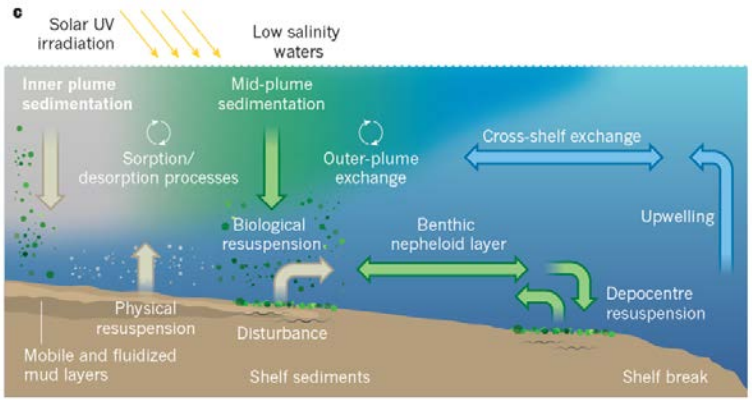
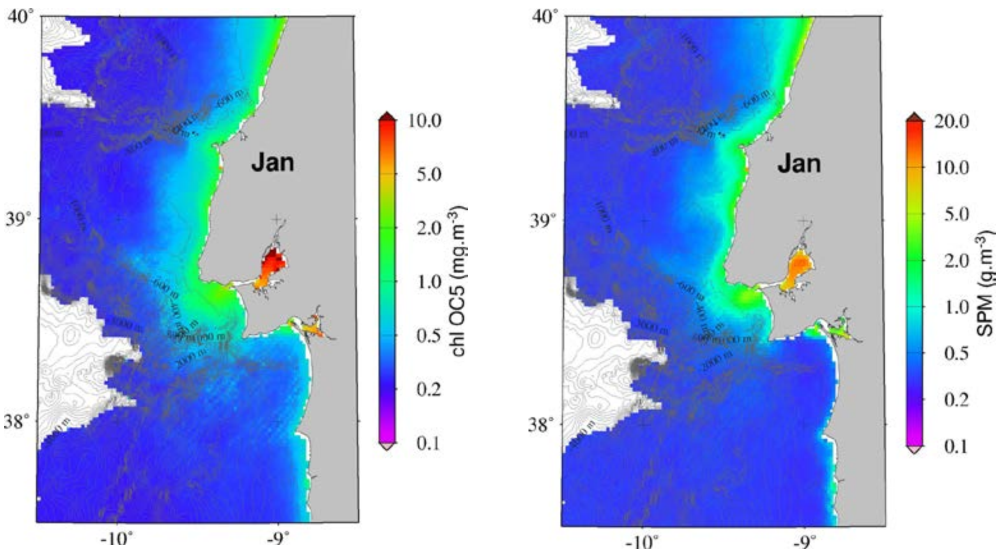
Carbon cycle in the coastal ocean

Hubert Loisel

LOG





IOCS 2017, Lisbonne

Between land and open ocean, the coastal ocean gathers a great variety of environments (delta, estuaries, coastal shelves, etc) where very contrasted physical and biological processes occur.

Strong disproportion between

Surface areas of continental shelves

7-10% of global ocean area

↔

Role in the carbon cycles and budgets

10–30% of global marine primary production

30–50% of inorganic carbon

Around 80% of organic carbon burial in sediments

Could contribute up to about 50% of the organic carbon supplied to the deep open ocean

Mackenzie et al., 2005; Jahnke, 2010

Despite their crucial role in the global carbon cycle, the diverse sources and sinks of carbon and their complex interactions in these waters remain poorly understood.

It has been postulated that the coastal ocean, as a whole, has shifted from a net heterotrophic to an increasingly net autotrophic state (*Bauer et al., 2013*).

This hypothesis is substantiated by:
- results from coarse-grained box models
- small amount of in situ data.

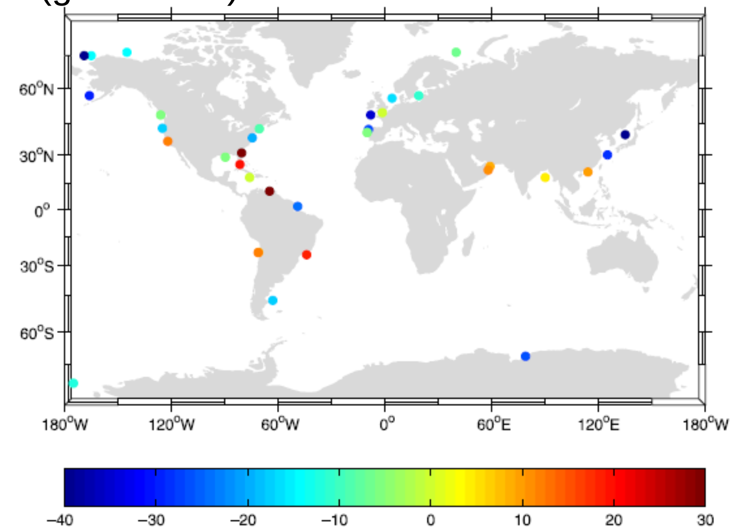
The OCR community can bring important insights to our understanding on the coastal ocean carbon

✓ Although it is important to establish whether such a shift has occurred, if it has, its exact magnitude and timing remain highly uncertain.

✓ What are the stocks and flux of DOC and POC ?

✓ What is the real contribution of coastal water to ocean global carbon cycle ?

Sea-atmos pCO_2 flux measurements ($g.C.m^{-2}.a^{-1}$)



Cai et al. 2006

Due to the large temporal scales involved, ocean color (and new high spatial resolution sensors) observations can bring relevant information over this highly dynamics interface in terms of carbon recycling

Problem to face and where to go ?

