



MINISTÉRIO DA CIÊNCIA E TECNOLOGIA  
**INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS**

# Medidas simultâneas de concentração de clorofila por LIDAR, fluorescência, MODIS e radiometria: resultados do cruzeiro FITOSAT I

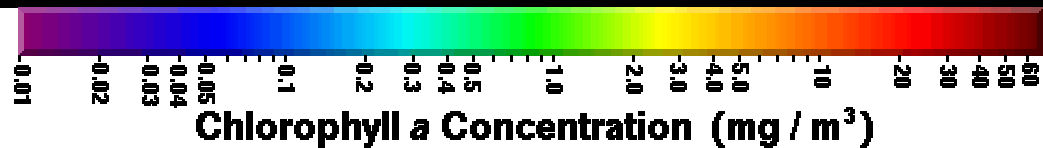
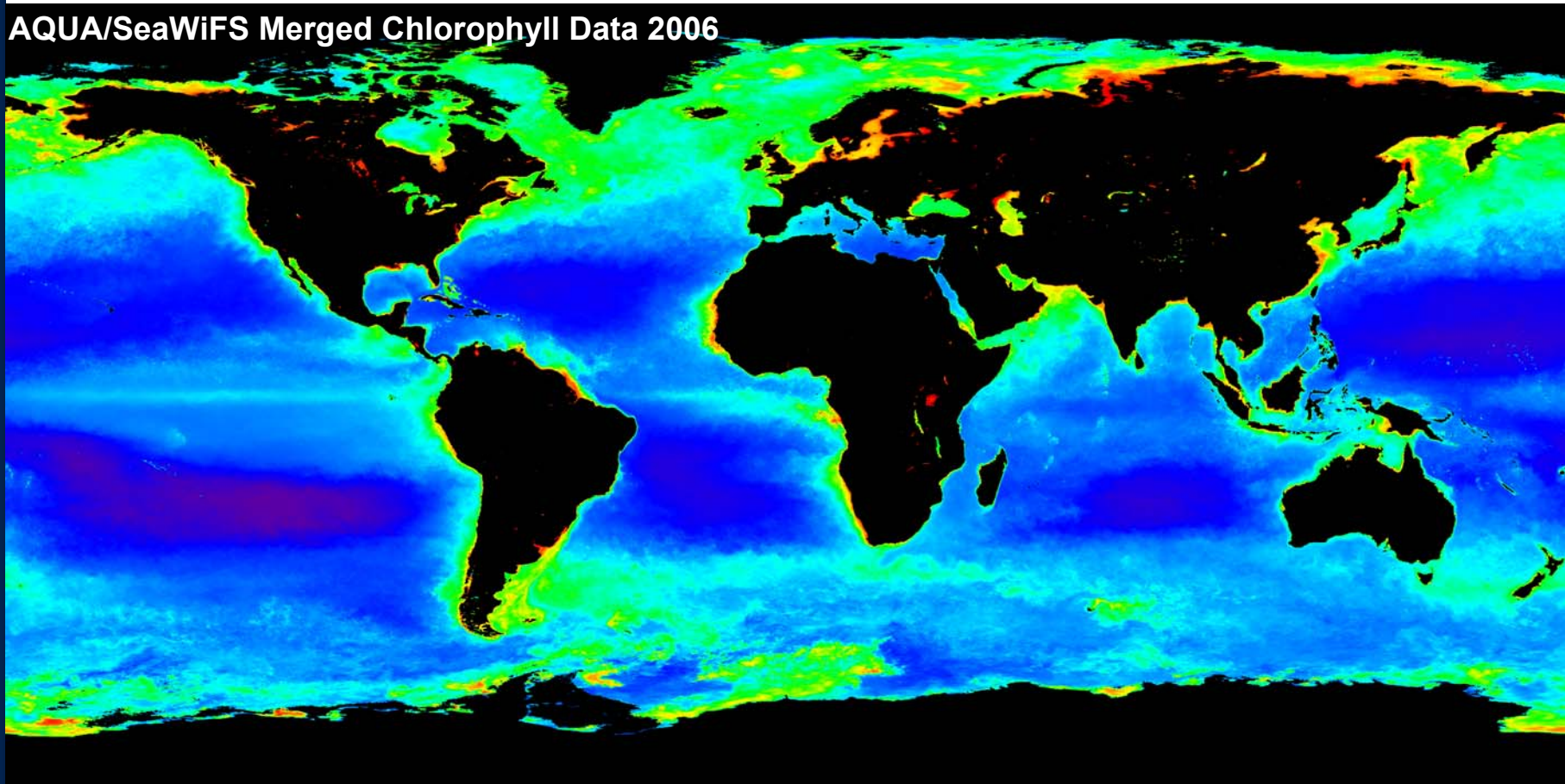
Milton Kampel, João A. Lorenzzetti, Cristina M. Bentz, Raul  
A. Nunes, Rodolfo Paranhos, Frederico M. Rudorff,  
Alexandre T. Politano



XII COLACMAR, Florianópolis, Abril 2007

# Sensoriamento remoto da cor do oceano

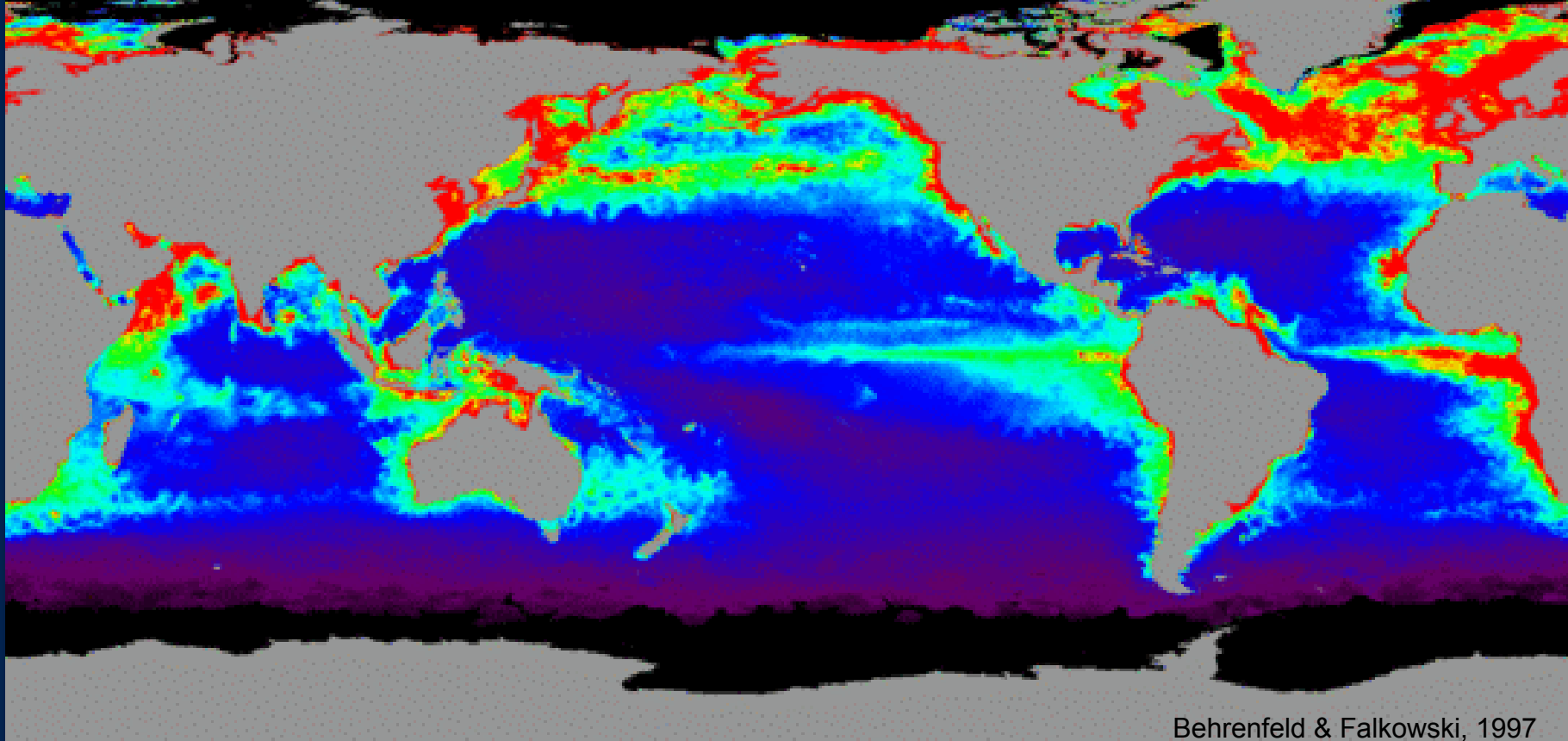
AQUA/SeaWiFS Merged Chlorophyll Data 2006



(Ocean Color Web)

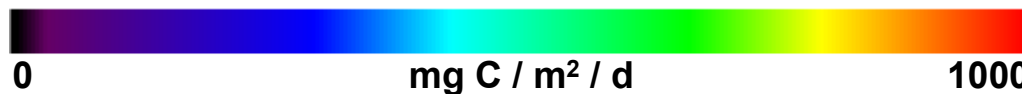
# Produção primária oceânica

Monthly Net Primary Production, July/2006: 4.15 Pg (1Pg=10<sup>15</sup> g)



