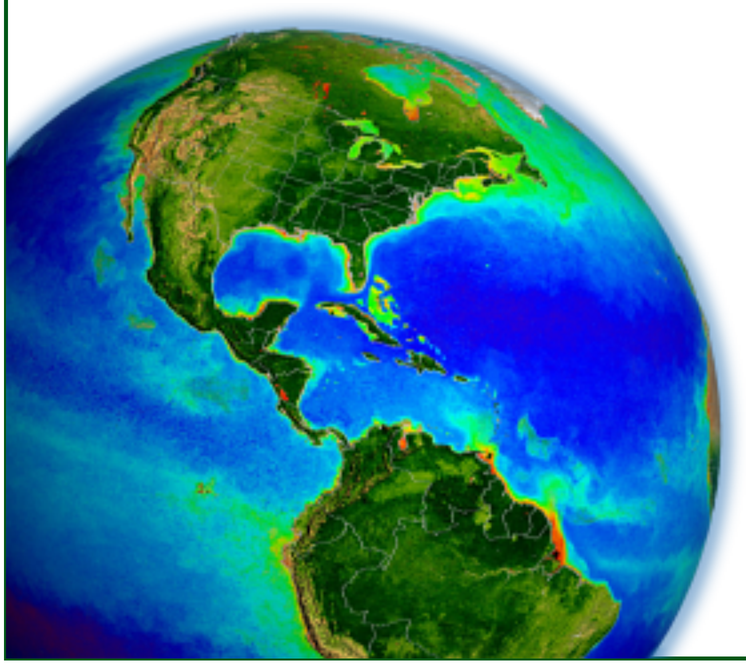
Remote Sensing Reflectance and Derived Products

Bryan A. Franz
Charles R. McClain
Gene C. Feldman

and the
Ocean Biology Processing Group



MODIS Science Team Meeting
15-16 April 2013

Collaborators

Gerhard Meister	*instrument calibration*
P. Jeremy Werdell	*in-water algorithms, SeaBASS*
Sean W. Bailey	*vicarious calibration, algorithms*
Zia Ahmad	*atmospheric correction*

and the Ocean Biology Processing Group

Contents

Overview of ocean color products

Status and validation of ocean remote sensing reflectance (Rrs) and chlorophyll products

Algorithm refinement

Future plans

What we proposed …

- development & maintenance of Rrs product
  - atmospheric correction algorithm
  - Instrument calibration (w/MCST) & vicarious calibration

- development & maintenance of several key bio-optical algorithms
  - Standard Chlorophyll and diffuse attenuation (Kd) products

- maintenance of ALL standard ocean color products not in active development (sensor-specific adaptations, validation)

- development of consensus inherent optical properties (IOP) algorithm
  - building on existing algorithms, develop software framework for evaluating, develop consensus through international working group

- support science team and research community in implementation and global evaluation of new product algorithms (evaluation products)

Current MODIS OC Standard Product Suite

Level-2 OC Product	Algorithm Reference
1. $R_{rs}(\lambda)$	
2. Ångstrom	*Wang 1994, Ahmad et al 2010, etc.*
3. AOT	
4. Chlorophyll *a*	*l. 1998 (OC3) updated by Werdell*
5. $K_d(490)$	*2) algorithm (similar to OC3)*
6. POC	*l. 2008*
7. PIC	*2005, Gordon et al. 2001*
8. CDOM_index	*entili 2009*
9. PAR	*2003*
10. iPAR	
11. nFLH	*Behrenfeld et al. 2009*

- $R_{rs}(412)$
- $R_{rs}(443)$
- $R_{rs}(469)$
- $R_{rs}(488)$
- $R_{rs}(531)$
- $R_{rs}(547)$
- $R_{rs}(555)$
- $R_{rs}(645)$
- $R_{rs}(667)$
- $R_{rs}(678)$

Current MODIS OC Evaluation Products

	Product Suite	# Products	Algorithm Reference
1.	GIOP	15	*Werdell et al. 2013*
2.	GSM	3	*Maritorena et al. 2002*
3.	QAA	5	*Lee et al. 2002, Lee et al. 2007*
4.	Zeu (Lee)	1	*Lee et al. 2007*
5.	Zeu (Morel)	1	*Morel et al. 2007*
6.	Kd(λ)	3	*Lee et al. 2005*
7.	Kd(PAR)	1	*Morel et al. 2007*
8.	CHL(OCI)	1	*Hu et. al 2012*

RecentChanges | FindPage | HelpContents | **OCProd**

Thank you for your changes. Your attention to detail is appreciated.

Clear message

Edit (Text) Edit (GUI) Info Attachments More Actions:

Satellite Data Products

Standard Products

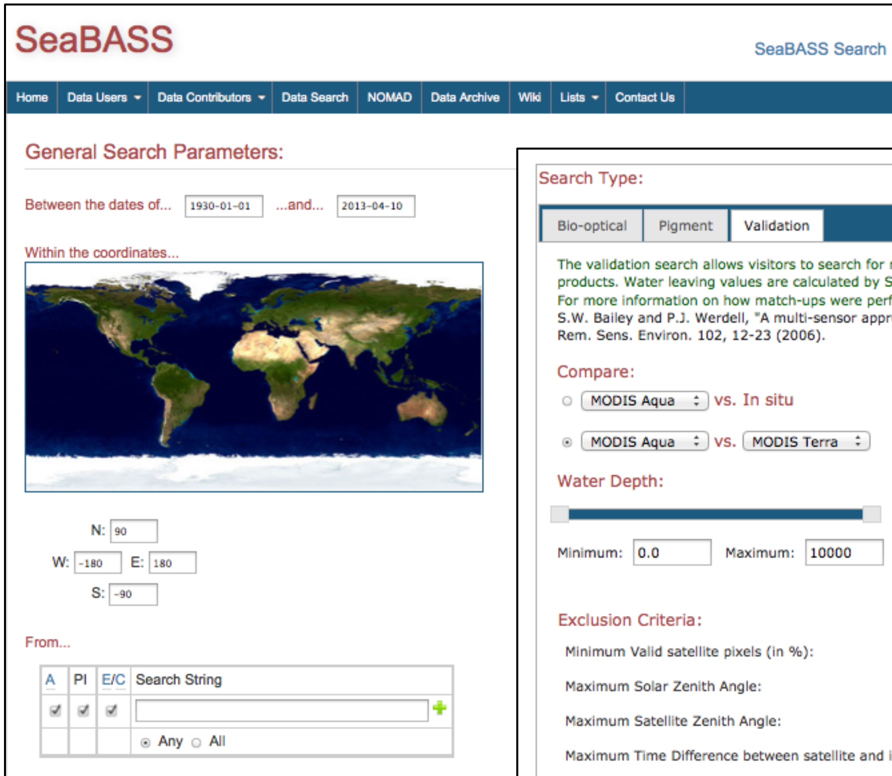
1. Remote Sensing Reflectance (Rrs)
2. Chlorophyll Concentration (chlor_a)
3. Diffuse Attenuation Coefficient at 490nm (Kd_490)
4. Particulate Organic Carbon Concentration (poc)
5. Particulate Inorganic Carbon Concentration (pic)
6. Colored Dissolved Organic Matter Index (cdom_index)
7. Daily Mean Photosynthetically Available Radiation (par)
8. Instantaneous Photosynthetically Available Radiation (ipar)
9. Normalized Fluorescence Line Height (nflh)

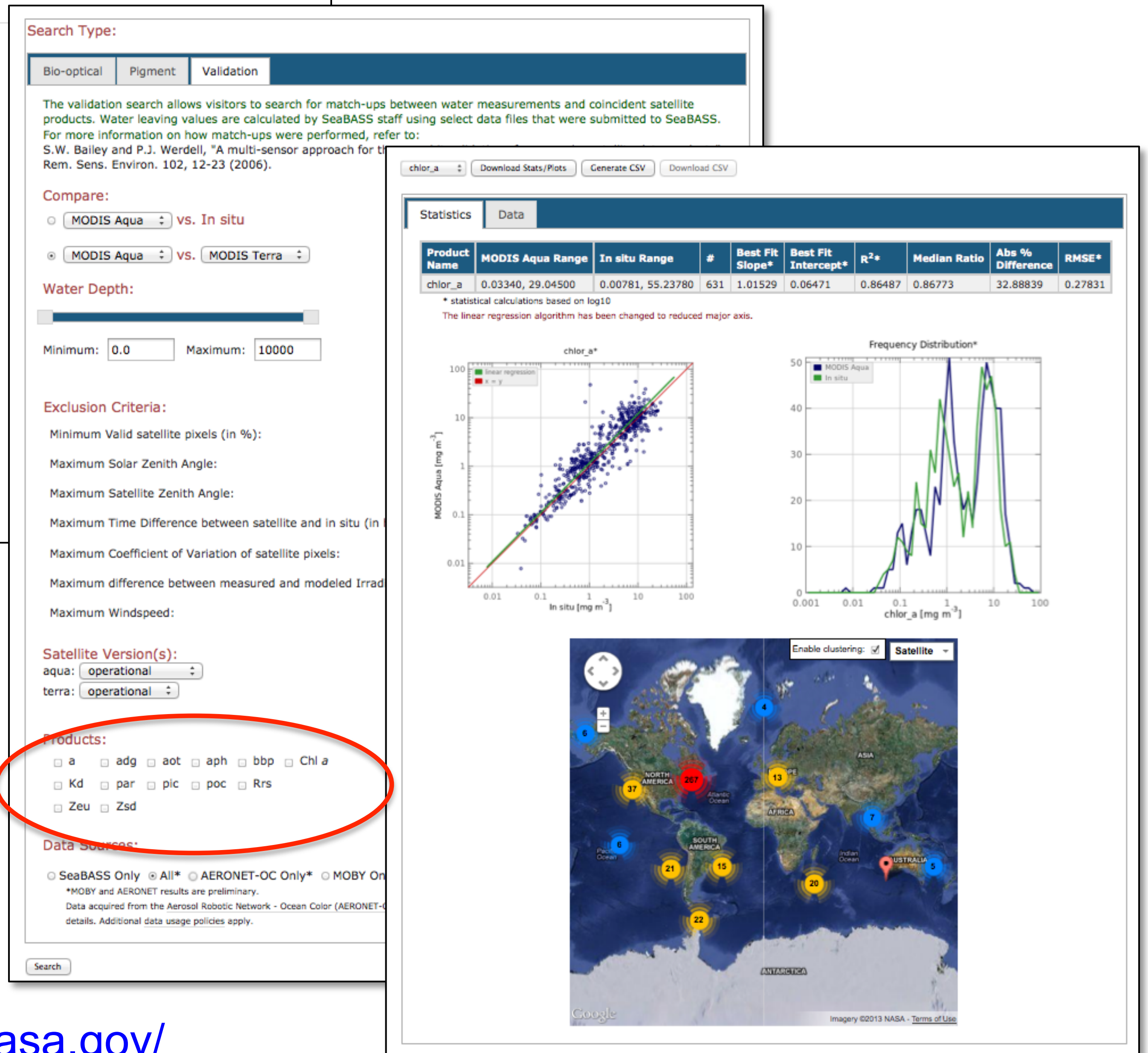
Evaluation Products

1. Chlorophyll Concentration from OCI (chl_oci)
2. Inherent Optical Properties from GIOP (giop)
3. Inherent Optical Properties from GSM (gsm)
4. Inherent Optical Properties from QAA (qaa)
5. Euphotic Depth from Lee (Zeu_lee)
6. Euphotic Depth from Morel (Zeu_morel)
7. Spectral Diffuse Attenuation Coefficients from Lee (Kd_lee)
8. Diffuse Attenuation Coefficients for PAR from Morel (Kd_par_morel)

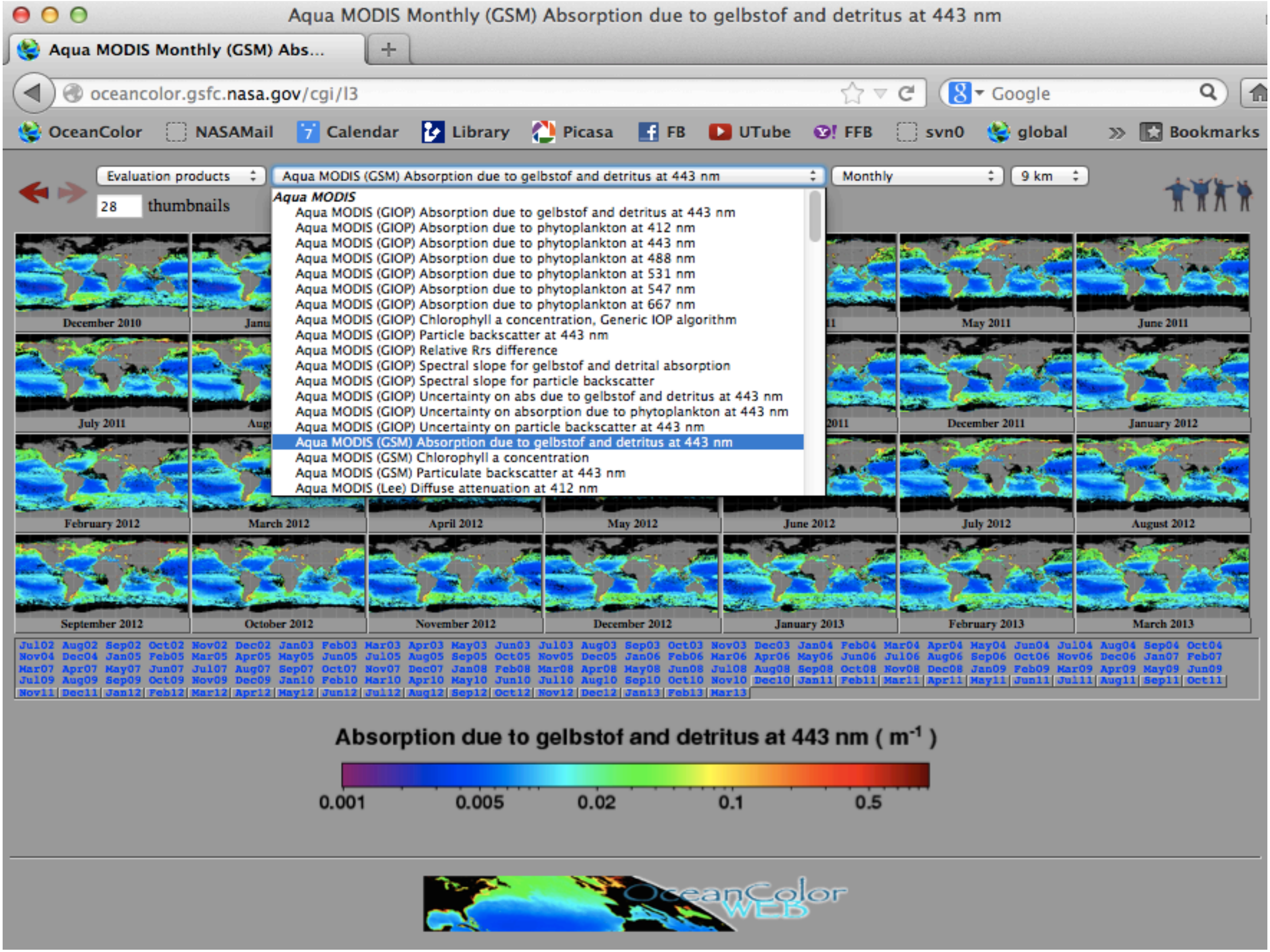
http://oceancolor.gsfc.nasa.gov/WIKI/OCProd.html

