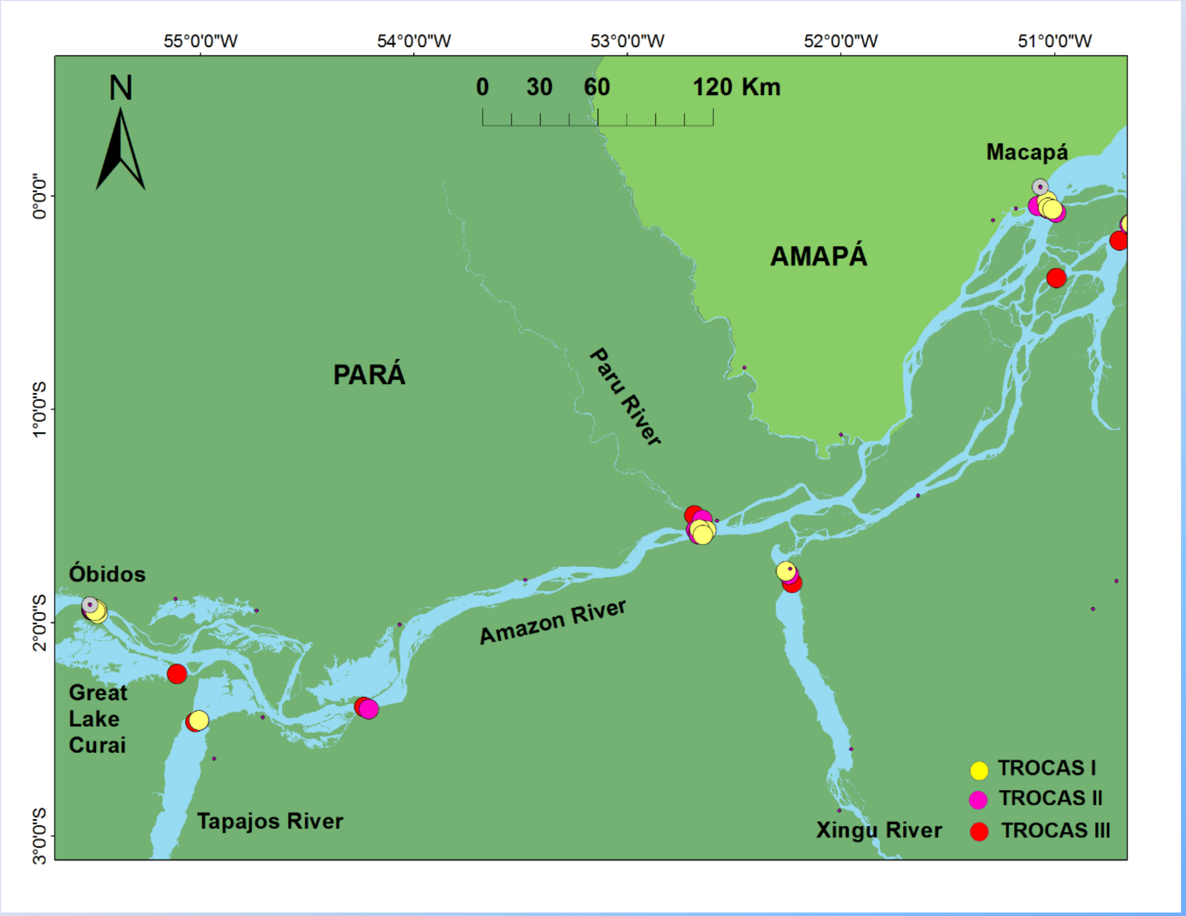
Uses semi-analytical method
Require knowledge of specific IOP (SIOPs)
Generally not applicable across different environment without field measured SIOPs

# Presentation Objective

- Present the in situ radiometric and bio-optical data collected until the moment to subsidize the discussion about my PhD goal: develop na algorithm to estimate CDOM and NAP separately.

- Why estimate CDOM and NAP separately?

# Study Area



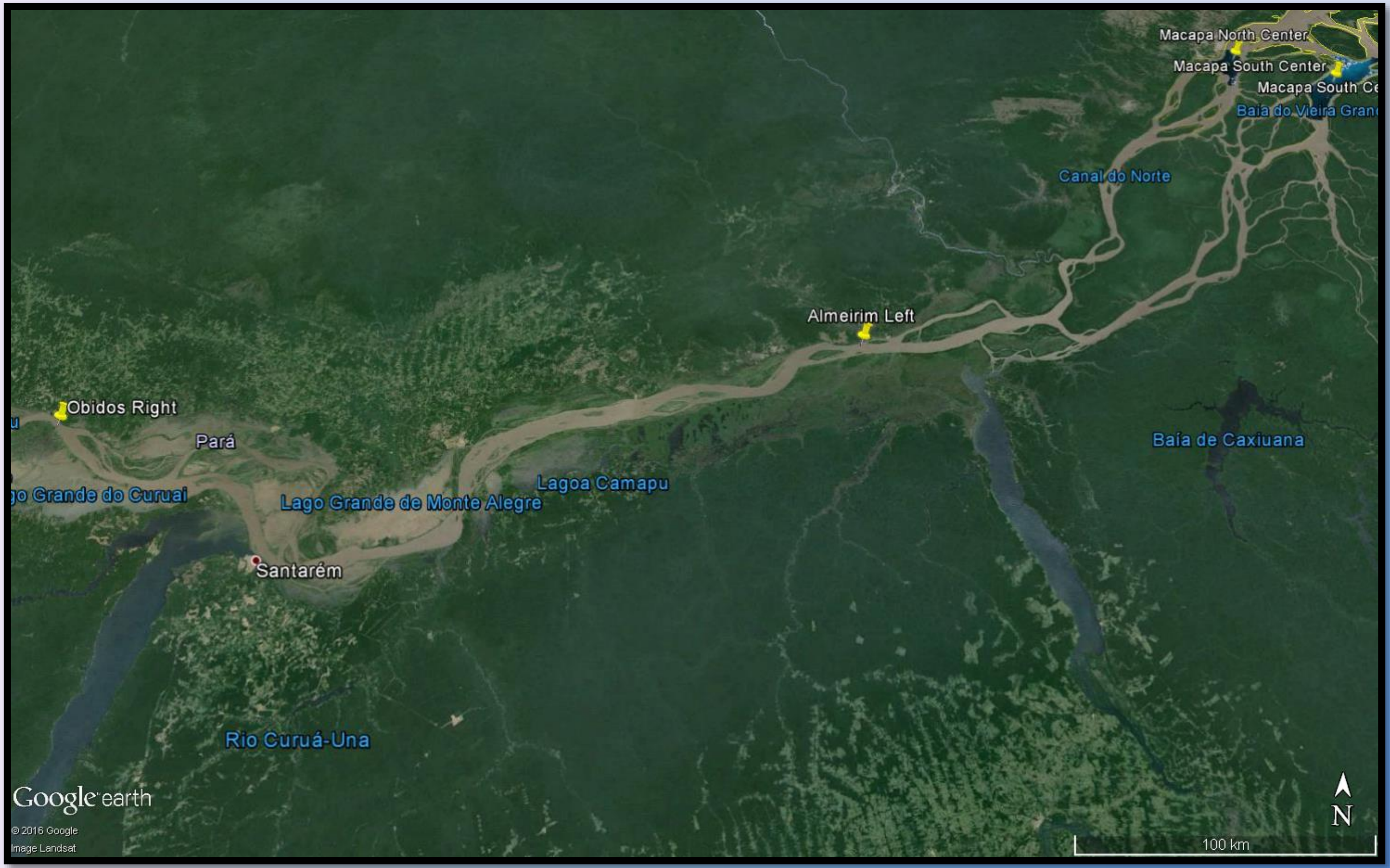

TROCAS I: Rising water (May)

TROCAS II: Low water (November)

TROCAS III: Falling water (July)

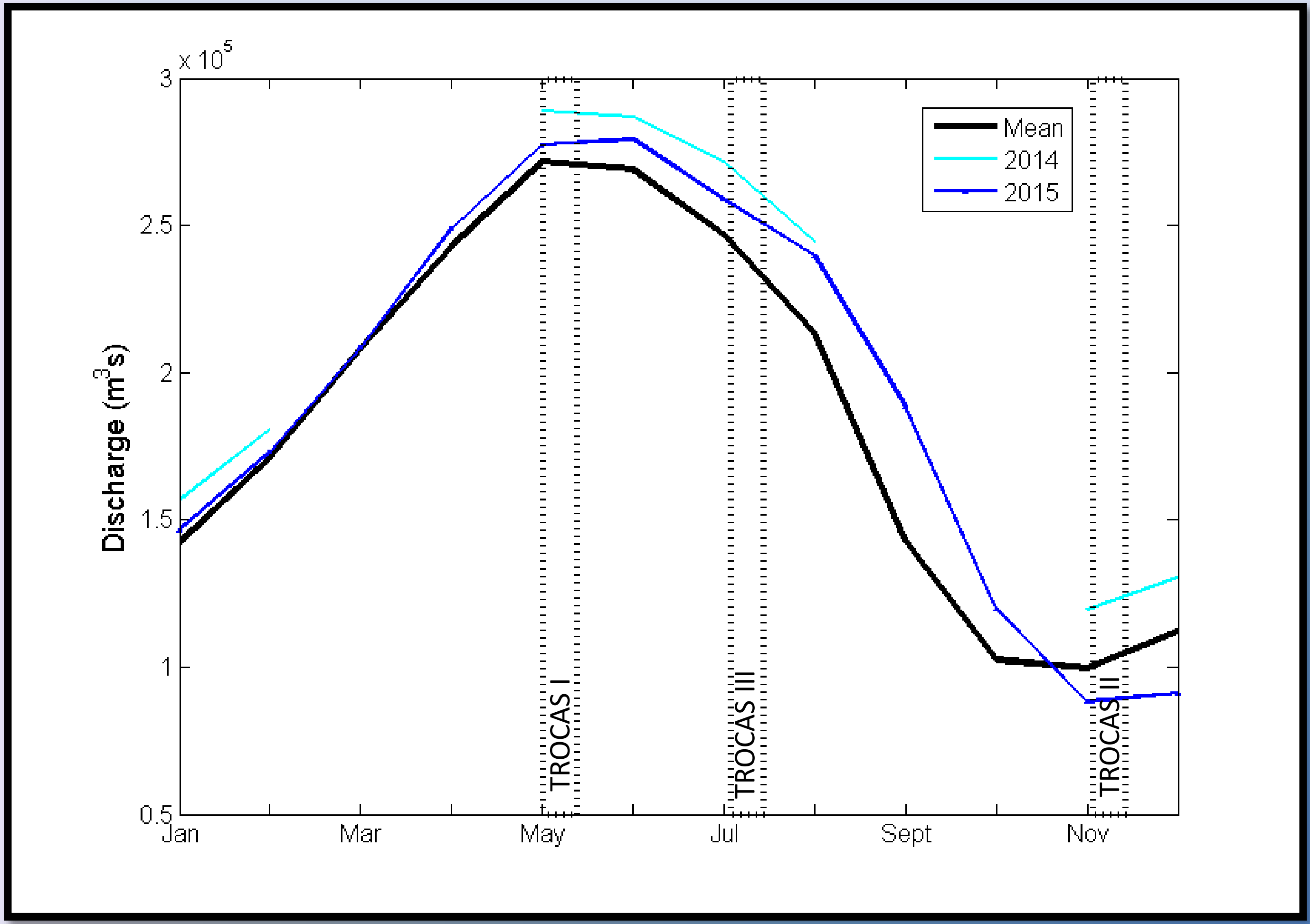
Despite of the Lower Amazon region be hydrologically relevant as it has already received the contribution of all major tributaries of the Amazon River, there is still a gap in the remote sensing literature.