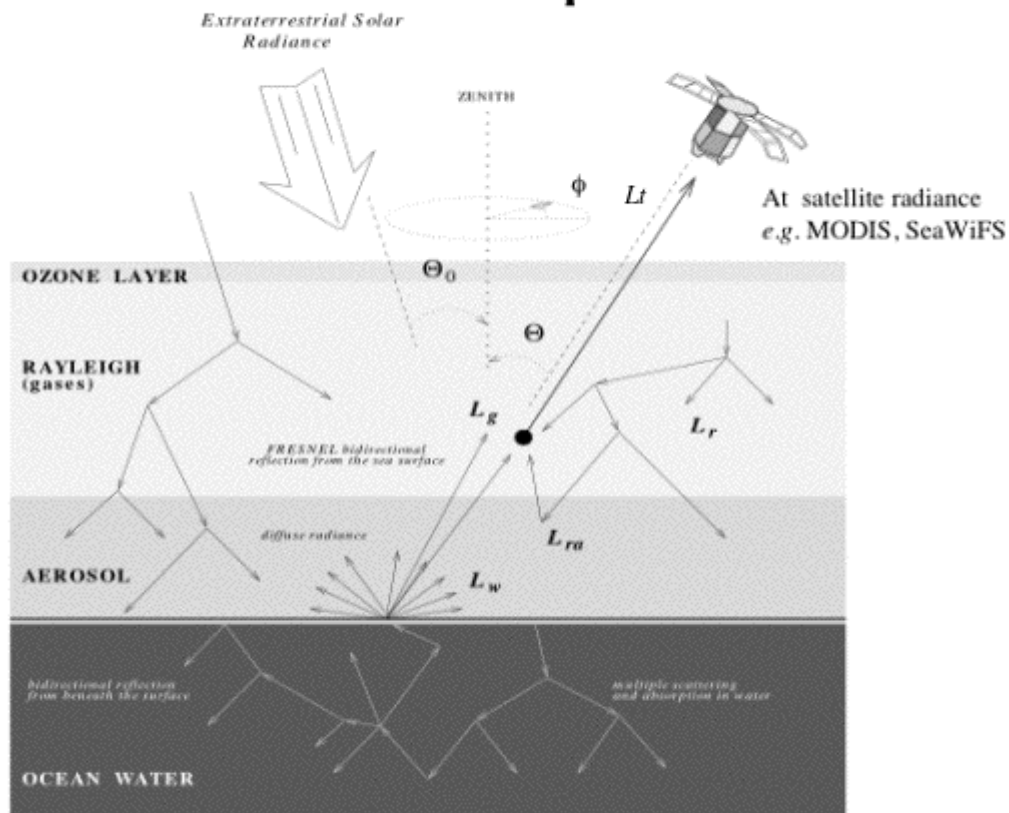
Behrenfeld & Falkowski, 1997

O'Malley, R. (OSU)



# Correção atmosférica

## Correction Equation



$$\rho_t(\lambda) = \rho_r(\lambda) + \rho_a(\lambda) + \rho_{ra}(\lambda) + t(\lambda)\rho_{wc}(\lambda) + t(\lambda)\rho_w(\lambda) + t(\lambda)\rho_g$$



# Algoritmos bio-ópticos empíricos

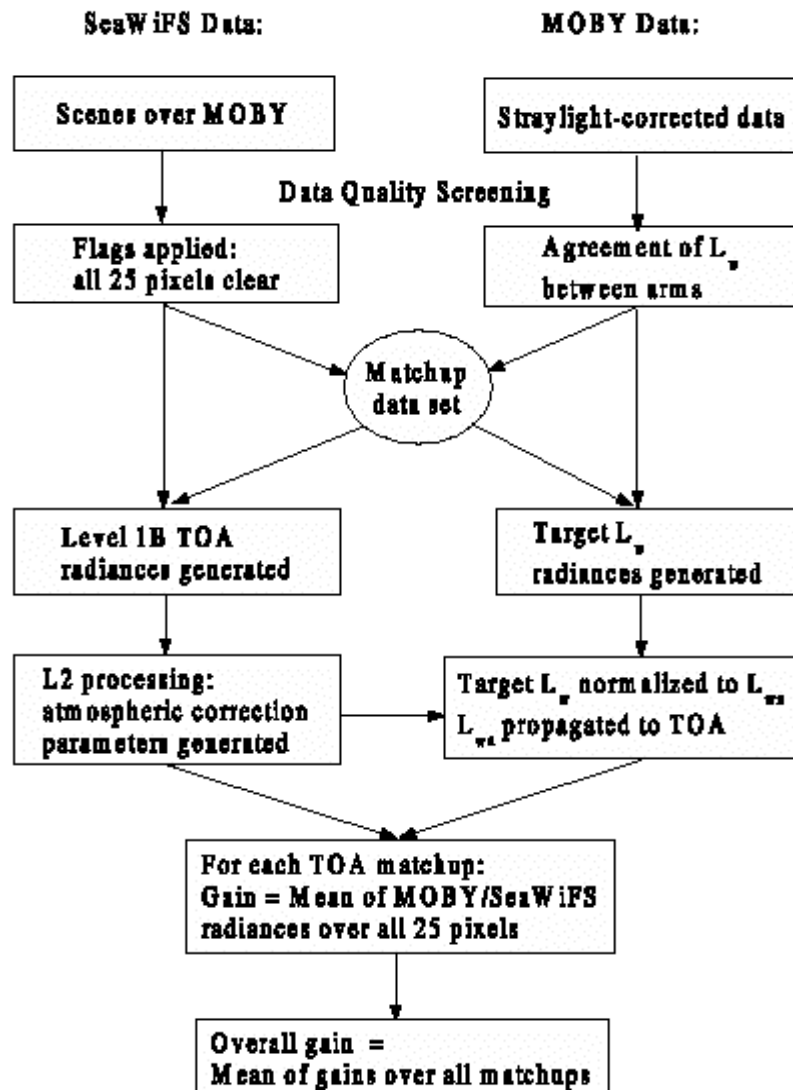
## ■ SeaWiFS OC4v4

$$C_a = 10^{0.366 - 3.067R + 1.930R^2 + 0.649R^3 - 1.532R^4}, \text{ where } R = \log_{10} \left( \frac{R_{rs443} > R_{rs490} > R_{rs510}}{R_{rs555}} \right)$$

## ■ MODIS OC3M

$$C_a = 10^{0.283 - 2.753R + 1.457R^2 + 0.659R^3 - 1.403R^4}, \text{ where } R = \log_{10} \left( \frac{R_{rs443} > R_{rs488}}{R_{rs551}} \right)$$

# Validação e calibração



**M  
O  
B  
Y**





# Projeto FITOSAT

## ■ Objetivo

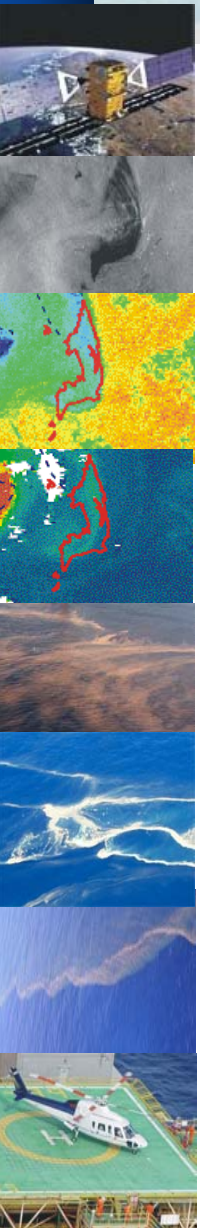
- Avançar no uso integrado de dados de SR e *in situ* para o monitoramento oceânico.

## ■ Coordenação

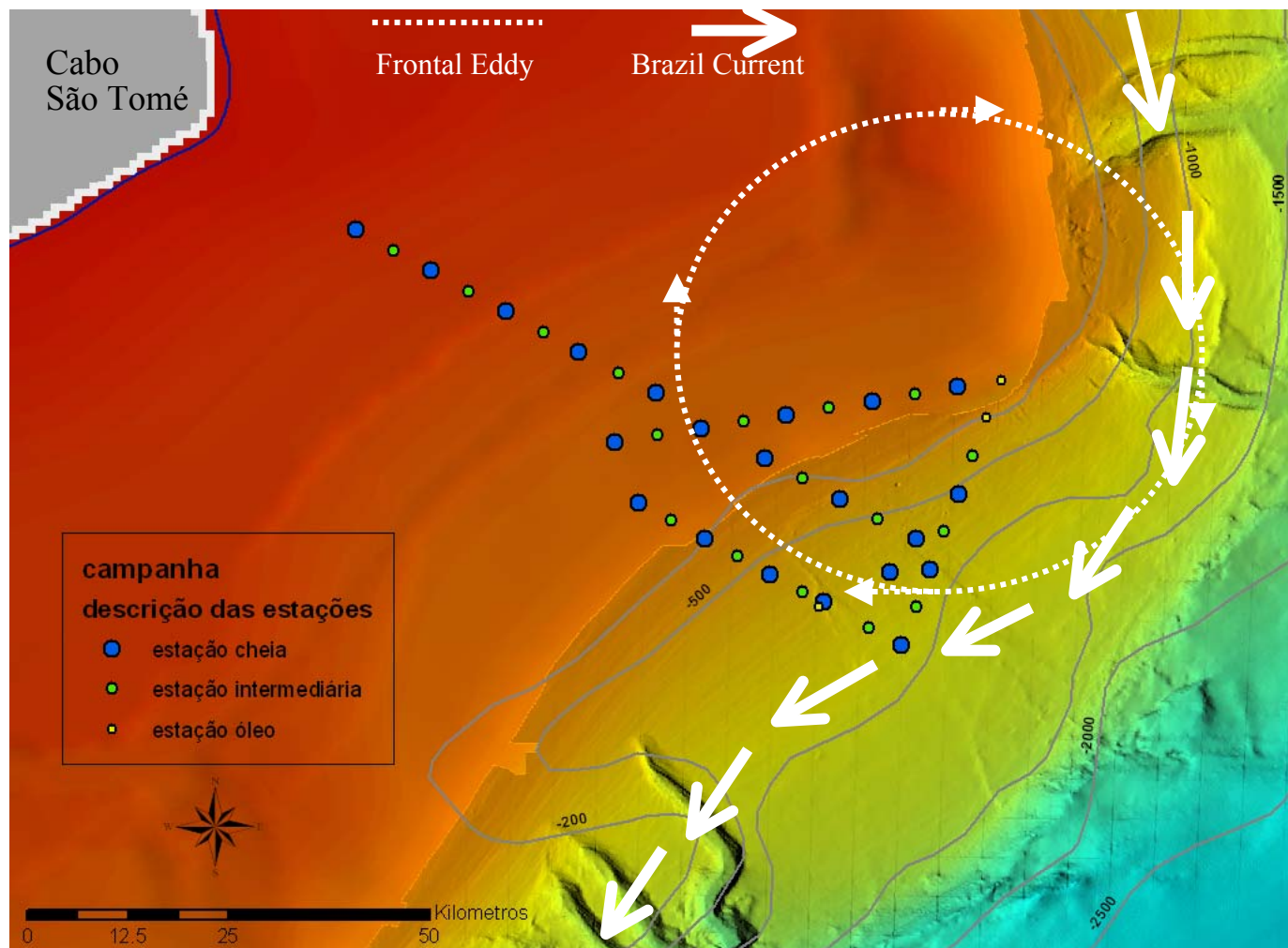
- *PETROBRAS/CENPES – Avaliação e Monitoramento Ambiental*

## ■ Equipe multidisciplinar

- *INPE*
- *Biologia Marinha-UFRJ*
- *PUC/RJ*
- *NTT-COPPE/UFRJ*
- *IEAPM - Marinha*
- *leAV – CTA/FAB, ...*