Ocean Color Product Validation





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


Aqua MODIS Monthly (GSM) Absorption due to gelbstof and detritus at 443 nm
Aqua MODIS Monthly (GSM) Abs...
oceancolor.gsfc.nasa.gov/cgi/l3
Google
OceanColor
NASAMail
Calendar
Library
Picasa
FB
UTube
FFB
svn0
global
Bookmarks
Evaluation products
Aqua MODIS (GSM) Absorption due to gelbstof and detritus at 443 nm
Monthly
9 km
28
thumbnails
Aqua MODIS
Aqua MODIS (GIOP) Absorption due to gelbstof and detritus at 443 nm
Aqua MODIS (GIOP) Absorption due to phytoplankton at 412 nm
Aqua MODIS (GIOP) Absorption due to phytoplankton at 443 nm
Aqua MODIS (GIOP) Absorption due to phytoplankton at 488 nm
Aqua MODIS (GIOP) Absorption due to phytoplankton at 531 nm
Aqua MODIS (GIOP) Absorption due to phytoplankton at 547 nm
Aqua MODIS (GIOP) Absorption due to phytoplankton at 667 nm
Aqua MODIS (GIOP) Chlorophyll a concentration, Generic IOP algorithm
Aqua MODIS (GIOP) Particle backscatter at 443 nm
Aqua MODIS (GIOP) Relative Rrs difference
Aqua MODIS (GIOP) Spectral slope for gelbstof and detrital absorption
Aqua MODIS (GIOP) Spectral slope for particle backscatter
Aqua MODIS (GIOP) Uncertainty on abs due to gelbstof and detritus at 443 nm
Aqua MODIS (GIOP) Uncertainty on absorption due to phytoplankton at 443 nm
Aqua MODIS (GIOP) Uncertainty on particle backscatter at 443 nm
Aqua MODIS (GSM) Absorption due to gelbstof and detritus at 443 nm
Aqua MODIS (GSM) Chlorophyll a concentration
Aqua MODIS (GSM) Particulate backscatter at 443 nm
Aqua MODIS (Lee) Diffuse attenuation at 412 nm
December 2010
May 2011
June 2011
July 2011
December 2011
January 2012
February 2012
March 2012
April 2012
May 2012
June 2012
July 2012
August 2012
September 2012
October 2012
November 2012
December 2012
January 2013
February 2013
March 2013
Absorption due to gelbstof and detritus at 443 nm (m⁻¹)
0.001
0.005
0.02
0.1
0.5
OceanColor WEB

MODIS Ocean Color Reprocessing

2010-2011 **preliminary C6**

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

2012 May **final C6**

MODIS-A (R2012.0) full-mission reprocessing to incorporate final MCST C6 calibration and OBPG RVS refinements.

2013 February **improved C6**

MODIS-A (R2013.0) partial-mission reprocessing (2011-2013) to incorporate refined MCST C6 calibration

Coming Soon

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

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

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

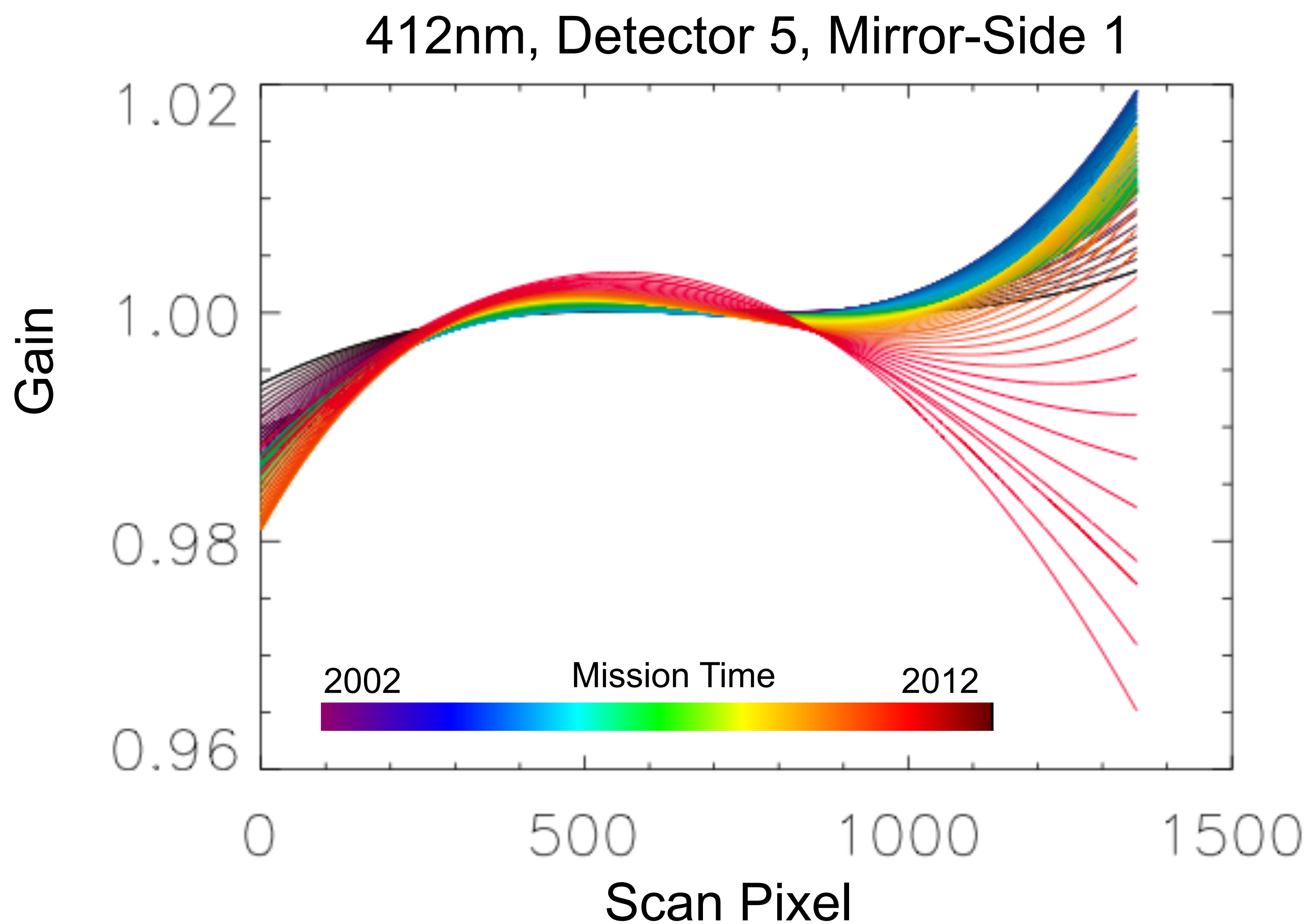
Additional cross-scan correction developed by OBPG

- 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 Wednesday

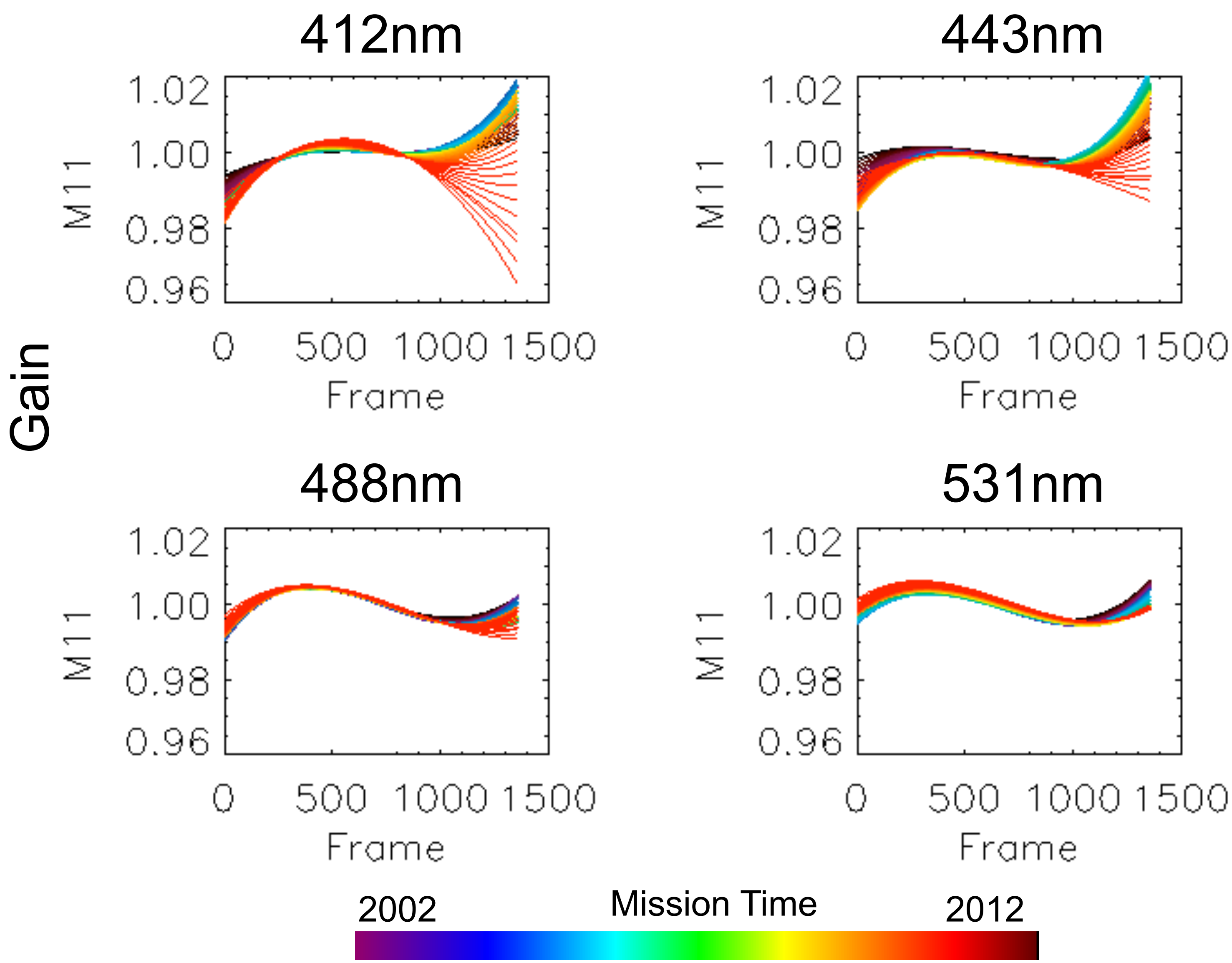
OBPG MODISA Cross-Scan Corrections at 412nm

relative to MCST desert-based C6 calibration



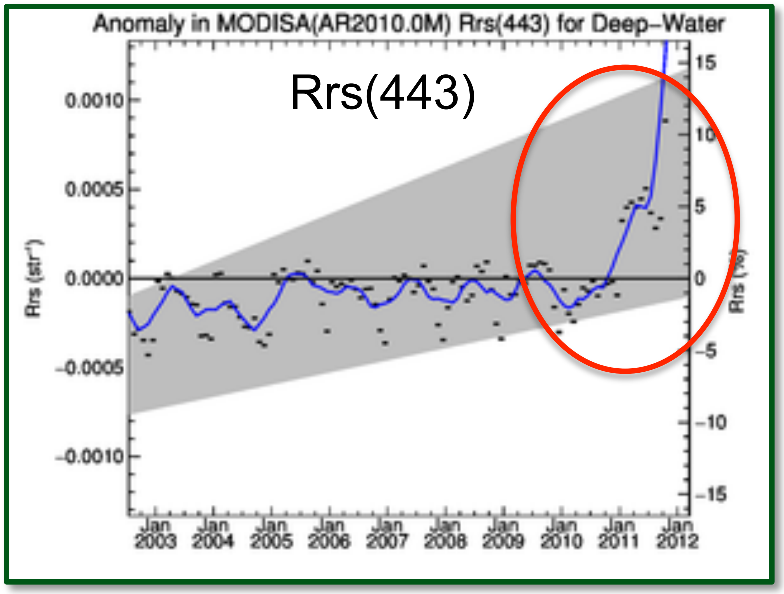
OBPG MODISA Cross-Scan Corrections

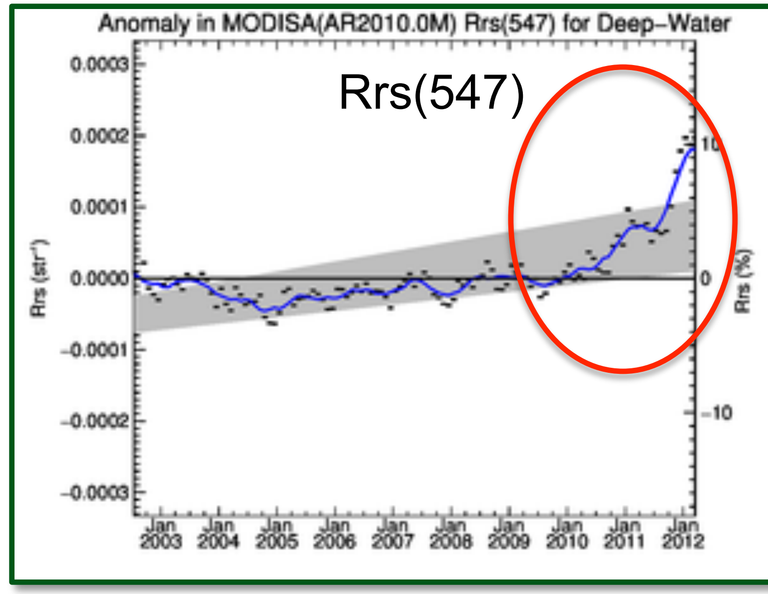
relative to MCST desert-based C6 calibration