- Atmospheric corrections
- Large bio-physical variability which directly drives the bio-optical algorithms accuracy for the estimation of Chl, DOC, POC, and SPM
- How to deal with the vertical dimension ?
- Adapted strategy for validation activities in coastal waters (strong spatial heterogeneity and temporal variability)
- The complexity of coastal waters imply to develop synergistic approaches based on the use of other satellite (active/passive), in situ, and models information

While *Chl* is the main open ocean color product over open ocean water, its retrieval over coastal waters is still challenging, despite some recent progresses.

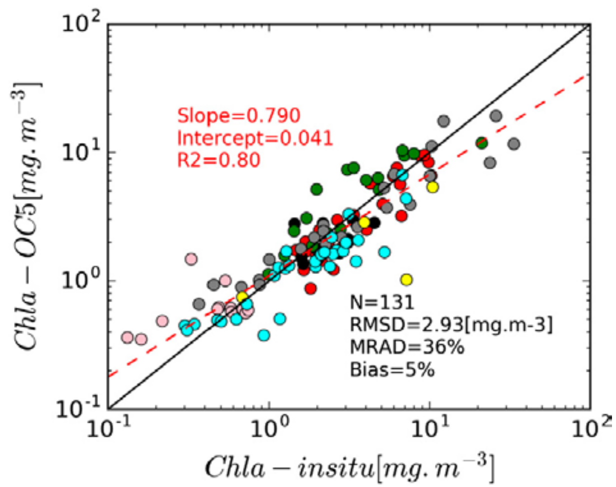
Many regional or global Chl algorithms based on different bands and methods are available:

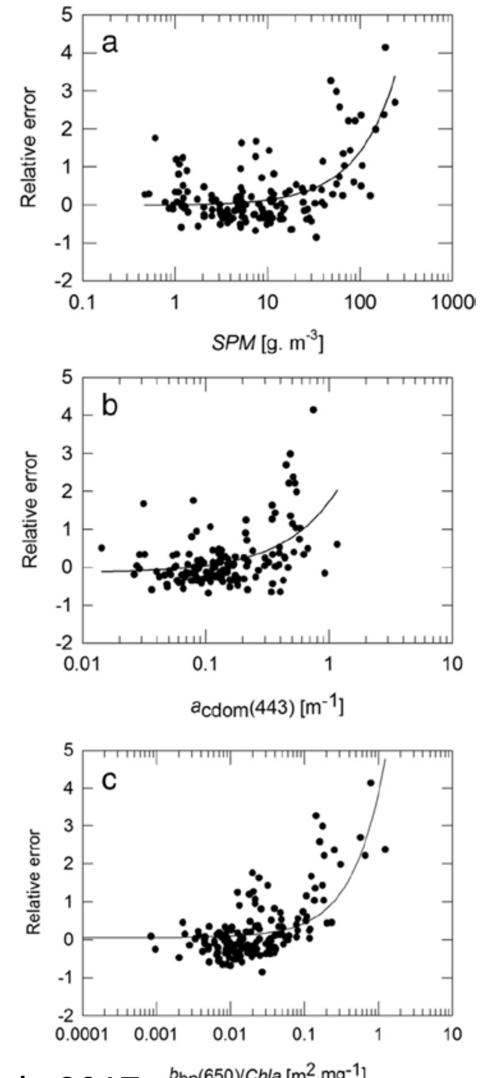
- Carder et al., 2009 semi-analytical/empirical 675 nm
  $Chla=w[Chl]_{sa}+(1-w)[Chl]_{emp}$; and $w=[0.03-a_{ph}(675)]/0.015$
- Tassan (1994) empirical approach (443/555) and (412/490)
- Cannizarro and Carder (2006) empirical approach visible and red bands
- Siswanto et al., (2011) empirical based on the Tassan's formulation
- Dall'Olmo et al., 2003; Gitelson et al., (2009); Gurlin et al. (2011) empirical based on red and NIR bands
- D'Alimonte et al. (2012) MLP all bands
- Gohin et al. (2002) semi-analytical all bands
- Brewin et al. (2015) – semi-analytical a_{ph}(676) (GIOPs) and assumption on the a_{ph}^*(676) value

+ Review for the detection of phytoplankton blooms (not only Chl) has been done by Blondeau-Patissier et al. (2014)

The OC5 algorithm seems to be a plausible way to assess Chl in coastal areas, but it should be confirmed with a global match-up exercise (and improvements should be done in very turbid areas)