# FITOSAT I - Batimetria e estações oceanográficas

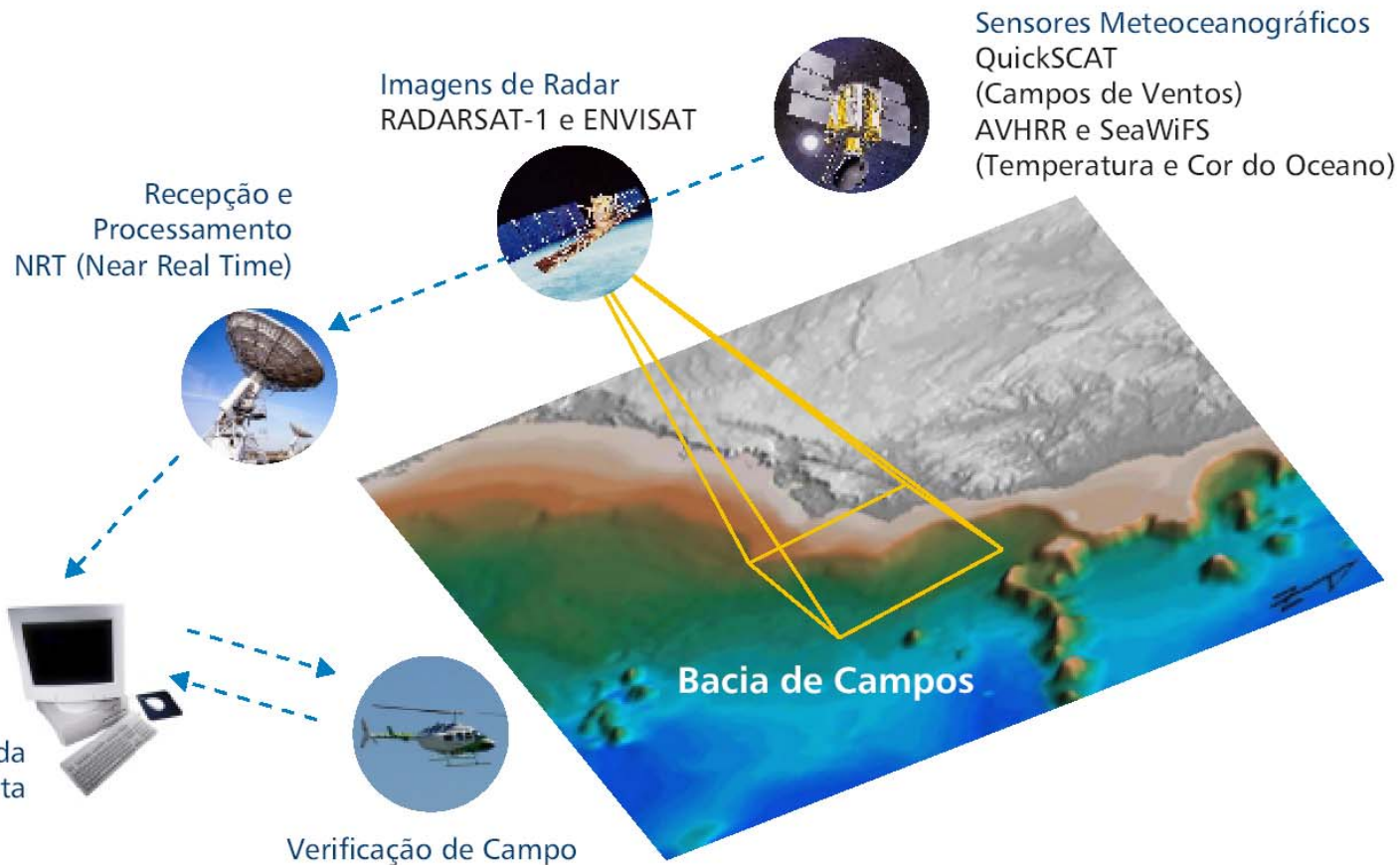
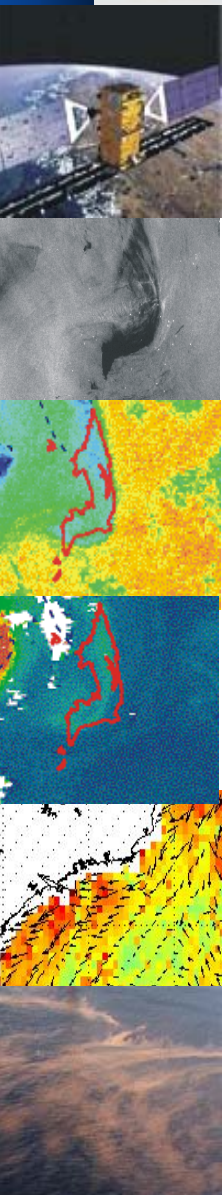


Fonte: Adaptado de Politano, A.T.





# Projeto FITOSAT

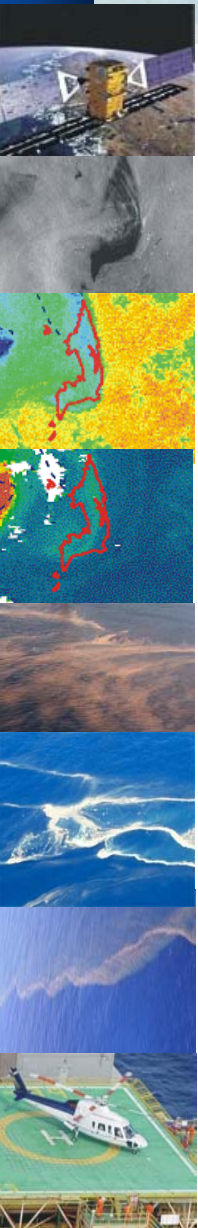




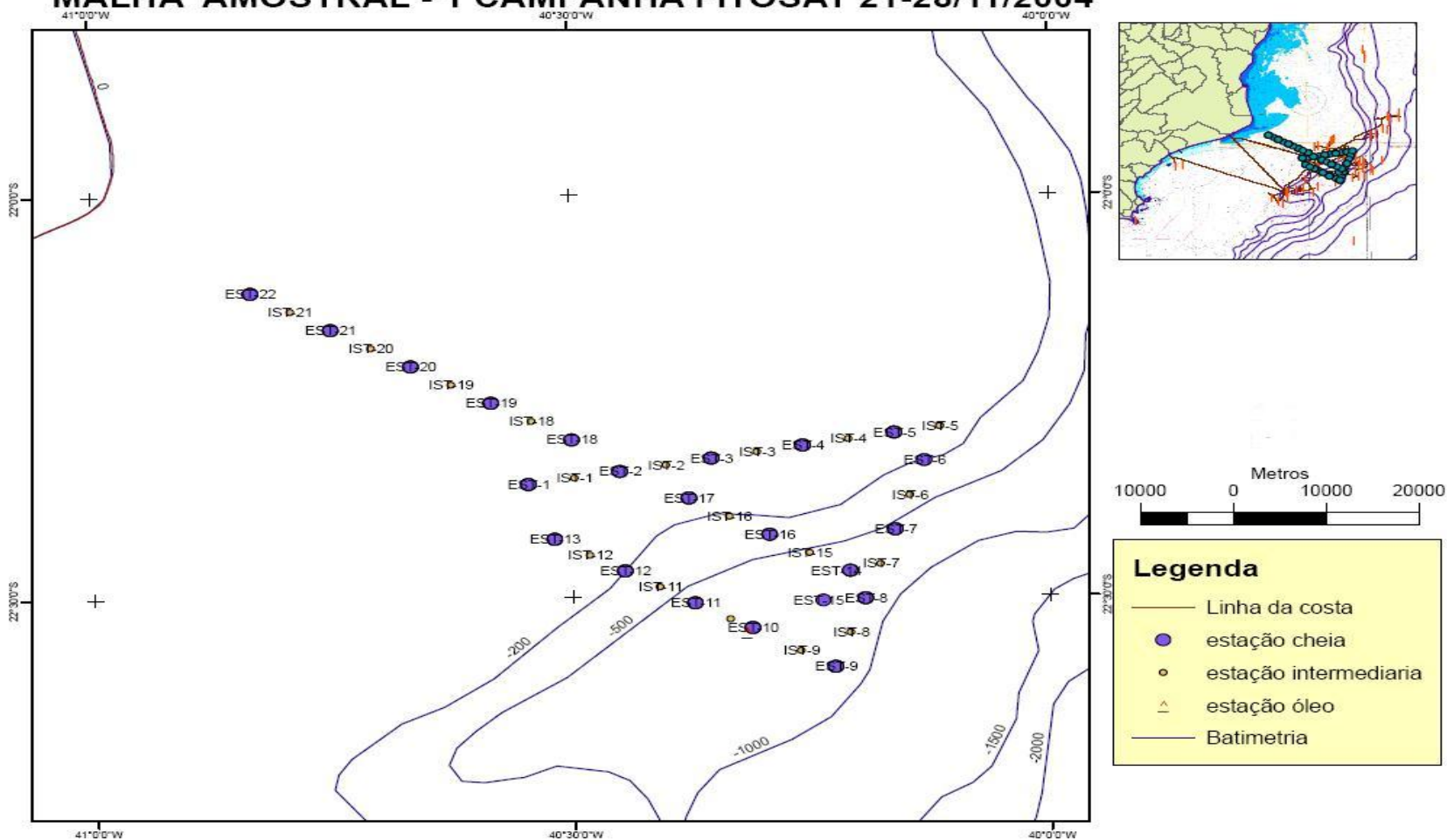
# Objetivo

- Comparar estimativas da concentração de clorofila-*a* superficial obtidas por LIDAR, MODIS, radiometria e fluorimetria.