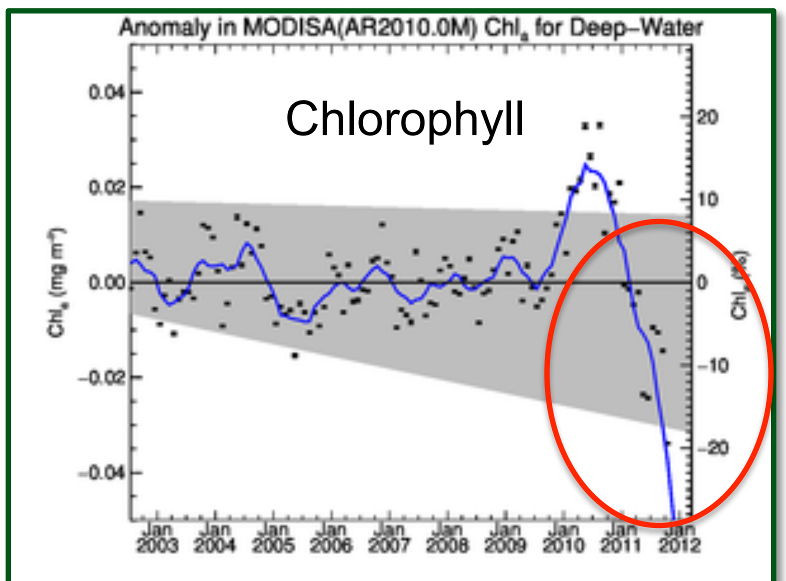
MODISA R2010.0 Temporal Anomalies (2002-2012)

Deep-Water



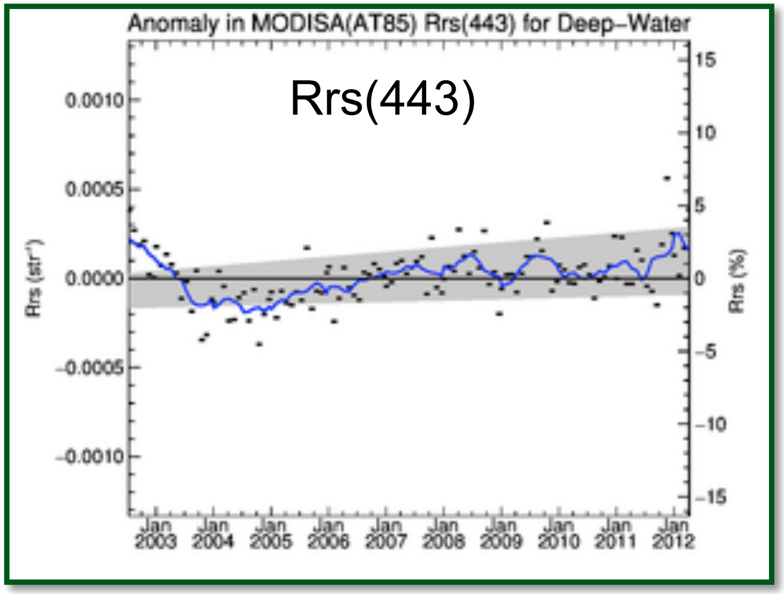


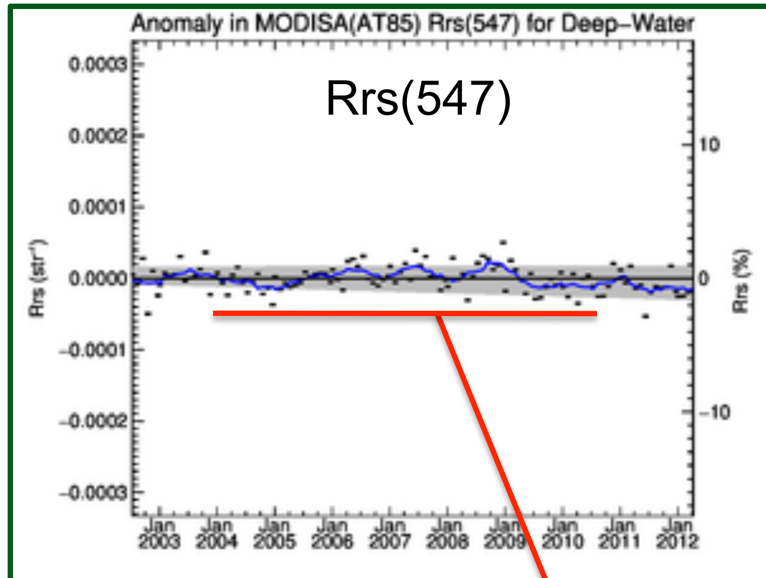
Big
Trending
Errors

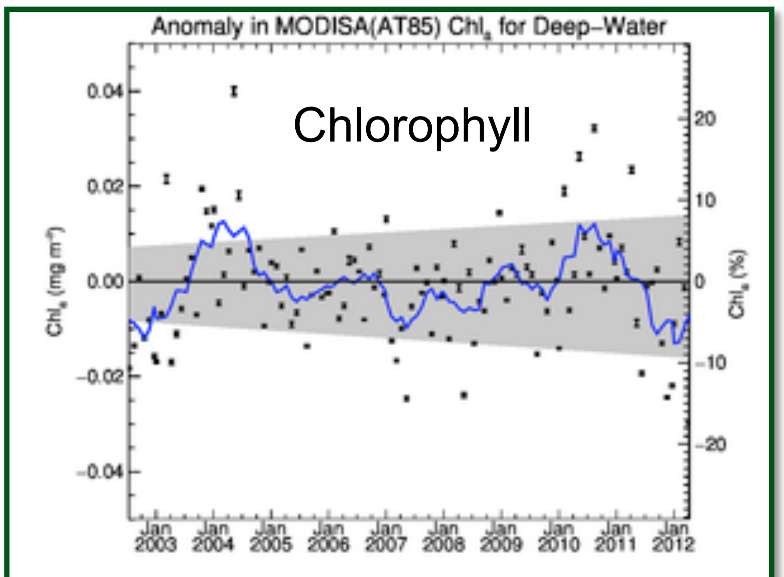


MODISA R2012.0 Temporal Anomalies (2002-2012)

Deep-Water



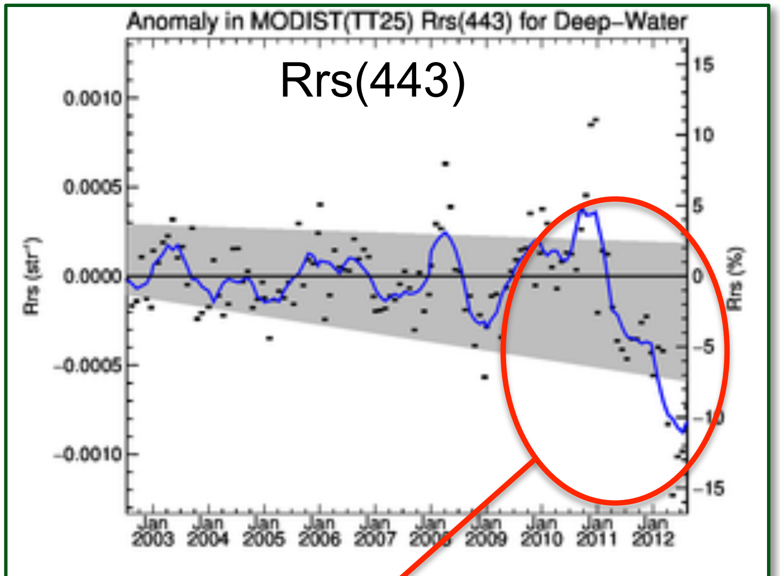


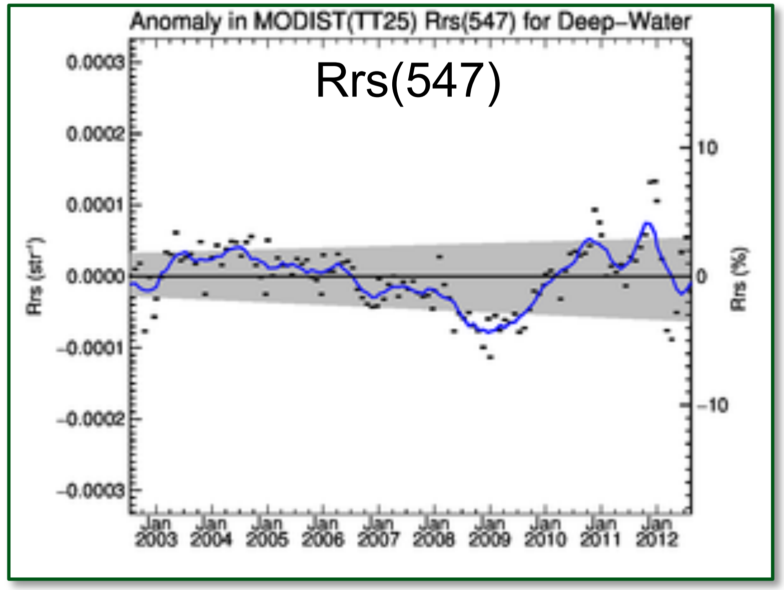


consistent with expectation

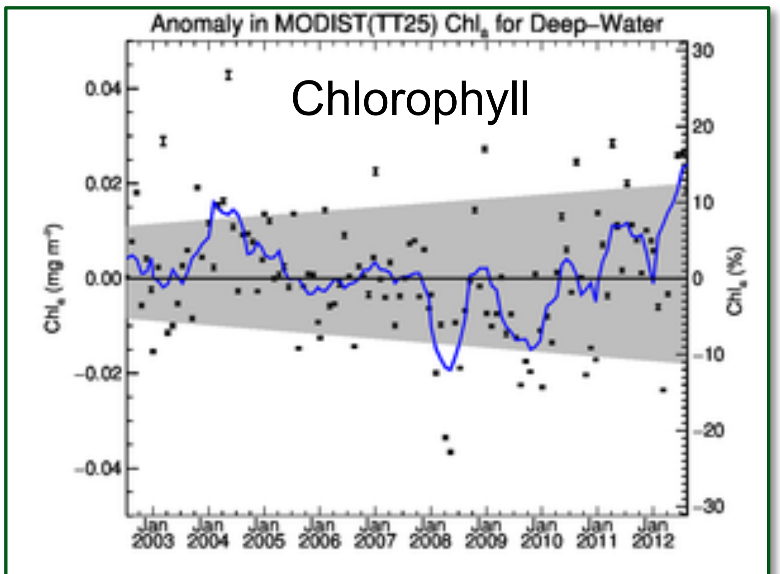
MODIST R2010.0 Temporal Anomalies (2002-2012)

Deep-Water





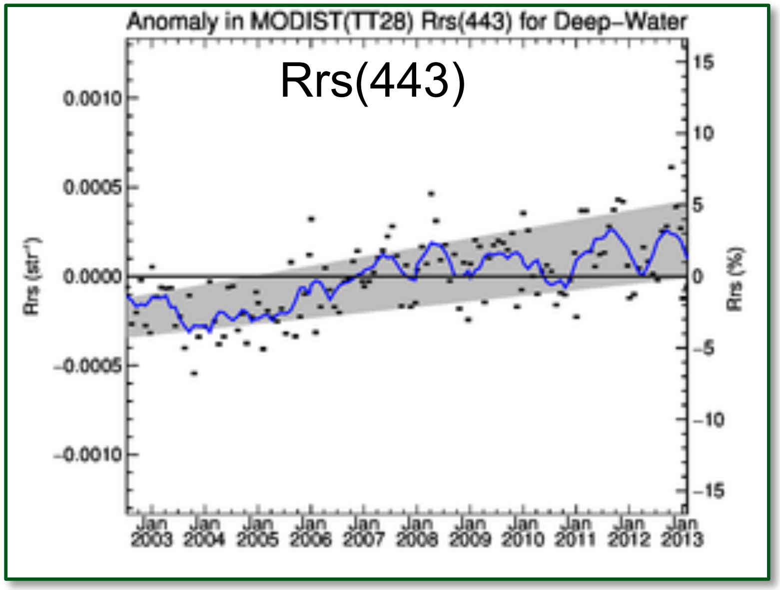
Big Trending Errors

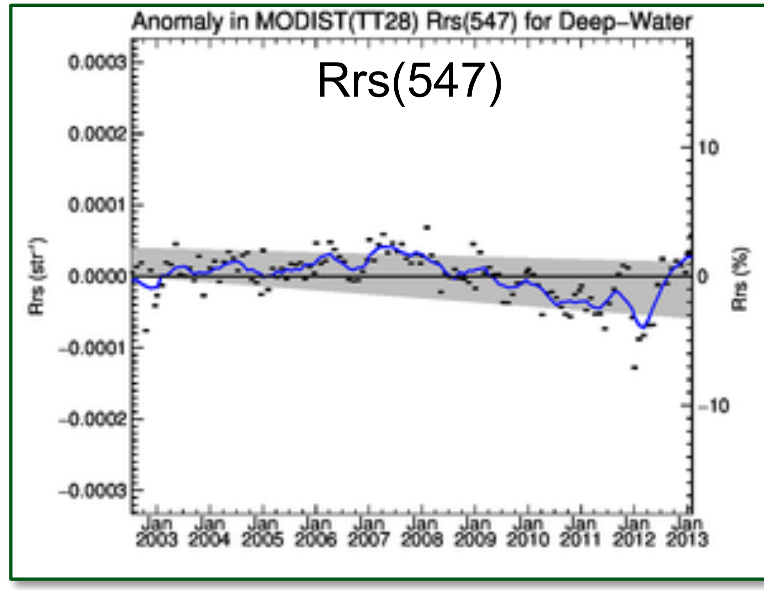


MODIST R2013.0 Temporal Anomalies (2002-2012)