# Study Area



Macapa North Center
Macapa South Center
Baía do Vieira Grand
Canal do Norte
Almeirim Left
Obidos Right
Pará
Baía de Caxiuana
Lagoa Camapu
Lago Grande de Monte Alegre
Santarém
Rio Curuá-Una
Google earth
© 2016 Google
Image Landsat
N
100 km

# Study Area




Discharge data obtained at ANA station in Obidos

Mean discharge (2005-2015)

# Methods

- Radiometric measurements:
  - Above water: FieldSpec ASD
  - In water: Satlantic Profile
- Residual Glint Correction:
  - Kutser et al. 2013
- Ratio of NIR wavelenghts:
- Turbid waters (Ruddick et al., 2006)
- Secchi Disk

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$L_u \longrightarrow R_{rs}$

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$L_u$ $E_d$ $K_d$
$R_{rs}$ PAR

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# Methods

- Radiometric measurements:
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$L_u$ $E_d$ $K_d$
$R_{rs}$ PAR

Fluorimeter for chl-a
Backscattering 470 and 700 nm
Temperature

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Problems:
Highly turbid water
Fluorimeter doesn’t work – too much sediments
Bb (470 nm and 700 nm) doesn’t work: saturates
Extinction of the light in the first meters (~3 m)
Too much tilt in the first meters.

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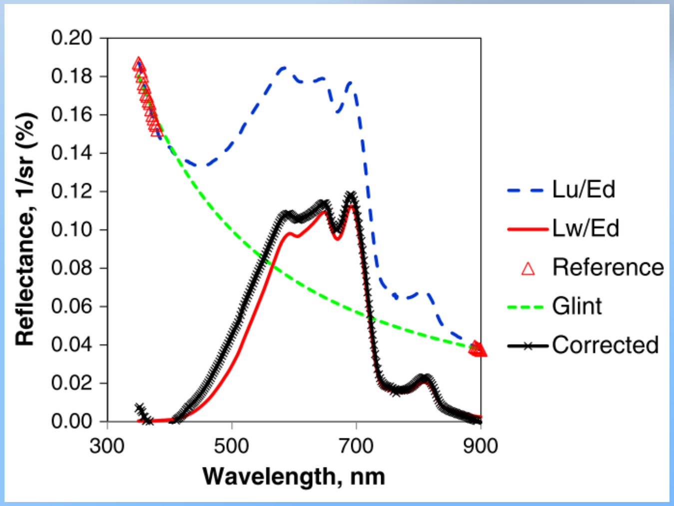


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Problem:
Strong waves at Macapa
and too turbid water

# Methods

- Absorption Coefficients:

- The filtered samples were storaged at ultrafreezer during the cruise.

- After the cruise the samples of absorptions coefficients were read using a spectrophotometer.

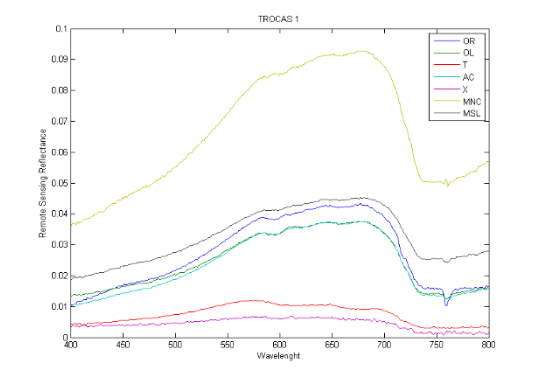
- A bench fluorimeter was used to read the chl-*a*.

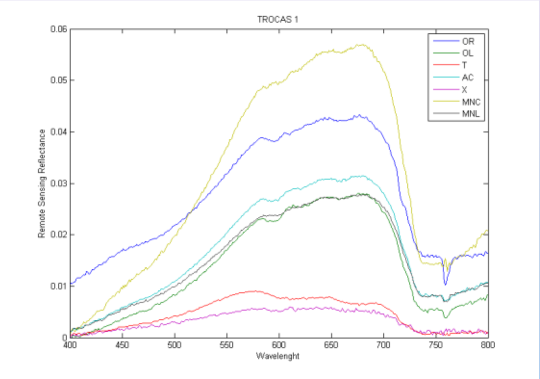
# Results

$R_{rs}$ (Mobley 1999)

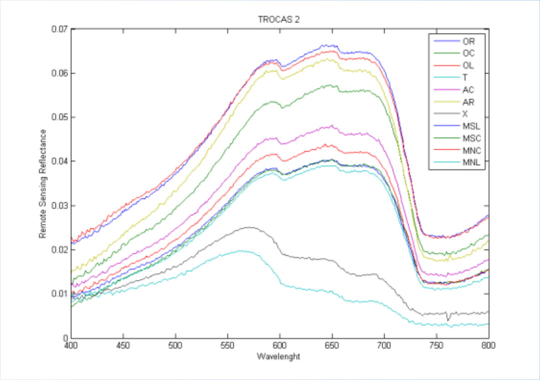
$R_{rs}$ (Kutser et al., 2013)