# Medidas *in situ*



## MALHA AMOSTRAL - 1 CAMPANHA FITOSAT 21-28/11/2004

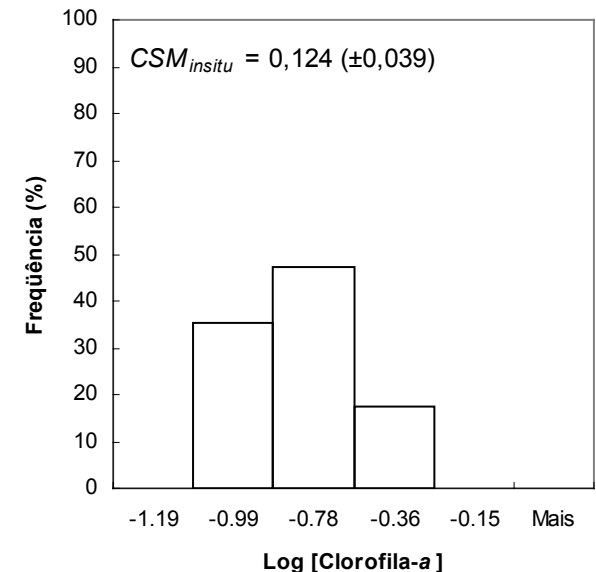


**Legenda**

- Linha da costa
- estação cheia
- estação intermediaria
- △ estação óleo
- Batimetria

# Medidas *in situ* - Fluorimetria

- Amostras de 2 L água com garrafas Niskin
- 18 estações, 21-25/11/2004
- Filtros Millipore 0,45  $\mu\text{m}$
- Turner Designs TD-700 (Parsons et al. 1984)
- 0,077 a 0,197  $\text{mg m}^{-3}$







# Medidas *in situ* - Radiometria

- 29 estações
- Spectron SE590
- 375-1075 nm → 400-700 nm (5 nm)
- Protocolo de Fougnie et al. (1999) com polarizador
- Integradas as bandas SeaWiFS e MODIS pelo método dos retângulos

# Medidas *in situ* - Radiometria

- Reflectância de sensoriamento remoto

$$R_{RS}(\lambda) = \frac{L_w(\lambda)}{E_d(\lambda)} \quad \text{Eq.1}$$

$$E_d(\lambda) = L(\lambda) \times f_c \times \pi \quad \text{Eq.2}$$

- OC2v4

$$C_a = 10,0^{(0,319 - 2,336R_{2S} + 0,879R_{2S}^2 - 0,135R_{2S}^3) - 0,071} \quad R_{2S} = \log_{10}(R_{555}^{490})$$

- OC4v4

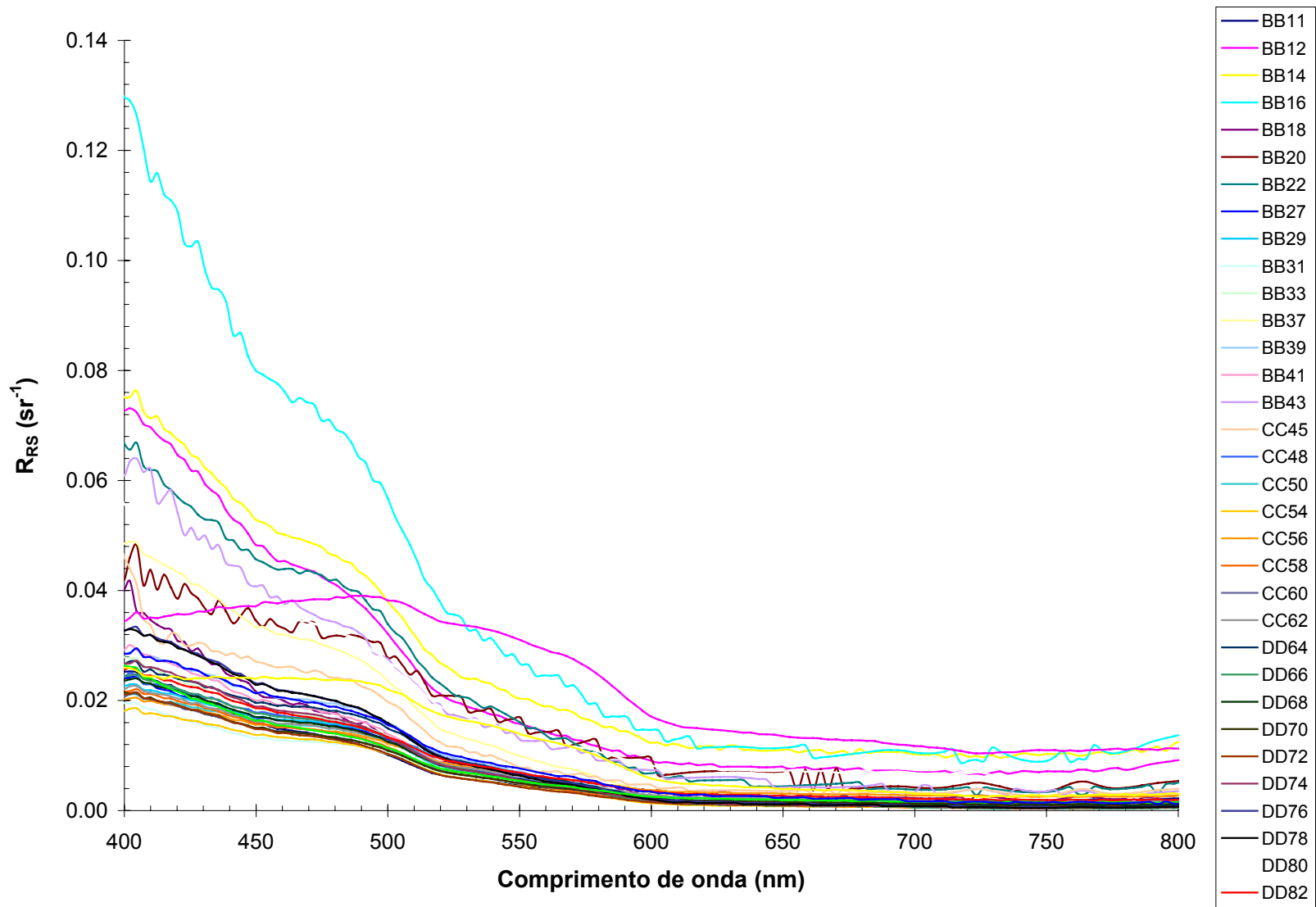
$$C_a = 10,0^{(0,366 - 3,067R_{4S} + 1,930R_{4S}^2 - 0,649R_{4S}^3 - 1,532R_{4S}^4)} \quad R_{4S} = \log_{10}(R_{\max})$$

- OC3M

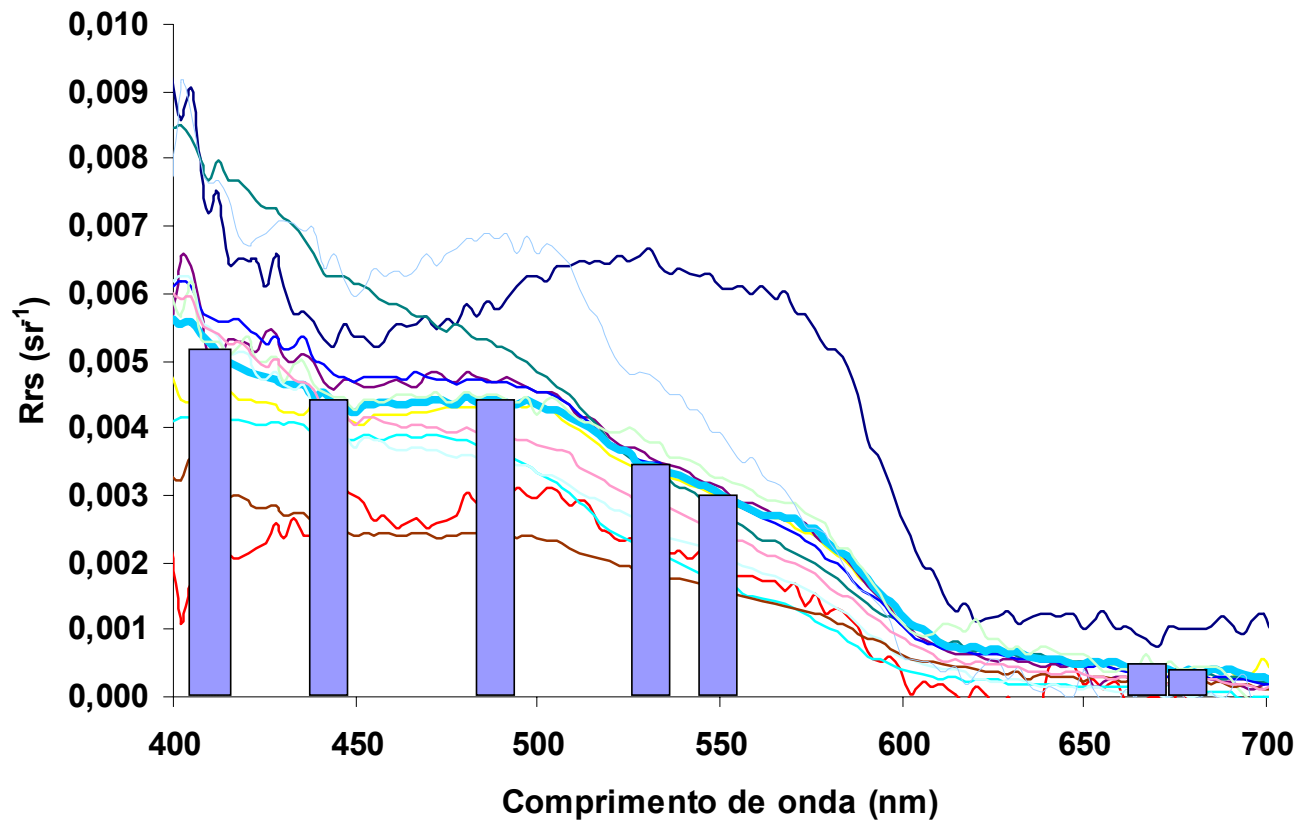
$$C_a = 10,0^{(0,283 - 2,753R_{3M} + 1,457R_{3M}^2 - 0,659R_{3M}^3 - 1,403R_{3M}^4)} \quad R_{3M} = \log_{10}(R_{\max})$$