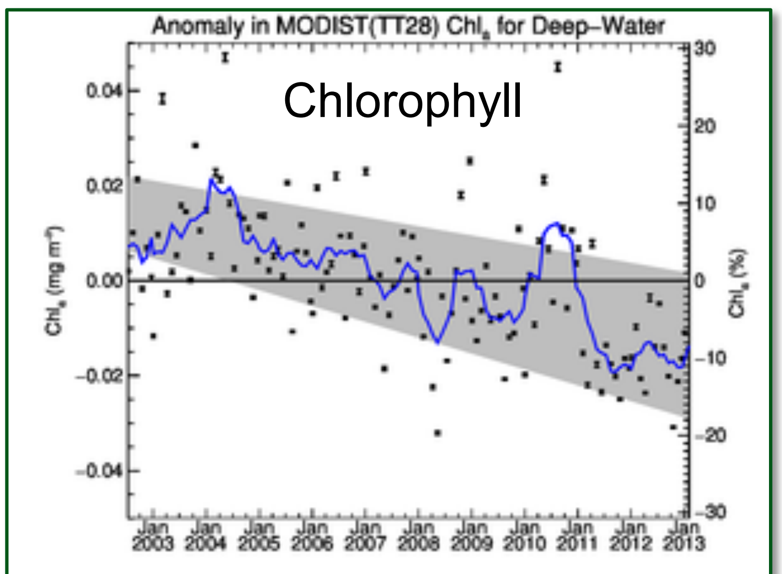
preliminary

Deep-Water



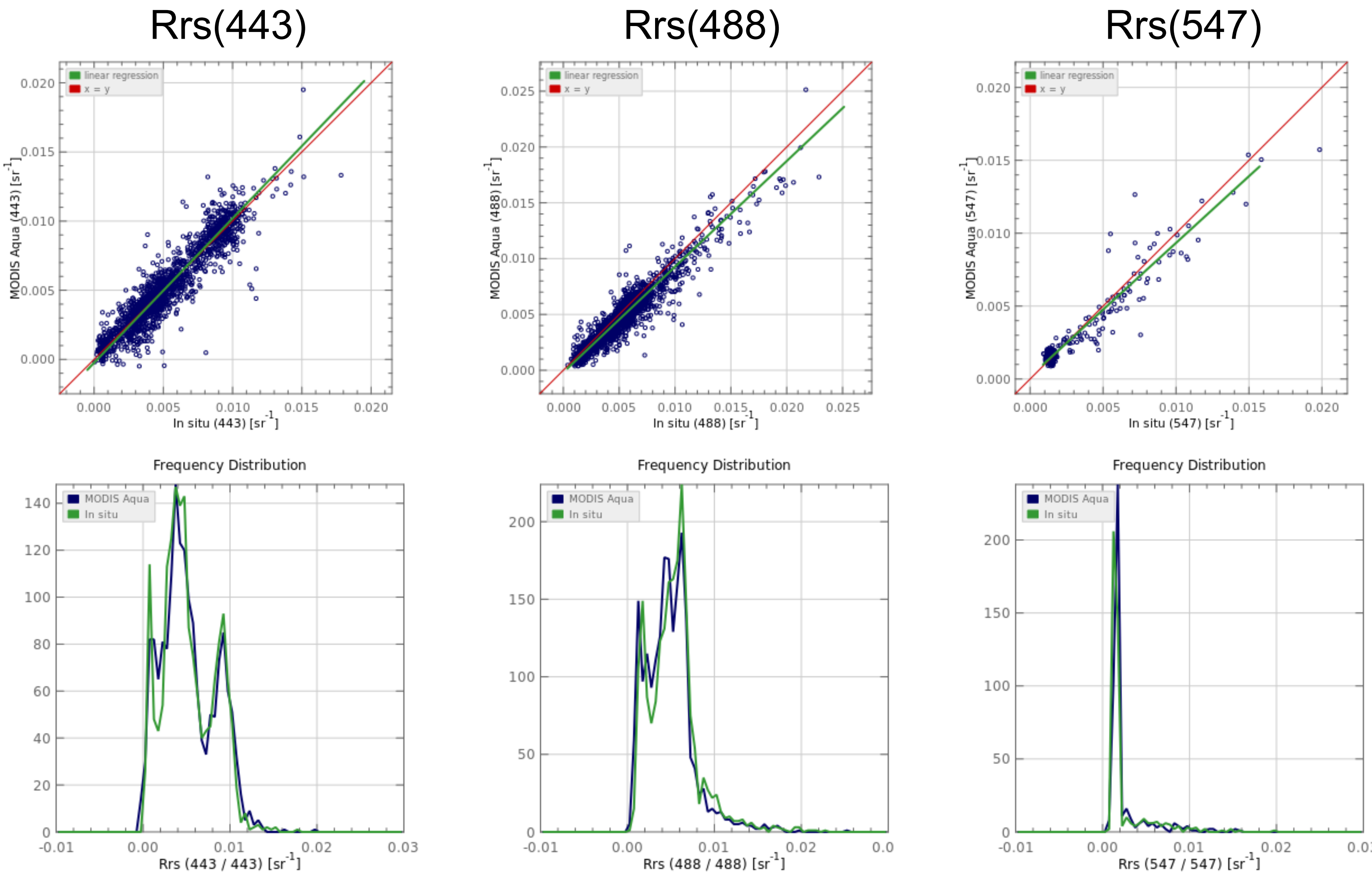


Test Results
after MCST C6 Calibration
and
OBPG cross-cal to MODISA
for RVS and polarization



SeaBASS + AERONET-OC

MODISA (R2013.0) Rrs vs Field Measurements

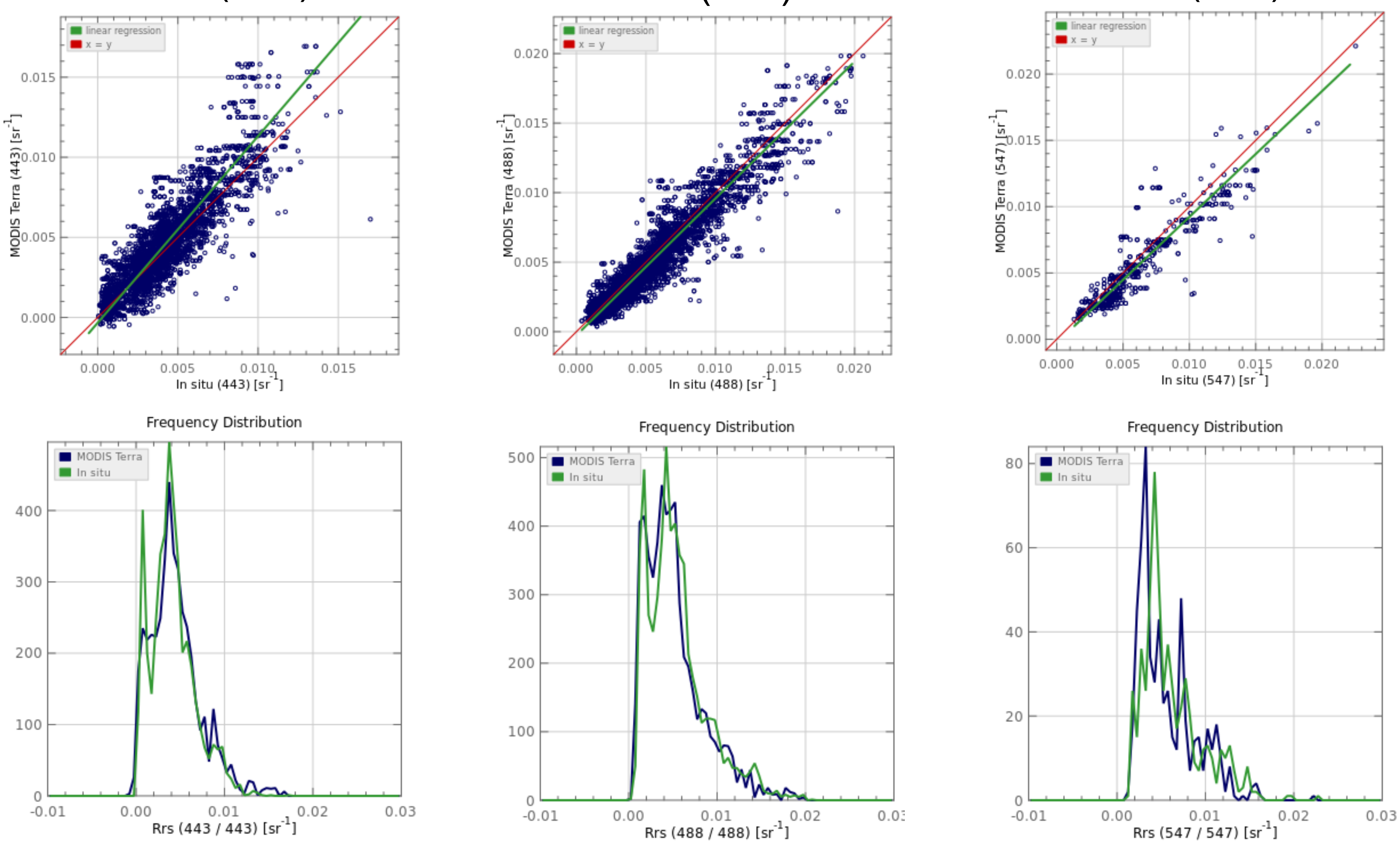


Mean APD 12%, Mean Bias < 10%, R^2 > 0.9

SeaBASS + AERONET-OC

MODIST (R2010.0) Rrs vs Field Measurements

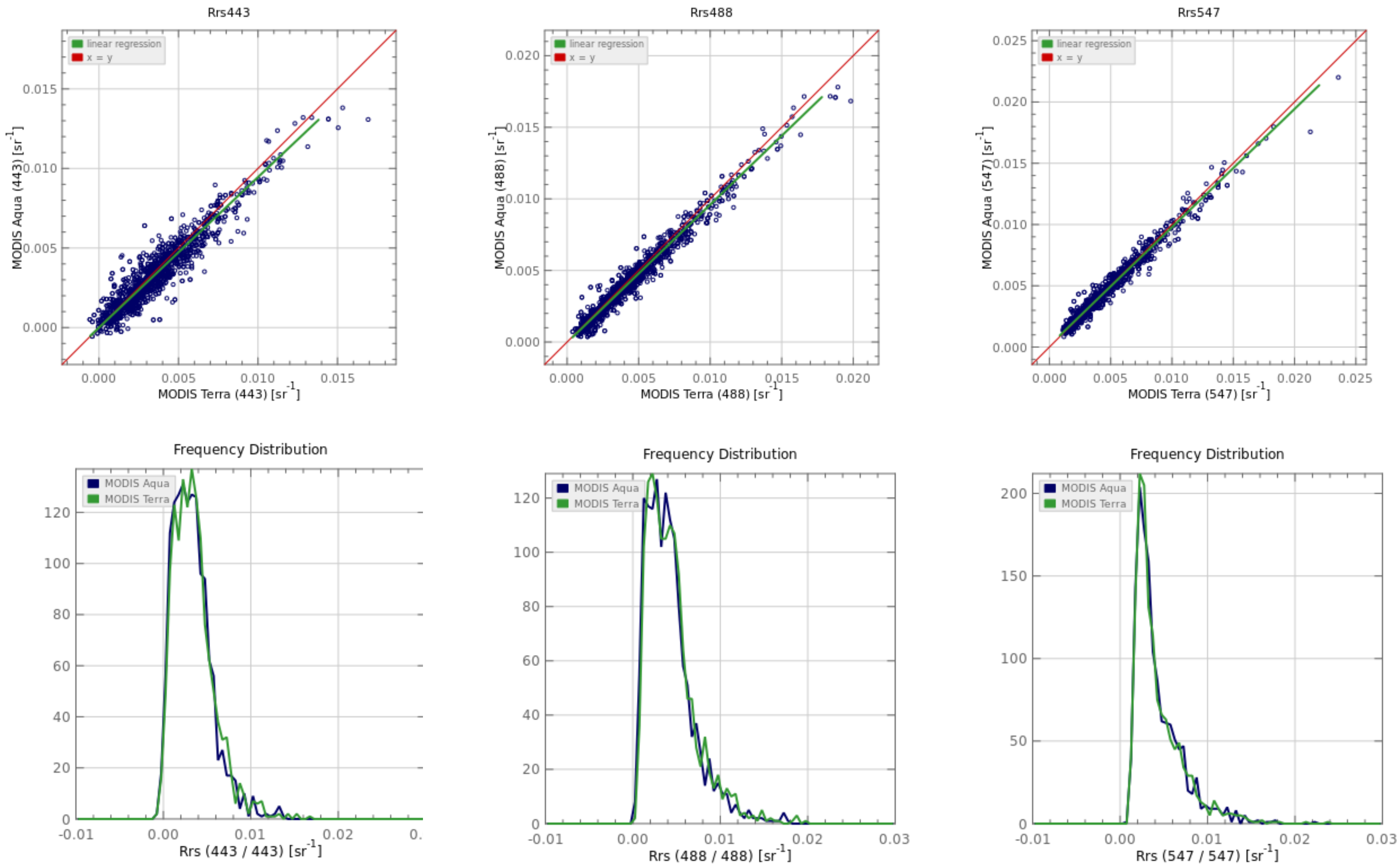
Rrs(443) Rrs(488) Rrs(547)



