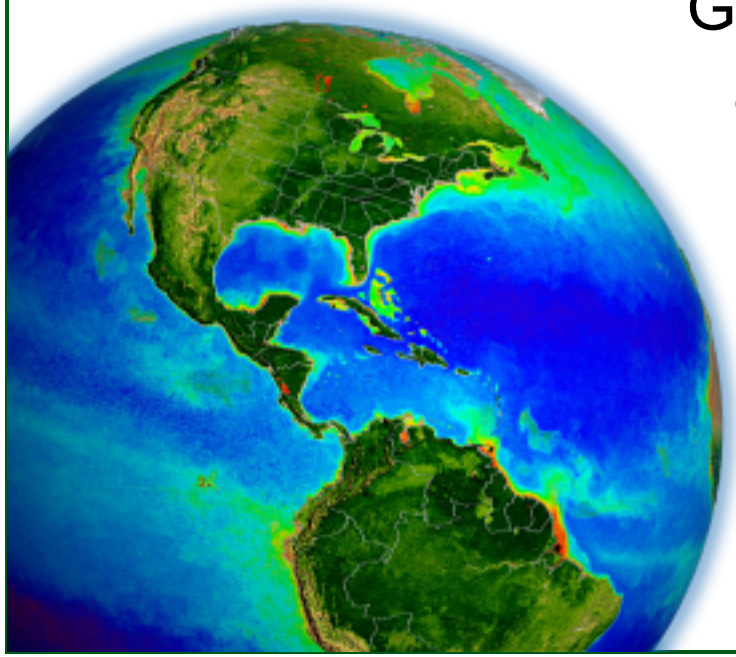
Remote Sensing Reflectance and Derived Products

Bryan Franz

Gerhard Meister, Jeremy Werdell
Ziauddin Ahmad, Sean Bailey

and the
Ocean Biology
Processing Group



MODIS Science Team Meeting

April 2014

Content

- Reprocessing history and current product quality
- Proposed chlorophyll algorithm refinement
- Changes for next reprocessing (R2014.0)

Current MODIS OC Standard Product Suite

Level-2 OC Product	Algorithm Reference
1. $R_{rs}(\lambda)$ →	$R_{rs}(412)$, $R_{rs}(443)$, $R_{rs}(469)$, $R_{rs}(488)$, $R_{rs}(531)$, $R_{rs}(547)$, $R_{rs}(555)$, $R_{rs}(645)$, $R_{rs}(667)$, $R_{rs}(678)$
2. Ångstrom	*Wang 1994, Ahmad et al 2010, etc.*
3. AOT	
4. Chlorophyll *a*	*l. 1998 (OC3) updated by Werdell*
5. $K_d(490)$	*l. 2000 (KD2) updated by Werdell*
6. POC	*al. 2008*
7. PIC	*2005, Gordon et al. 2001*
8. CDOM_index	*Gentili 2009*
9. PAR	*nz, & Werdell 2003*
10. iPAR	
11. nFLH	*Behrenfeld et al. 2009*

Calibration Refinements to Improve Rrs Quality

1. Starting from MCST instrument calibration.

2. Add time-dependent corrections to reduce residual artifacts in cross-scan variability and detector and mirror-side striping.

   Meister and Franz, 2013

3. Add (for Terra) time-dependent polarization sensitivity changes (from -5% to +40%, 412 end of scan).

   see talk by Meister on Thursday

4. Add vicarious calibration to remove mean bias in Rrs retrievals relative to ground truth (MOBY).

MODIS Vicarious Gains

	412	443	469	488	531	547	555	645	667	678	748	859	869
Aqua	0.9731	0.9910	1.0132	0.9935	1.002	0.9994	1.0012	1.0280	0.9996	0.9998	0.9989	1.0254	1.0
Terra	0.9805	0.9985	0.9986	0.9930	0.9987	0.9976	0.9908	1.0337	0.9945	1.0012	0.9990	1.0060	1.0

MODIS-Aqua Ocean Color Reprocessing

2010-2011 **preliminary C6 calibration**

R2010.0: multi-mission reprocessing (MODISA, MODIST, SeaWiFS, OCTS, CZCS) using common algorithms.

2012 May **final C6 calibration**

R2012.0: MODISA full-mission reprocessing to incorporate final MCST C6 calibration and OBPG RVS refinements.

2013 February **improved C6 calibration**

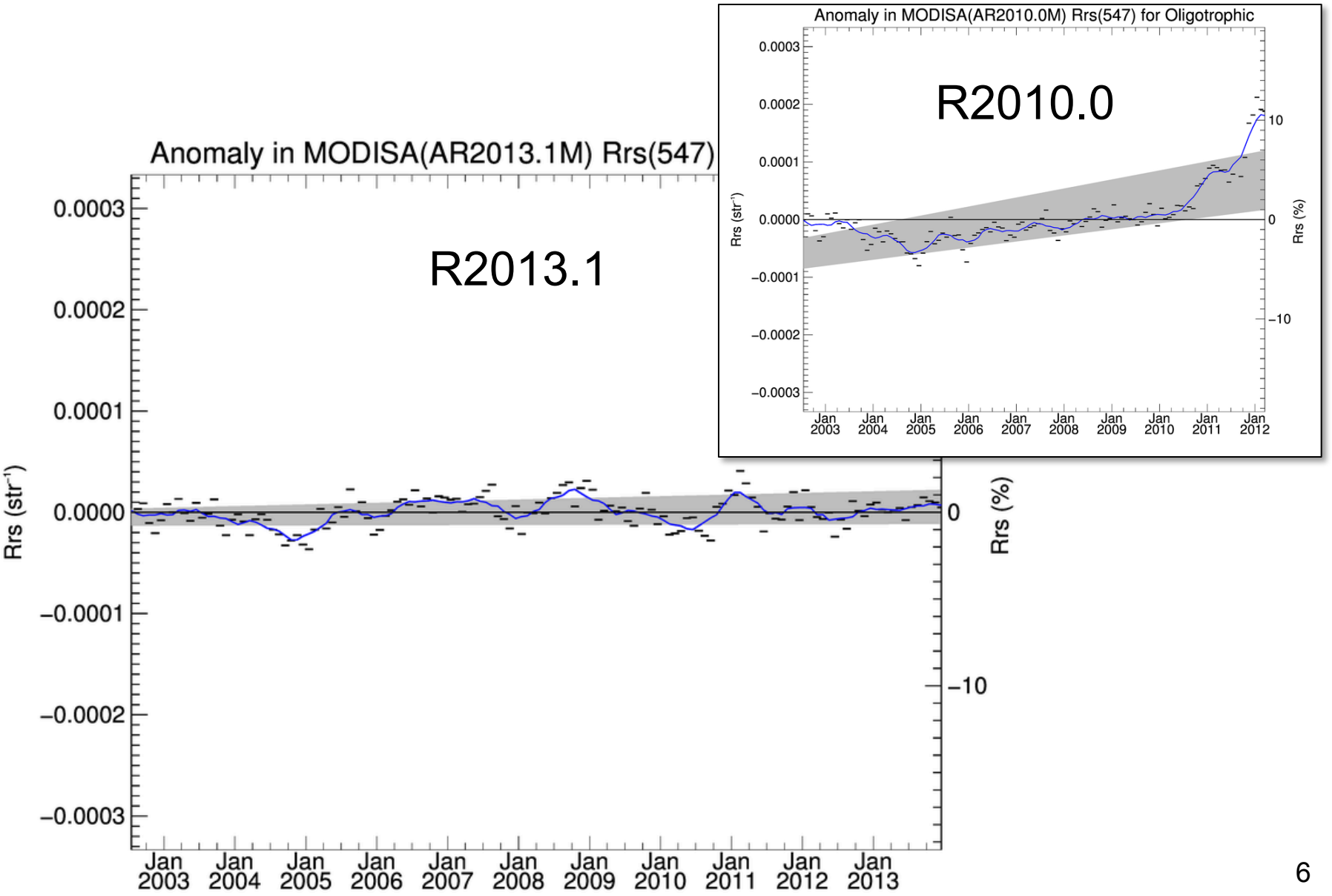
R2013.0: MODISA partial-mission reprocessing (period 2011-2013) to incorporate refined MCST C6 calibration.

2013 September & November

R2013.1, R2013.1.1: end of mission only, minor calibration updates

http://oceancolor.gsfc.nasa.gov/WIKI/OCReproc.html

Clear-Water Rrs(547) Anomaly Trend

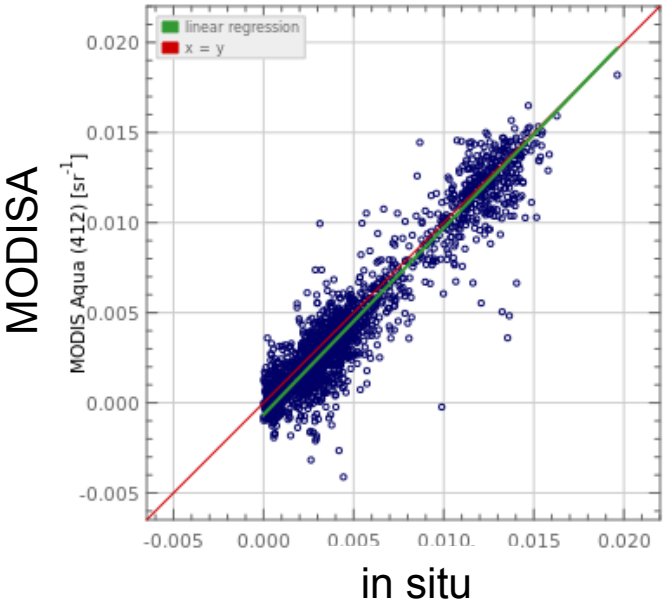


SeaBASS + AERONET-OC

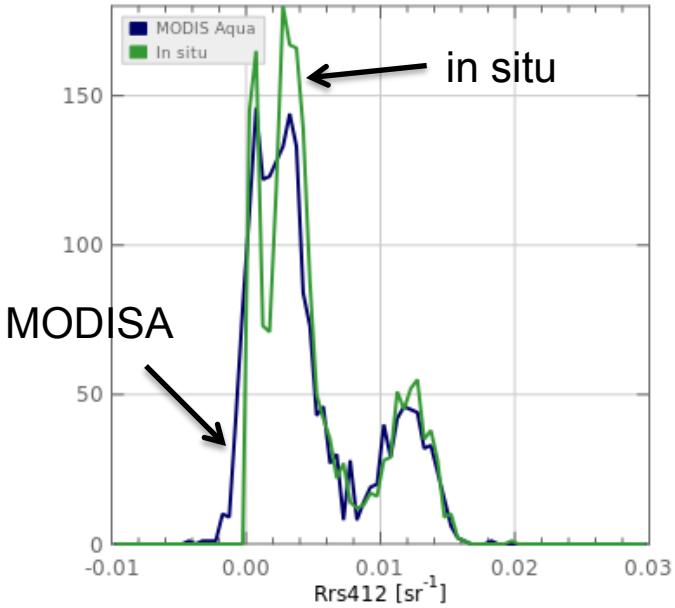
MODISA (R2013.1) Rrs vs Field Measurements

Product Name	MODIS Aqua Range	In situ Range	#	Best Fit Slope	Best Fit Intercept	R^2	Median Ratio	Abs % Difference	RMSE
Rrs412	-0.00411, 0.01820	0.00000, 0.01964	1945	1.03539	-0.00065	0.90481	0.90307	22.21457	0.00147
Rrs443	-0.00065, 0.01950	0.00005, 0.01783	1774	1.04628	-0.00026	0.88967	1.00894	12.06771	0.00109
Rrs488	0.00033, 0.02513	0.00039, 0.02289	2127	0.94853	-0.00021	0.89894	0.91509	12.00520	0.00106
Rrs531	0.00092, 0.01682	0.00130, 0.02110	639	0.87525	0.00017	0.91346	0.97562	11.98040	0.00096
Rrs547	0.00088, 0.01590	0.00091, 0.01984	469	0.91611	0.00018	0.92442	1.04480	13.38668	0.00072
Rrs667	-0.00016, 0.01186	0.00002, 0.01100	709	0.98687	-0.00002	0.91982	0.94565	37.48856	0.00017
Rrs678	-0.00015, 0.00283	0.00004, 0.00295	373	0.94854	-0.00000	0.89380	1.00161	32.16394	0.00008

Rrs(412)