# Radiometria *in situ*



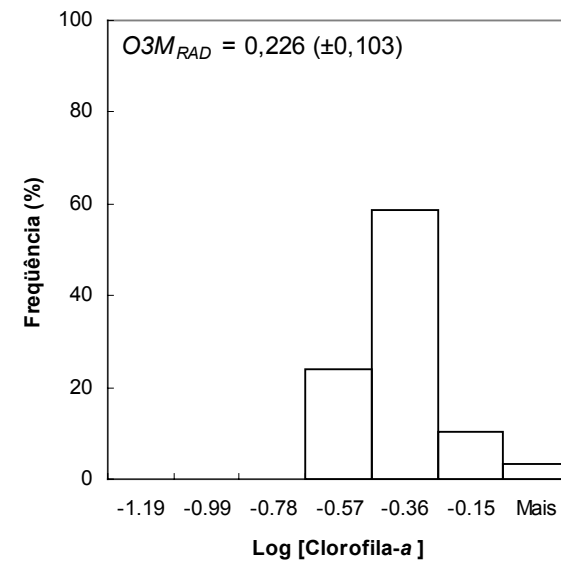
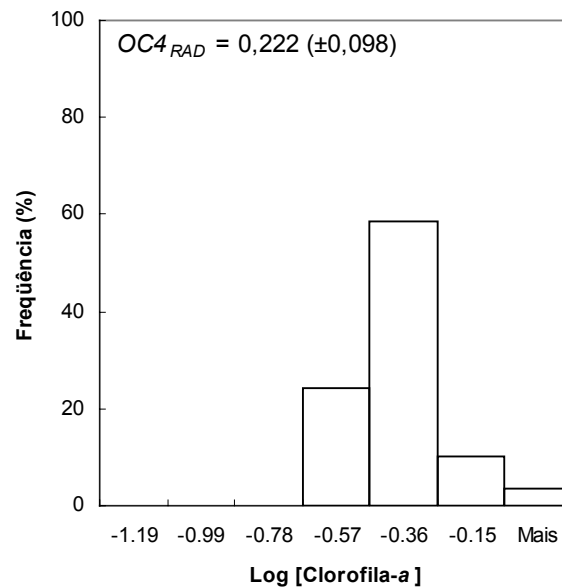
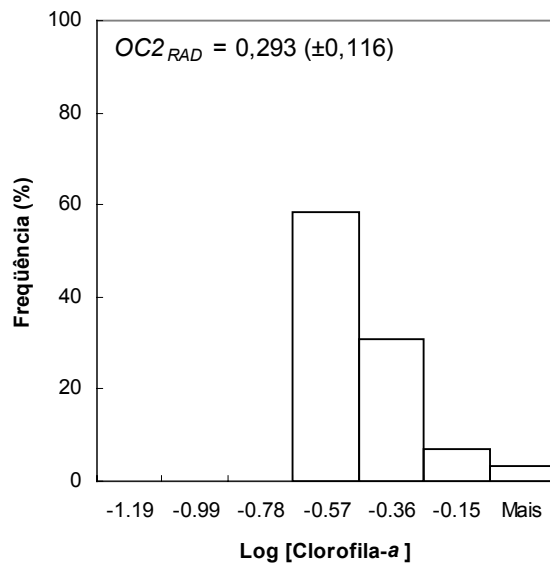
# Medidas *in situ* - Radiometria





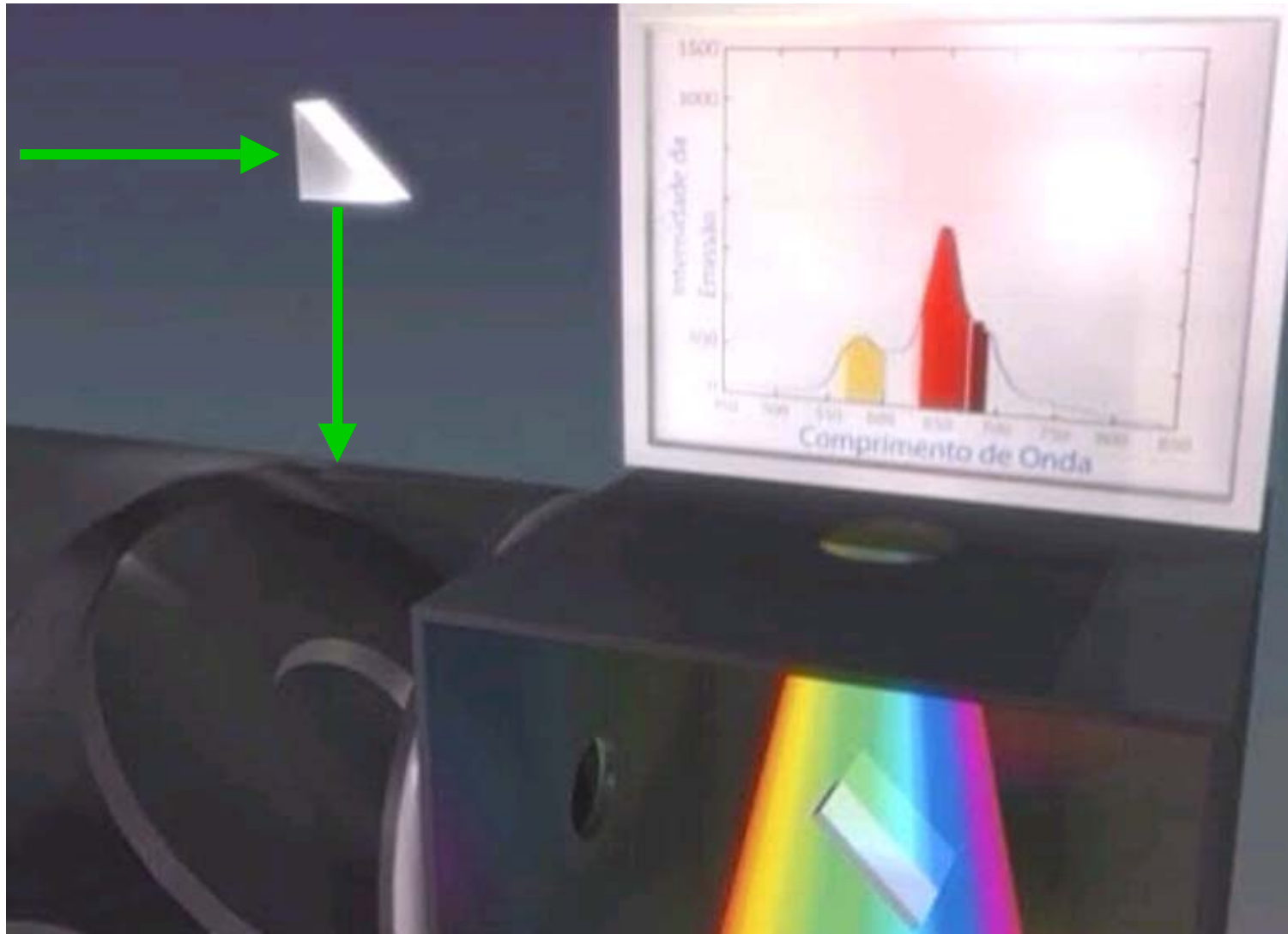


# Medidas *in situ* - Radiometria

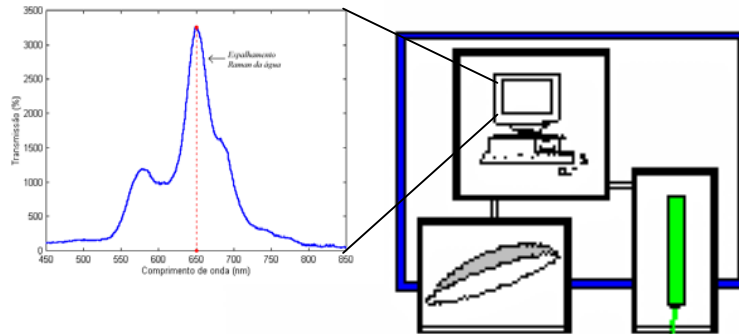




# LIDAR



# LIDAR



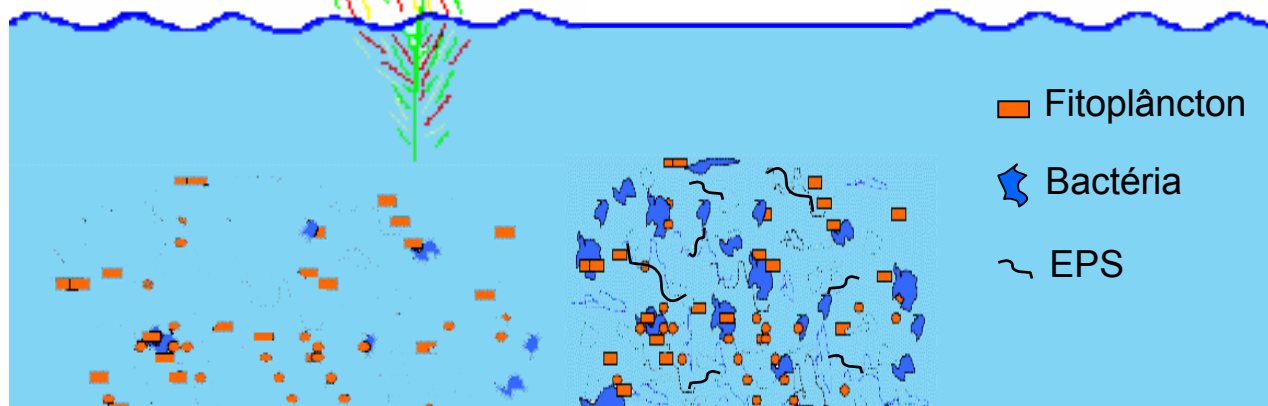
Deteccção da radiação retroespalhada no campo de visão do sistema de detecccção

## Lidar:

- Fonte de luz para excitação (laser, em geral)
- Sistema de detecccção
- Sistema de controle e processamento de dados