Mean APD 13-20%, Mean Bias < 15%, R^2 > 0.8

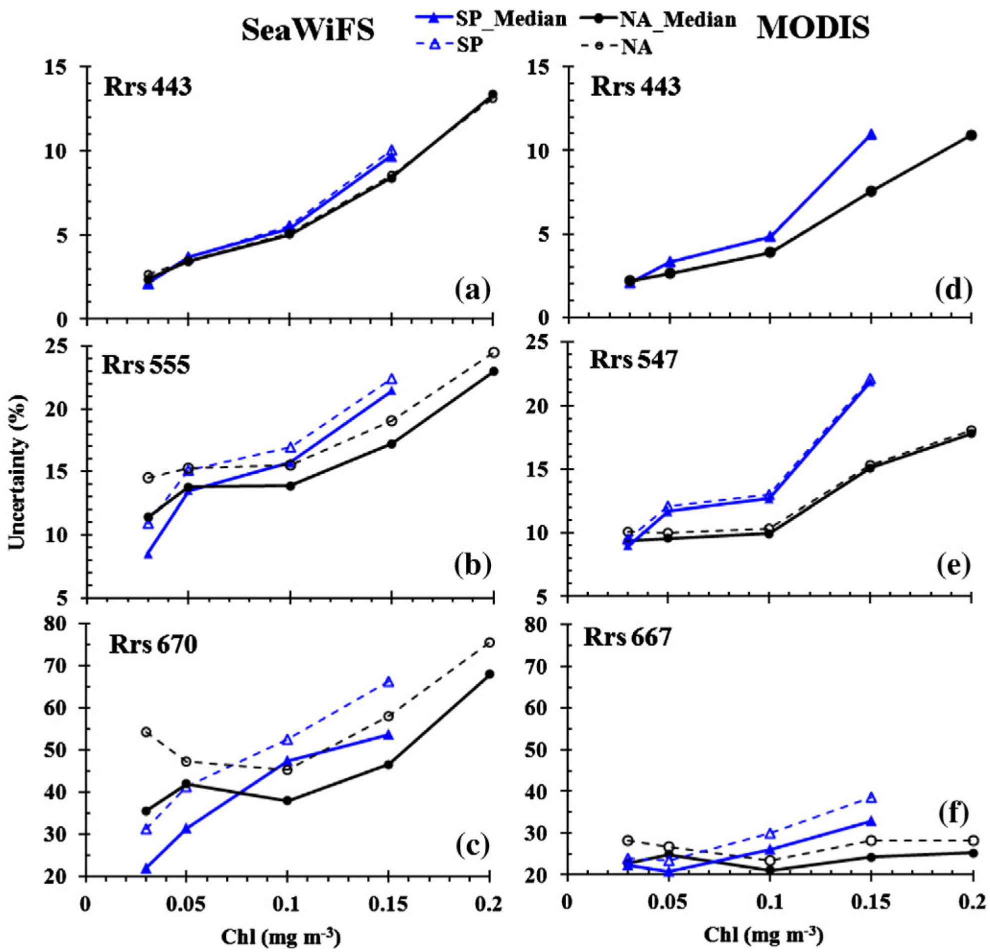
MODIST (R2010.0) vs MODISA (R2013.0)

Rrs(443) Rrs(488) Rrs(547)



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

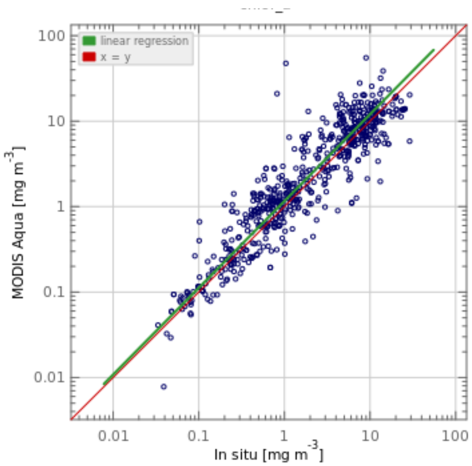
Rrs Uncertainty



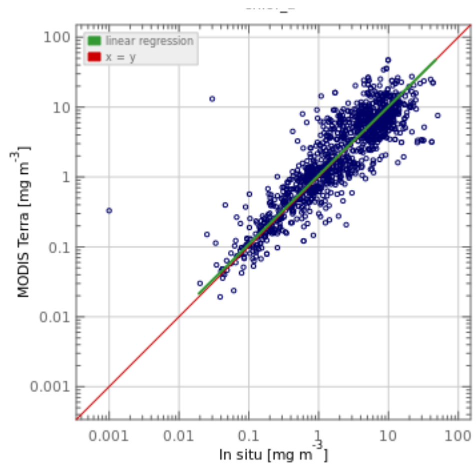
Hu,C., L. Feng, Z. Lee (2013). Uncertainties of SeaWiFS and MODIS remote sensing reflectance: Implications from clear water measurements, Remote Sensing of Environment, Volume 133, 15.

Chl_a in Good Agreement with Field Measurement

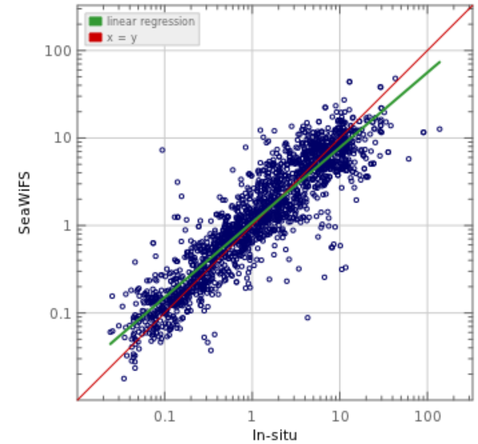
MODISA

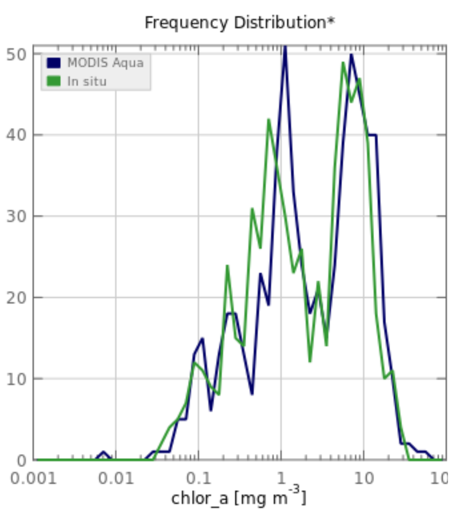


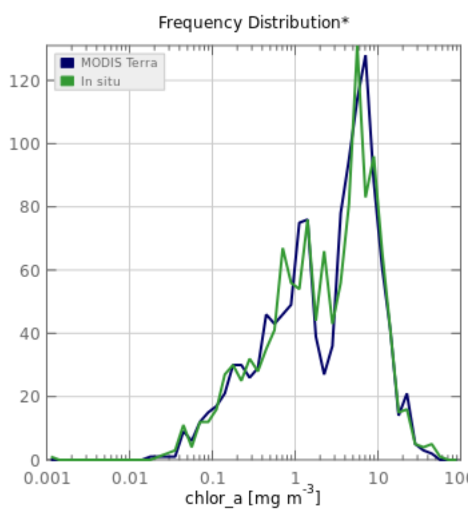
MODIST

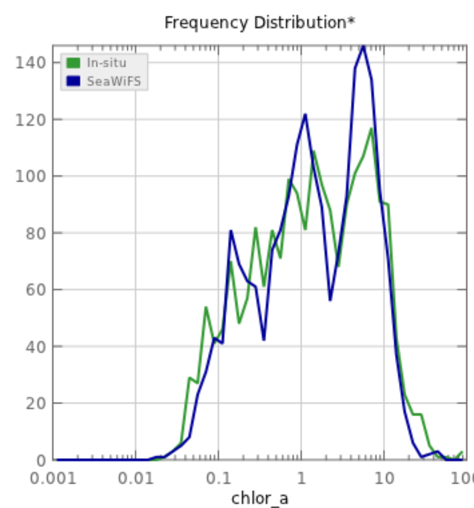


SeaWiFS



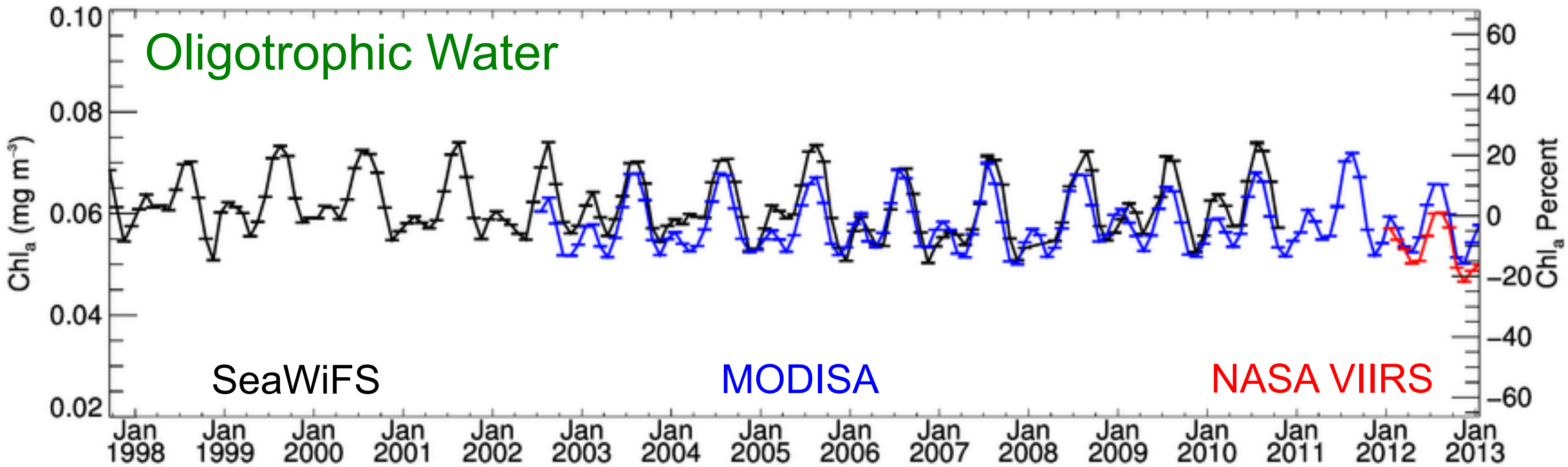


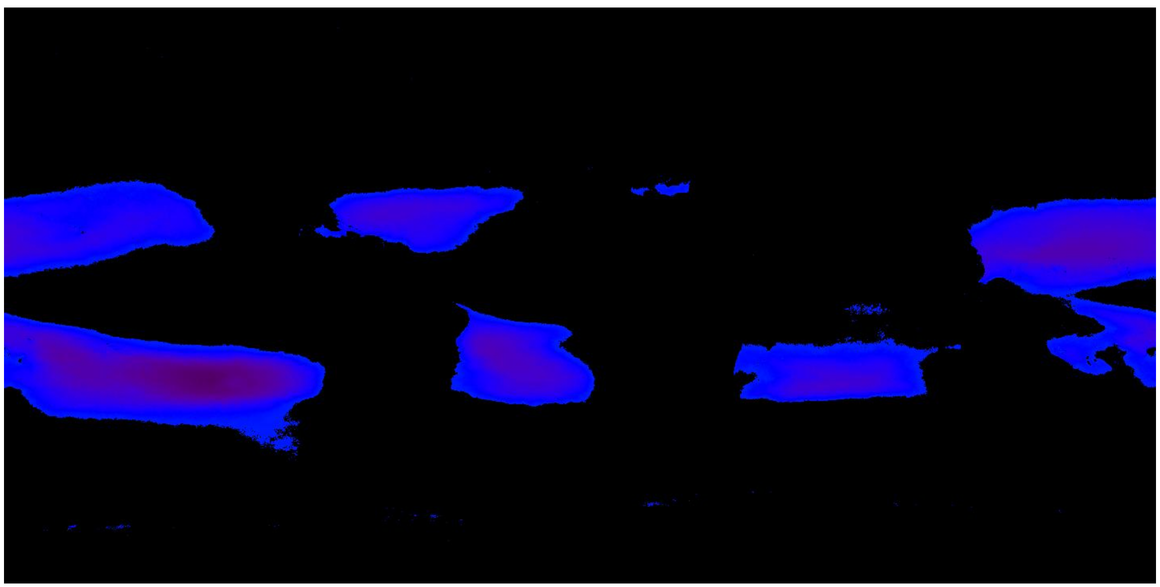




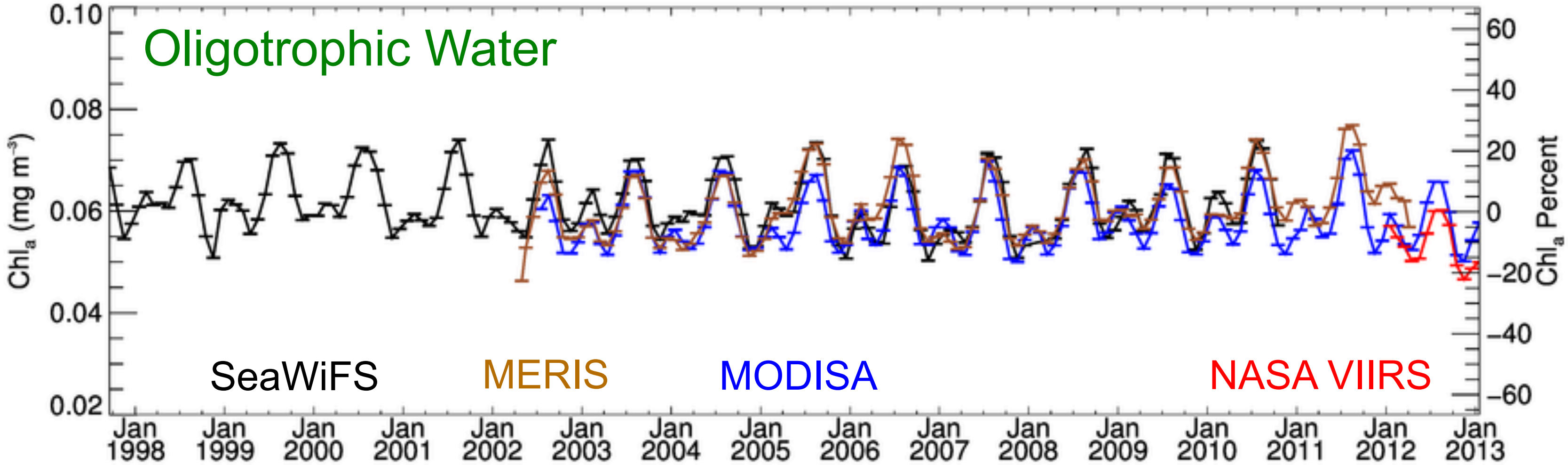
Mean APD 35%, Mean Bias < 15%, R^2 > 0.8