Frequency Distribution

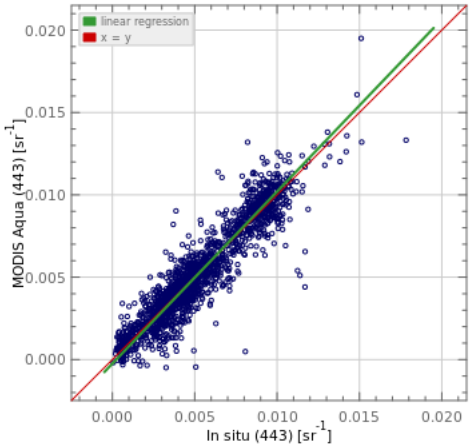


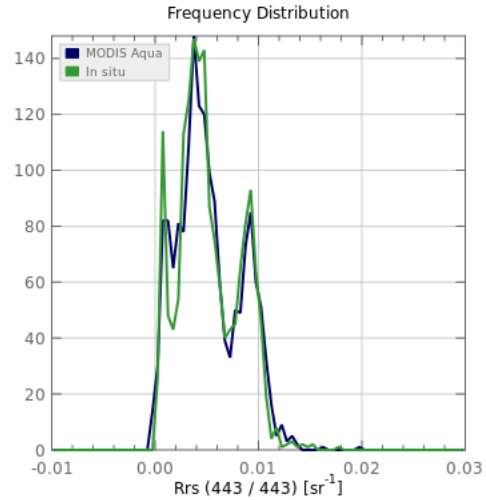
http://seabass.gsfc.nasa.gov/

SeaBASS + AERONET-OC

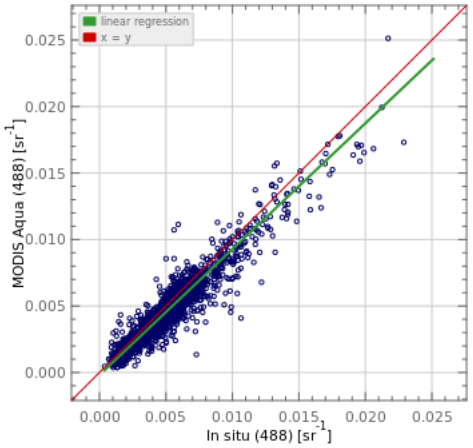
MODISA (R2013.1) Rrs vs Field Measurements

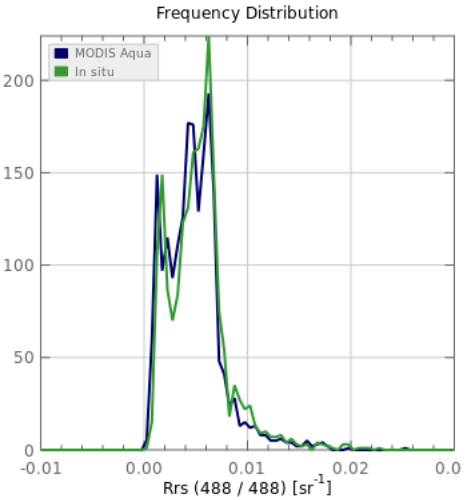
Rrs(443)



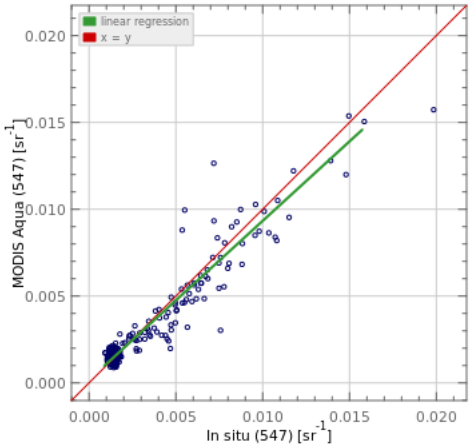


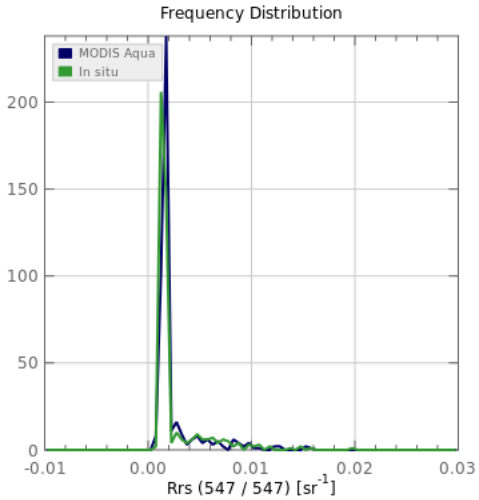
Rrs(488)





Rrs(547)





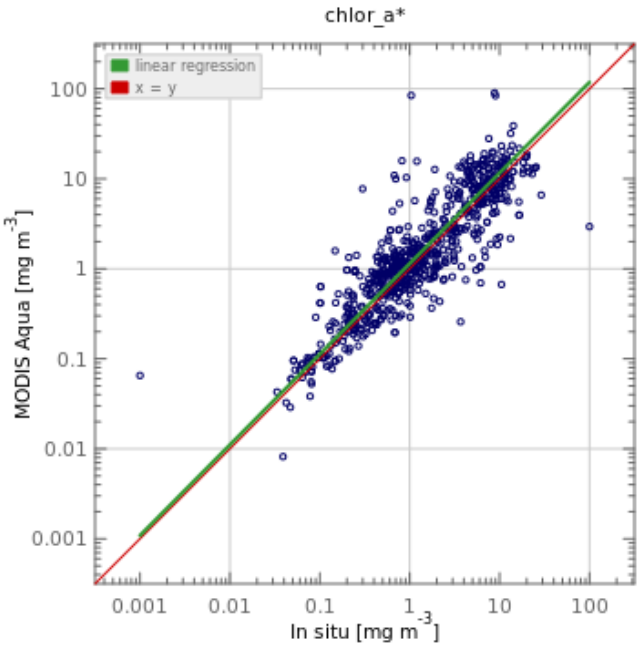
Mean APD 12-13%, Mean Bias < 10%, $R^2 > 0.9$

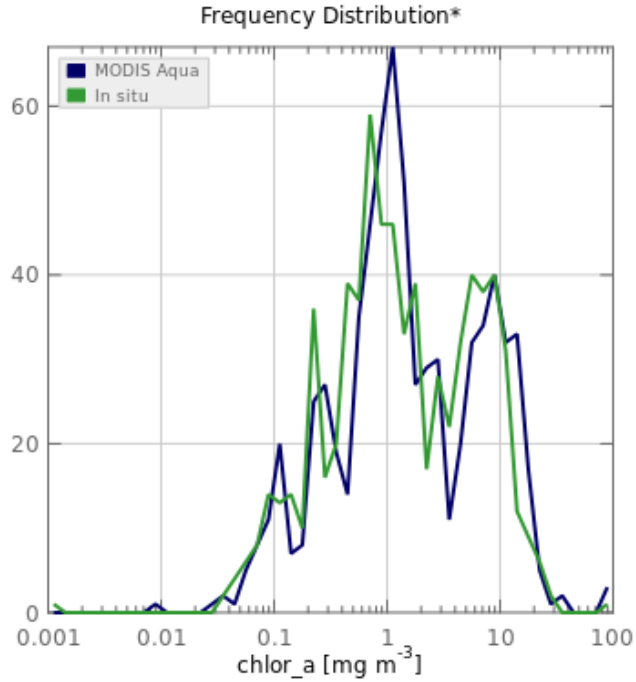
MODISA (R2013.1) Chlorophyll Validation

Product Name	MODIS Aqua Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R^2*	Median Ratio	Abs % Difference	RMSE*
chlor_a	0.00818, 90.17510	0.00100, 100.00000	721	1.00727	0.05792	0.80370	1.12256	38.54489	0.32837

* statistical calculations based on log10

The linear regression algorithm has been changed to reduced major axis.





Mean APD 38%, Mean Bias 12%, R^2 0.8

MODIS-Terra Ocean Color Reprocessing

2010-2011 **preliminary C6 calibration**

R2010.0: multi-mission reprocessing (MODIS-A, MODIS-T, SeaWiFS, OCTS, CZCS) using common algorithms.

2013 August **improved C6 calibration**

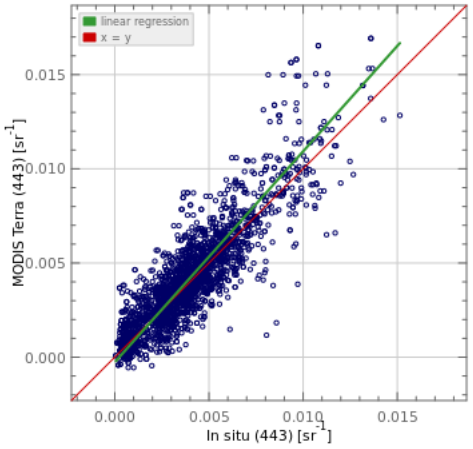
R2013.0: MODIS-T reprocessing to incorporate MCST C6 calibration and OBPG RVS and polarization sensitivity refinements.

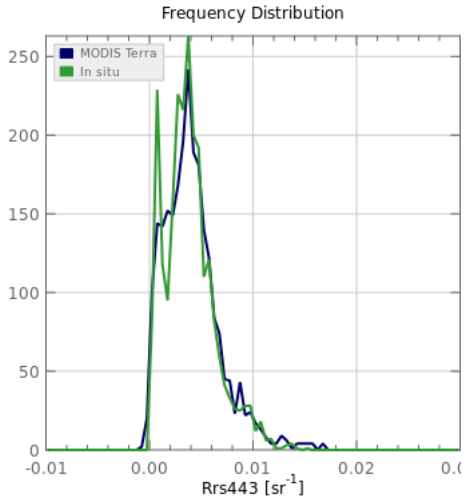
http://oceancolor.gsfc.nasa.gov/WIKI/OCReproc.html

SeaBASS + AERONET-OC

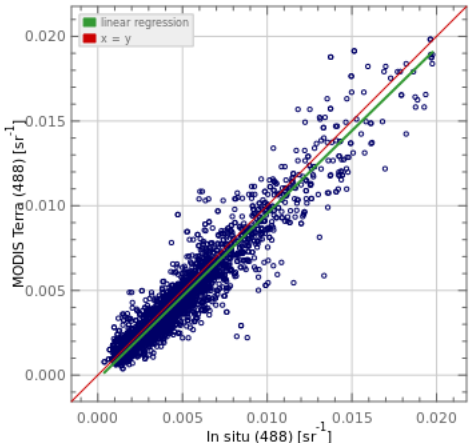
MODIST (R2013.0) Rrs vs Field Measurements

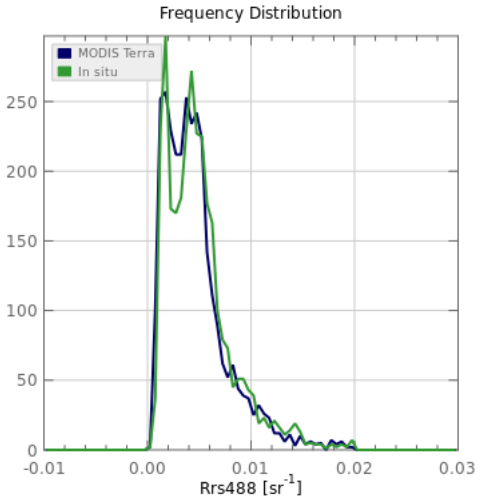
Rrs(443)



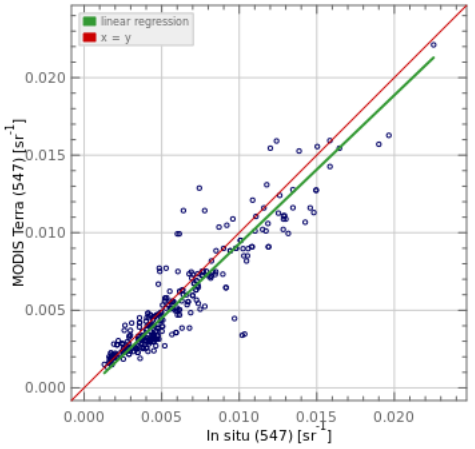


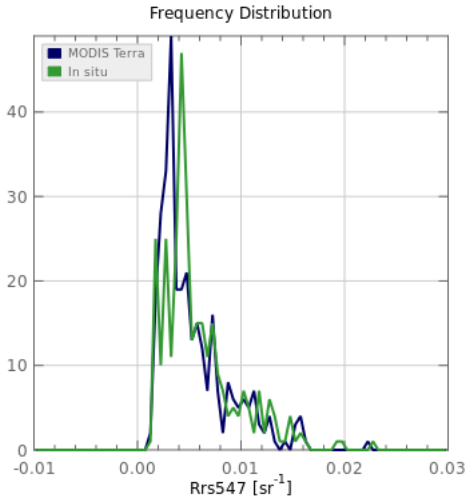
Rrs(488)