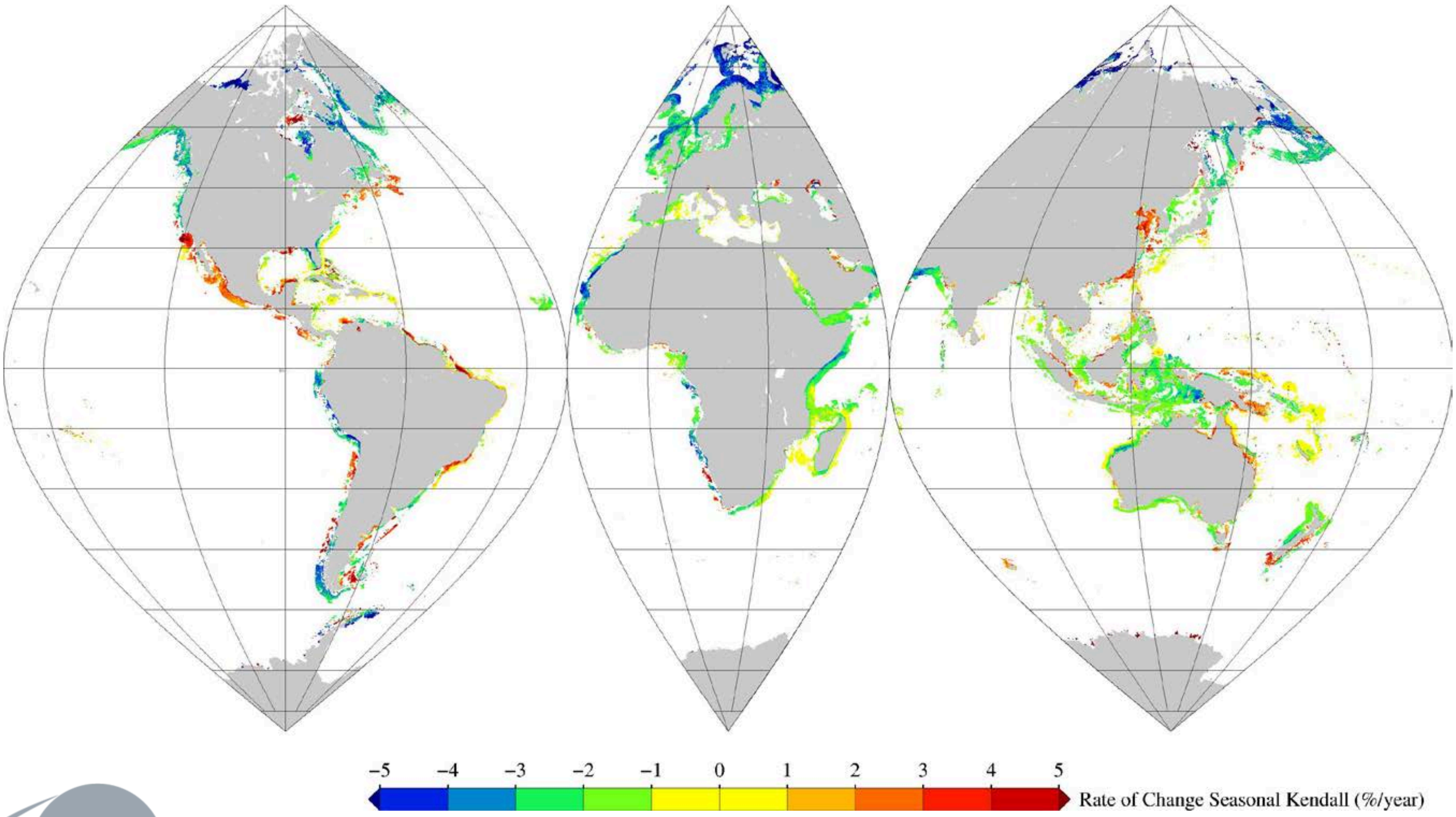
- ***The Ganges Delta, Bay of Bengal and Arabian Sea***
  Tilstone et al., 2009, 2011
- ***Bay of Biscay***
  Novoa et al., 2012
- ***The Rhone river plume***
  Fontana, et al., 2009
- ***The Ligurian and Tyrrhenian seas***
  Lapucci et al., 2012
- ***The Alboran sea***
  Gomez-Jakobsen et al.,2016
- ***Baltic sea***
  Pitarch, et al., 2016
- ***Vietnam coastal waters***
  Loisel et al., 2017
- ***Rio de la Plata*: does not work**
  Camiolo et al., 2016





Loisel et al., 2017

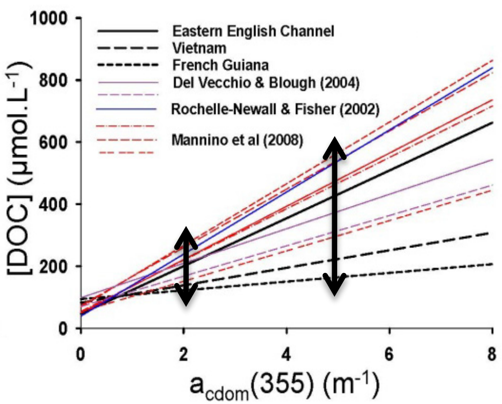
Chl trend over the MERIS time period



GlobCoast

In contrast to open ocean waters, DOC, can be estimated in coastal waters, especially in waters with DOC terrigenous origin.

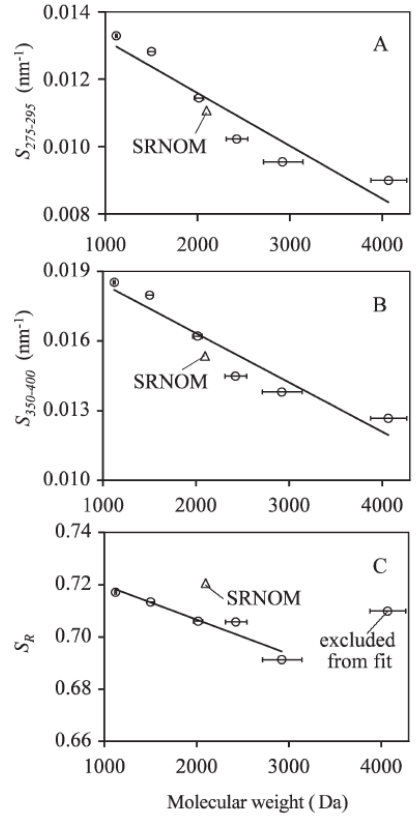
DOC vs. CDOM have been largely documented but highly variable



Vantrepotte et al. (2015)

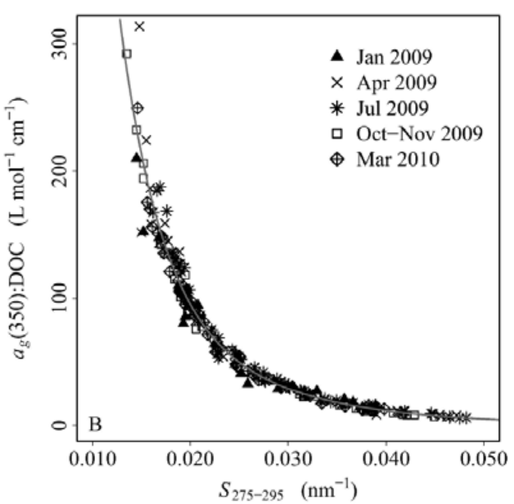
G. M. Ferrari, (2000); Del Vecchio and N. V. Blough, (2004); Guéguen, et al. (2005); Del Castillo and R. L. Miller (2008); Mannino et al. (2008); Lopez, et al. (2012); L. Yang et al., (2013); Rochelle-Newall et al., (2014).