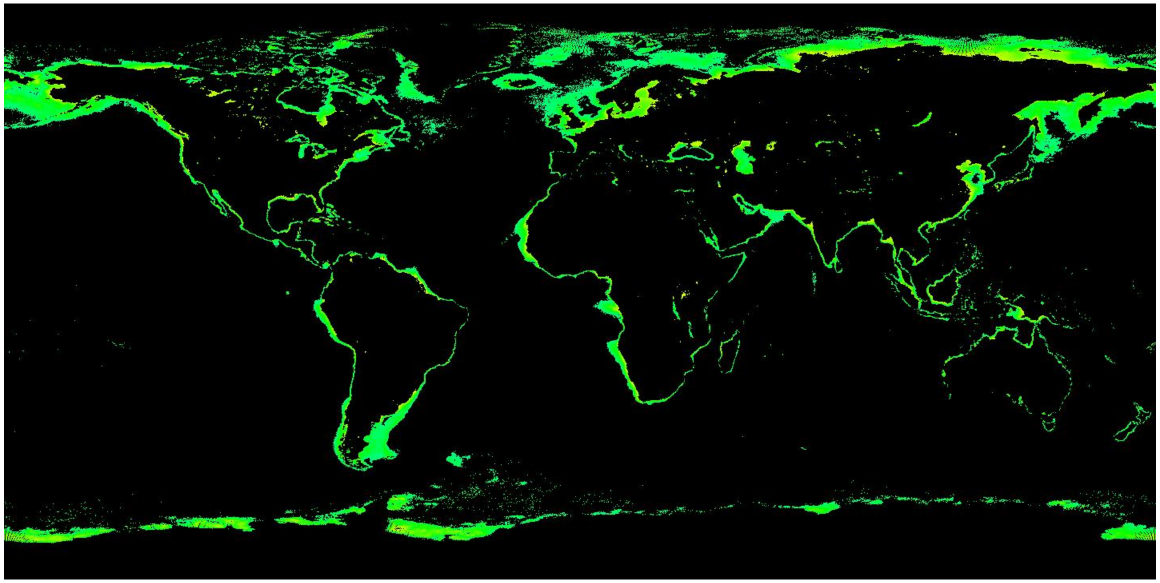
Multi-mission Chlorophyll Record



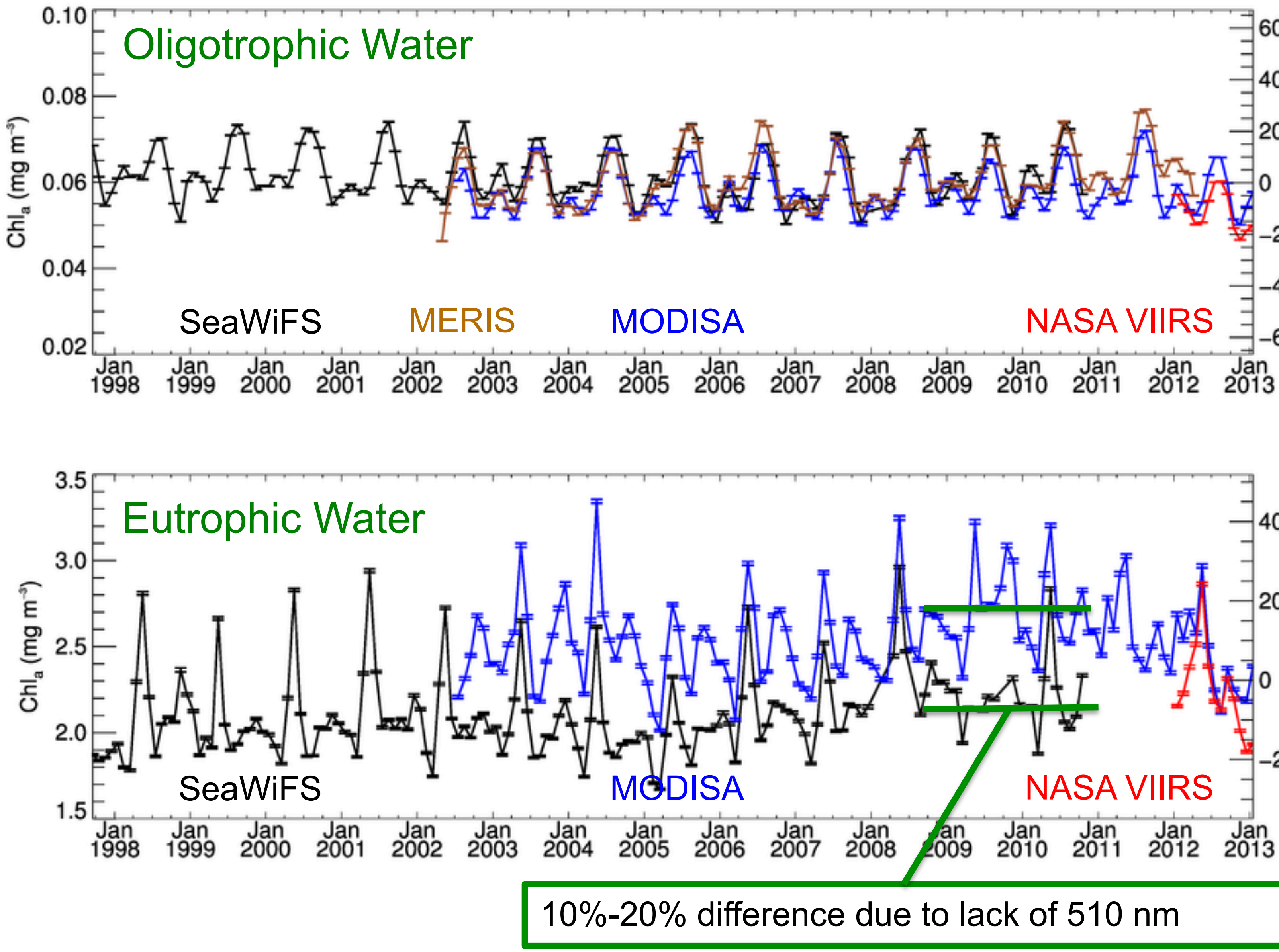


Multi-mission Chlorophyll Record

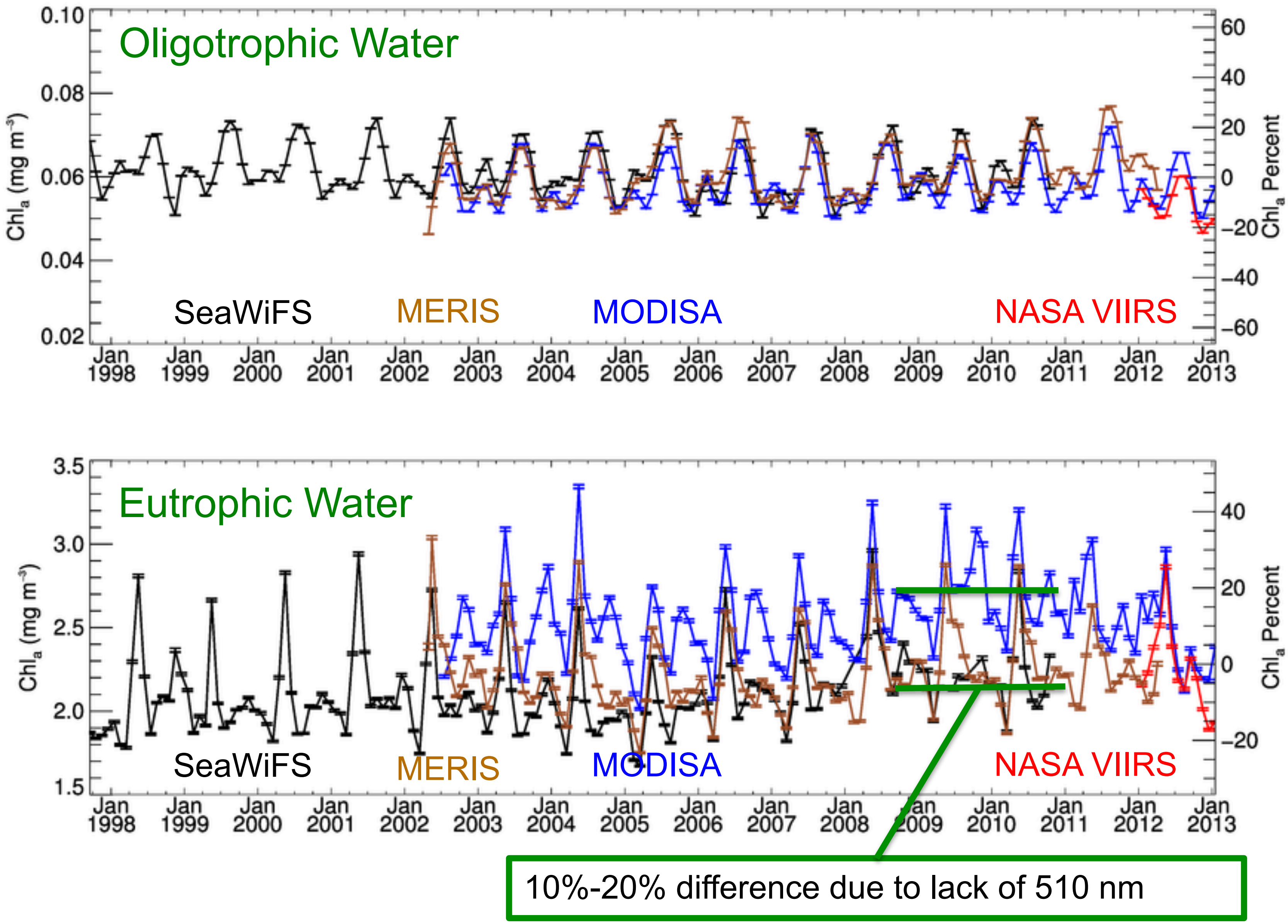




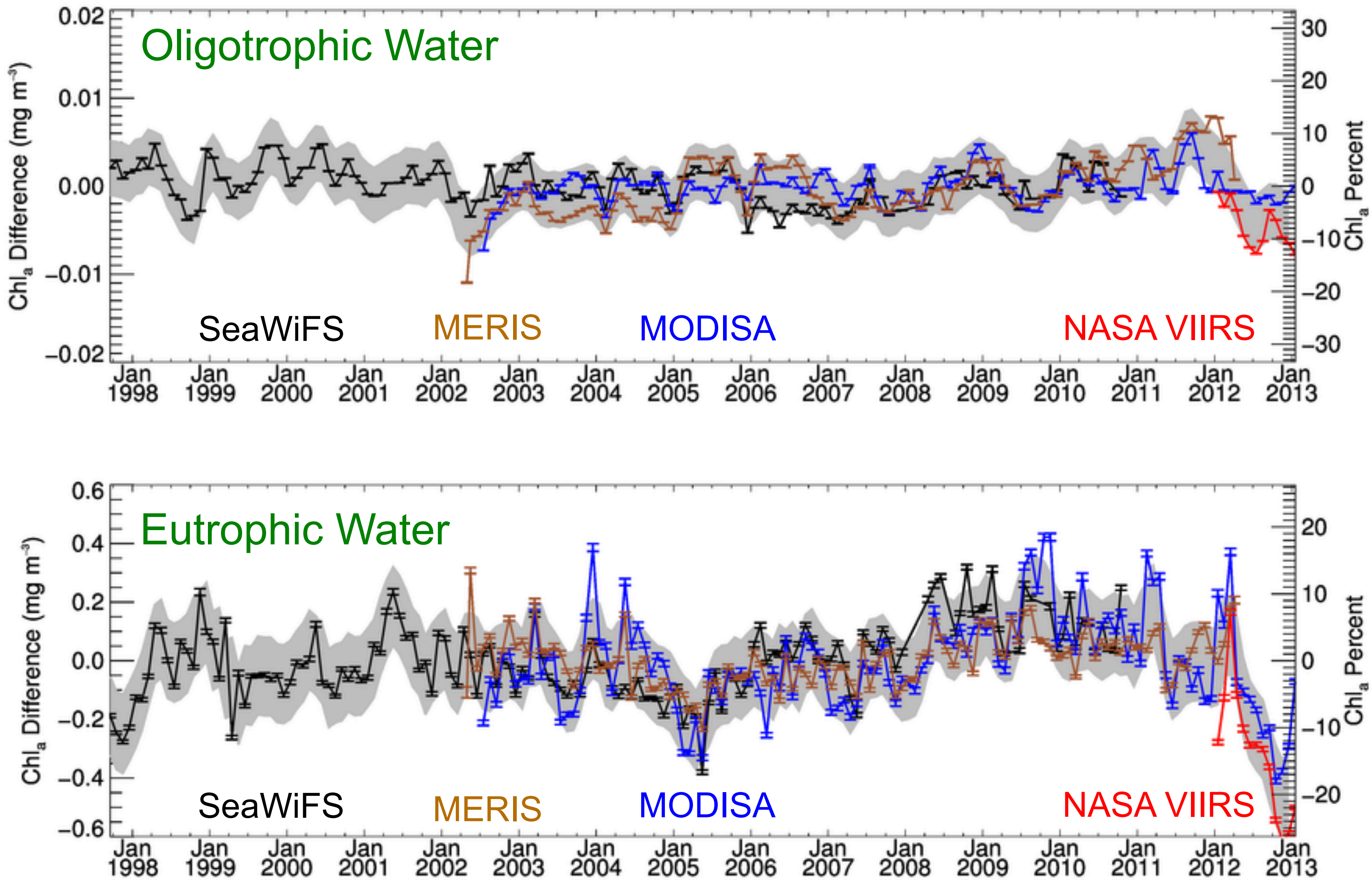
Multi-mission Chlorophyll Record



Multi-mission Chlorophyll Record

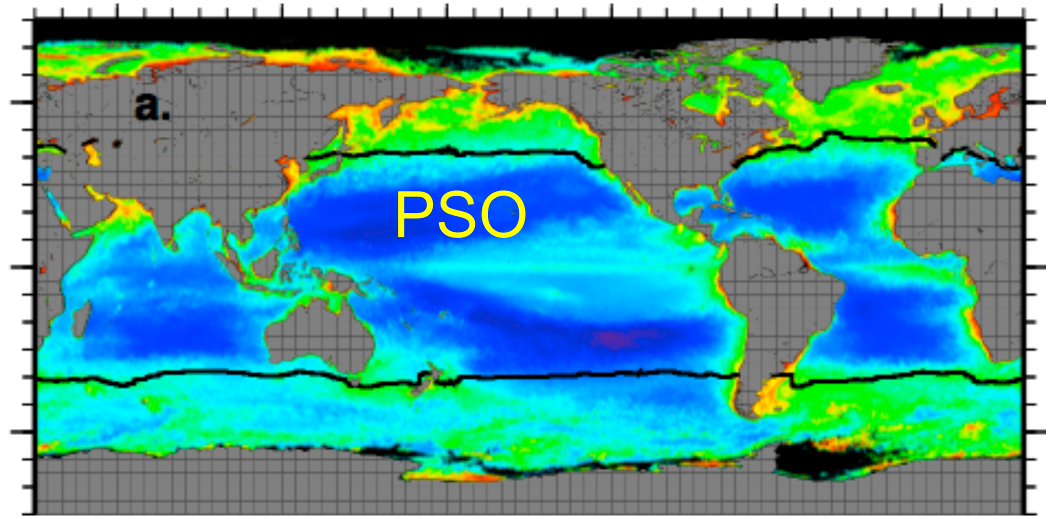


Multi-mission Chlorophyll Anomaly Record

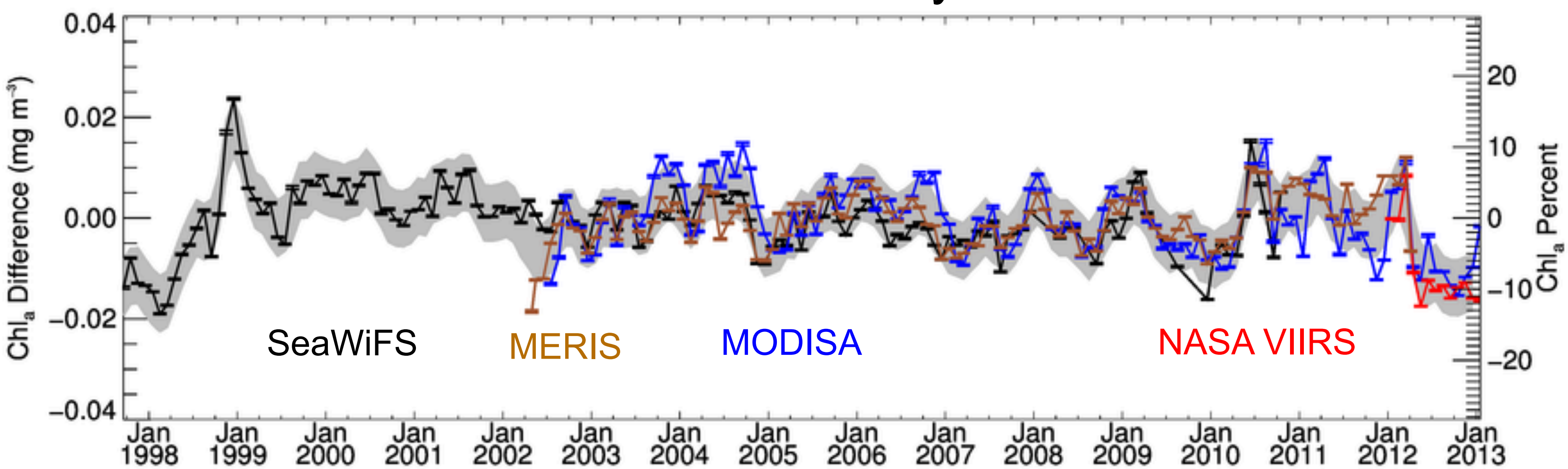


Multi-mission Chlorophyll Anomaly Record

Following