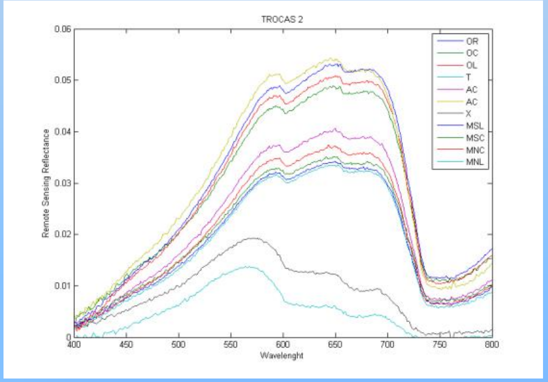
T1



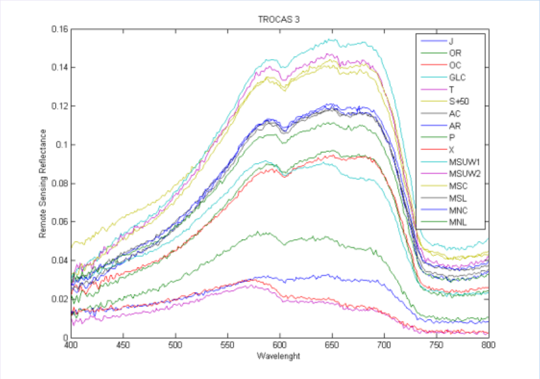



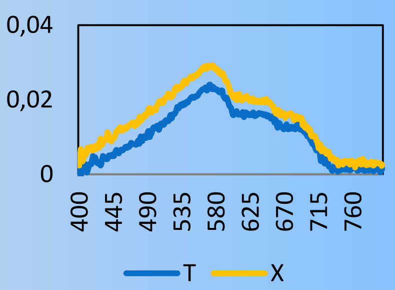

T2

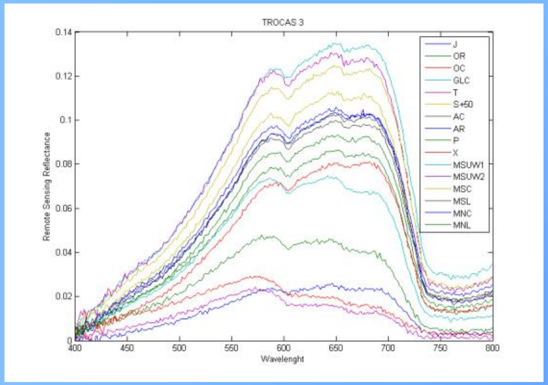



T3



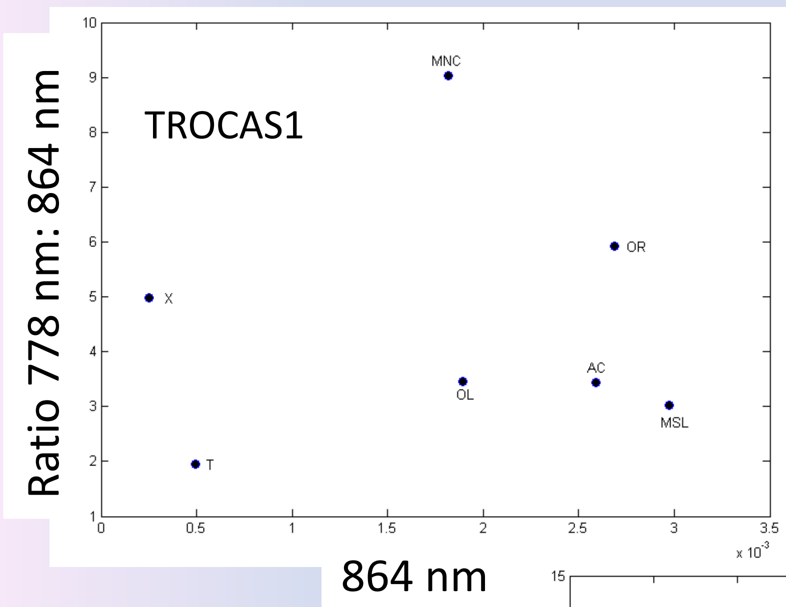



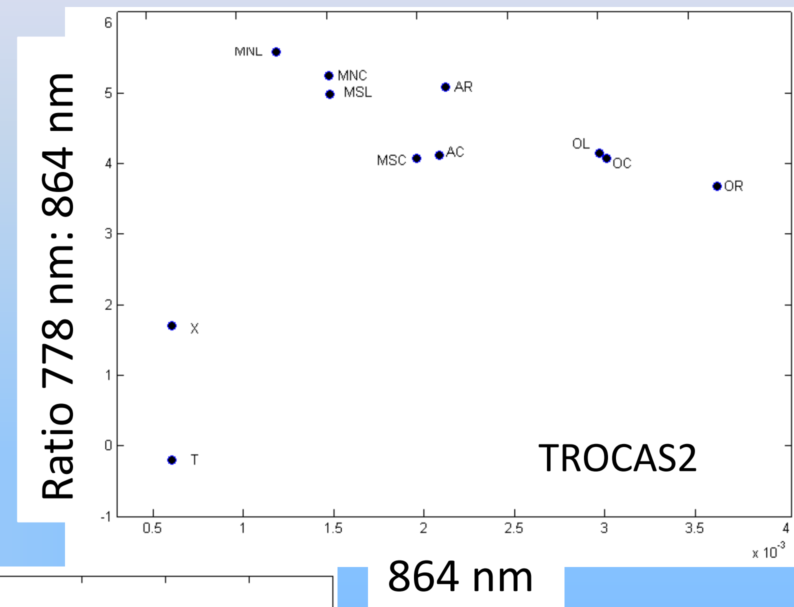



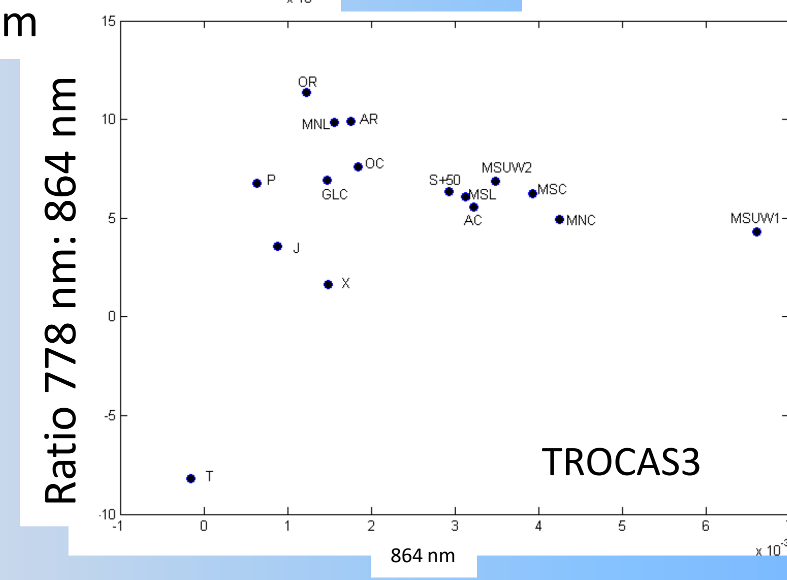
# Results

CLEAR

EXTREMELY TURBID

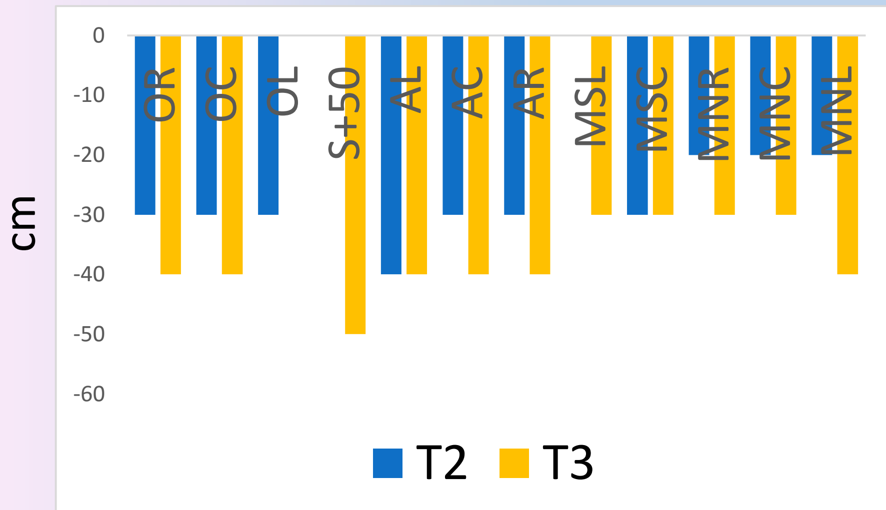


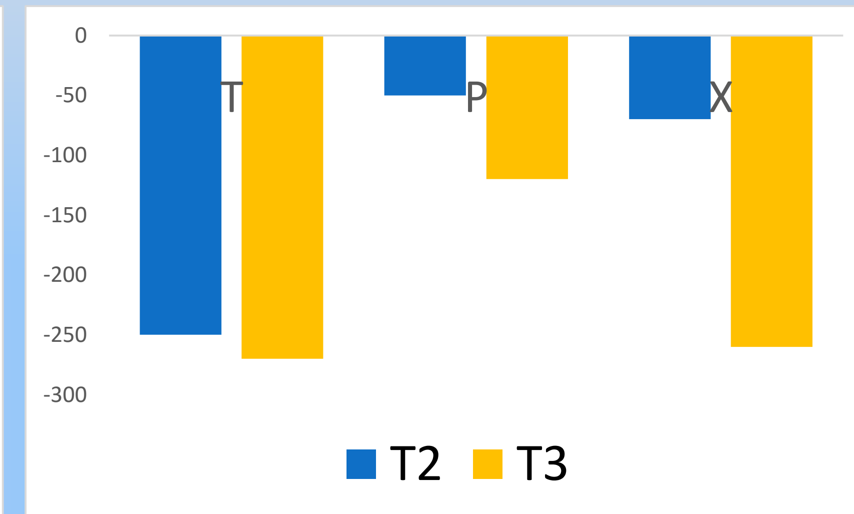



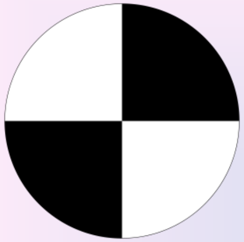
# Results

Amazon River




Clear water River





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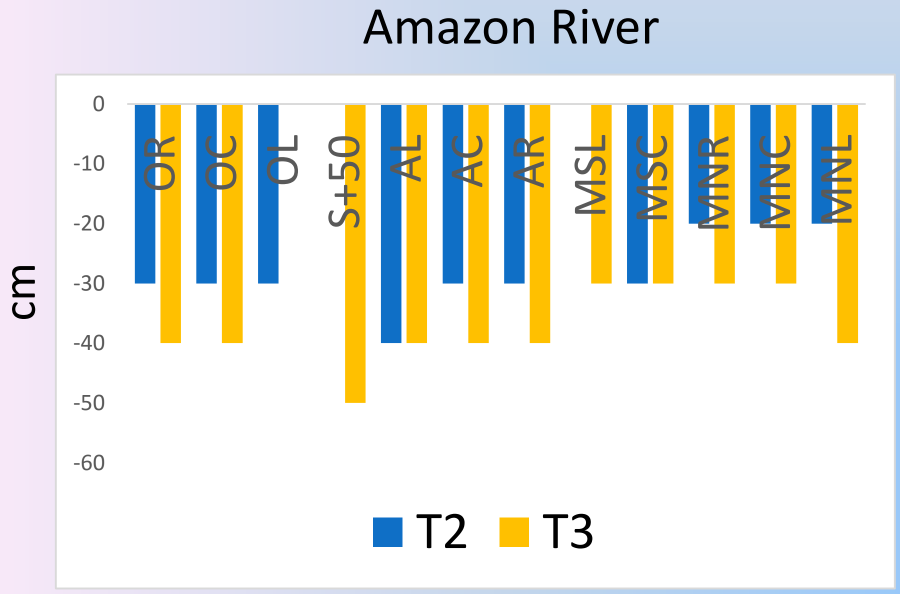
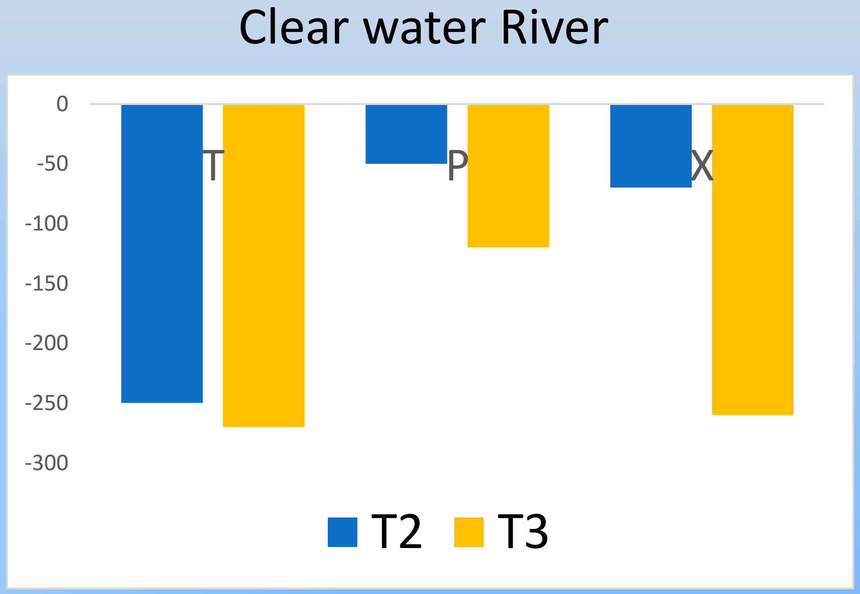
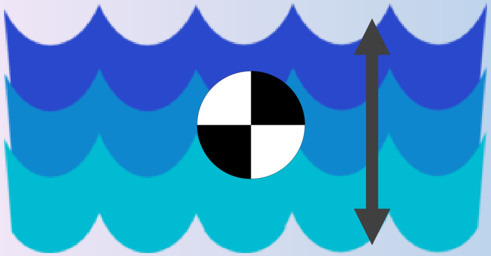


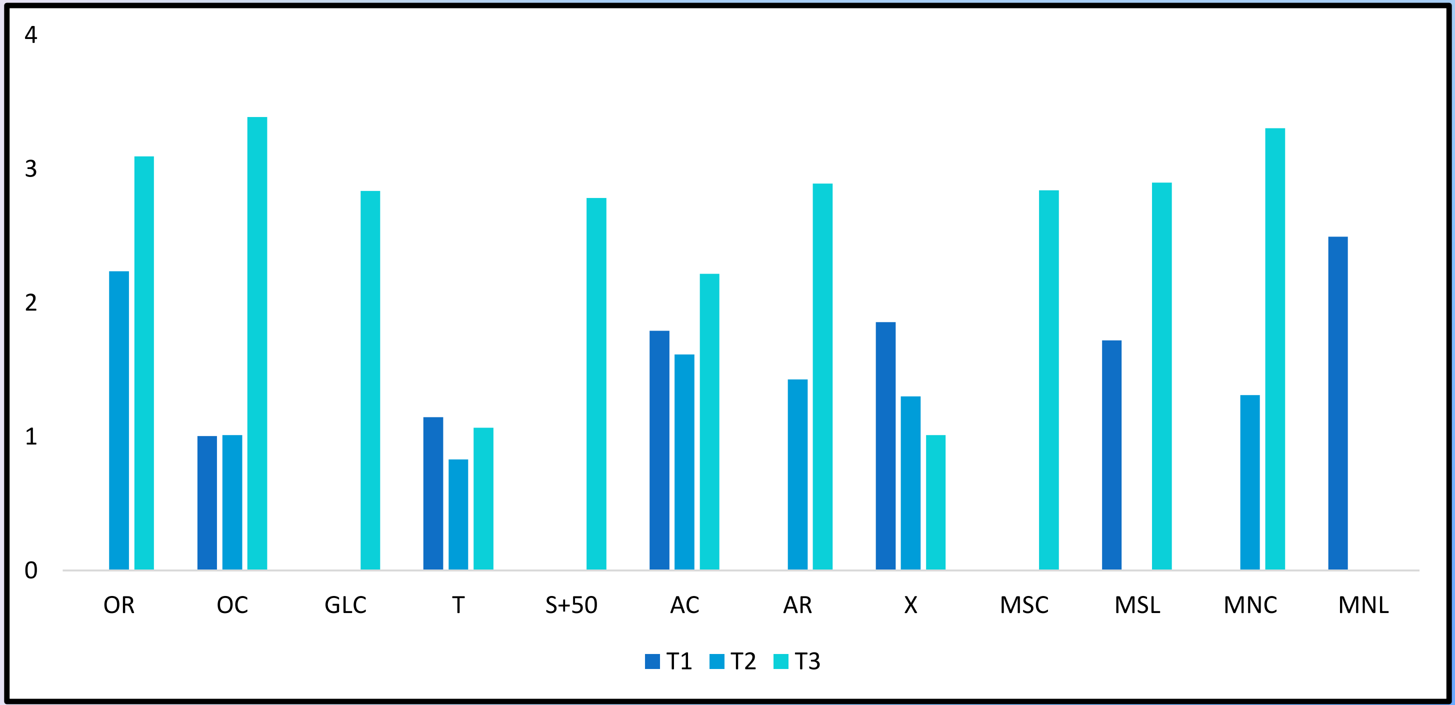
Problem: Besides strong waves at Macapa and too turbid water, all the Lower Amazon region are influenced by the tide and sometimes the Amazon River intrudes others rivers in certain times of the day.