Rrs(547)

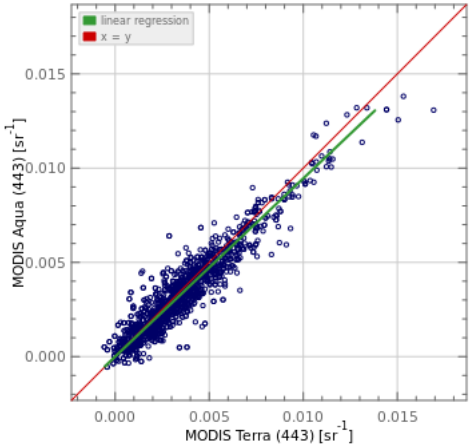


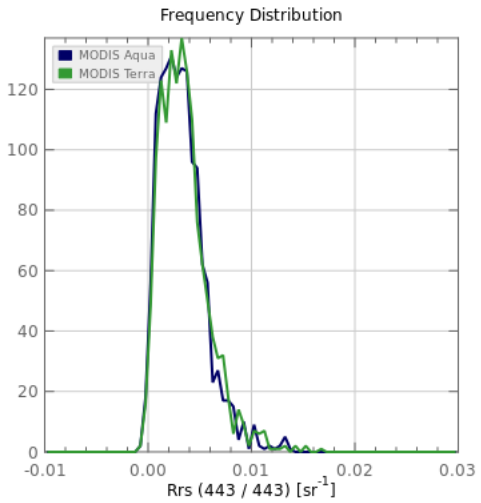


Mean APD 13-20%, Mean Bias < 10%, R^2 0.8-0.9

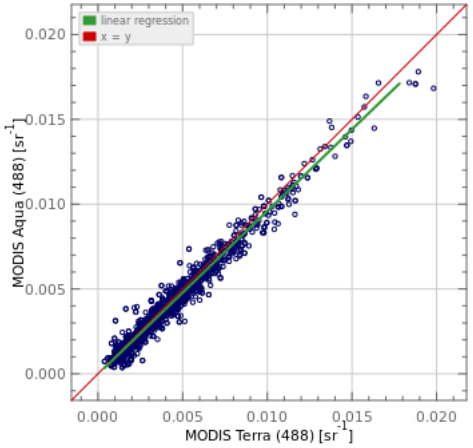
MODIST (R2013.0) vs MODISA (R2013.1)

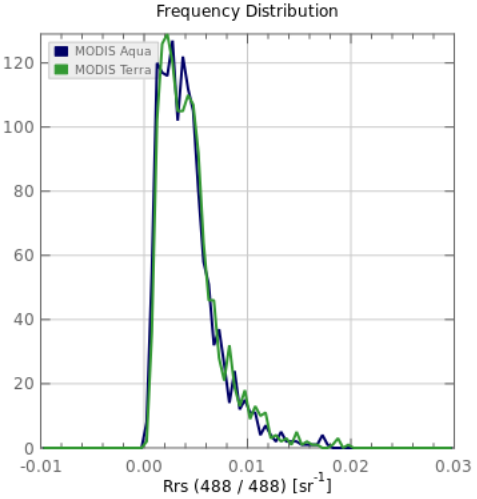
Rrs(443)



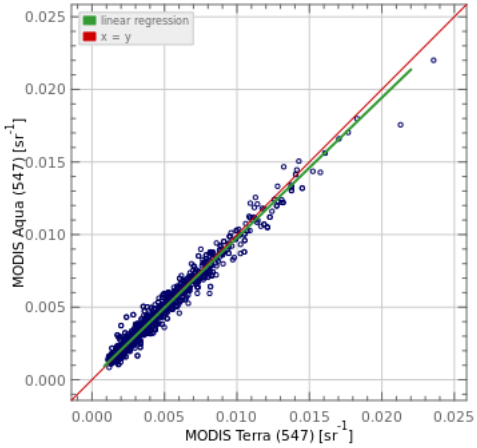


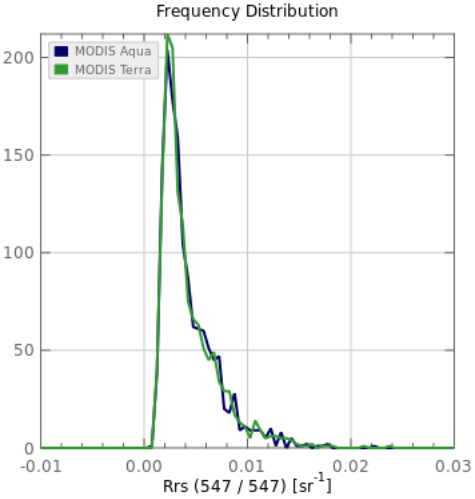
Rrs(488)





Rrs(547)

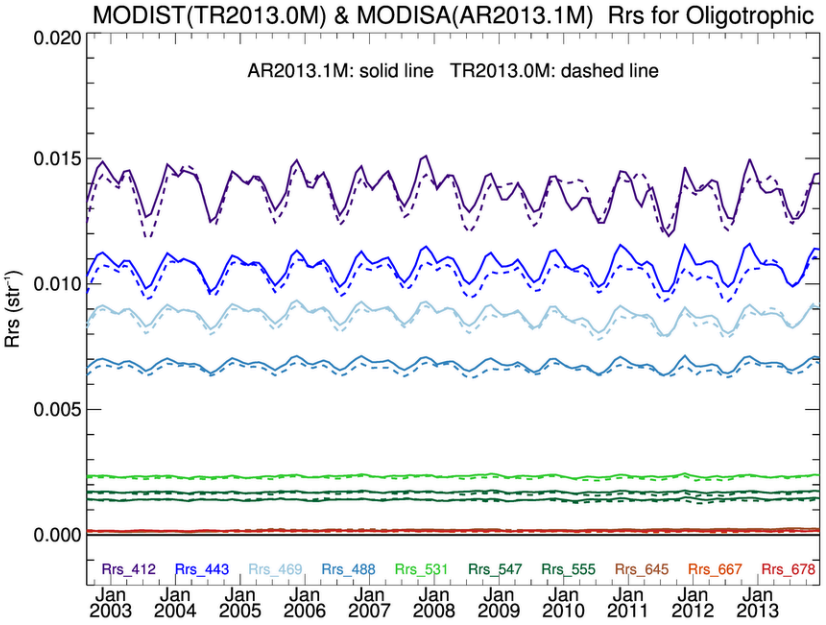




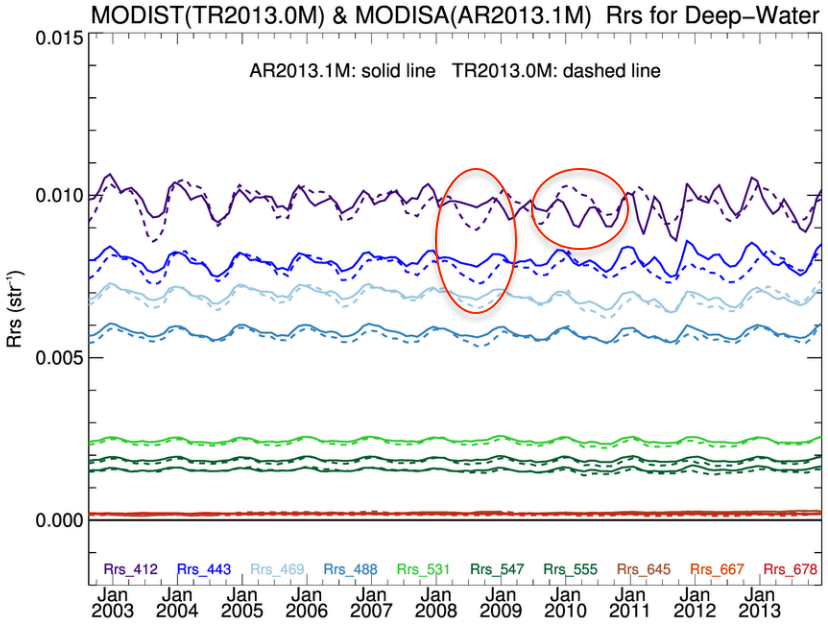
MODIS to MODIS scatter 1/2 the MODIS to in situ scatter!

MODISA and MODIST Rrs(λ) Time-Series

Very Clear Water



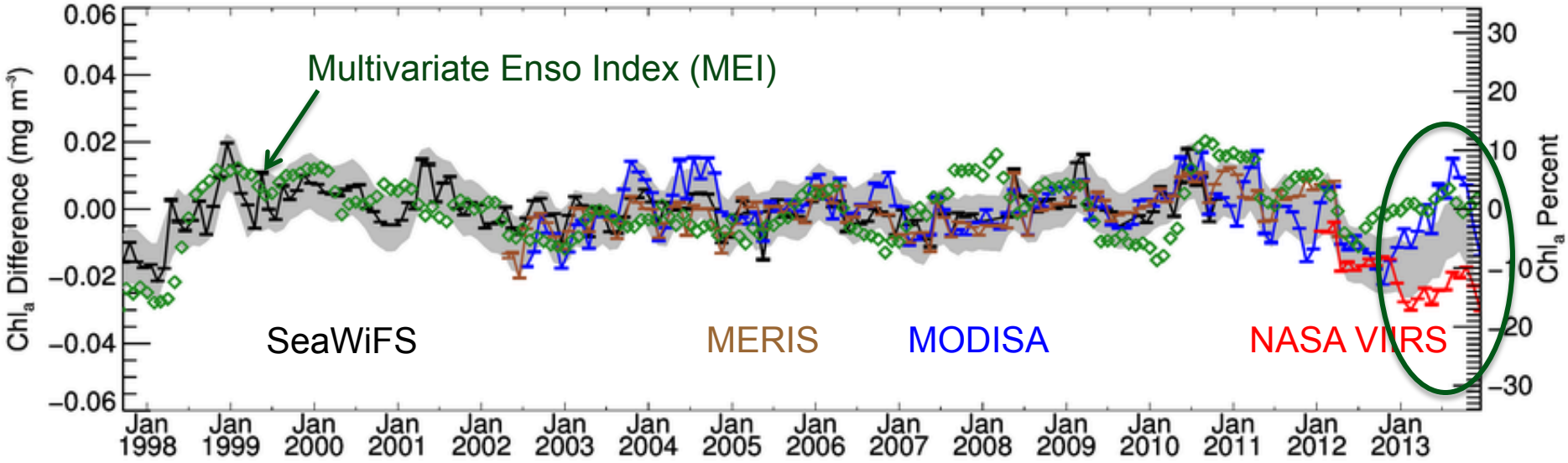
Global Deep Water



mean ratio between missions within 3% in most bands

Multi-Mission Chlorophyll Time-Series

Deep-Water Chlorophyll Anomaly



~5% month-to-month temporal precision

Chlorophyll Algorithm Refinement

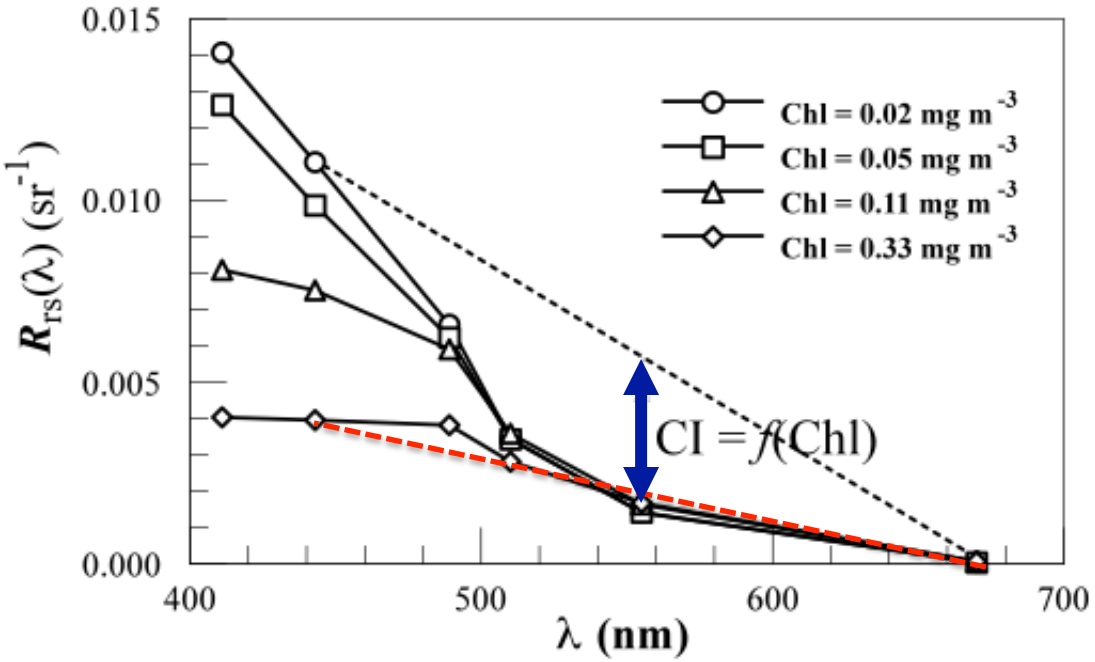
line-height approach

Chlorophyll *a* algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference

Chuanmin Hu,[1] Zhongping Lee,[2] and Bryan Franz[3]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, C01011, doi:10.1029/2011JC007395, 2012

diminishing sensitivity



Chlorophyll Algorithm Refinement

a hybrid approach

New CI Line Height Algorithm
better at low chlorophyll

$$CI = R_{rs}(555) - [R_{rs}(443) + (555\text{–}443)/(670\text{–}443) * (R_{rs}(670) - R_{rs}(443))],$$

which is equivalent to $CI \approx R_{rs}(555) - 0.5(R_{rs}(443) + R_{rs}(670))$.