Berenfeld et al. 2006
Mean SST > 15C

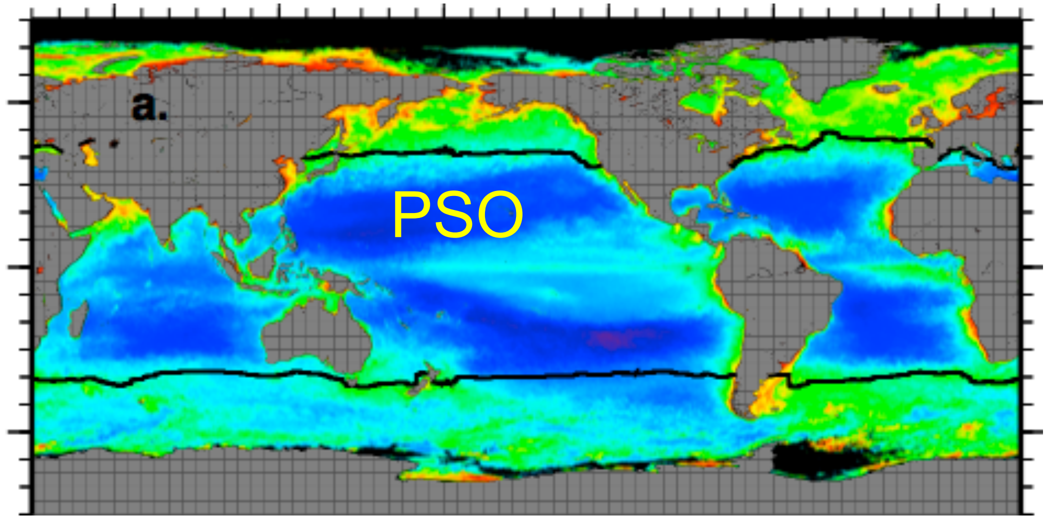


PSO Anomaly

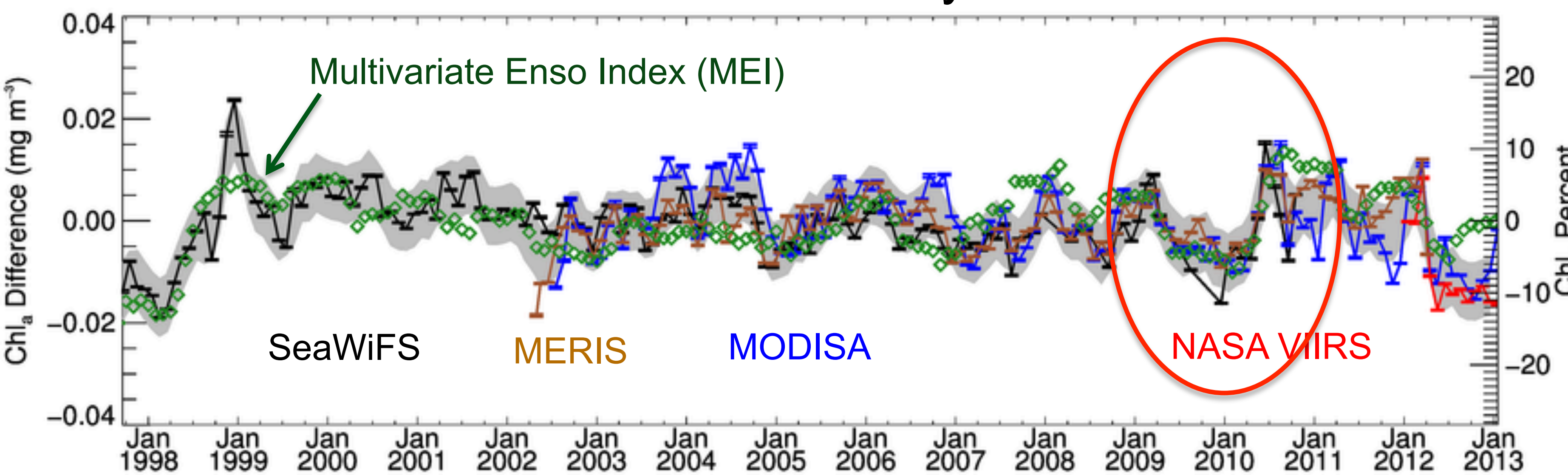


Multi-mission Chlorophyll Anomaly Record

Following
Berenfeld et al. 2006
Mean SST > 15C

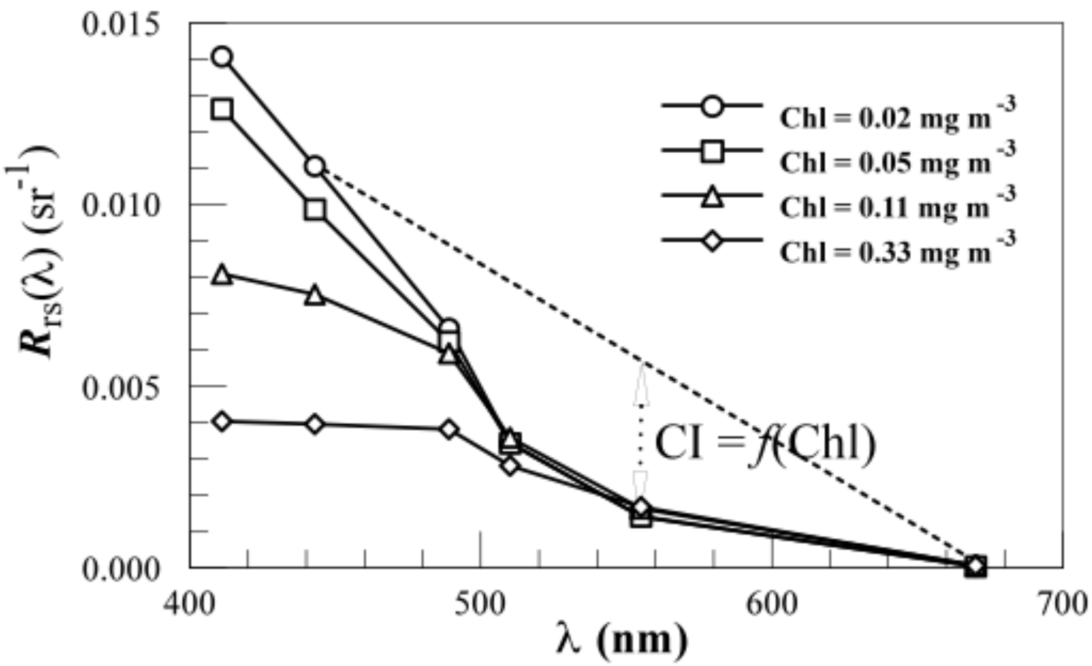


PSO Anomaly



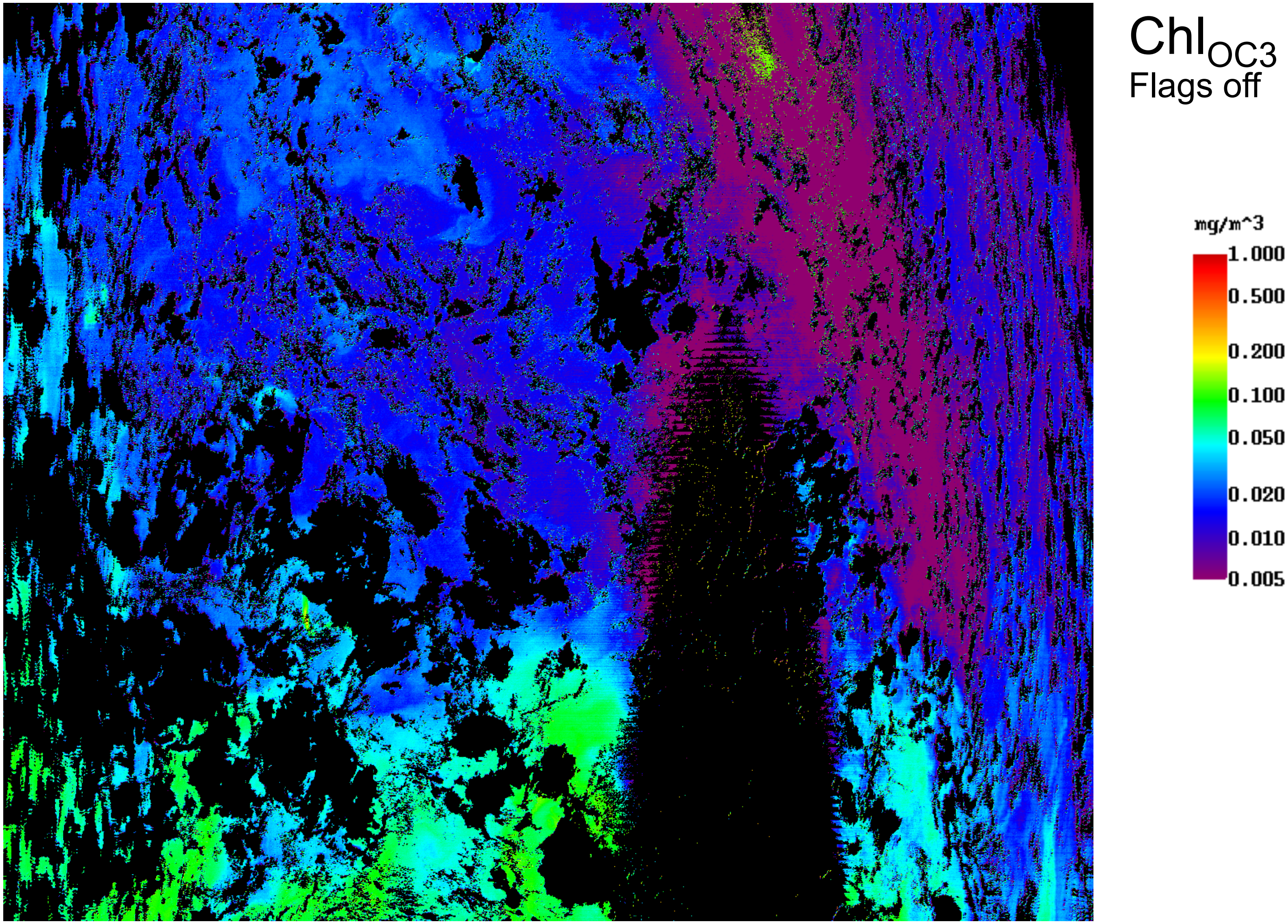
Chlorophyll Algorithm Refinement

OCI algorithm: Line height algorithm for chlorophyll < 0.25 mg m^{-3}, merged with OC3/OC4 max band ratio algorithm for chlorophyll > 0.3 mg m^{-3}.