CDOM slope in the UV domain represents a relevant indicator of DOM molecular weight



J. R. Helms et al. (2008)

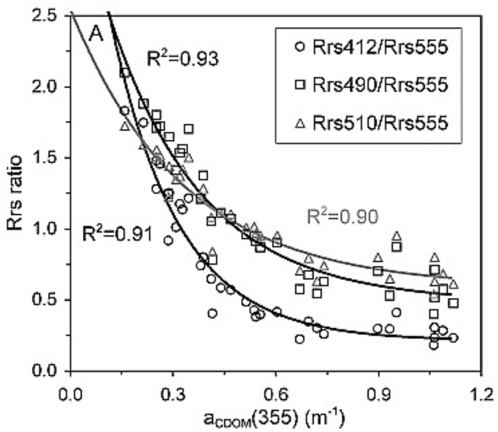
Algorithms have been developed to assess DOC from terrigeneous origin

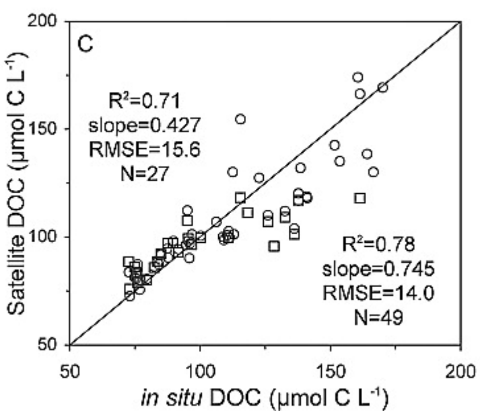


Fichot and Benner (2012)

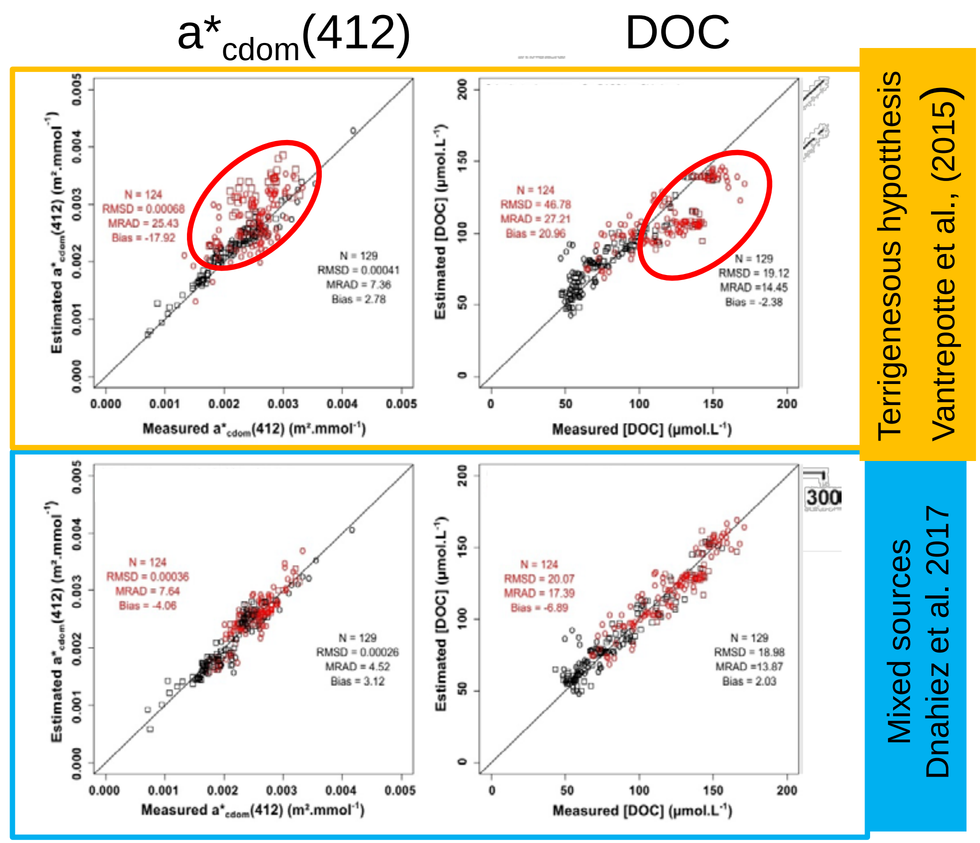
Fichot and Benner (2011, 2012)
Vantrepotte et al. (2015)

While regional/seasonal approaches have shown promising results to assess DOC, a recent study has shown that the more generale approach based on the a_{cdom} spectral slope may accounted for marine produced DOM





Mannino et al. (2008)