Standard OCx Band Ratio Algorithm
better at mid to high chlorophyll

$$\mathrm{Chl_{OC4}} = 10^{y}$$

$$y = a_0 + a_1\chi + a_2\chi^2 + a_3\chi^3 + a_4\chi^4$$

$$\chi = \log_{10}(R) \text{ and } R = \max(R_{rs}(443, 490, 510))/R_{rs}(555)$$

Chl ≤ 0.25 mg m^{-3}

Chl > 0.3 mg m^{-3}

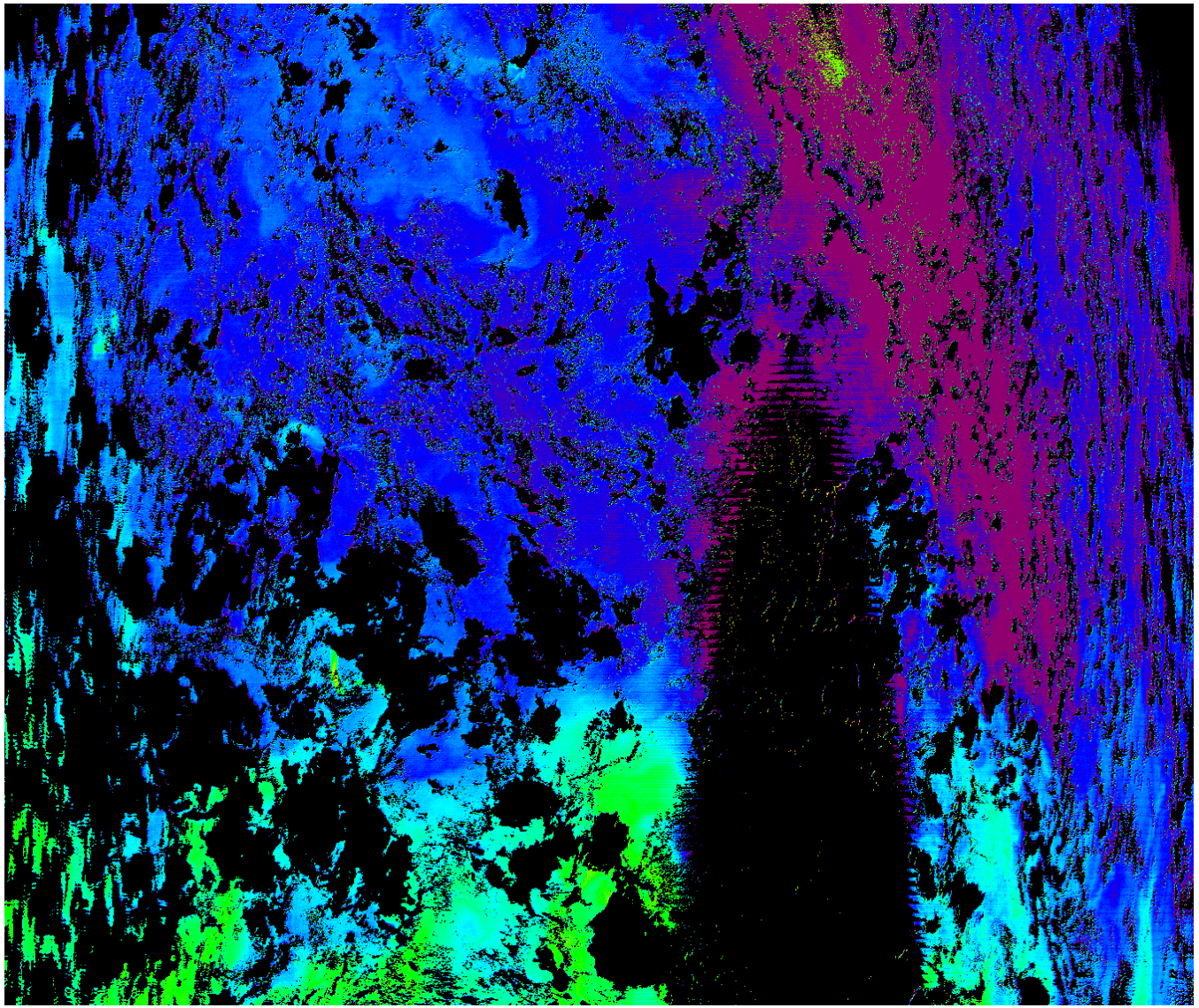
Proposed OCxI Algorithm

$$\mathrm{Chl_{OCI}} = \mathrm{Chl_{CI}}\left[\text{for } \mathrm{Chl_{CI}} \le 0.25 \text{ mg m}^{-3}\right]$$

$$\mathrm{Chl_{OC4}}\left[\text{for } \mathrm{Chl_{CI}} > 0.3 \text{ mg m}^{-3}\right]$$

$$\alpha \times \mathrm{Chl_{OC4}} + \beta \times \mathrm{Chl_{CI}}\left[\text{for } 0.25 < \mathrm{Chl_{CI}} \le 0.3 \text{ mg m}^{-3}\right]$$