Uncertainty due the visual inspection

# Results

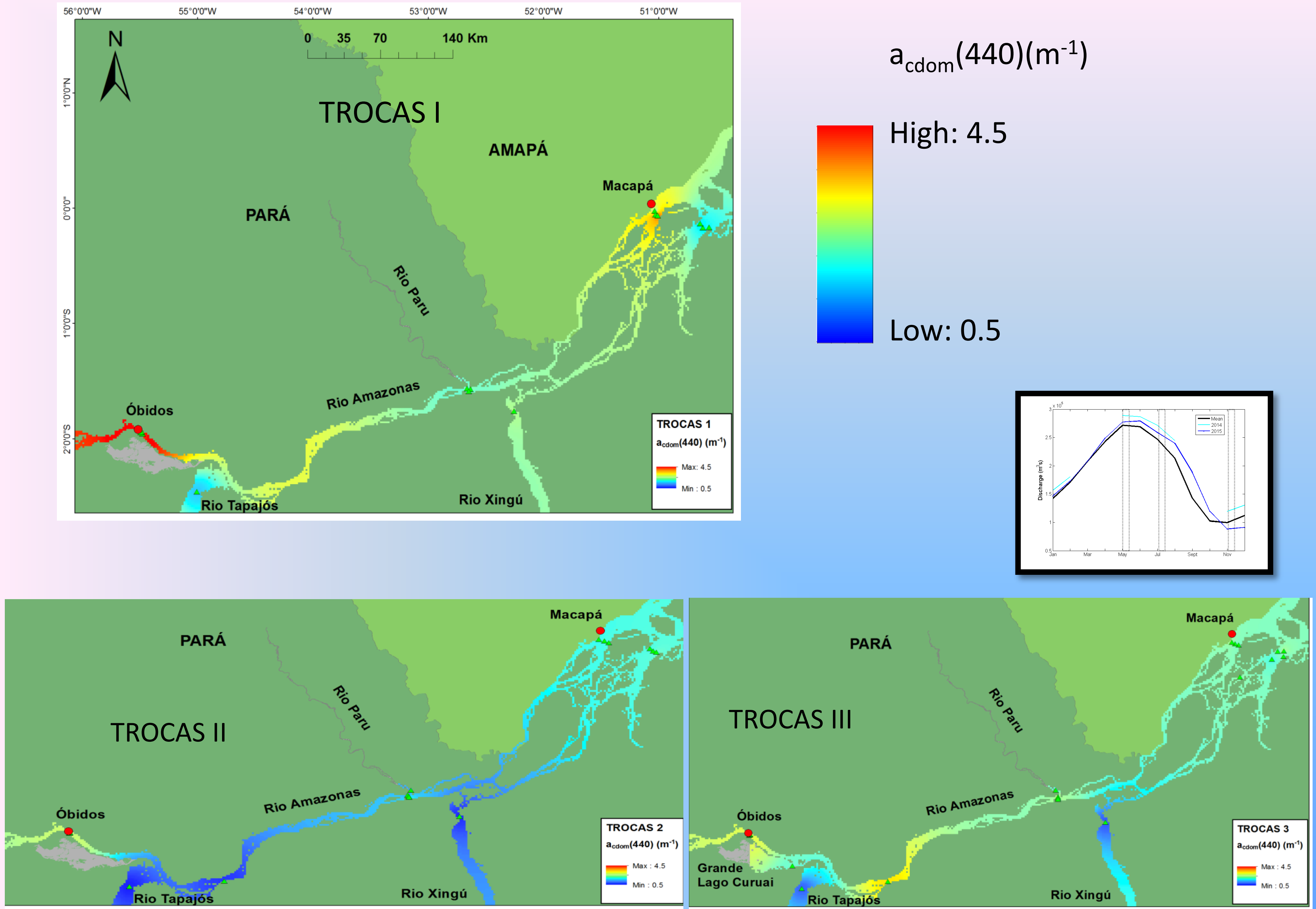
- Satlantic data: Still working on!

$K_d$(PAR)

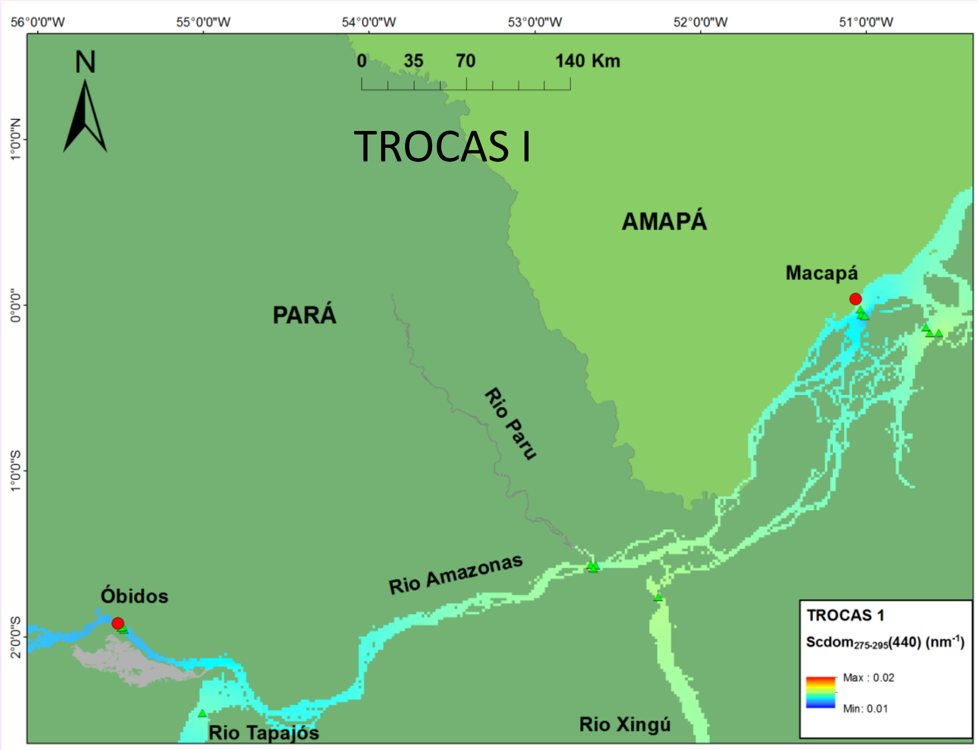



$K_d$(PAR) > 2 $m^{-1}$ = turbid waters

Kirk (2011)
and Koenings and Edmundson (1991)



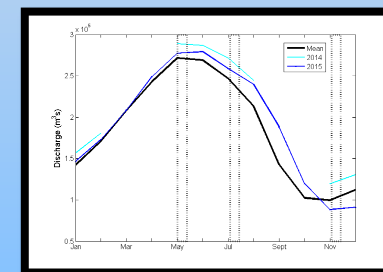
TROCAS I
56°0'0"W
55°0'0"W
54°0'0"W
53°0'0"W
52°0'0"W
51°0'0"W
1°0'0"N
0°0'0"
1°0'0"S
2°0'0"S
N
0 35 70 140 Km
AMAPÁ
PARÁ
Macapá
Rio Paru
Rio Amazonas
Óbidos
Rio Tapajós
Rio Xingú
TROCAS 1
$a_{cdom}(440)$ ($m^{-1}$)
Max: 4.5
Min : 0.5
$a_{cdom}(440)(m^{-1})$
High: 4.5
Low: 0.5
Mean
2014
2015
Jan
Mar
May
Jul
Sept
Nov
TROCAS II
PARÁ
Macapá
Rio Paru
Rio Amazonas
Óbidos
Rio Tapajós
Rio Xingú
TROCAS 2
$a_{cdom}(440)$ ($m^{-1}$)
Max : 4.5
Min : 0.5
TROCAS III
PARÁ
Macapá
Rio Paru
Rio Amazonas
Óbidos
Grande
Lago Curuai
Rio Tapajós
Rio Xingú
TROCAS 3
$a_{cdom}(440)$ ($m^{-1}$)
Max : 4.5
Min : 0.5