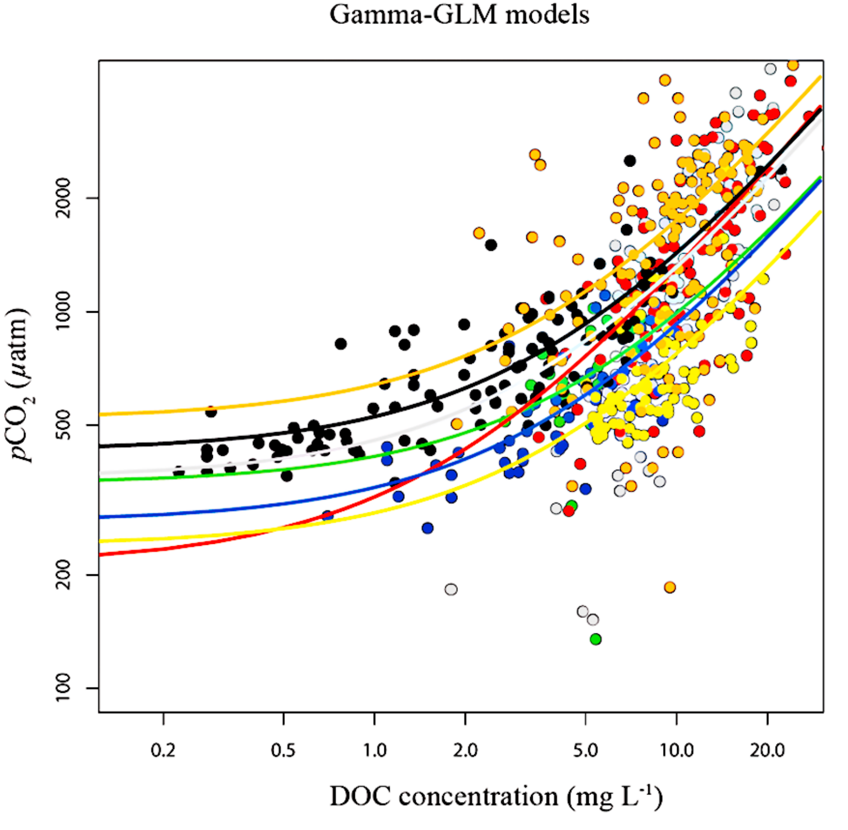
$$a^*_{cdom}(412) = a^*_{cdom}(412)_{est} - 0.00112 \cdot \frac{a_{cdom}(320)}{a_{cdom}(412)} + 0.004283$$

Danhiez et al. (2017) and Loisel et al., 2014 for a_{cdom}

DOC could also, combined with other information such as SST and SSS, be used to estimate pCO_2 from OCR over coastal areas.

Based on observations gathered over 112 lakes in Norway, the concentration of DOC, has been identified as a key driver of partial pressure of CO_2 (pCO_2)

(*Larsen et al., 2011*)

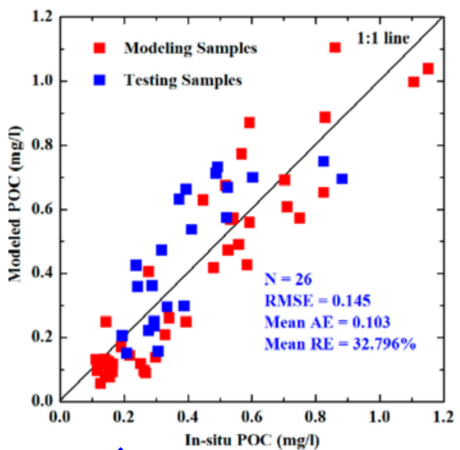


What about coastal areas ?

Such relation has to be studied

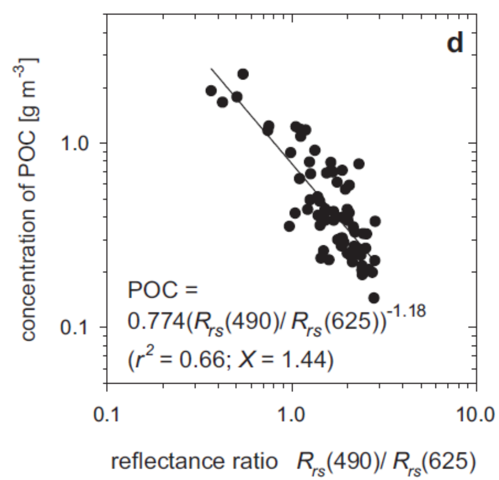
While standard open ocean approaches can not be applied to assess POC in coastal waters (shown in many studies), recent empirical (regional) algorithms have been developed to assess POC in coastal areas.

Pearl River estuary
(Liu et al., 2015)

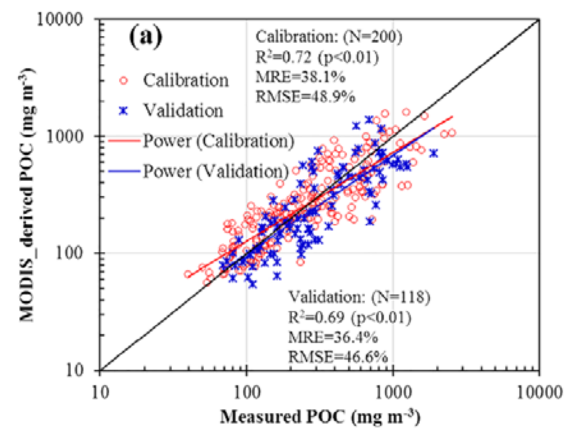


$$\begin{cases} POC_{modeled} = 0.0078 + 1.3973 \cdot Ratio_1 - 1.2397 \cdot Ratio_2 \\ Ratio_1 = r_{equi}(678) / r_{equi}(488) \\ Ratio_2 = r_{equi}(748) / r_{equi}(412) \end{cases}$$

Baltic sea
(Wozniac et al., 2016)



Lousiana coast
(Le et al., 2017)