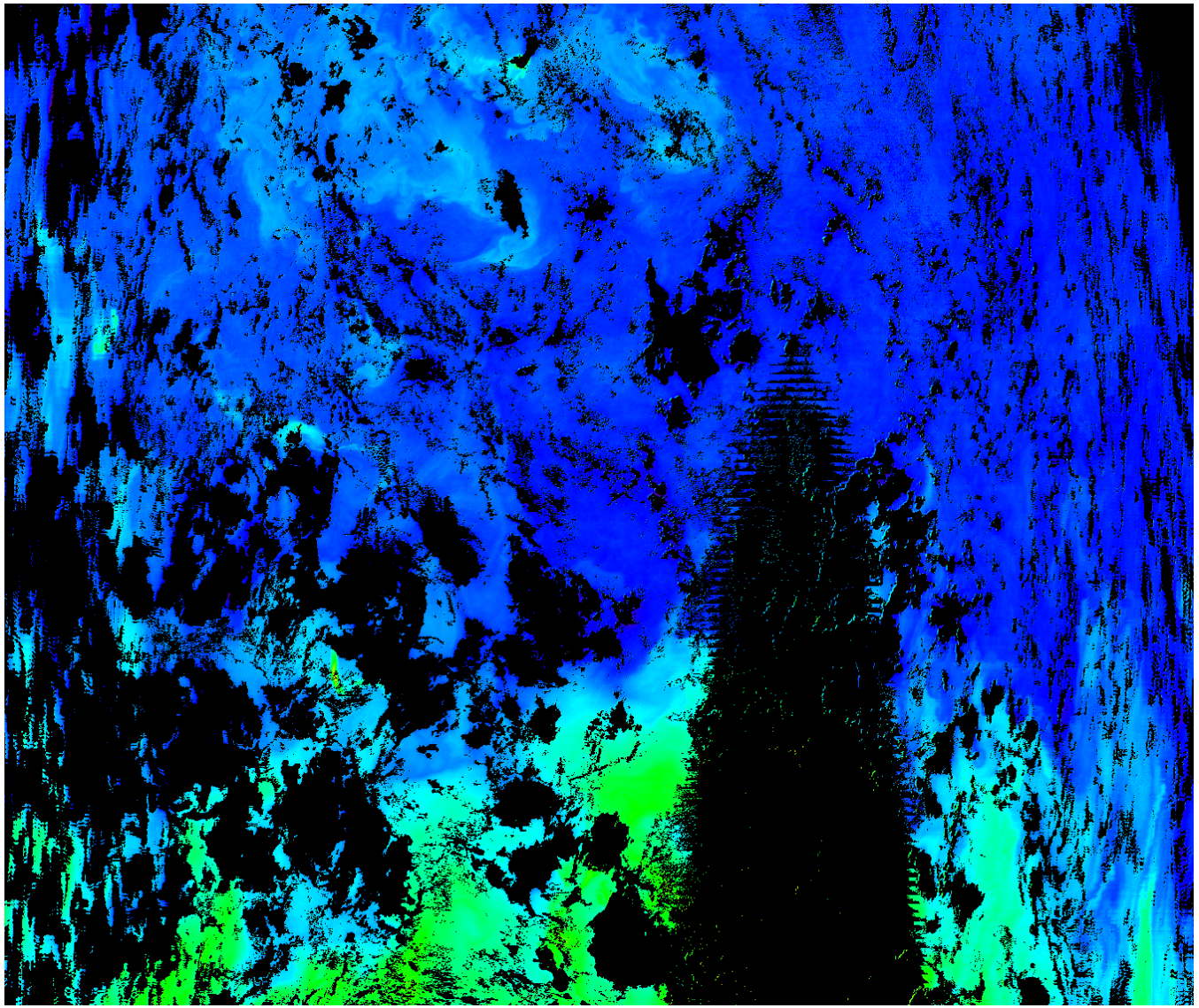
MODISA Standard OC3 Chlorophyll



Chl_{OC3}
Flags off

mg/m^3
1.000
0.500
0.200
0.100
0.050
0.020
0.010
0.005

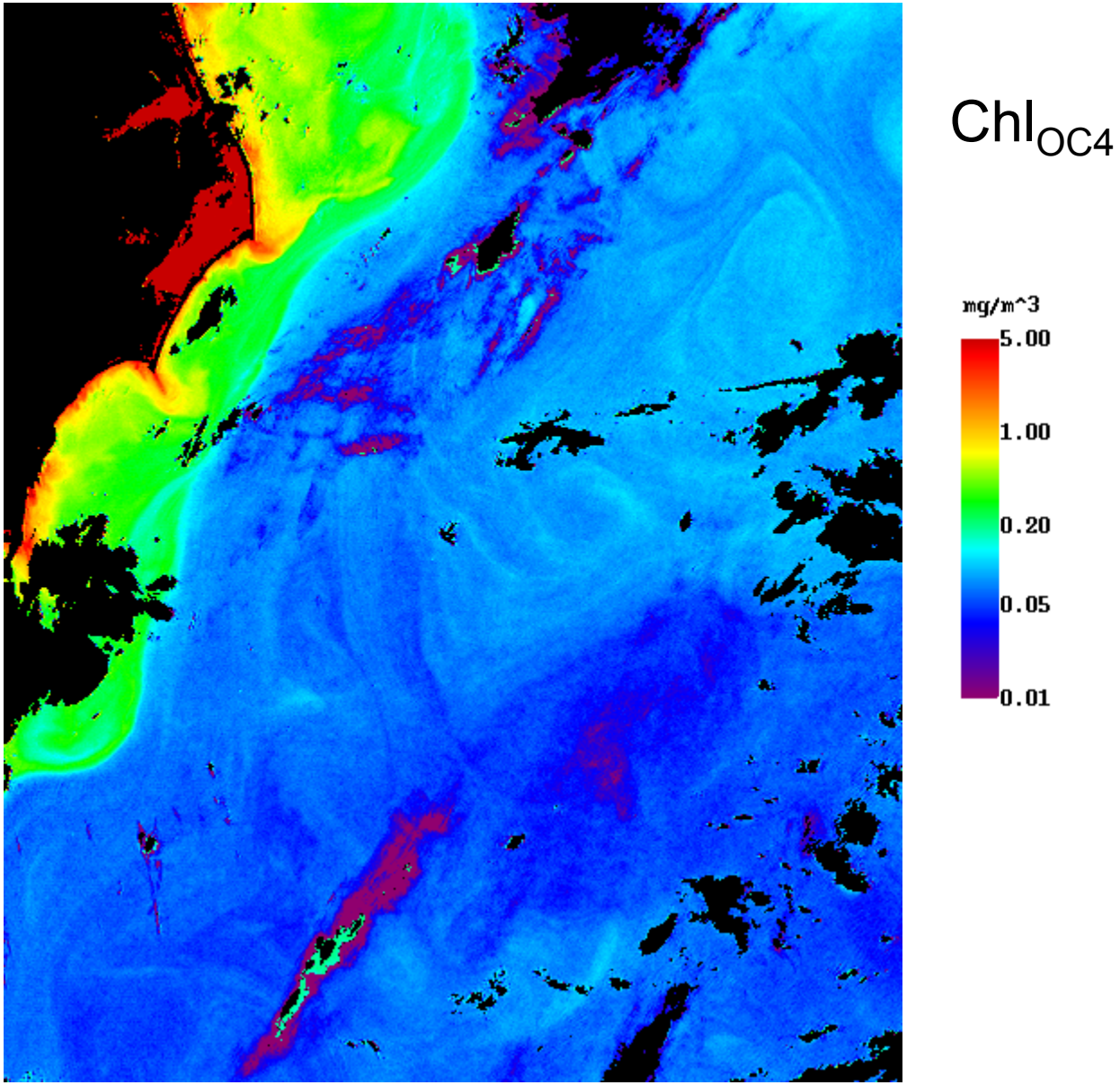
MODISA Evaluation OCI Chlorophyll



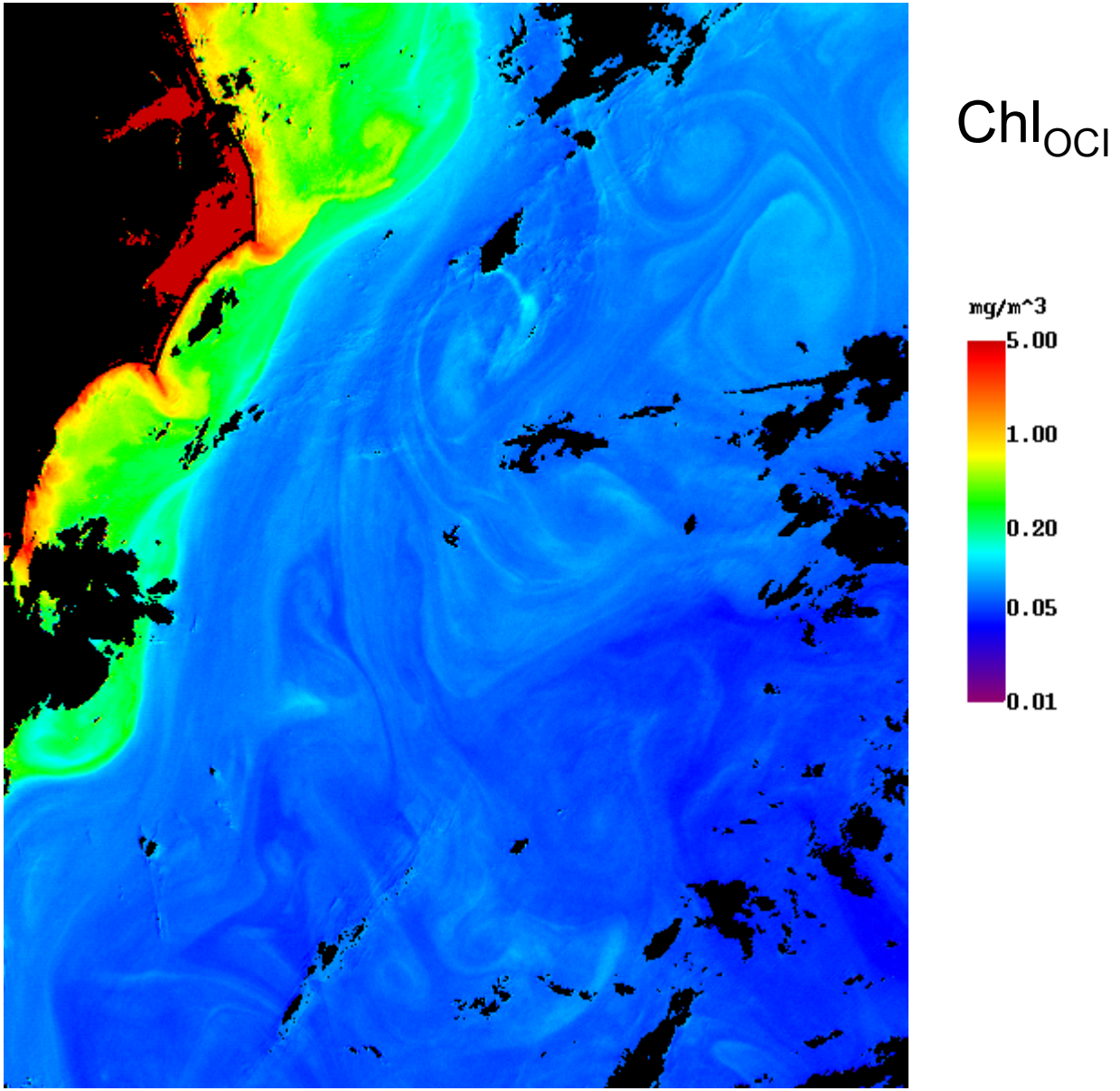
Chl_{OCI}
Flags off

mg/m^3
1.000
0.500
0.200
0.100
0.050
0.020
0.010
0.005

SeaWiFS Standard OC4 Chlorophyll

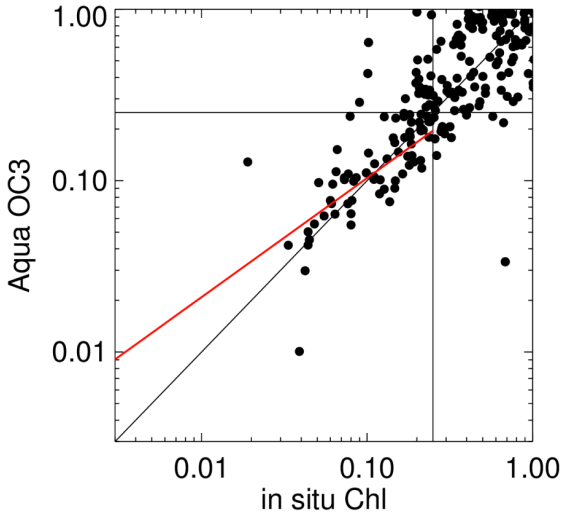


SeaWiFS Evaluation OCI Chlorophyll

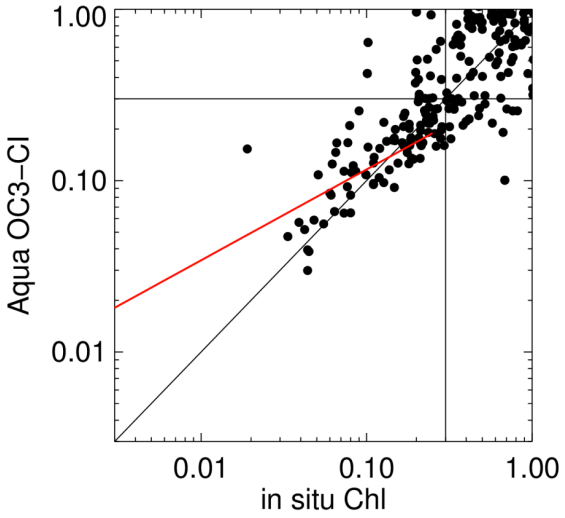


Aqua match-ups for OCI chl < 0.25 mg m^{-3}

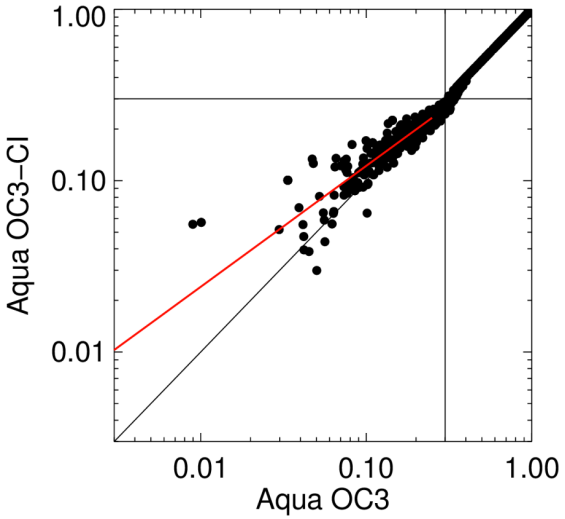
red line is best fit (Type II, RMA)
r^2, slope, and RMSE log-transformed statistics
sample size is 96



r^2	
	0.30
Slope	0.69
RMSE	0.124
Ratio	0.95
MPD	28.2



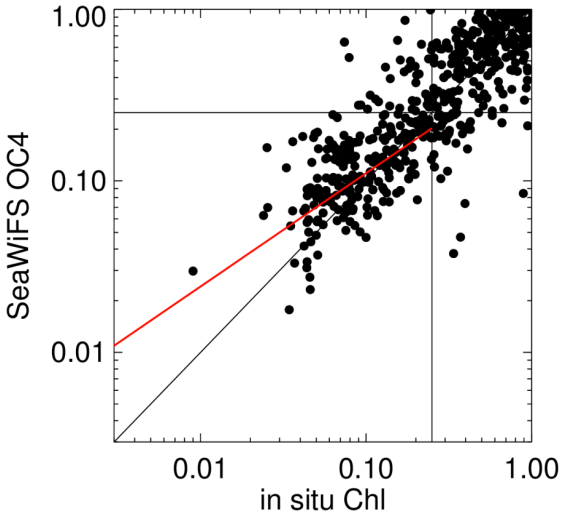
r^2	
	0.31
Slope	0.53
RMSE	0.093
Ratio	0.93
MPD	26.1



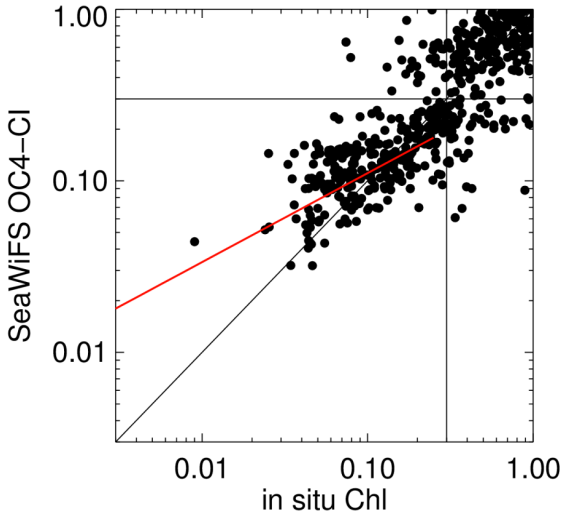
r^2	
	0.78
Slope	0.71
RMSE	0.076
Ratio	1.01
MPD	7.8