$S_{cdom}(275\text{-}295)(nm^{-1})$

High: 0.02

Low: 0.01

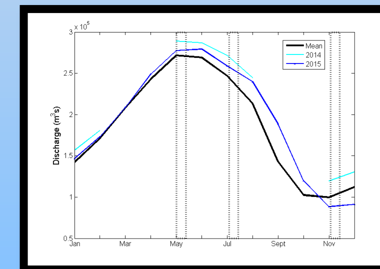


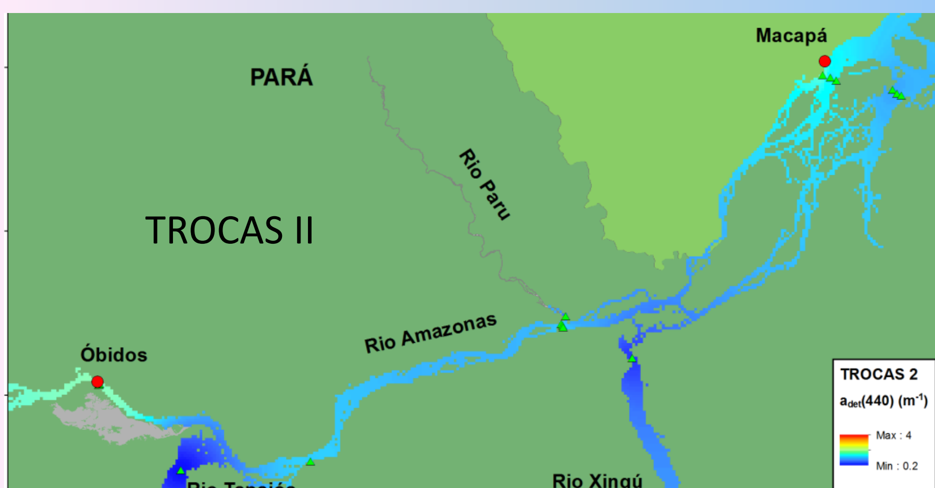


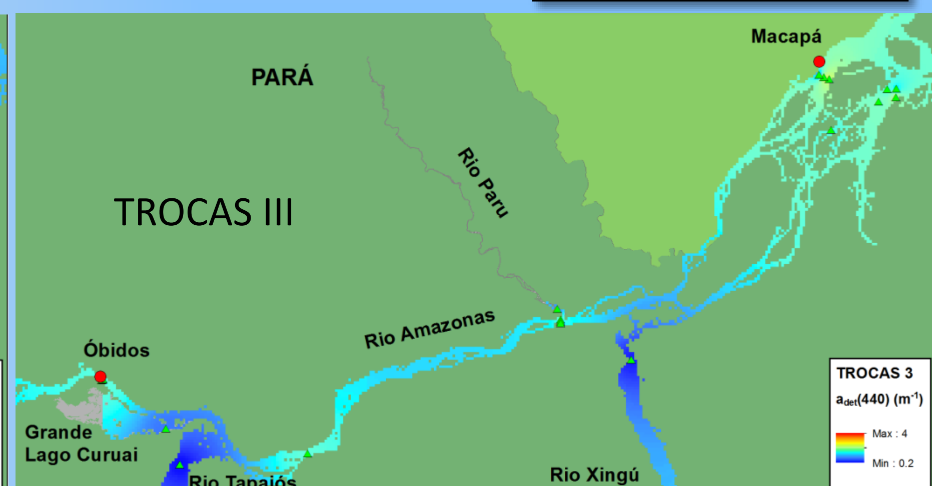

$a_{det}(440)(m^{-1})$

High: 4

Low: 0.2

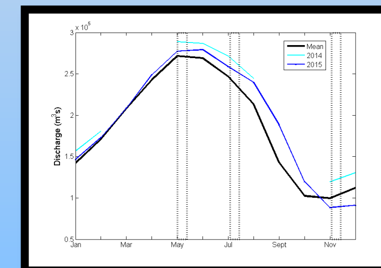


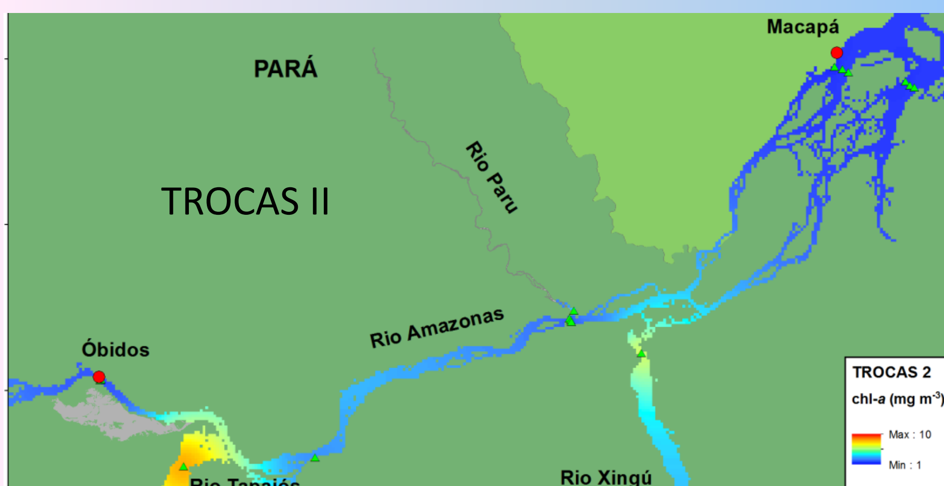



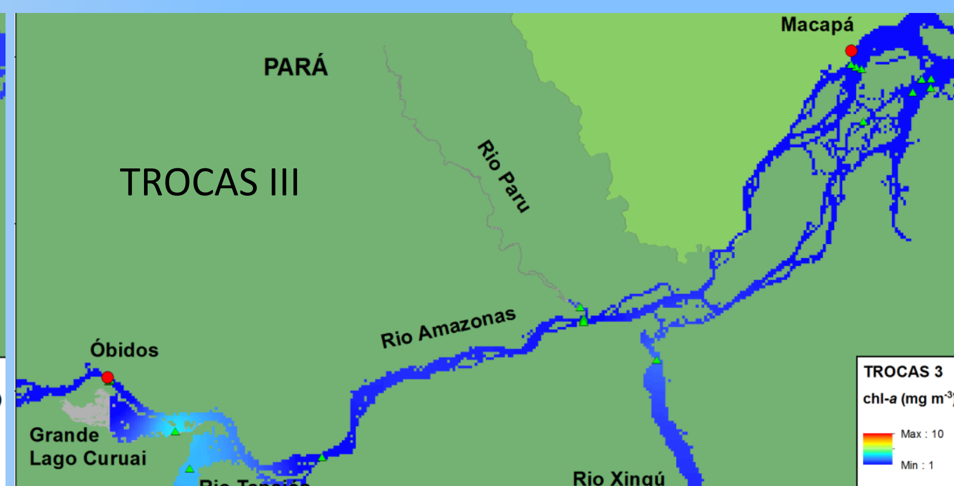



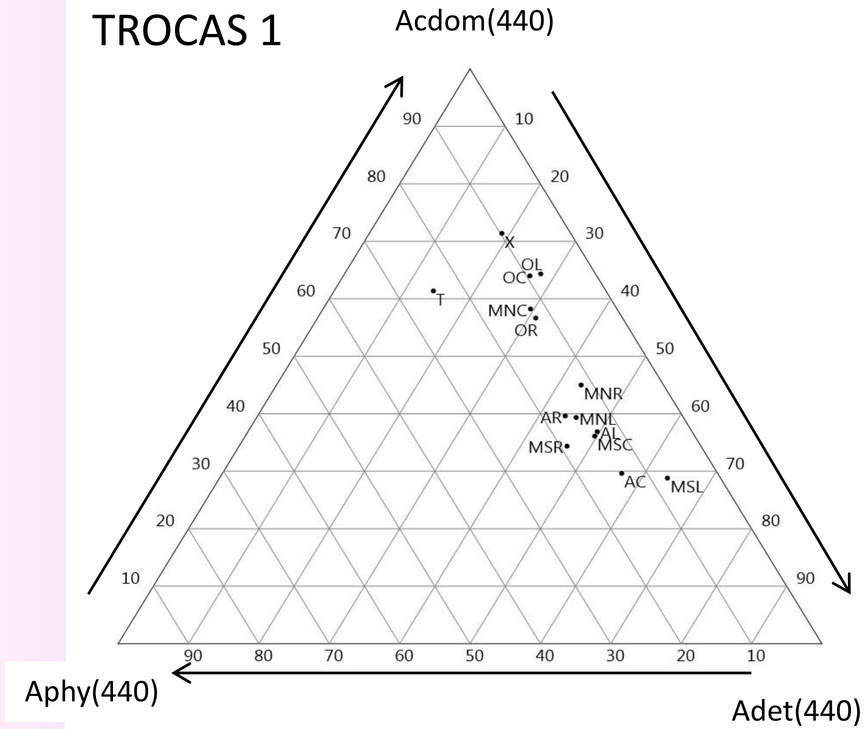

chl-*a*(mg m$^{-3}$)

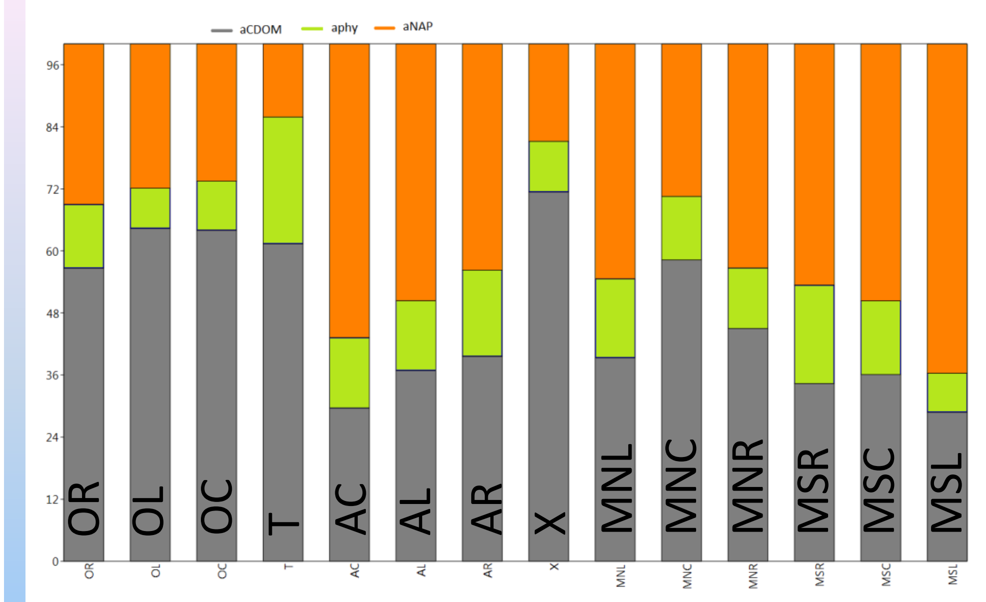

| | Min | Max |
|---|---|---|
| T1 | 0.39 | 28.29 |
| T2 | 1.25 | 8.80 |
| T3 | 0.39 | 3.78 |