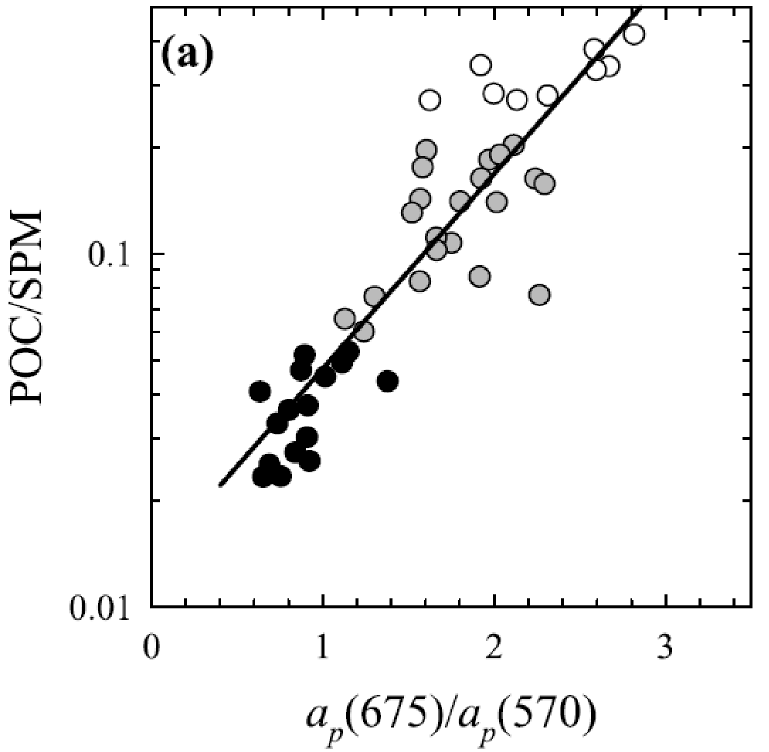


$$POC = 10^{(-115.69 * Rrs(490) - 53.64 * Rrs(510) + 172.13 * Rrs(555) - 40.06 * Rrs(670) - 0.54)} \quad (R^2 = 0.64, \ N = 230)$$

Semi-analytical approaches could provide a good alternative to empirical/regional approaches for the assessment of POC over global coastal waters

Semi-analytical approach

(Wozniak et al., 2010)

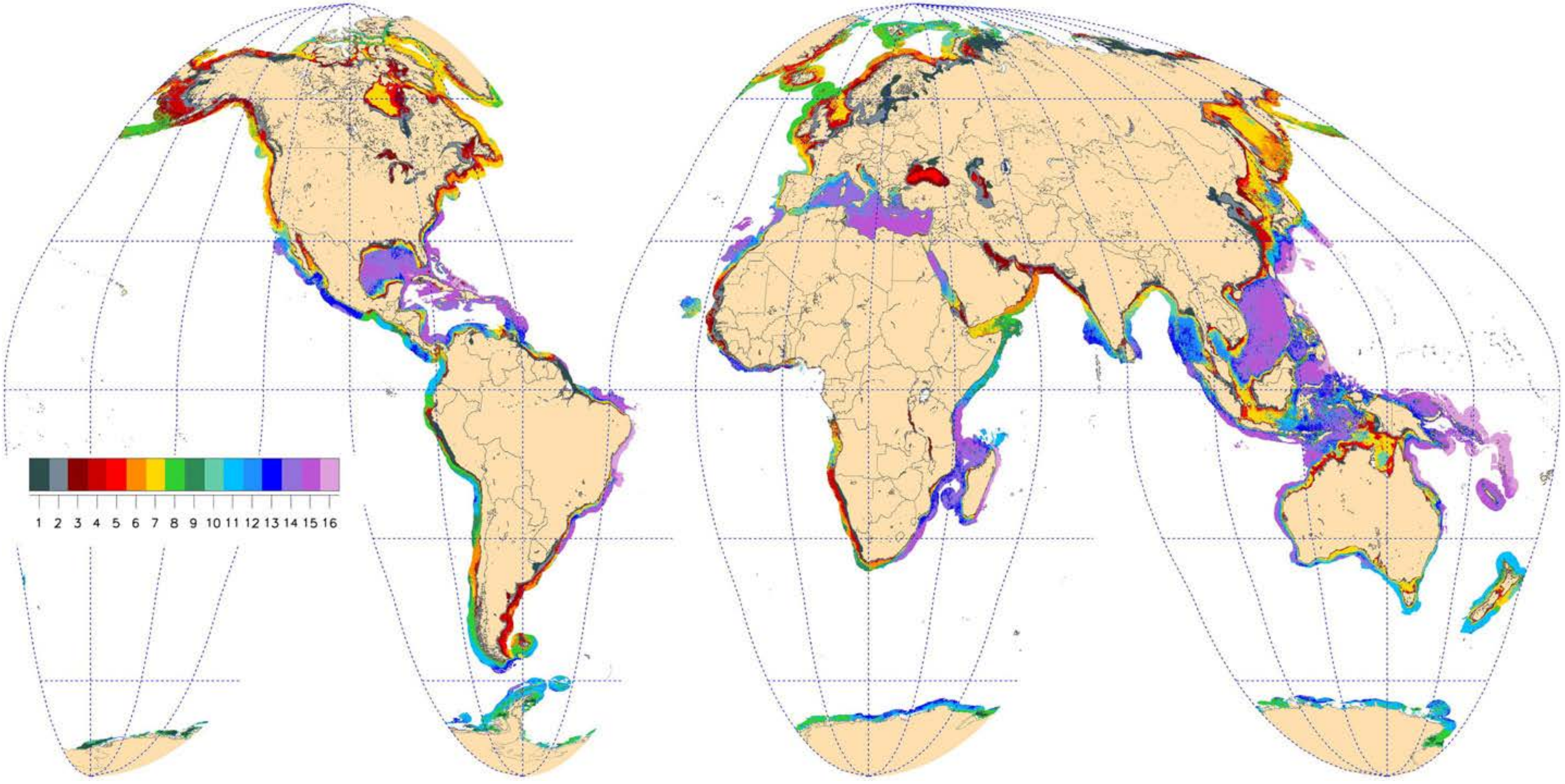


- Multi-step algorithm
- Require a good retrieval of *SPM*, $a_p(675)$, and $a_p(570)$

$$a_p = a_{nw} - a_{cdom}$$
$$a_p = a_{phy} + a_{nap}$$

- This relationship seems robust (ok over the LOG data set)

An accurate assessment of Chl, DOC, and POC at global scale is tightly related to our capacity to account for the large bio-optical variability of these bio-optically complex waters.