SeaWiFS match-ups for OCI chl < 0.25 mg m^{-3}

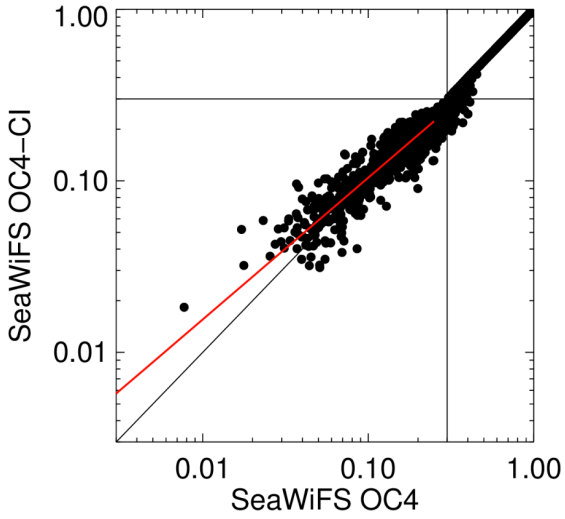
red line is best fit (Type II, RMA)
r^2, slope, and RMSE log-transformed statistics
sample size is 314



r^2	
	0.35
Slope	0.66
RMSE	0.104
Ratio	1.02
MPD	36.4



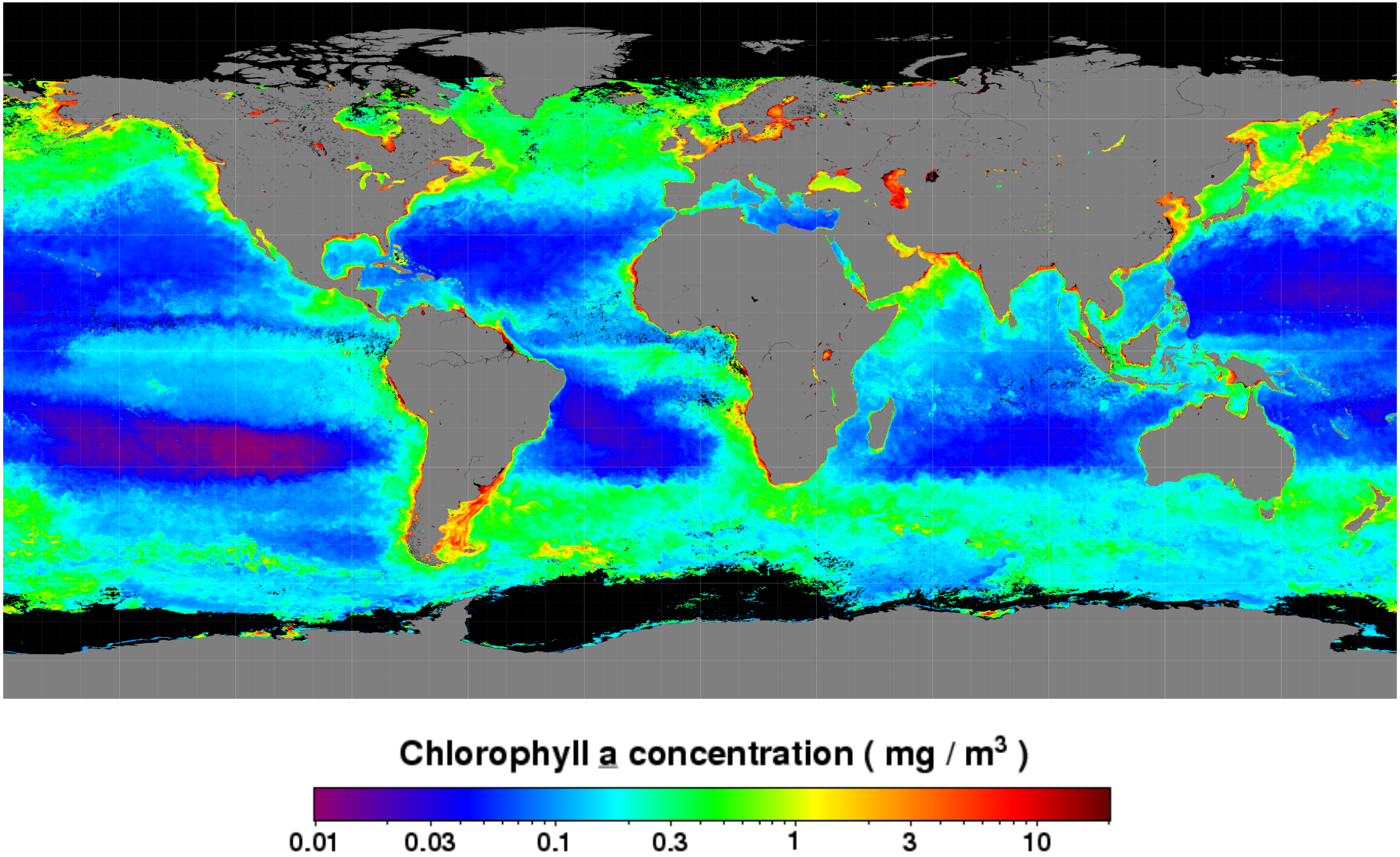
r^2	
	0.32
Slope	0.52
RMSE	0.085
Ratio	0.99
MPD	36.3



r^2	
	0.85
Slope	0.83
RMSE	0.074
Ratio	0.96
MPD	11.4

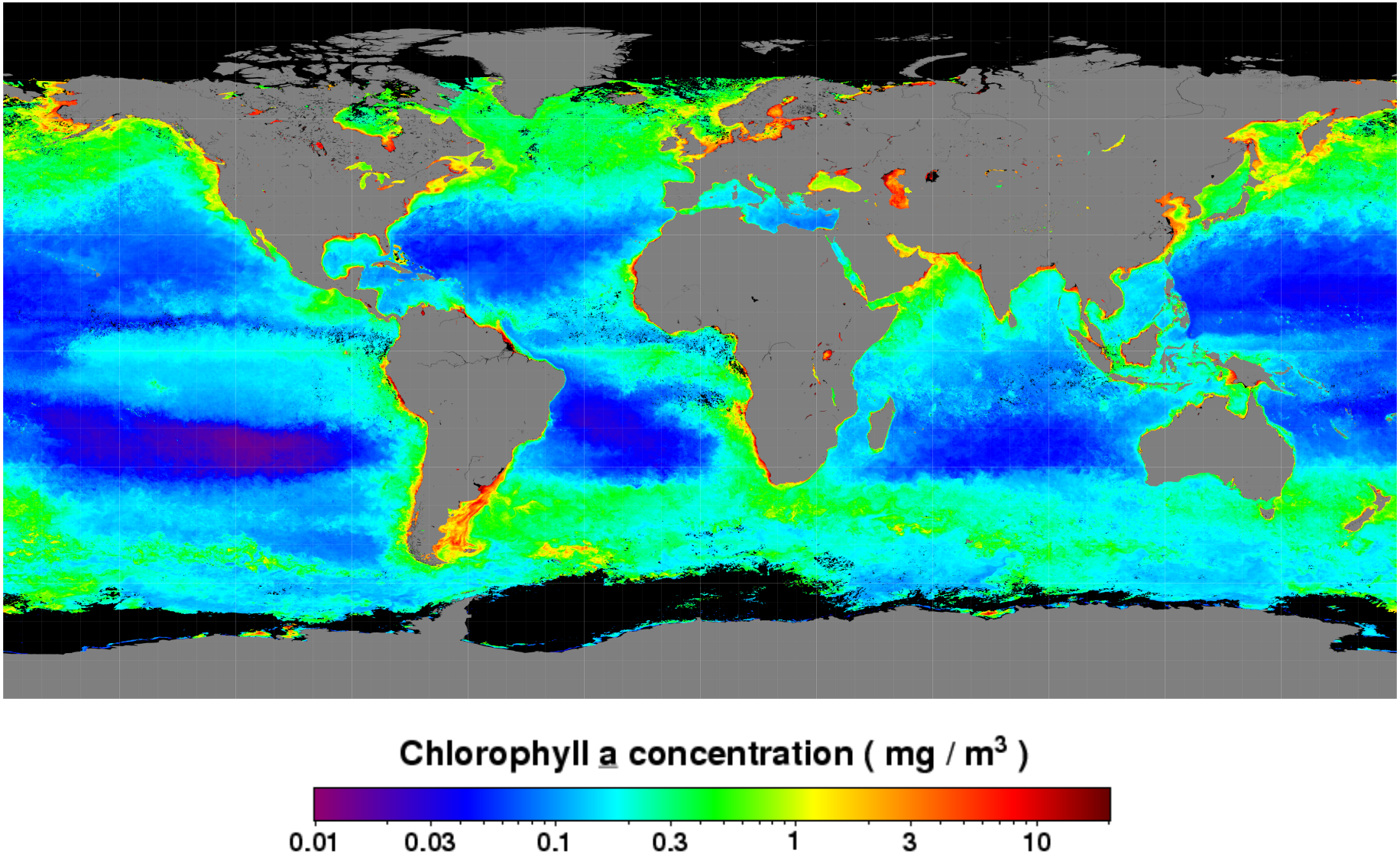
MODISA Standard OC3 Chlorophyll

Fall 2002



MODISA Evaluation OCI Chlorophyll

Fall 2002



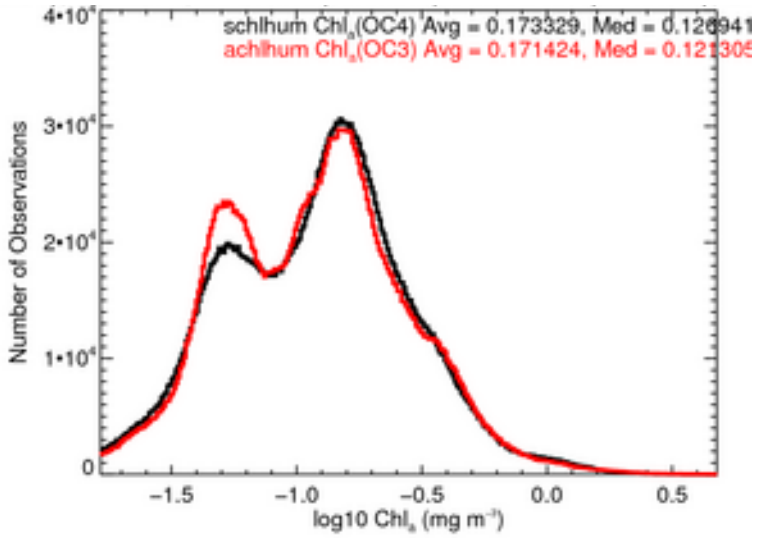
Improved Agreement in Chl Distribution

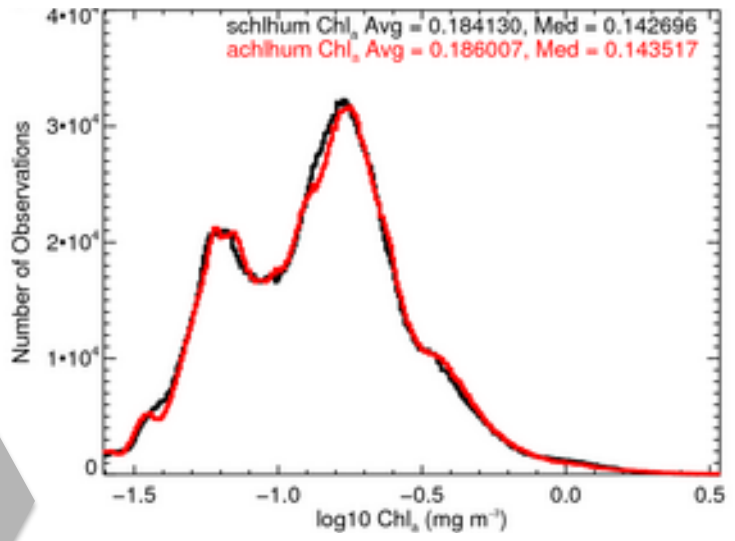
Deep-Water Monthly Mean, MODISA (red) & SeaWiFS (black)

Standard (OC3 & OC4)

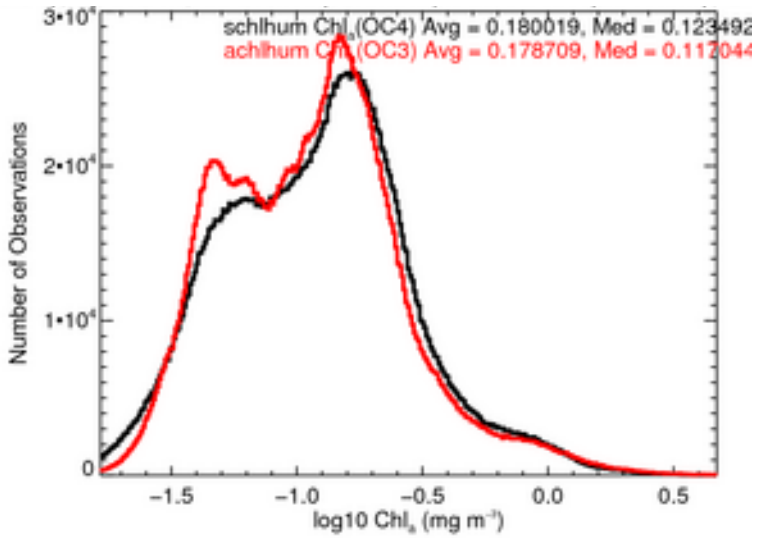
Evaluation (OCI)

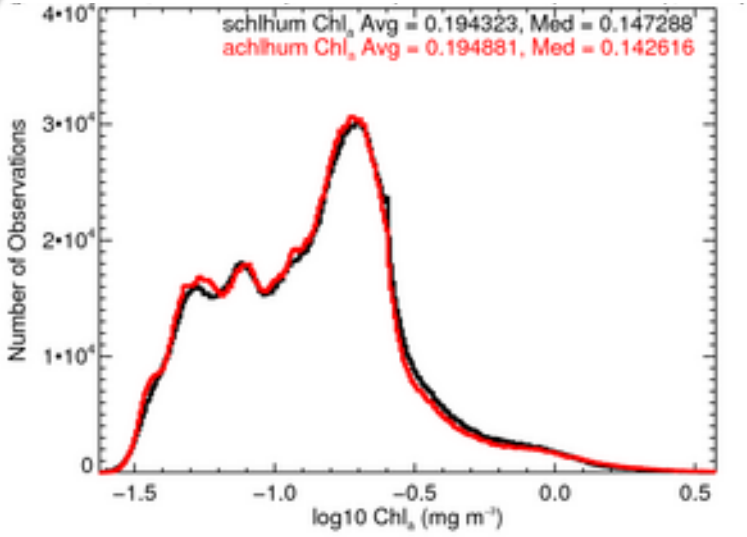
Fall 2002





Fall 2010





Next multi-mission OC reprocessing (R2014.0) in progress

OCTS ➡ SeaWiFS ➡ CZCS ➡ MERIS ➡ MODISA ➡ MODIST ➡ VIIRS

Includes instrument and vicarious calibration updates

Incorporates algorithm refinements

- revised ancillary ozone dataset normalized to SBUV record
- chlorophyll algorithm enhanced with OCI
- updates to PIC algorithm (Balch)
- updates to PAR algorithm (Frouin)
- etc.