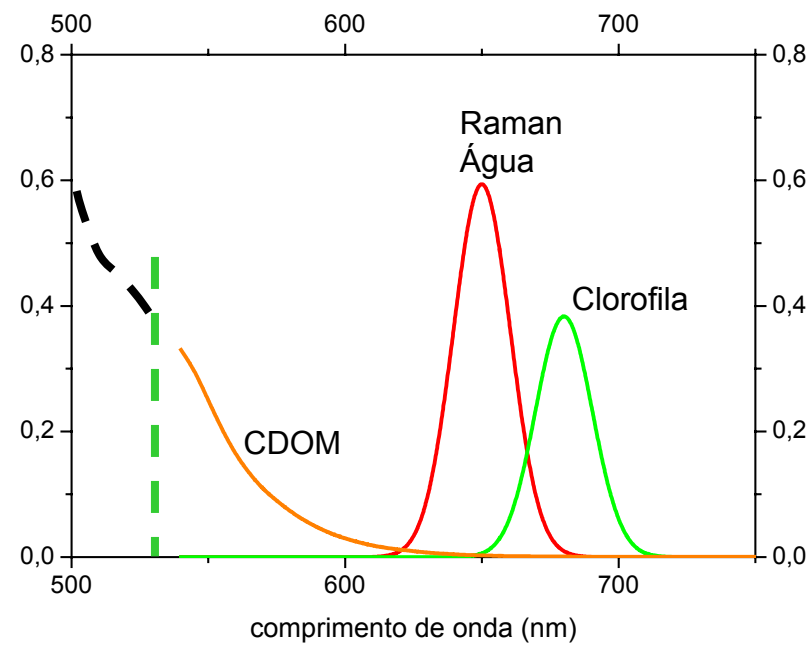
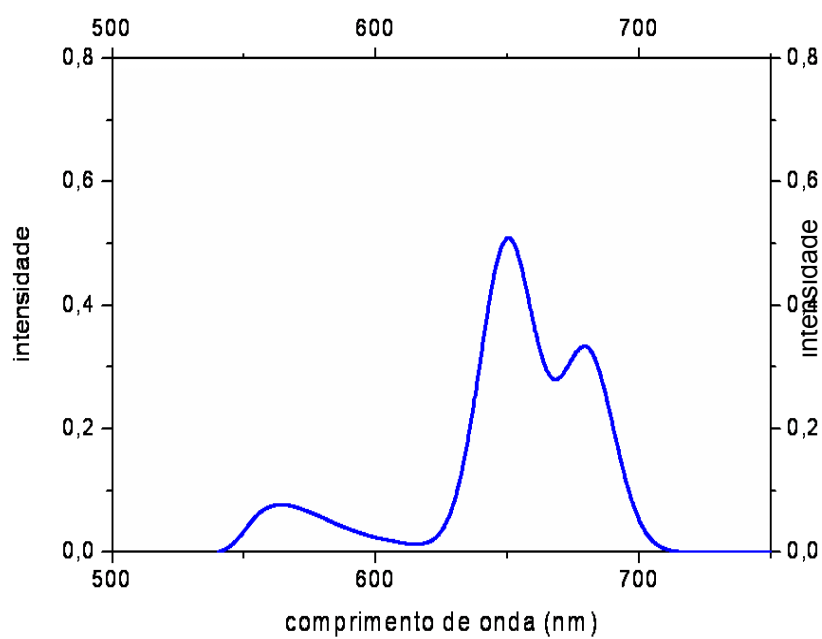
## Interações com:

- Água
- Fitoplâncton
- Material particulado
- Matéria Orgânica Dissolvida



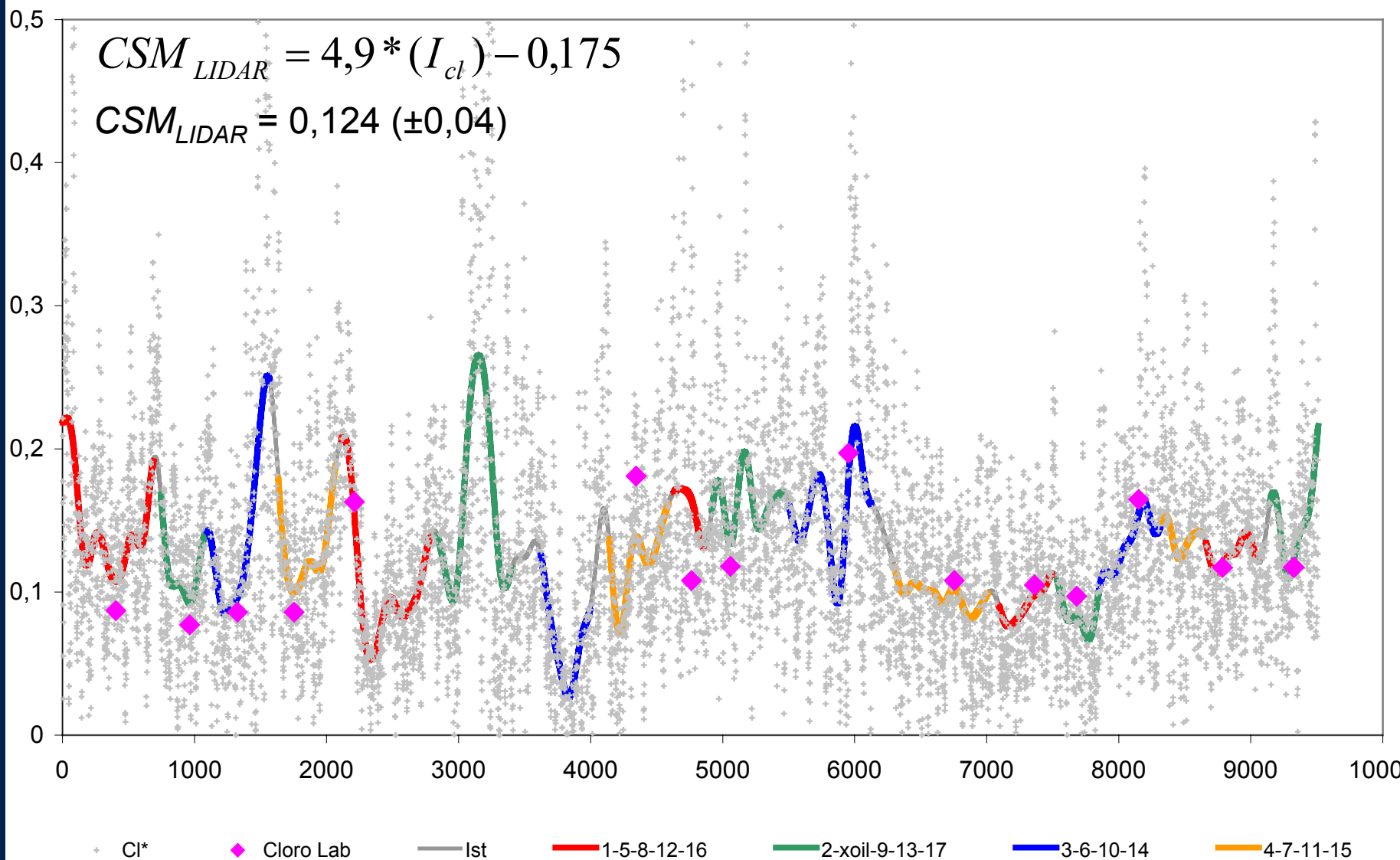
- Fitoplâncton
- ★ Bactéria
- ~ EPS

# LIDAR - Espectros





# LIDAR



# LIDAR

Clorofila	Absoluta	LIDAR (corrigida)		
		(totalidade)	(vizinhança)	(FFT-80)
Est 01	0,087	0,133	0,124	0,134
Est 02	0,077	0,098	0,092	0,105
Est 03	0,086	0,133	0,117	0,129
Est 04	0,086	0,114	0,100	0,116
Est 05	0,163	0,080	0,092	0,083
Est 07	0,181	0,106	0,106	0,111
Est 08	0,108	0,144	0,150	0,148
Est 09	0,118	0,152	0,151	0,151
Est 10	0,197	0,148	0,130	0,148
Est 11	0,108	0,090	0,094	0,090
Est 12	0,105	0,080	0,080	0,084
Est 13	0,097	0,072	0,071	0,077
Est 14	0,165	0,125	0,113	0,124
Est 16	0,117	0,116	0,116	0,118
Est 17	0,117	0,136	0,133	0,136
<b>Media</b>	<b>0,121</b>	<b>0,115</b>	<b>0,111</b>	<b>0,117</b>
<b>DesvPad</b>	<b>0,04</b>	<b>0,03</b>	<b>0,02</b>	<b>0,03</b>
<b>CV%</b>	<b>31,13</b>	<b>22,91</b>	<b>21,39</b>	<b>21,39</b>



# MODIS (*MOD*erate-*res*olution *Im*aging *S*pectroradiometer)

Uso Principal	Banda Original	Largura de Banda <sup>1</sup>	Radiância Espectral <sup>2</sup>	SNR <sup>3</sup> Requerido
Cor do oceano/	8	405-420	44.9	880
Fitoplancton/	9	438-448	41.9	838
Biogeoquímica	10	483-493	32.1	802
	11	526-536	27.9	754
	12	546-556	21.0	750
	13	662-672	9.5	910
	14	673-683	8.7	1087
	15	743-753	10.2	586
	16	862-877	6.2	516

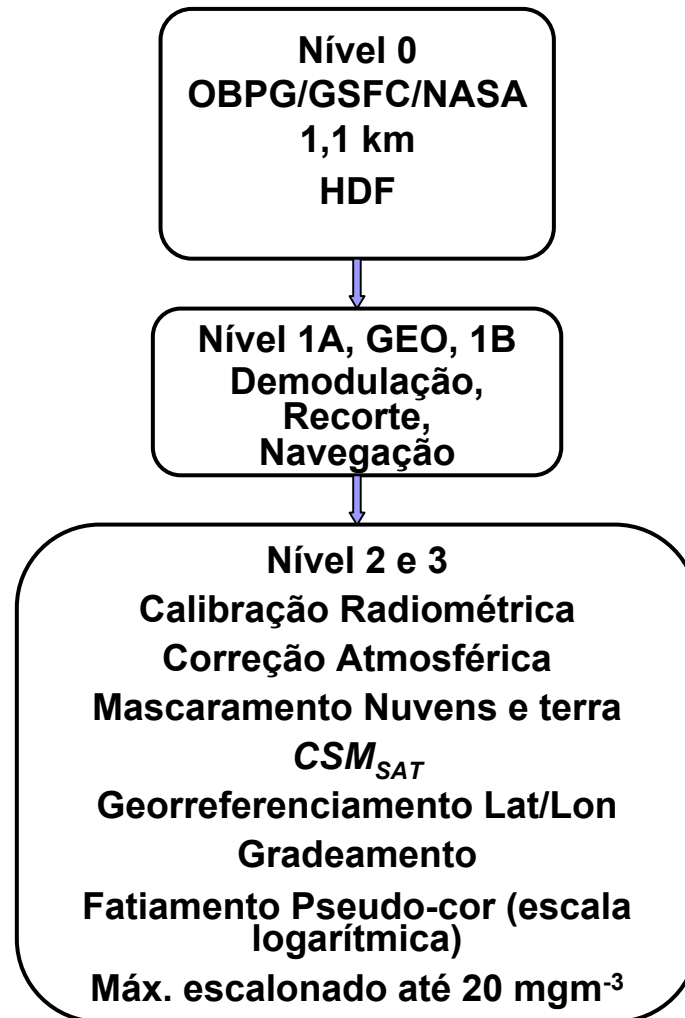
# MODIS

- Resolução 1,1 km
- Formato HDF (OBPG/GSFC/NASA)
- SeaDAS/Linux
- 1 algoritmo empírico - OC3M (O'Reilley et al. 2000)
- 2 algoritmos semi-analíticos - GSM01 (Maritorena et al. 2002) e Carder (Carder et al. 2004)

$$L_{WN}(\lambda) = \frac{tF_0(\lambda)}{n_w^2} \sum_{i=1}^2 g_i \left\{ \frac{b_{bw}(\lambda) + b_{bp}(\lambda_0)(\lambda/\lambda_0)^{-\eta}}{b_{bw}(\lambda) + b_{bp}(\lambda_0)(\lambda/\lambda_0)^{-\eta} + a_w(\lambda) + Cloa_{ph}^*(\lambda) + a_{cdm}(\lambda_0)\exp[-S(\lambda - \lambda_0)]} \right\}^{-i}$$