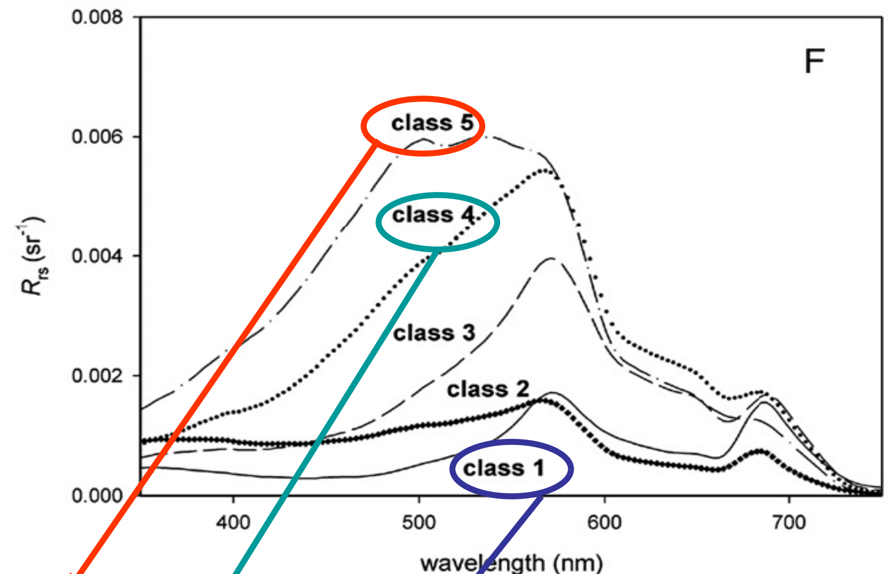
15 classes for the global coastal ocean

Melin and Vantrepotte, 2015

A tight relationship does exist between a radiometric class and a bio-optical environment

Observed in many contrasted areas:

Tokyo Bay
Feng et al., 2005
English Channel
Lubac and Loisel, 2007
Bay of Bengal and Arabian sea
Tistone et al., 2011
Eastern English Channel/Southern north sea/French Guyana
Vantrepotte et al., 2012

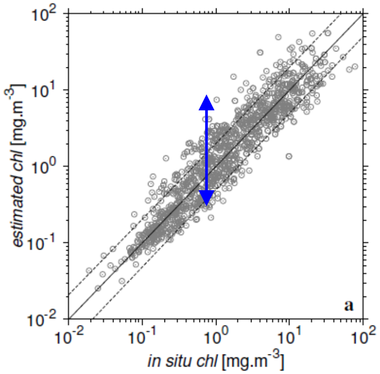


b_{bp}/b_p	
0.018	Water mass dominated by mineral and detritus
0.015	Water mass dominated by detritus
0.005	Phytoplankton bloom

From Lubac and Loisel, 2007

The scatter observed during development and validation phases is not randomly distributed but, instead, bio-optically organized

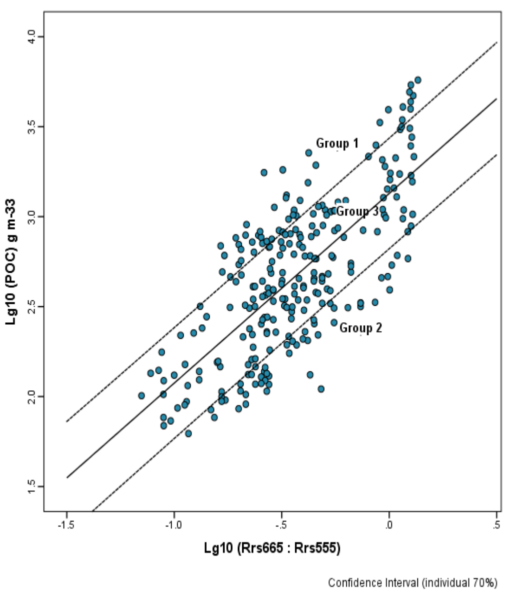
Chl validation



	Whole OC4v4	Whole OC3M	b_{bp}/Chl OC4v4	a_{phy}/Chl OC4v4	a_{cdm}/a_{nw} OC4v4	b_{bp}/Chl OC3M	a_{phy}/Chl OC3M	a_{cdm}/a_{nw} OC3M
RMS-W	25.25	24.80	23.29/**21.8**	25.48	25.48	24.76/**24.47**	24.62	24.62
RMS-1			24.30/**23.2**	24.80	21.70	31.48/**32.28**	30.22	25.74
RMS-4			30.42/**27.0**	24.37	28.61	27.07/**23.93**	21.89	25.73
AD-W	3.80	−5.04	−0.59/**-3.02**	4.25	4.25	−8.26/**-10.2**	−4.06	−4.06
AD-1			−17.18/**-17.2**	−9.85	−9.14	−27.48/**-28.9**	−21.05	−15.73
AD-4			20.75/**18.4**	10.50	13.74	12.87/**13.4**	5.11	4.09

Chl is over-estimated in waters with specific IOP values higher than averaged values, and vice versa