Expands standard product suite

- inherent optical properties (IOPs) and uncertainties

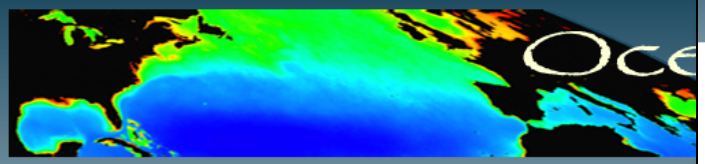
Changes data formats

- moving to CF-compliant netCDF4

ATBD refresh

Algorithm Theoretical Basi ×

oceancolordev.domain.pub/cms/atbd



- About Us
- User Support Services
- Analyses
- Forum
- Data
- Products
- Documents
- Tools
- Login

Products and Algorithms

- **Algorithm Theoretical Basis Documents (ATBD)**
- Standard Products
- Evaluation Products
- Intermediate/Ancillary Products

Algorithm Theoretica

Chlorophyll A

The operational algorithm for deriving near-
was updated using in situ data from NOMA
constructed from data archived in SeaBASS
regions and were collected by participants i
and international collaborators. The algorith
transformed geophysical variable to a log-tr
consistent with past versions of OC. Each s
product chlor_a. The default algorithm vari
default chlorophyll is also used for any inter
reflectance corrections).

Particulate Organic Carbon

The purpose of this algorithm is to calculate
(nLw) at specific wavelengths. These wavel
algorithm, the details of which depend on t
SeaWiFS and MODIS. For each of these the

(Non CMS Sites: Chlorophyll A | Partic
New Vers: Chlorophyll A | Particulate

chlorophyll a | Ocean Colo ×

oceancolordev.domain.pub/cms/atbd/chlor_a/html/mainpage.html#sec_1

Legacy Website still available

- About Us
- User Support Services
- Analyses
- Forum
- Data
- Products
- Documents
- Tools
- Login

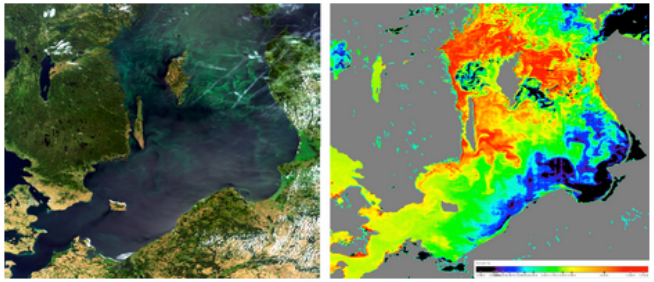
chlorophyll a

- Main Page
- Related Pages
- Search

chlorophyll a

1. Algorithm Summary Overview

chlorophyll a (chlor_a)



Natural RGB image (left) and sample corresponding chlorophyll a concentration (right)

The operational algorithm for deriving near-surface chlorophyll-a concentrations (OC; O'Reilly et al. 2000 sec_8 2) was updated using in situ data from NOMAD version 2. NOMAD is a publicly available, global bio-optical data set constructed from data archived in SeaBASS. The data span a wide range of water types from coastal and offshore regions and were collected by participants in the NASA Ocean Biology & Biogeochemistry Program and by voluntary and international collaborators. The algorithm form describes the polynomial best fit that relates the log-transformed geophysical variable to a log-transformed ratio of remote-sensing reflectances. The polynomial form is consistent with past versions of OC. Each sensor is assigned a default chlorophyll algorithm, which can be output as product chlor_a. The default algorithm varies by sensor due to limitations on the available spectral bands. The default chlorophyll is also used for any intermediate calculations which require chlorophyll (e.g., f/Q bi-directional reflectance corrections).

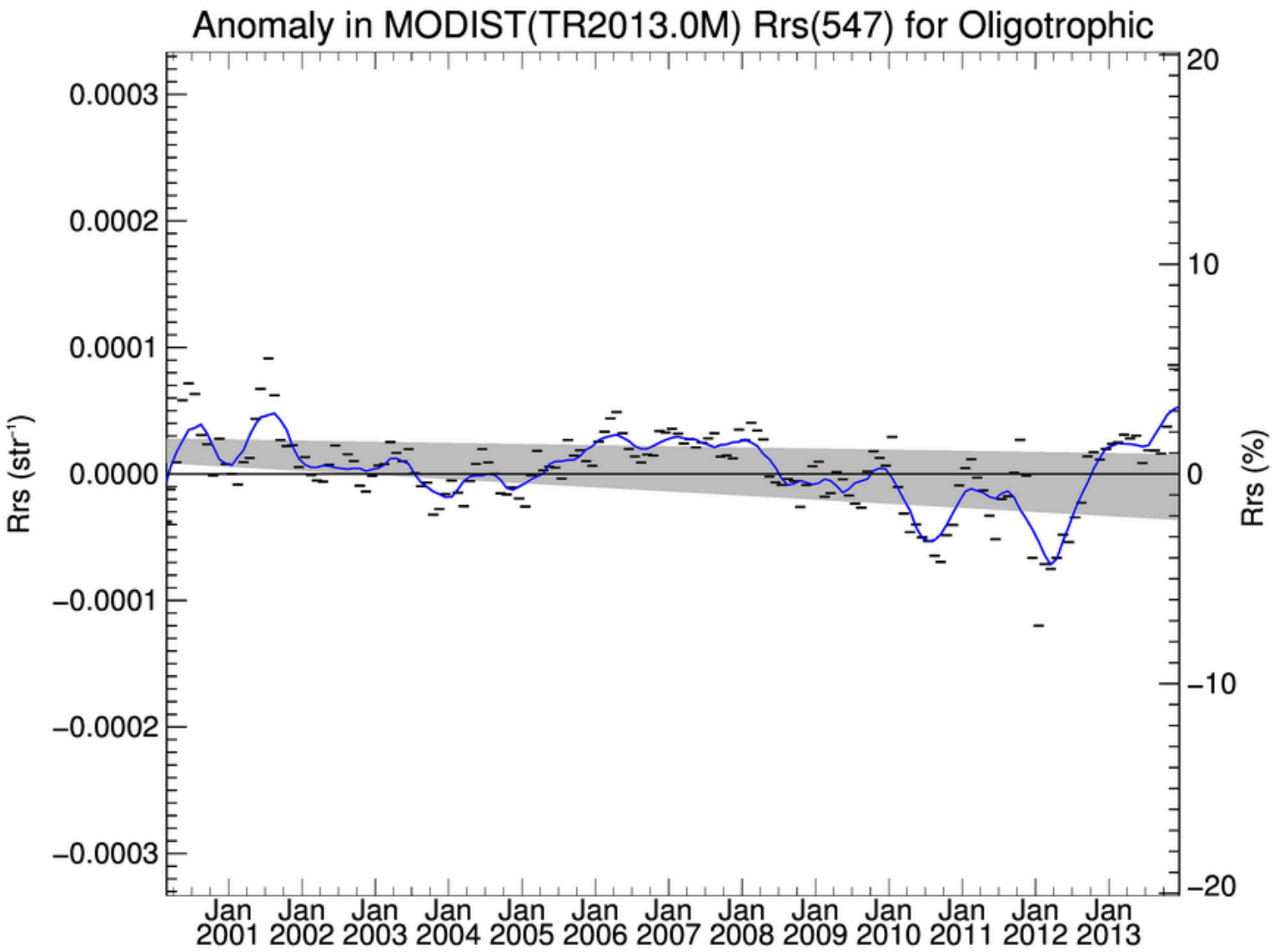
2. Algorithm Framework Description

... flowchart and description of flowchart ... ... equations ...

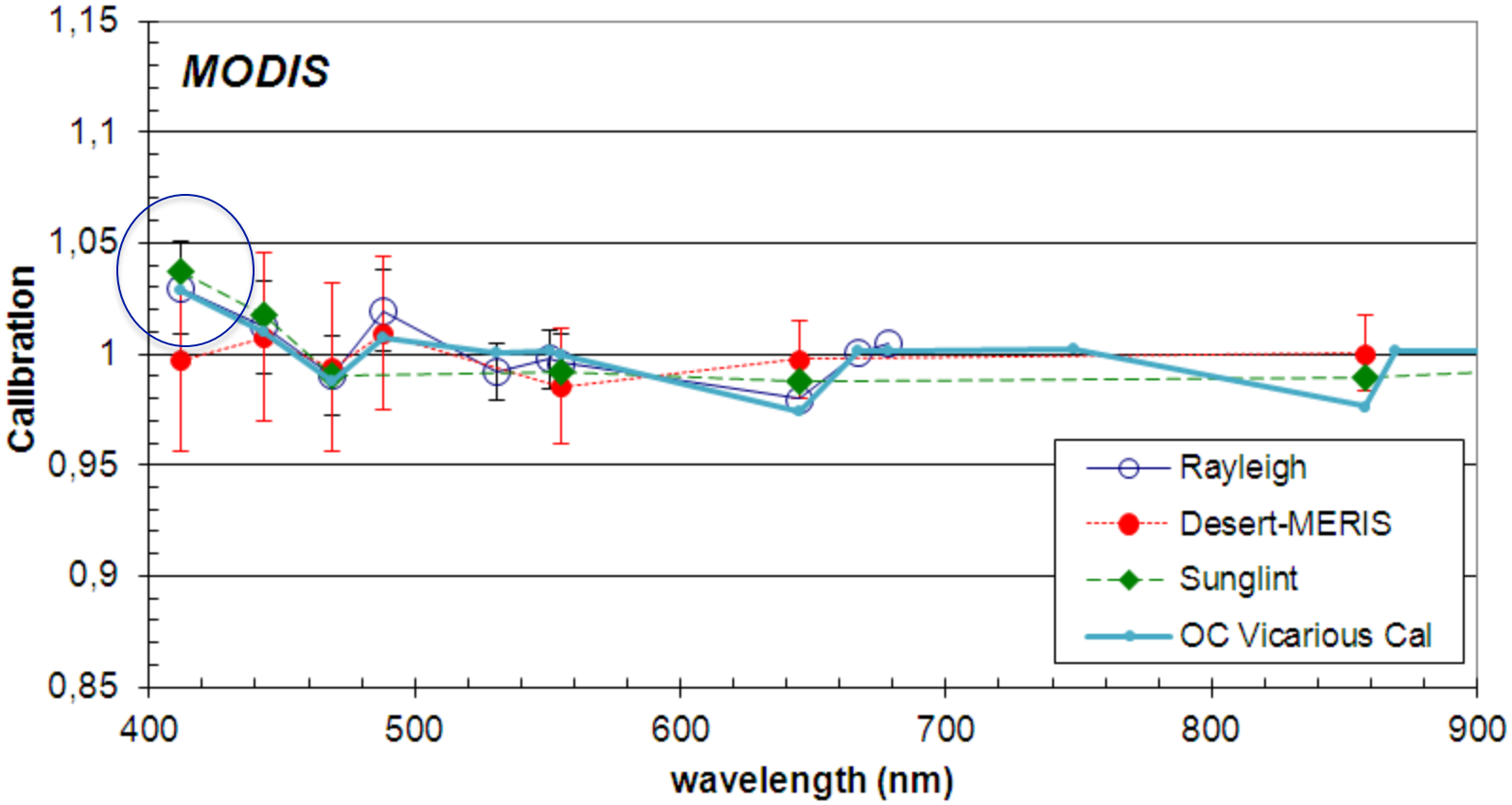
requirements: polynomials bisect the full dynamic range of the development data set $OC_4 = OC_4E = OC_4O = OC_3S = OC_3M = OC_3C = OC_3E = OC_3O = OC_2S = OC_2M = OC_2E = OC_2O$