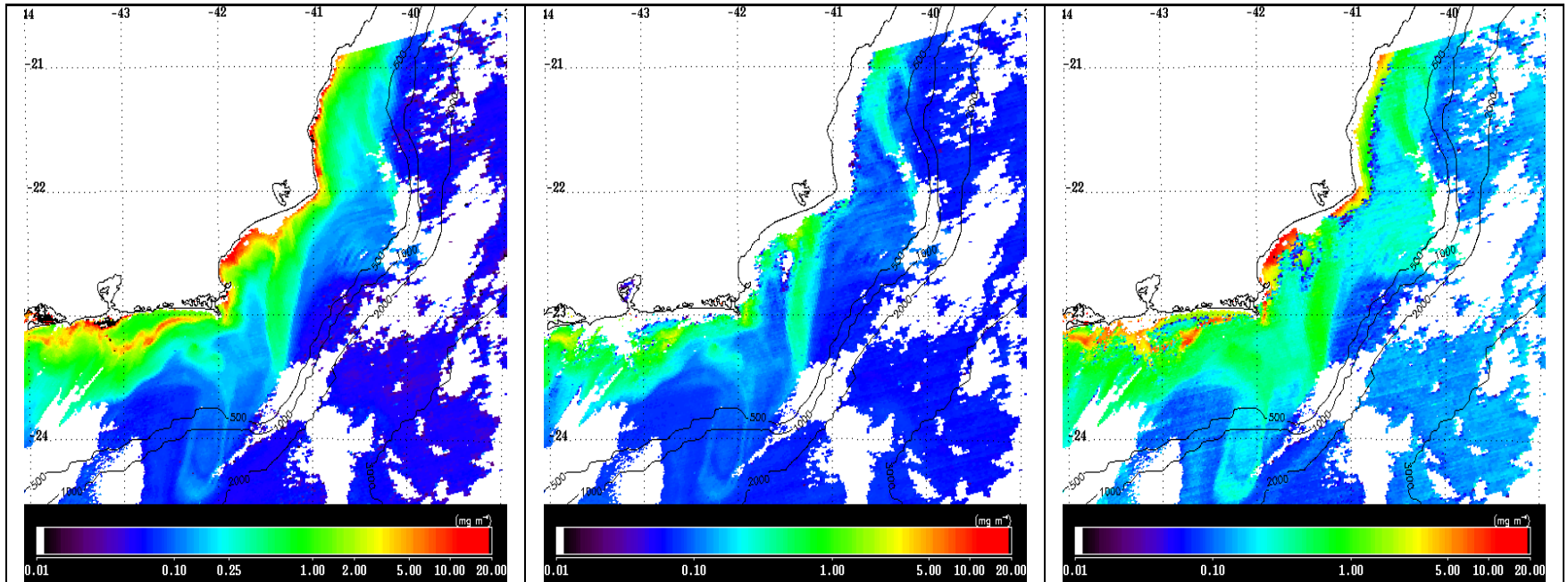


# MODIS





# MODIS – 25/11/2004



OC3M

GSM01

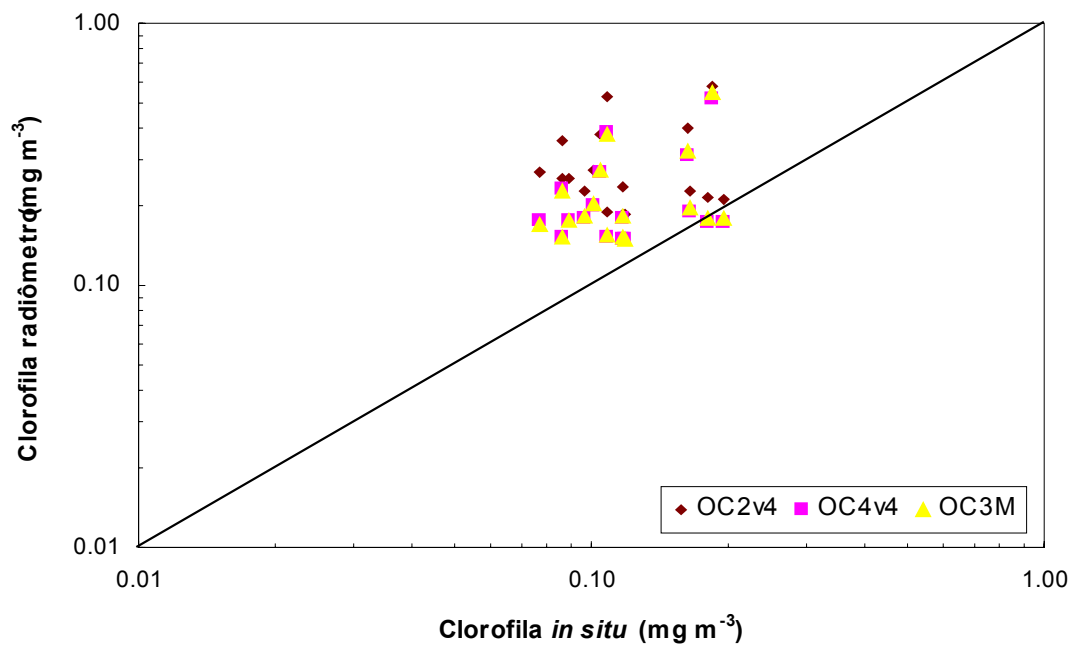
Carder



# Resultados - Comparações

Algoritmo/LIDAR	<i>rmse-L</i>	<i>rmse</i>	N
OC3M <sub>SAT</sub>	0,36	0,11	10
GSM01 <sub>SAT</sub>	0,28	0,08	10
Carder <sub>SAT</sub>	1,14	0,34	10
CSM <sub>LIDAR</sub>	0,48	0,14	14

# Fluorimetria x Radiometria



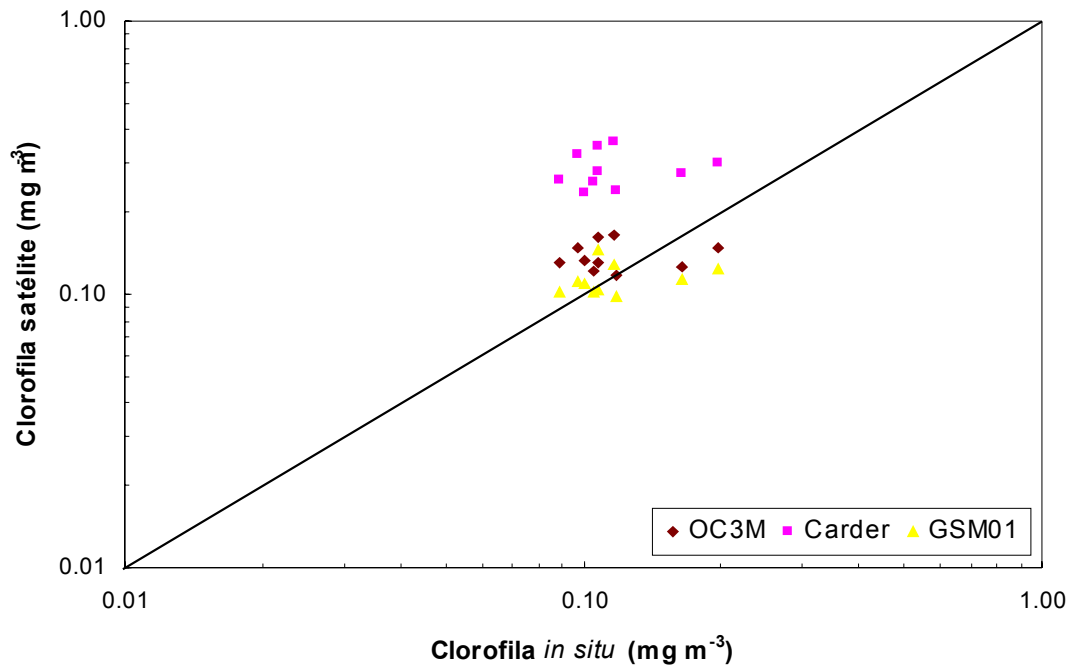


# Comparações - MODIS

Algoritmo/LIDAR	<i>rmse-L</i>	<i>rmse</i>	<b>N</b>
OC2v4 <sub>RAD</sub>	1,36	0,40	17
OC4v4 <sub>RAD</sub>	0,93	0,28	17
OC3M <sub>RAD</sub>	0,93	0,28	17
CSM <sub>LIDAR</sub>	0,48	0,14	14