POC development



a_{cdom}/a_{nw} = 31%
POC/SPM = 0.17
POC/Chl = 174

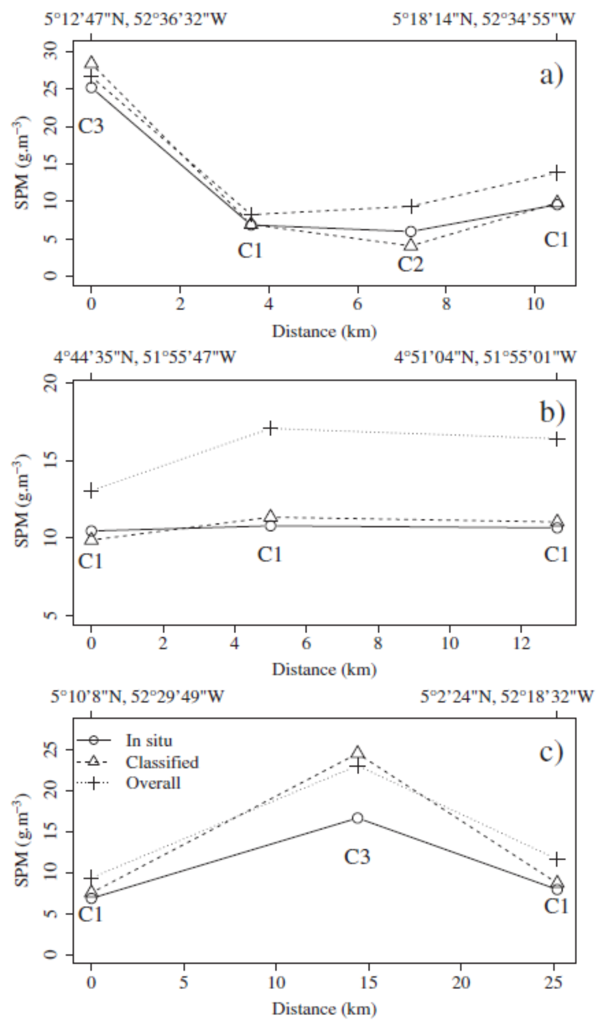
The POC vs. R_{rs}(red)/R_{rs}(green) is greatly controlled by the bio-optical environment

a_{cdom}/a_{nw} = 43 %
POC/SPM = 0.036
POC/Chl = 70

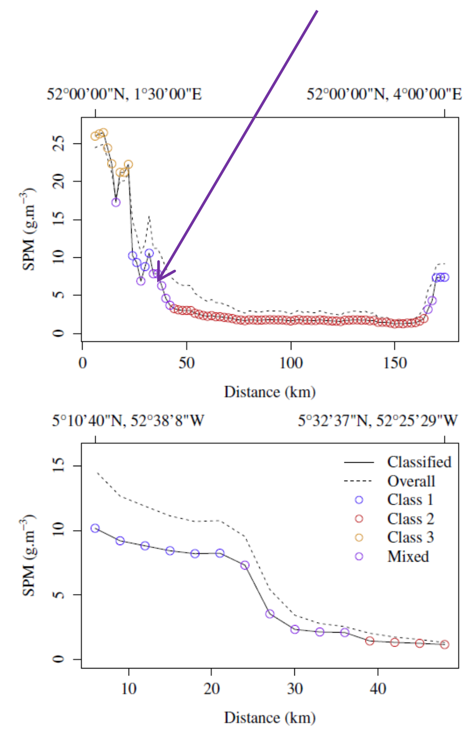
Loisel et al., 2010 and poster of Trung Kien Tran

Classification-based algorithms are promising avenue for a better assessment of Carbone Related Parameters in coastal areas, but require a very large data set for a their development.

- A trade-off between a limited number of class and their representativeness should be found
- Bio-optical algorithms should be developed for each class (**which imply a limited number of class**)
- Inversion over mixed pixels is obtained using a weighted function where the belonging probability of a given class is provided by the novelty detection technique (*Melin et al., 2011*)



$$X_{Mix} = \frac{X_i P_i + X_j P_j}{(P_i + P_j)}$$



Vantrepotte et al., 2012

Some recommendations

- Where are the critical shortcomings and needs?

  A common global Chl, POC, DOC, IOPs, Rrs data base for coastal waters.

- What is ready for operational agencies to pick up?

  SPM (in g.m^{-3})

  DOC-terrestrial

- Algorithms development and validation: what actions are needed?

  - A global inter-comparison of Chl, SPM, DOC algorithms is needed (and can be done quickly – for SPM already some studies)
  - Class based algorithms should be developed

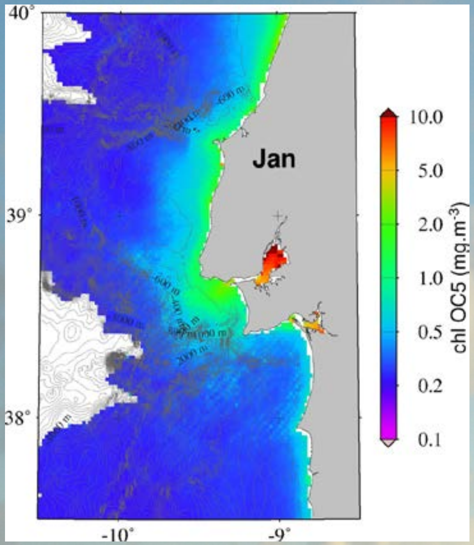
- What is needed from in situ observations?

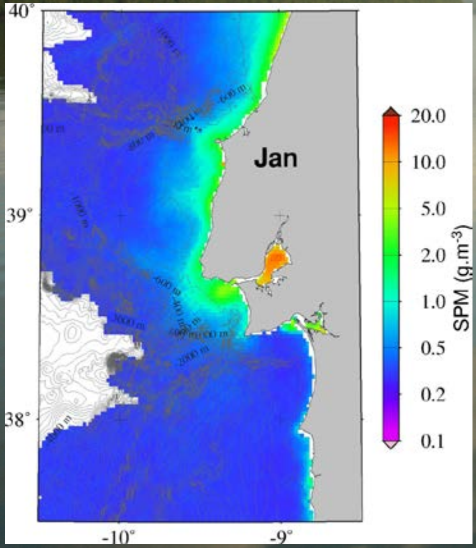
  - Vertical information on Chl, POC, and DOC (besides other standard measurements)

- What are the priority directions, evolution of needs?

  -

Obrigado


Jan
chl OC5 (mg.m-3)
10.0
5.0
2.0
1.0
0.5
0.2
0.1
40°
39°
38°
-10°
-9°


Jan
SPM (g.m-3)
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
40°
39°
38°
-10°
-9°