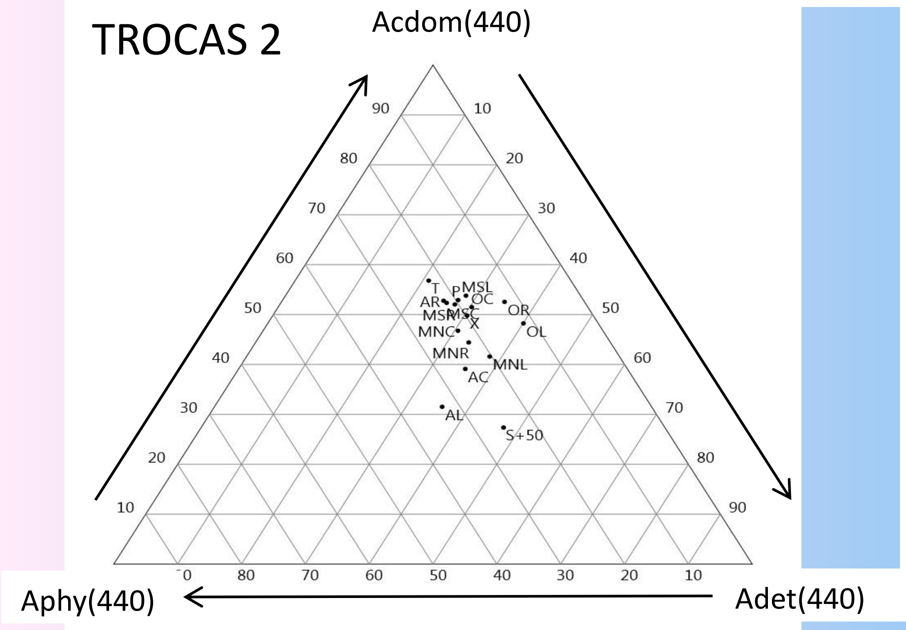



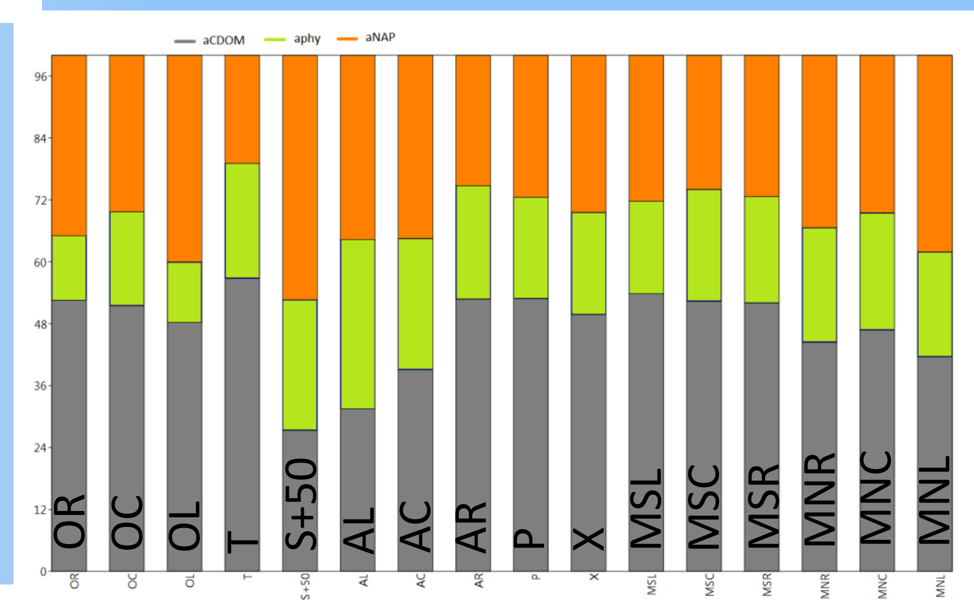





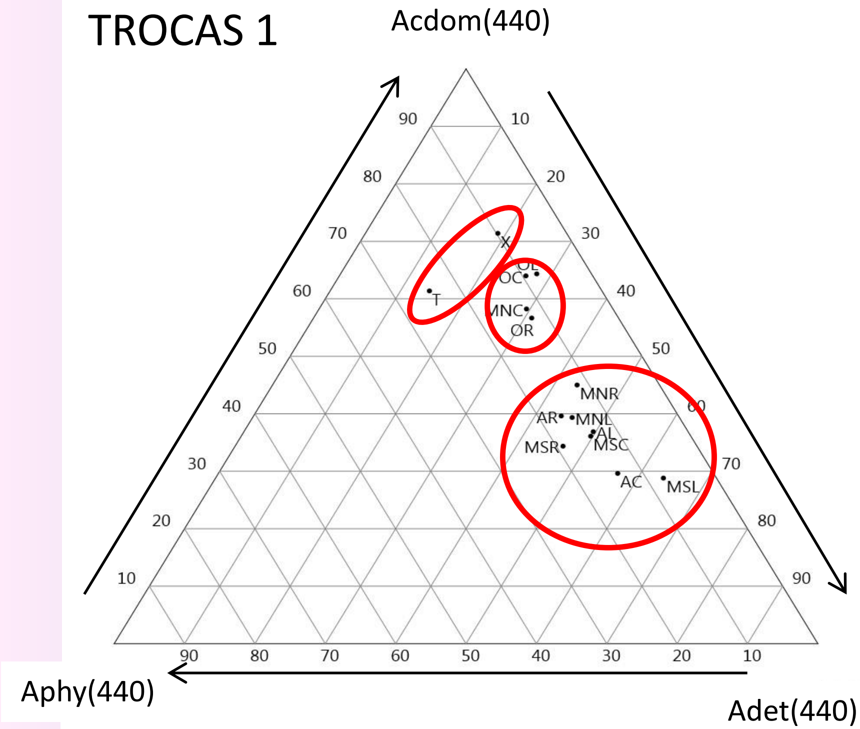



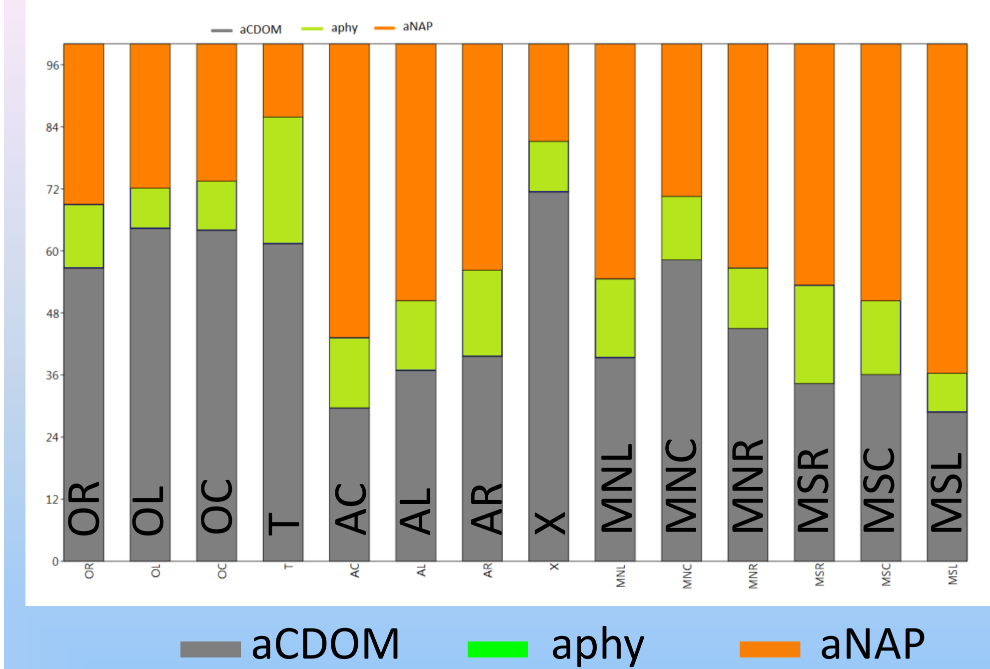

aCDOM aphy aNAP



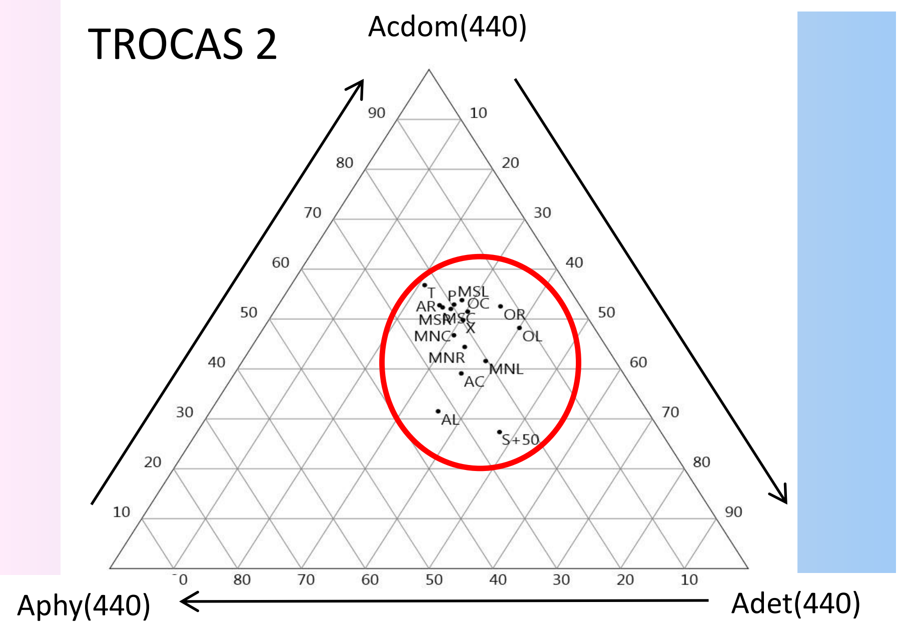



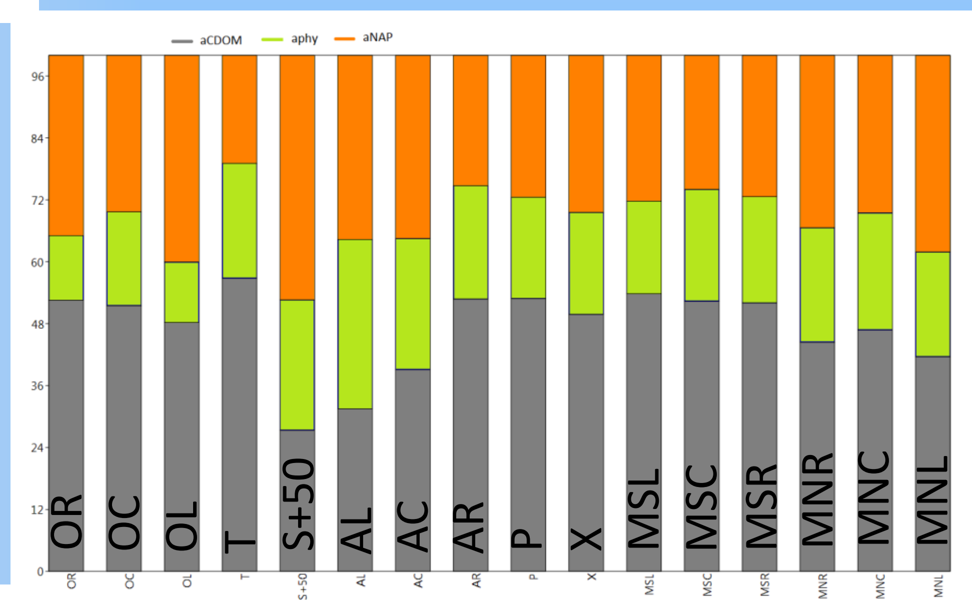
# TROCAS 1

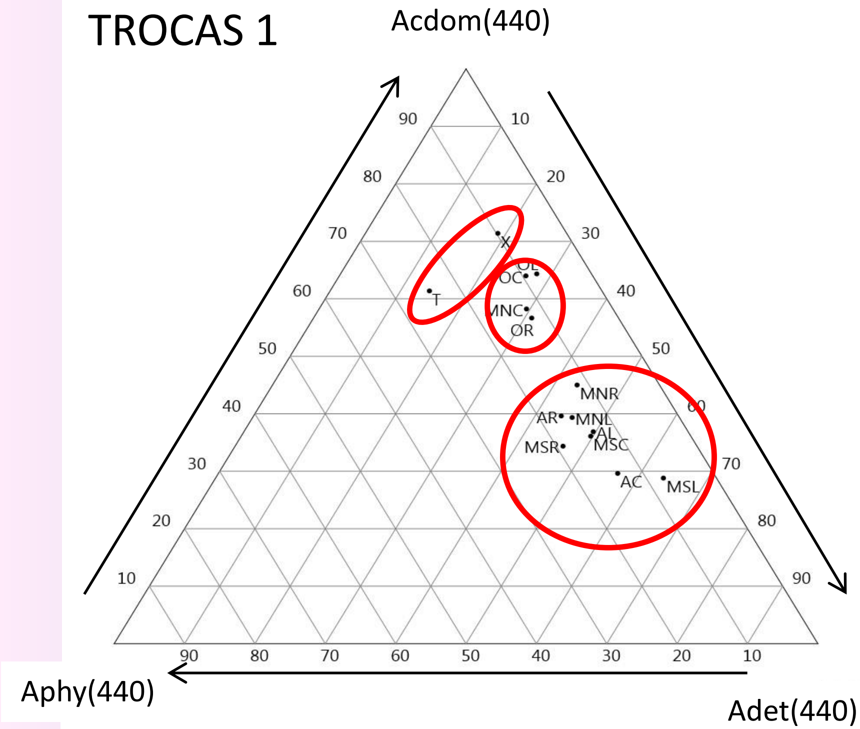


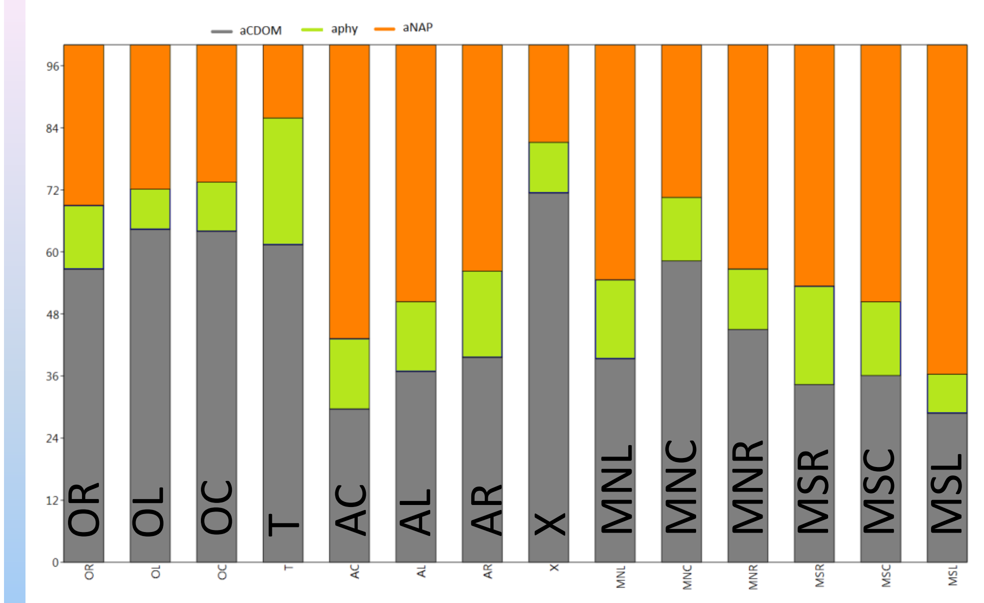




# TROCAS 2

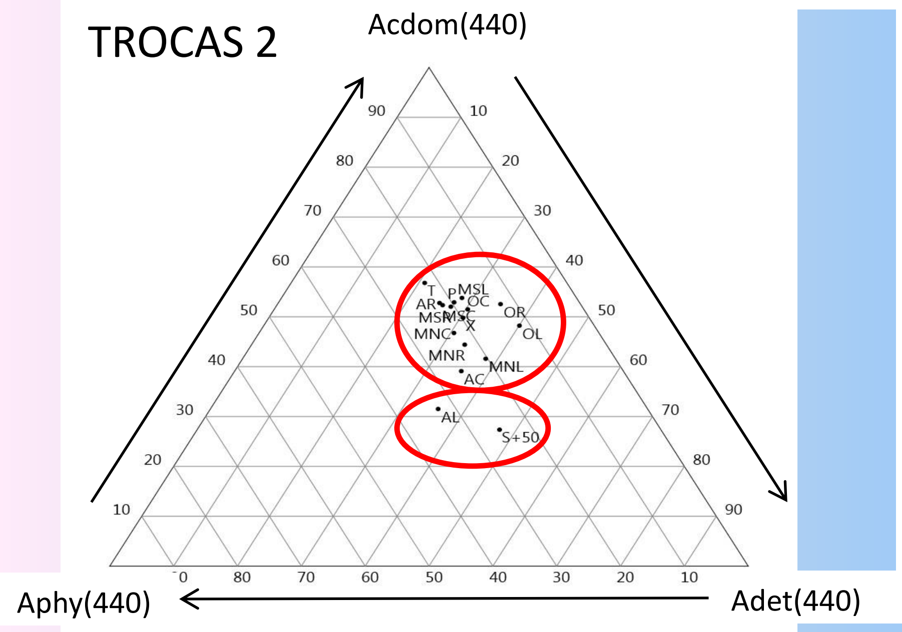


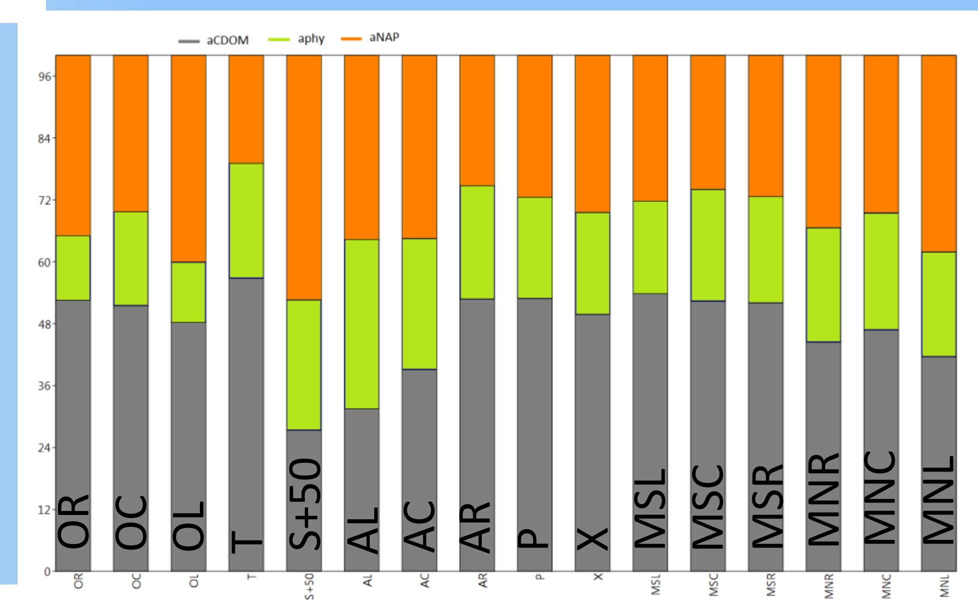





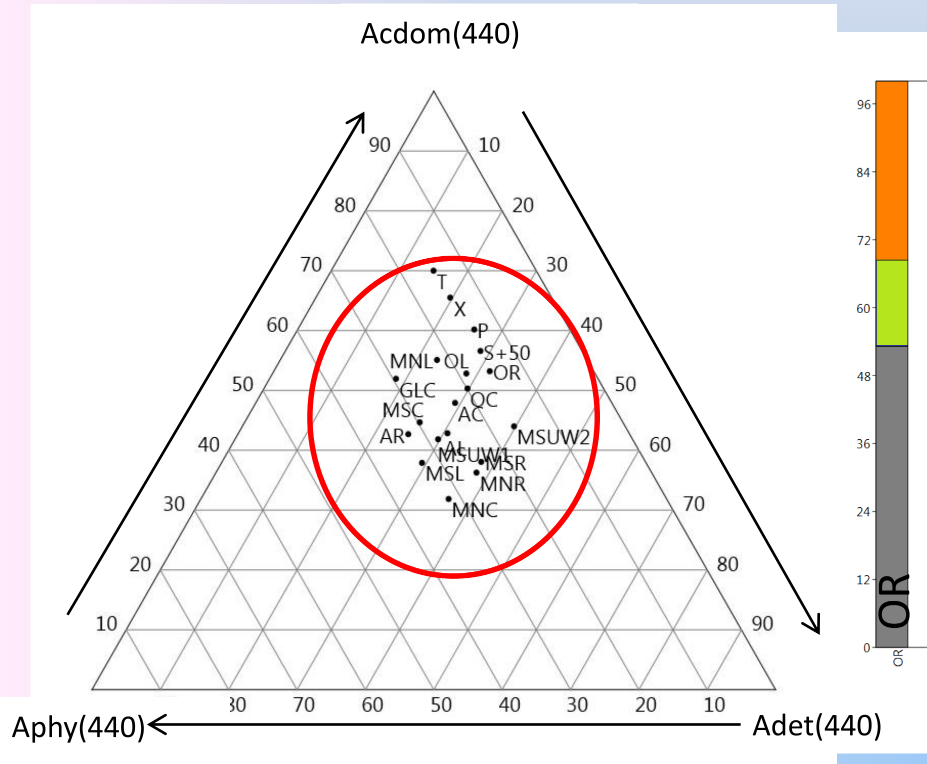



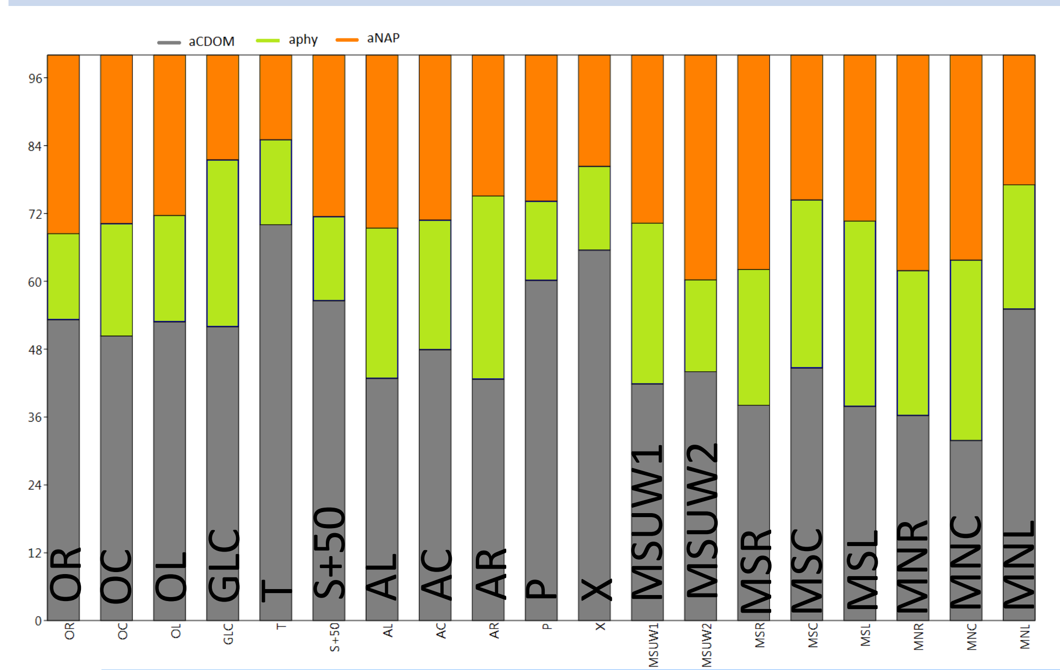

aCDOM aphy aNAP



TROCAS 3



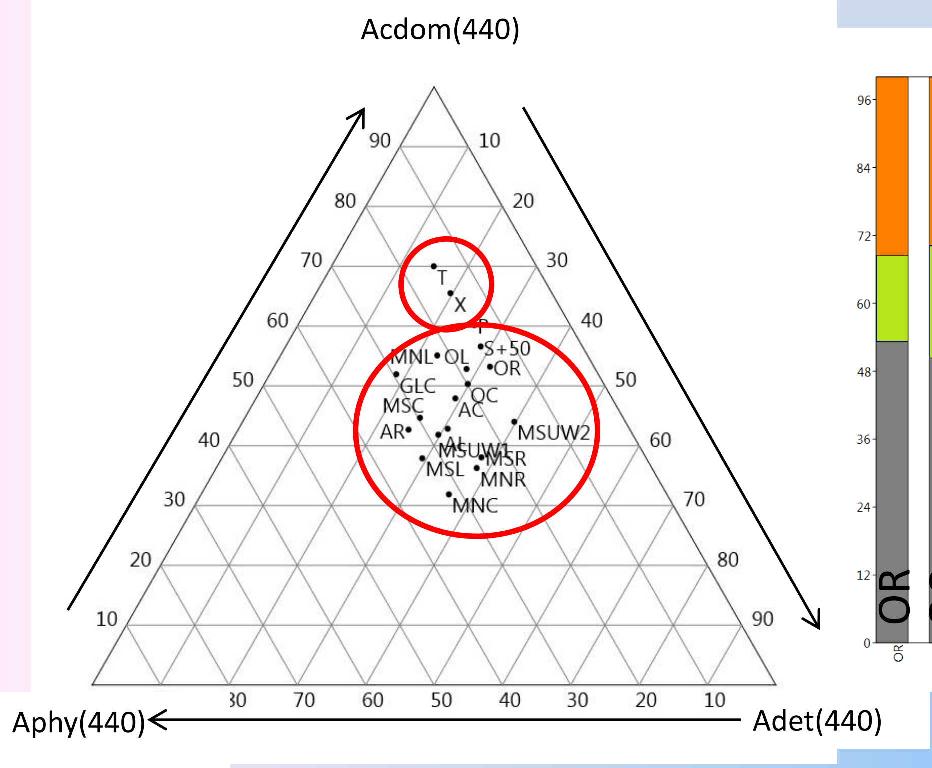



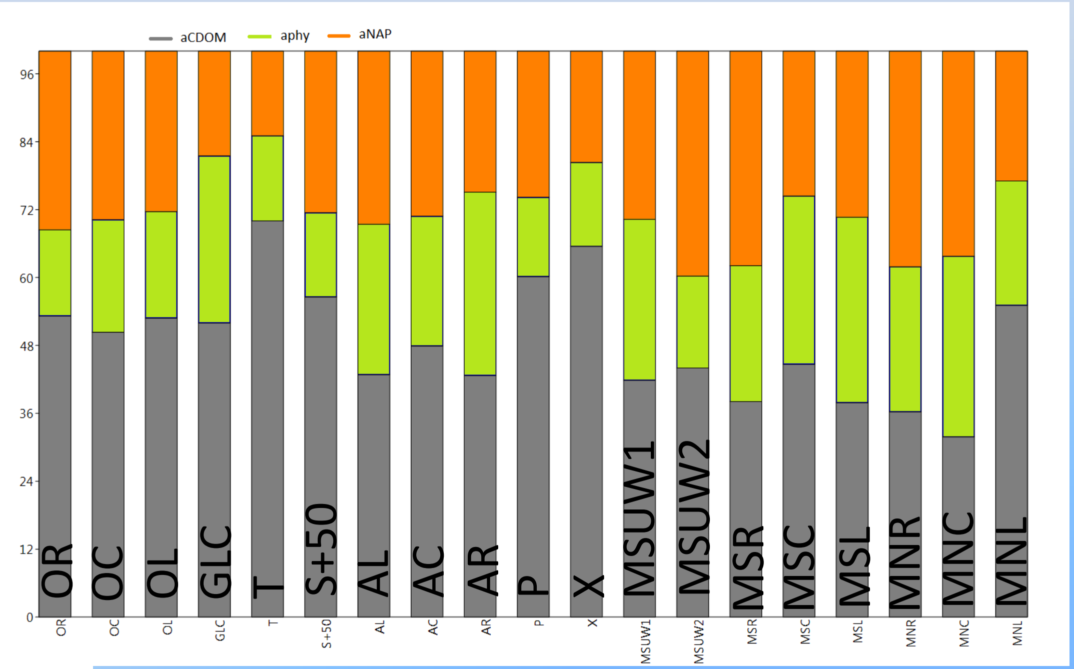

Chl-*a* concentration (mg m$^{-3}$)

Min 0.39

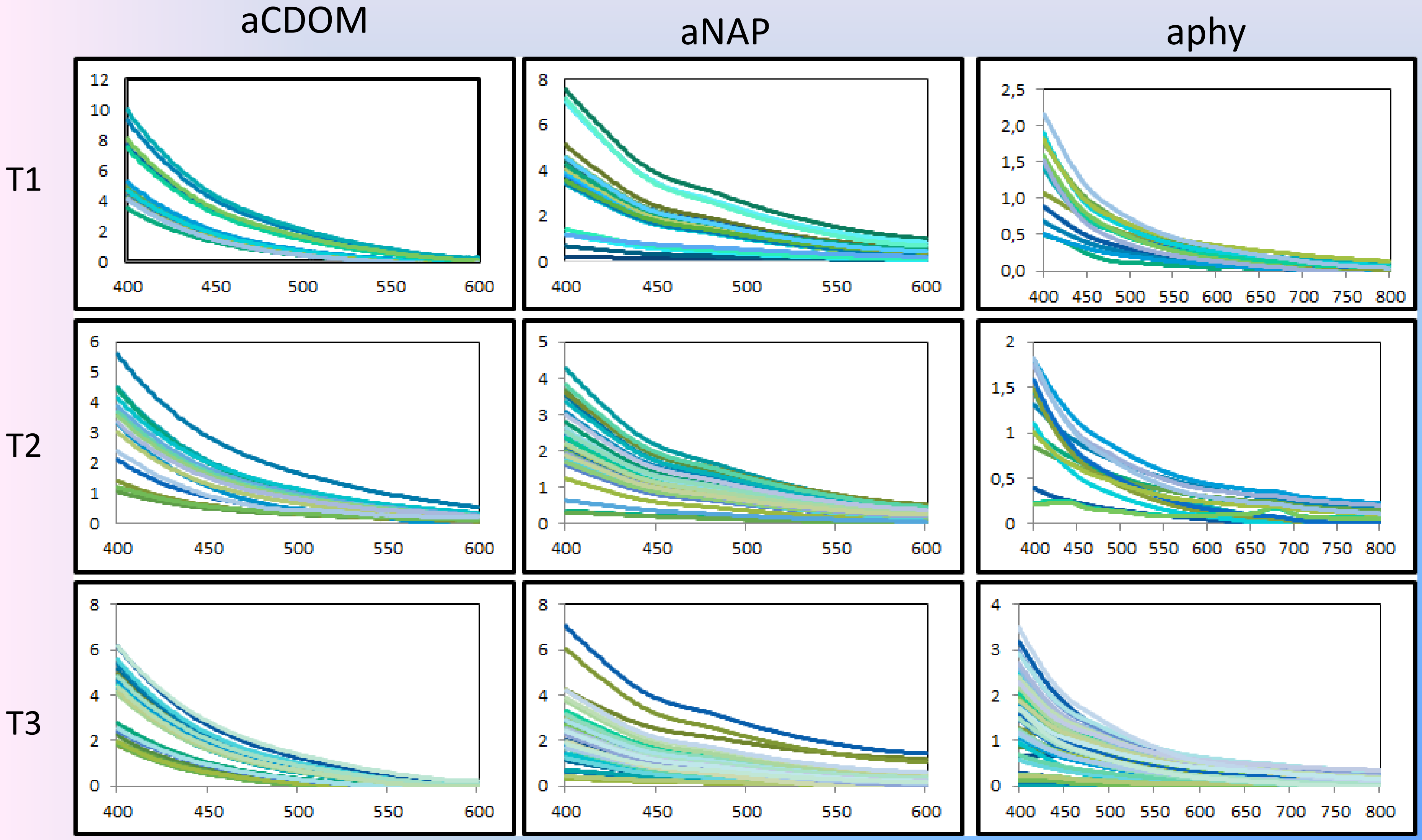
Max 3.78