Thank You

MODIST Clear-Water Rrs(547) Anomaly



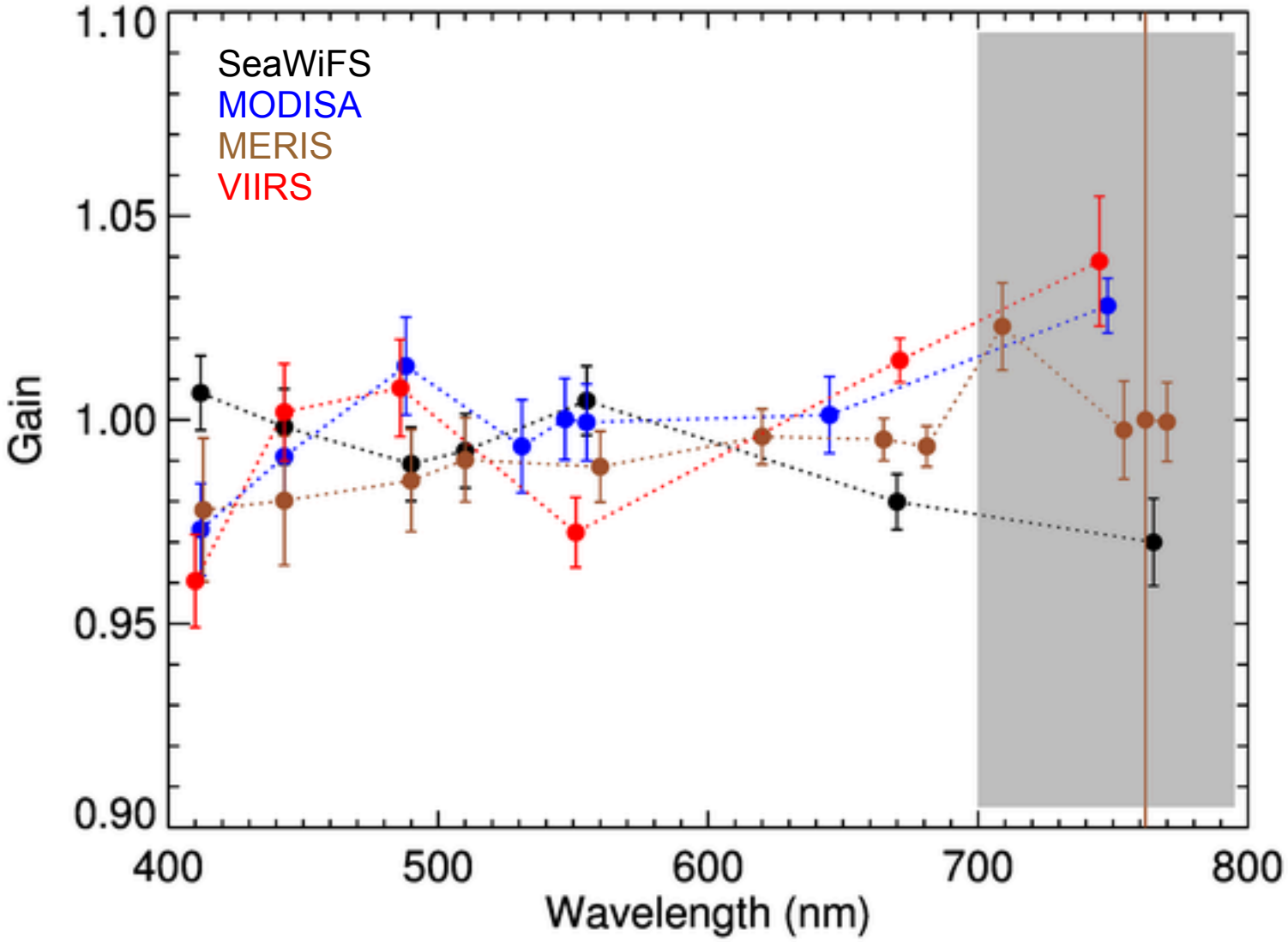
Vicarious Calibration – is it the instrument?



Results from Bertrand Fougnie, *Centre National d'Etudes Spatiales, France*

NASA-derived Vicarious Gains

consistent processing algorithms and vicarious calibration methods and sources



MODISA Temporal Calibration Approach

MCST final calibration for Collection 6 uses Earth view data

- lunar calibration + desert observations for 412 and 443
- largely reproduces previous SeaWiFS cross-cal results

But still some issues for ocean color

- significant residual time-trend at 412 (due to scan-edge changes)
- residual cross-scan and striping artifacts

Additional cross-scan correction developed by OBPG

- relative to MCST C6 desert-based calibration
- based on contemporaneous Aqua L3 15-day Rrs
- derive time-varying RVS shape per detector & mirror-side
- applied to all OC bands 412-678

See talk by Gerhard Meister on Thursday

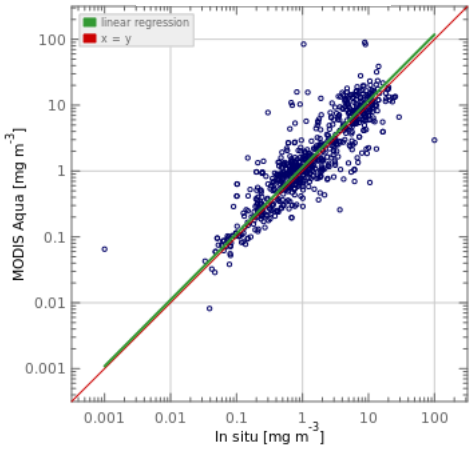
Derived Products in Good Agreement with Field Measurement and Between Sensors

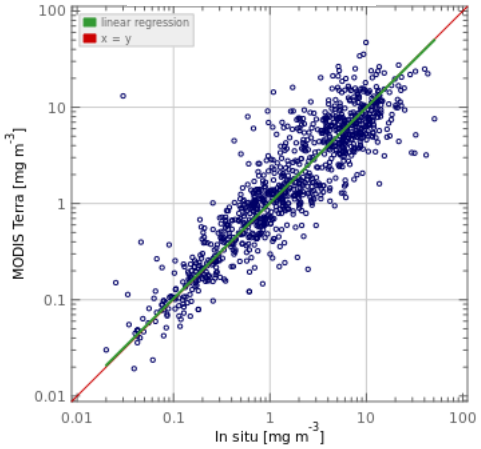
MODISA

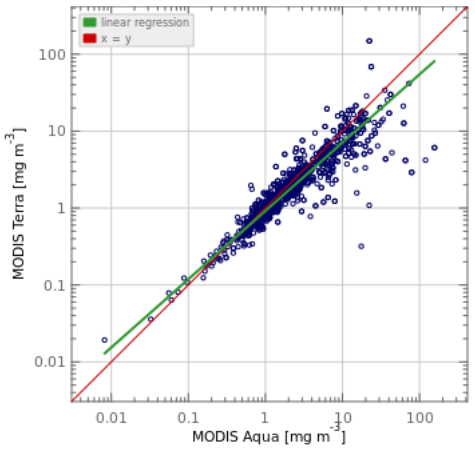
MODIST

MODISA vs MODIST

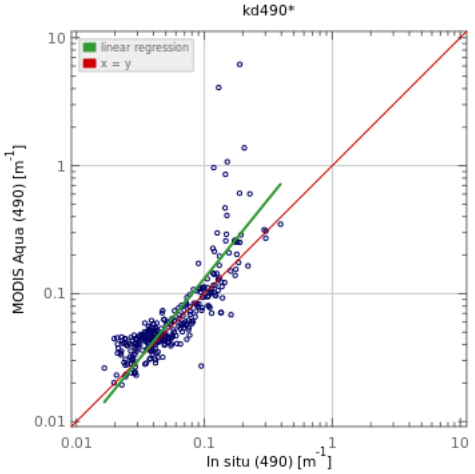
Chlorophyll

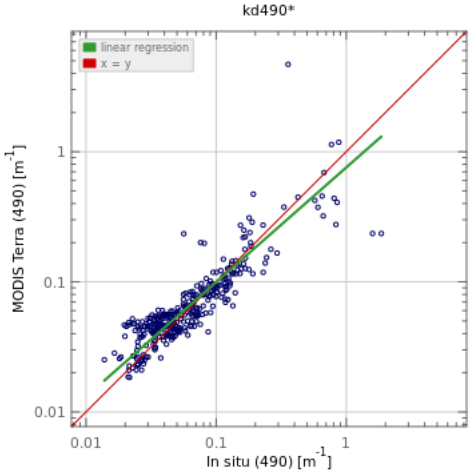


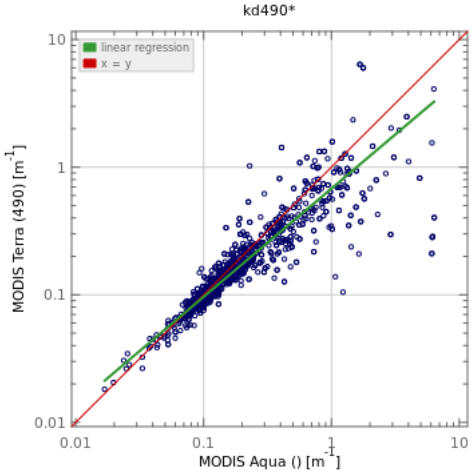




Diffuse Attenuation





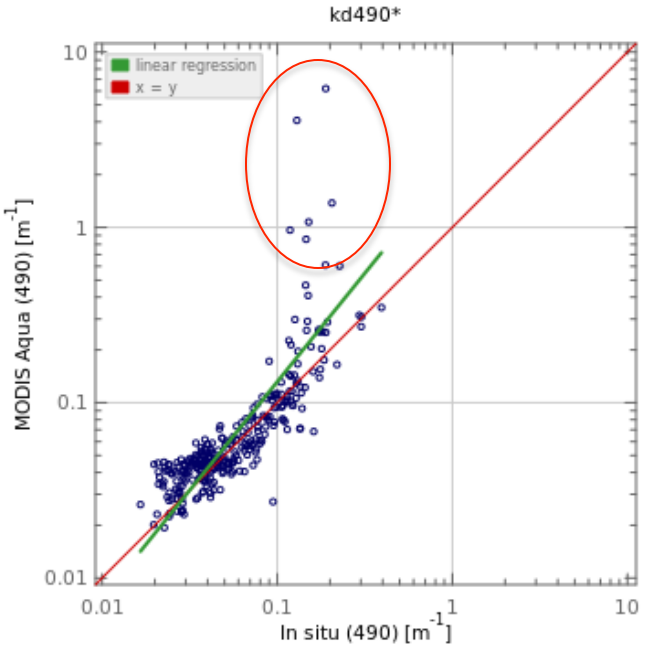


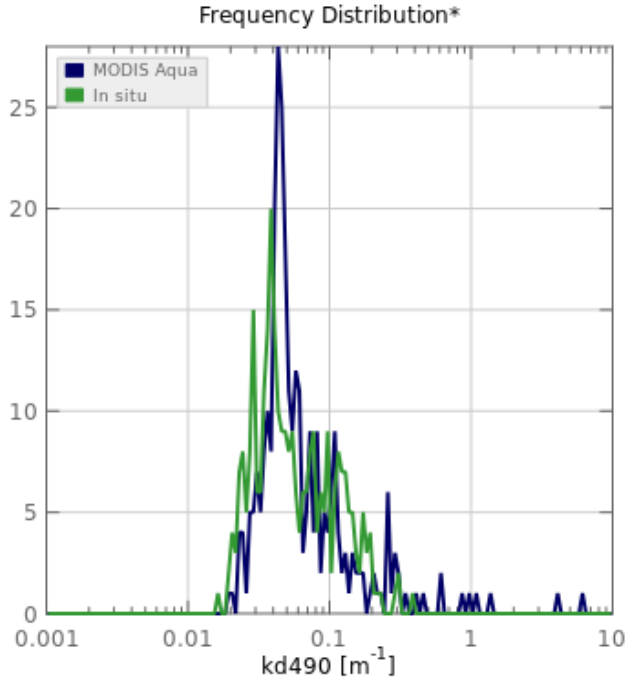
MODISA (R2013.1) Diffuse Attenuation

Product Name	MODIS Aqua Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R^2*	Median Ratio	Abs % Difference	RMSE*
kd490	0.01936, 6.19469	0.01655, 0.39400	296	1.23765	0.35640	0.72581	1.10898	19.91821	0.21023

* statistical calculations based on log10

The linear regression algorithm has been changed to reduced major axis.





Mean APD 20%, Mean Bias 10%, R^2 0.7