# Fluorimetria x MODIS





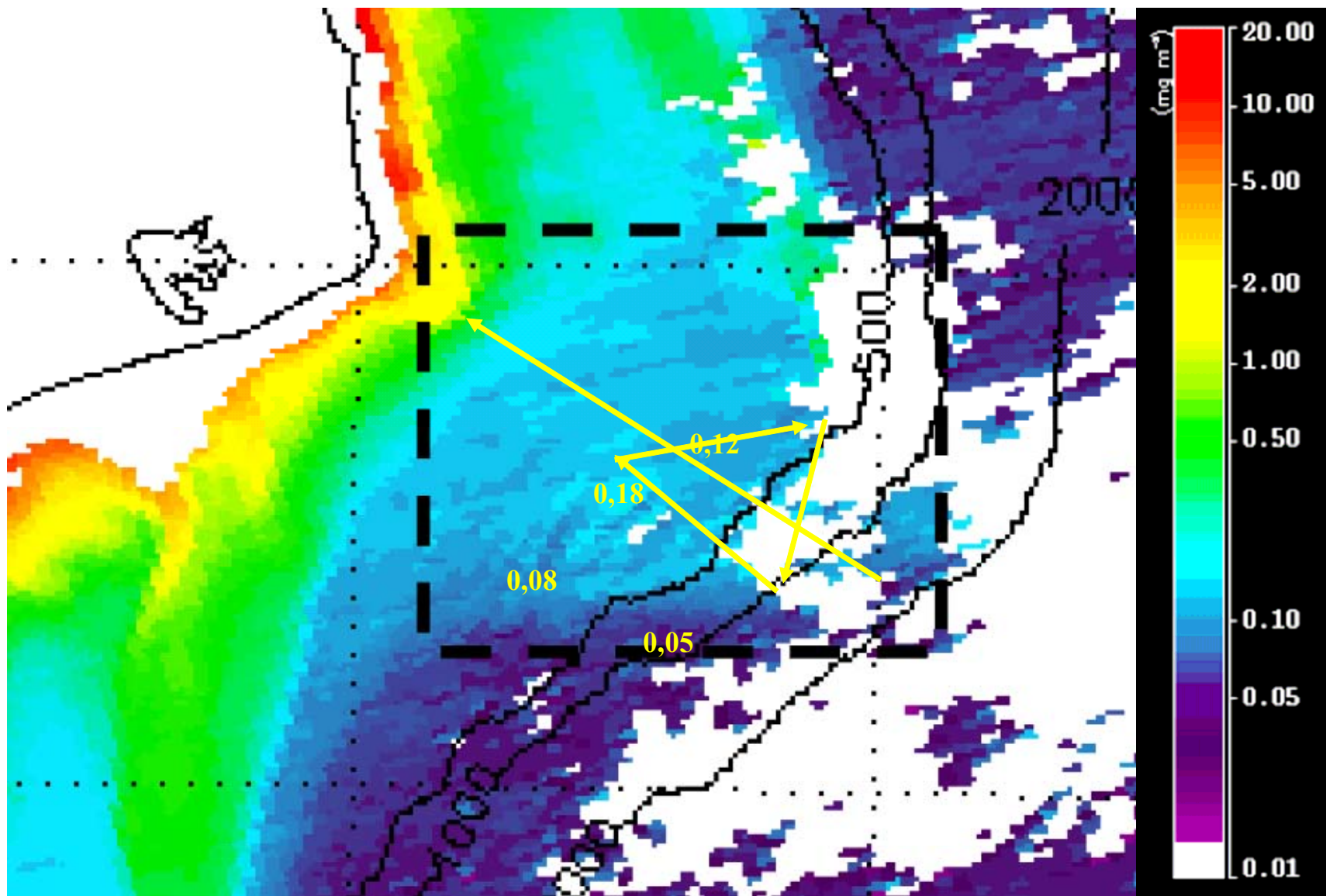


# Comparações - LIDAR

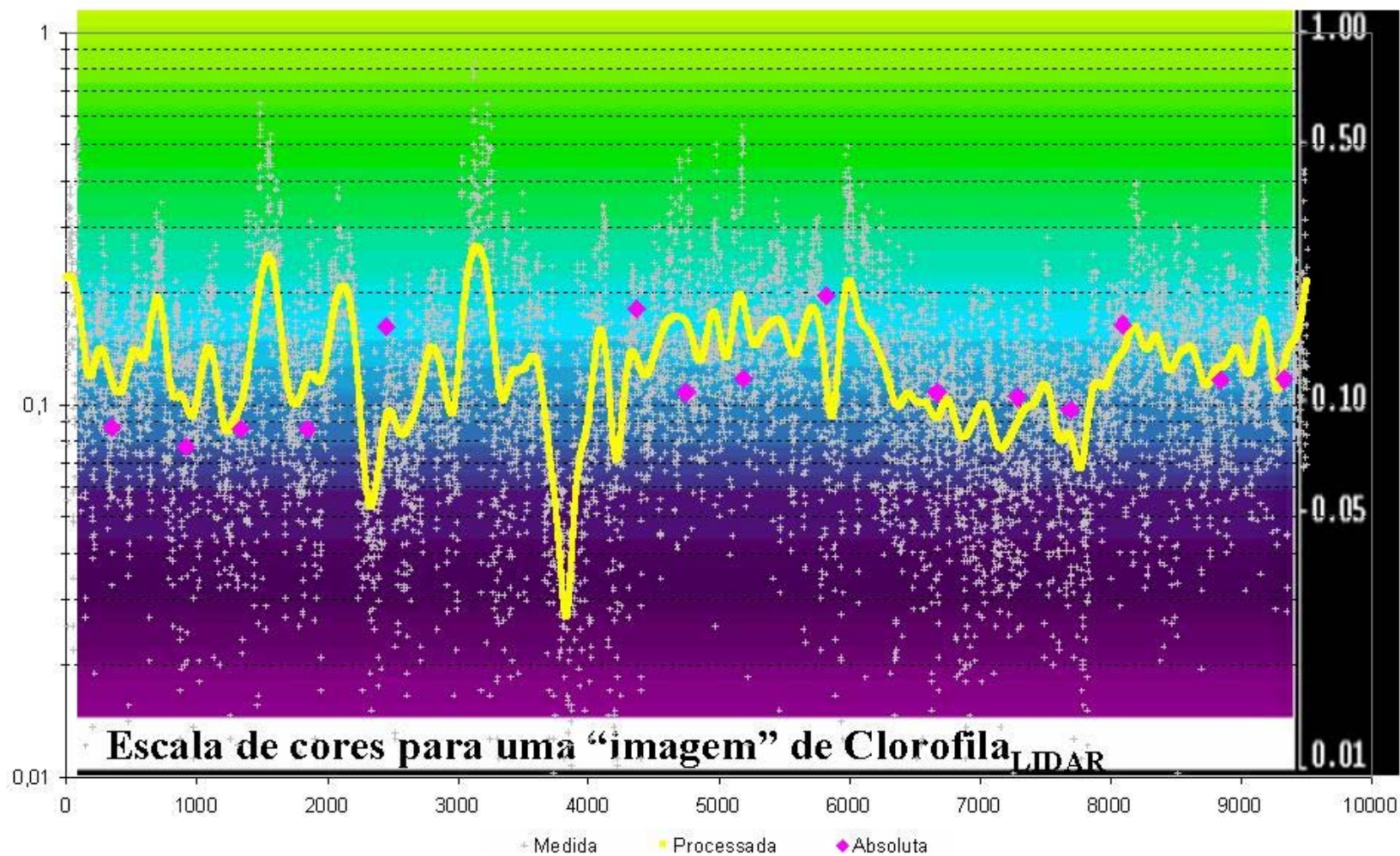
Algoritmo/LIDAR	<i>rmse-L</i>	<i>rmse</i>	<b>N</b>
OC2v4 <sub>RAD</sub>	1,36	0,40	17
OC4v4 <sub>RAD</sub>	0,93	0,28	17
OC3M <sub>RAD</sub>	0,93	0,28	17
OC3M <sub>SAT</sub>	0,36	0,11	10
GSM01 <sub>SAT</sub>	0,28	0,08	10
Carder <sub>SAT</sub>	1,14	0,34	10



# MODIS x LIDAR



# MODIS x LIDAR







# Outras comparações (em andamento)

Radiômetro versus in situ					
	Chla_insitu	OC2	OC4	OC3M	
Chla_insitu	1.00				
OC2	0.13	1.00			
OC4	0.33	0.96	1.00		
OC3M	0.37	0.94	1.00	1.00	
Algoritmo	rmse	rmse-L	RDP	ADP	
OC2v4	0.40	1.36	147.00	147.00	
OC4v4	0.28	0.93	80.02	82.17	
OC3M	0.28	0.93	81.31	82.56	
Satélite versus in situ					
	Chla_insitu	OC3M	carder	gsm_01	
Chla_insitu	1.00				
OC3M	0.10	1.00			
carder	0.11	0.92	1.00		
gsm_01	0.28	0.87	0.82	1.00	
Algoritmo	rmse	rmse-L	RDP	ADP	
OC3M	0.11	0.36	15.09	21.84	
Carder	0.34	1.14	109.02	109.02	
gsm_01	0.08	0.28	-0.84	12.20	
Lidar versus in situ					
	Chla_insitu	Lidar			
Chla_insitu	1.00				
Lidar	0.19	1.00			
Algoritmo	rmse	rmse-L	RDP	ADP	
Lidar	0.14	0.48	8.83	30.85	
Satélite versus Lidar					
	OC3M_sat	carder	gsm_01	Lidar	
OC3M_sat	1.00				
carder	0.97	1.00			
gsm_01	0.92	0.93	1.00		
Lidar	0.41	0.35	0.55	1.00	
Algoritmo	rmse	rmse-L	RDP	ADP	
OC3M_sat	0.10	0.34	14.76	20.89	
carder	0.40	1.34	148.48	148.48	
gsm_01	0.08	0.28	-4.88	14.64	

Satélite versus Radiômetro					
	OC3M_sat	OC3M_rad			
OC3M_sat	1.00				
OC3M_rad	-0.23	1.00			
Algoritmo	rmse	rmse-L	RDP	ADP	
OC3M_rad	0.19	0.62	43.77	45.67	
Radiômetro versus Lidar					
	OC2_rad	OC4_rad	OC3M_rad	Lidar	
OC2_rad	1.00				
OC4_rad	0.96	1.00			
OC3M_rad	0.93	0.99	1.00		
Lidar	-0.43	-0.49	-0.53	1.00	
Algoritmo	rmse	rmse-L	RDP	ADP	
OC2v4	0.43	1.47	166.16	166.16	
OC4v4	0.43	1.47	166.16	100.92	
OC3M	0.33	1.10	102.71	104.20	
Radiômetro					
	OC2	OC4	OC3M		
Chla_insitu					
OC2	1.00				
OC4	0.96	1.00			
OC3M	0.94	1.00	1.00		
Algoritmo	rmse	rmse-L	RDP	ADP	
OC2v4_OC30	0.13	0.43	32.60	32.60	
OC4v4_OC3M	0.01	0.04	-1.27	2.27	
OC2_OC4	0.13	0.44	34.09	34.09	
Satélite					
	Chla_insitu	OC3M	carder	gsm_01	
Chla_insitu	1.00				
OC3M	0.10	1.00			
carder	0.11	0.92	1.00		
gsm_01	0.28	0.87	0.82	1.00	
Algoritmo	rmse	rmse-L	RDP	ADP	
OC3M_gsm	0.08	0.26	15.85	15.85	
Carder_gsm	0.34	1.15	110.56	110.56	
OC3M_carder	0.27	0.89	-37.05	37.05	

# Conclusões

- As concentrações de clorofila foram bem estimadas pelos métodos empregados, ainda que os algoritmos empíricos aplicados aos dados radiométricos *in situ* e aos dados de satélite tenham superestimado os valores de CSM.
- O algoritmo semi-analítico GSM01 aplicado aos dados MODIS apresentou melhor desempenho que OC3M e Carder, respectivamente.



# Conclusões

- O uso sistemático do Lidar pode contribuir para o aprimoramento dos modelos utilizados na extração de informação de sensores orbitais.
- Outras comparações entre os dados radiométricos *in situ*, LIDAR e de satélite serão realizadas de modo a explorar melhor estas técnicas de amostragem e assim, avançar no estudo ecossistêmico da região.



***Muito Obrigado !***

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**23 11 2004**