# TROCAS 3


Acdom(440)
Aphy(440)
Adet(440)
T
X
P
S+50
MNL
OL
OR
GLC
OC
MSC
AC
AR
AL
MSUW2
MSUW1
MSR
MSL
MNR
MNC


aCDOM
aphy
aNAP
OR
OC
OL
GLC
T
S+50
AL
AC
AR
P
X
MSUW1
MSUW2
MSR
MSC
MSL
MNR
MNC
MNL

# Results


aCDOM
aNAP
aphy
T1
T2
T3
12
10
8
6
4
2
0
400
450
500
550
600
2,5
2,0
1,5
1,0
0,5
0,0
650
700
750
800

# Results

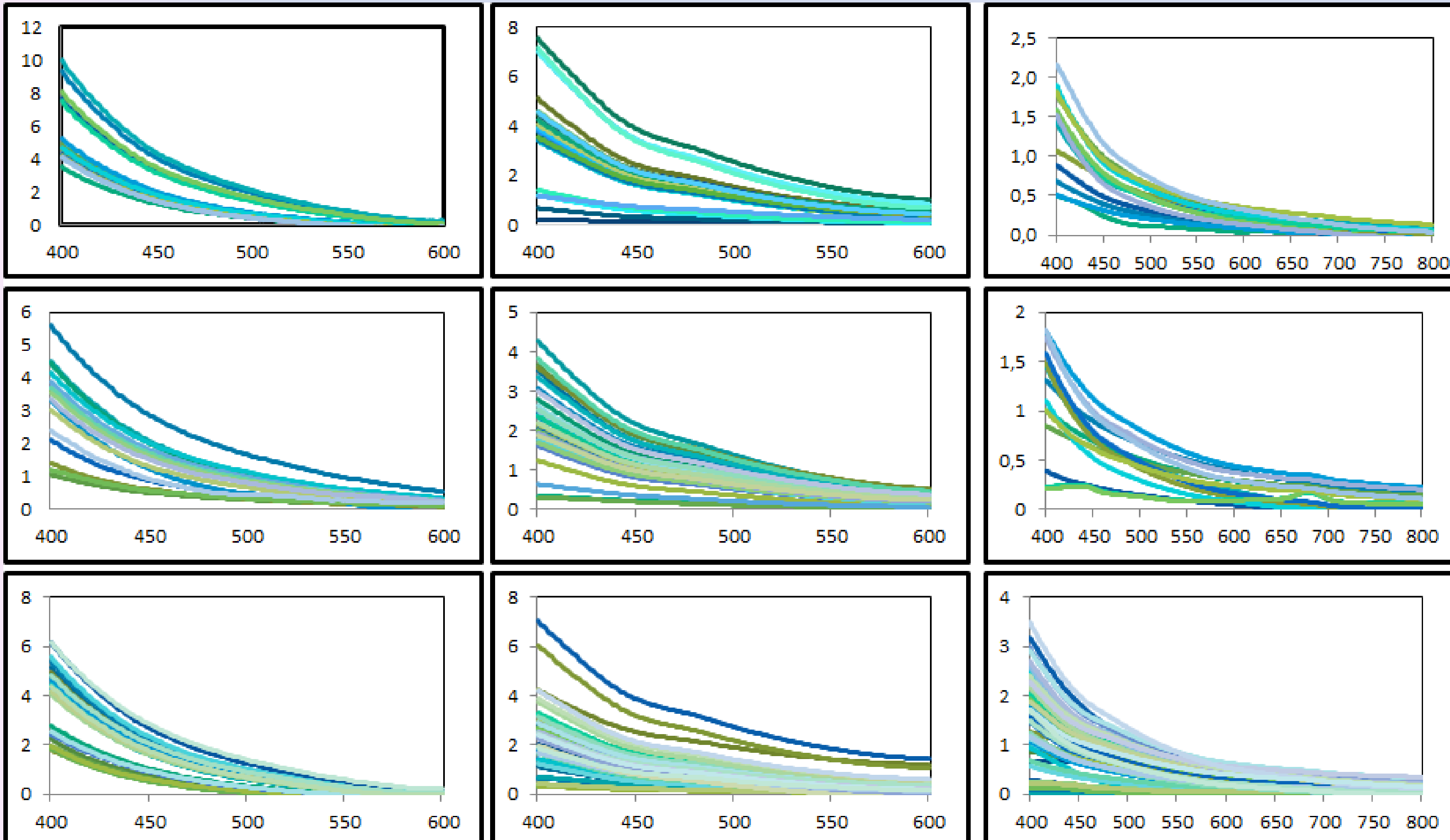
Problem: some negative aphy after 640 nm

aCDOM aNAP aphy

T1

T2

T3



# Other measurements

- Conductivity
- DO
- Temperature
- pH
- TSS
- DOC
- DOM
- POM
- pCO2
- DIC
- Methane
- Nutrients
- ADCP
- Etc.........

# Summary

- The Rrs were all very characteristic of highly turbid waters, and the Rrs of Tapajos and Xingu it has phytoplankton signature.

- Preliminary analysis of this data set shows that during the high water stage, the Amazon River is dominated by CDOM and detritus, while the Tapajós and Xingú rivers are dominated by chl-*a* and CDOM.

- During the falling and low water stage, the absorption coefficients are well mixed at all the stations, with a slightly high chl-*a* at the Tapajós River.

- It was possible to see the HIGH VARIABILITY of the bio-optical properties in waters of the Lower Amazon River during three discharge water stages: high, low and falling water.

# Summary

- Correction of residual glint?
- Semi-analytic algorithm?
- Matrix inversion method?
- Empirical algorithm?
- Other?

# Summary

- Correction of residual glint?
- Semi-analytic algorithm?
- Matrix inversion method?
- Empirical algorithm?
- Other?

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