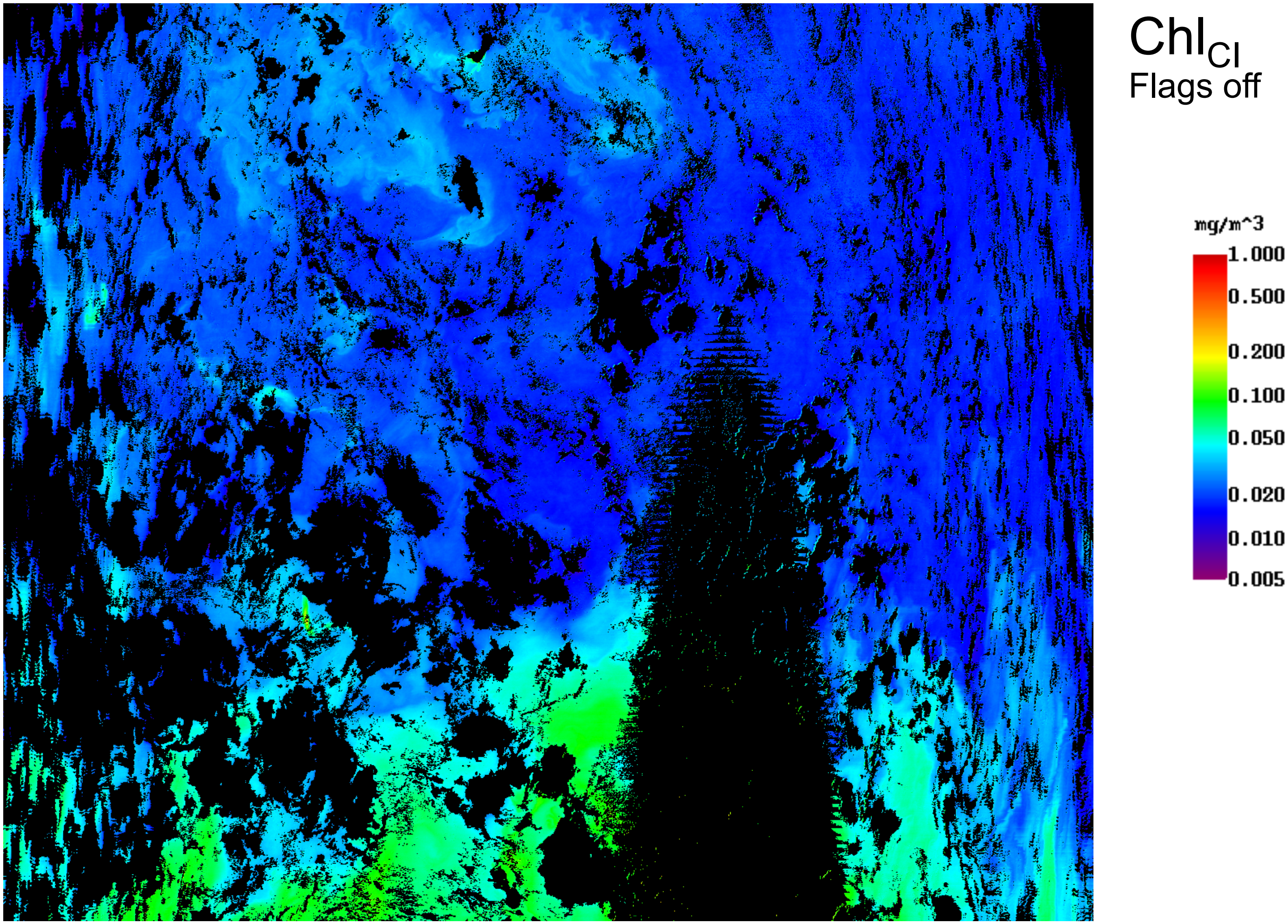
Hu, C., Z. Lee, and B.A. Franz (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference, J. Geophys. Res., 117, C01011, doi:10.1029/2011JC007395.

MODISA Standard OC3 Chlorophyll

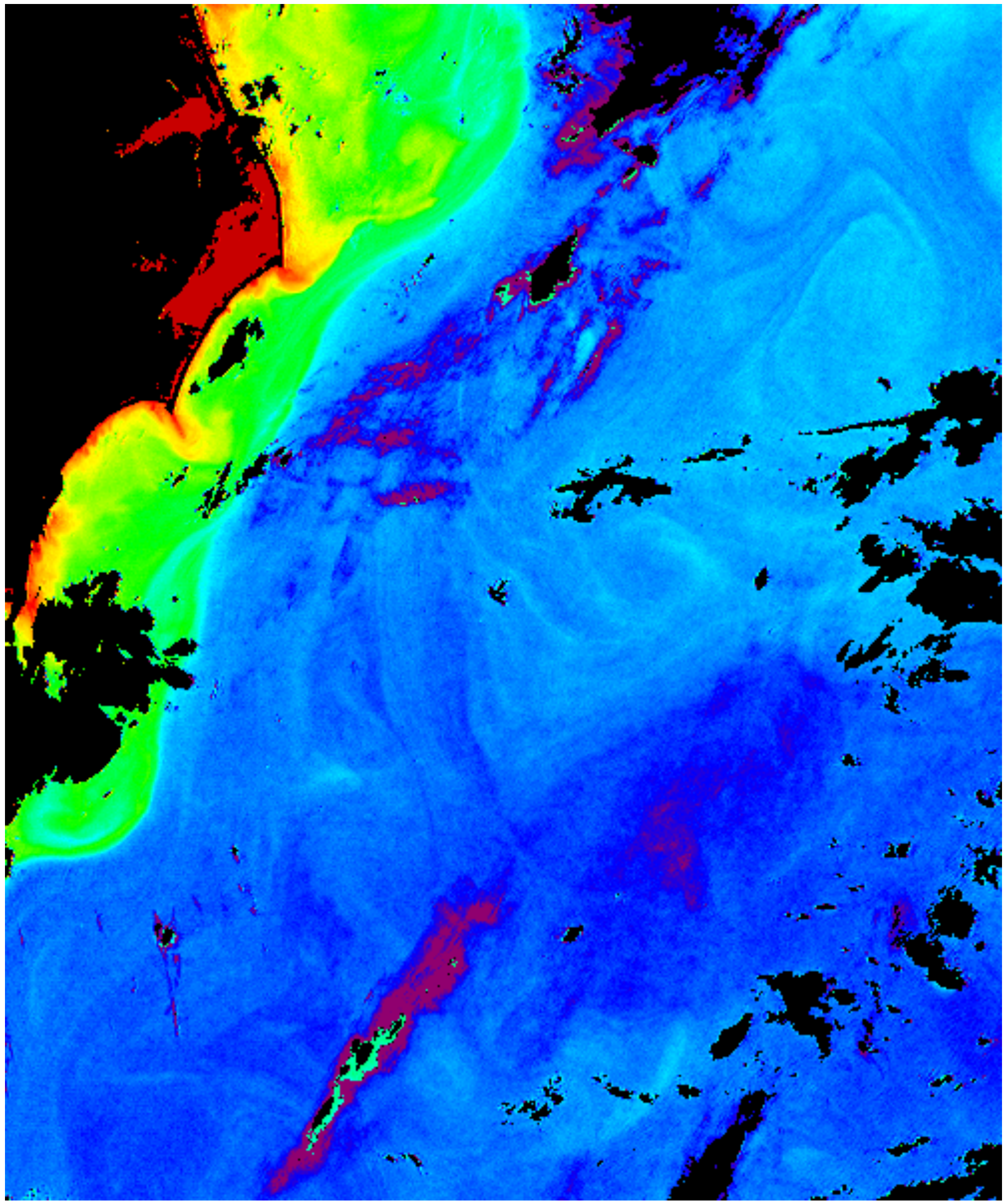


Chl_{OC3}
Flags off

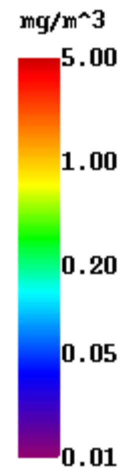
MODISA Evaluation OCI Chlorophyll



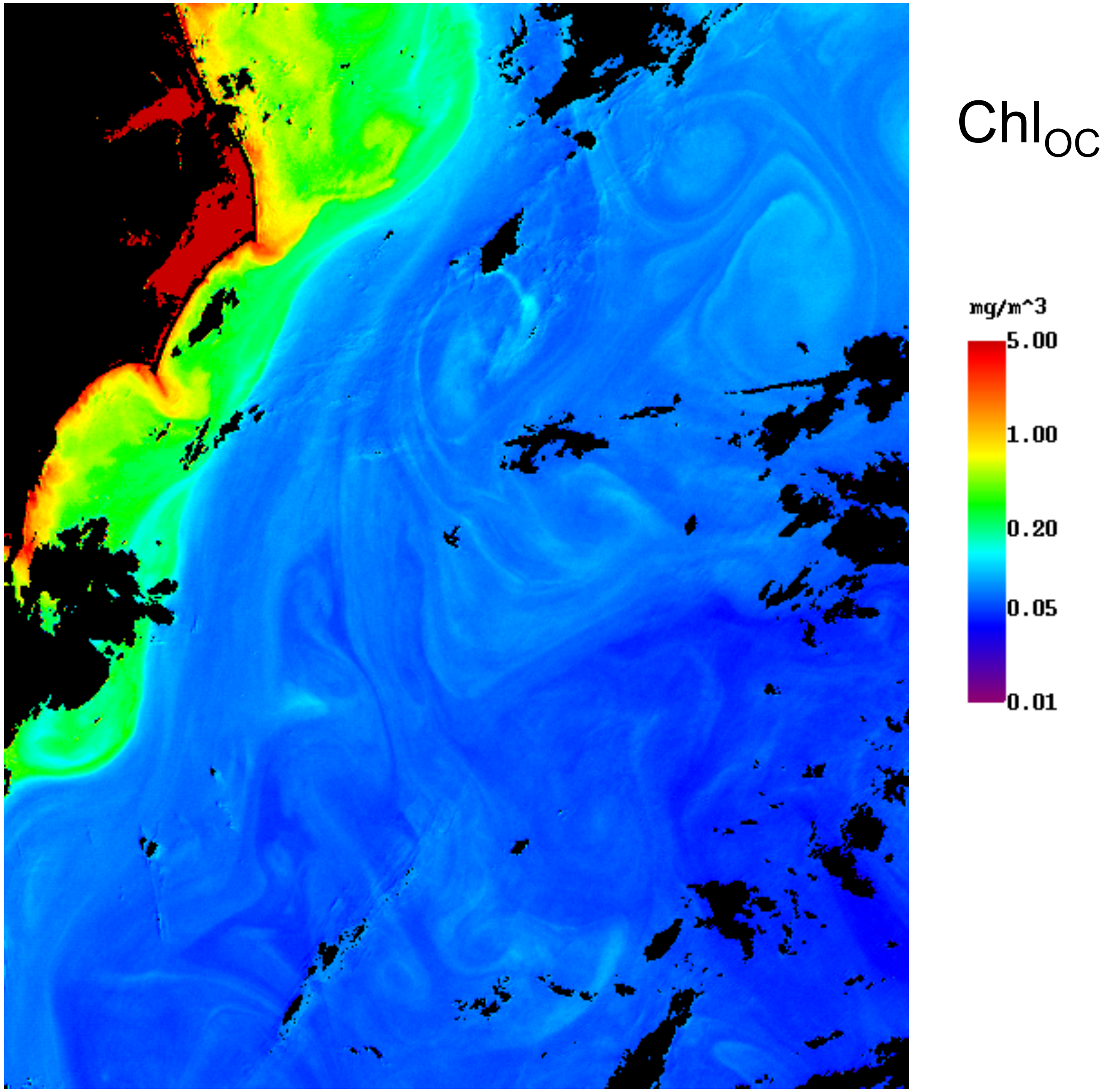
SeaWiFS Standard OC4 Chlorophyll



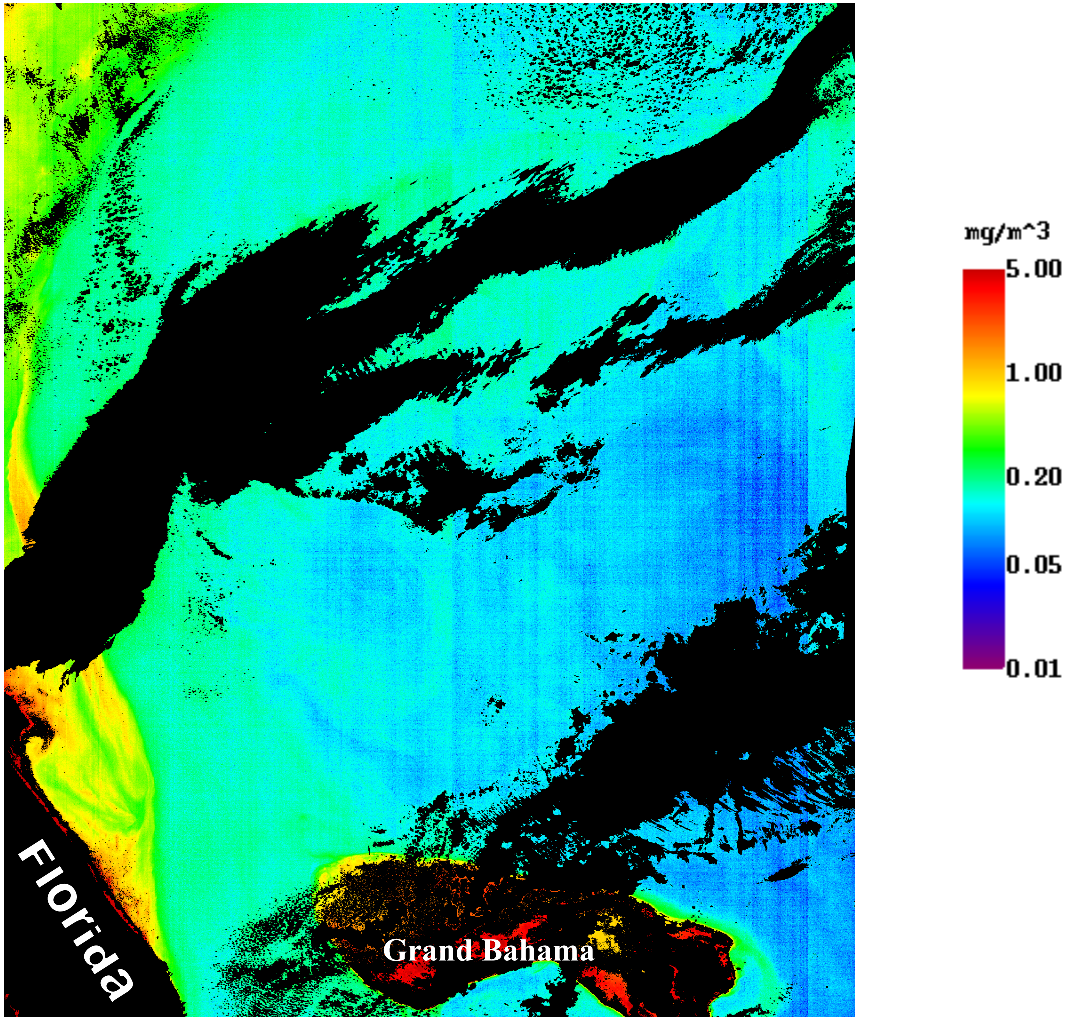
Chl_{OC4}



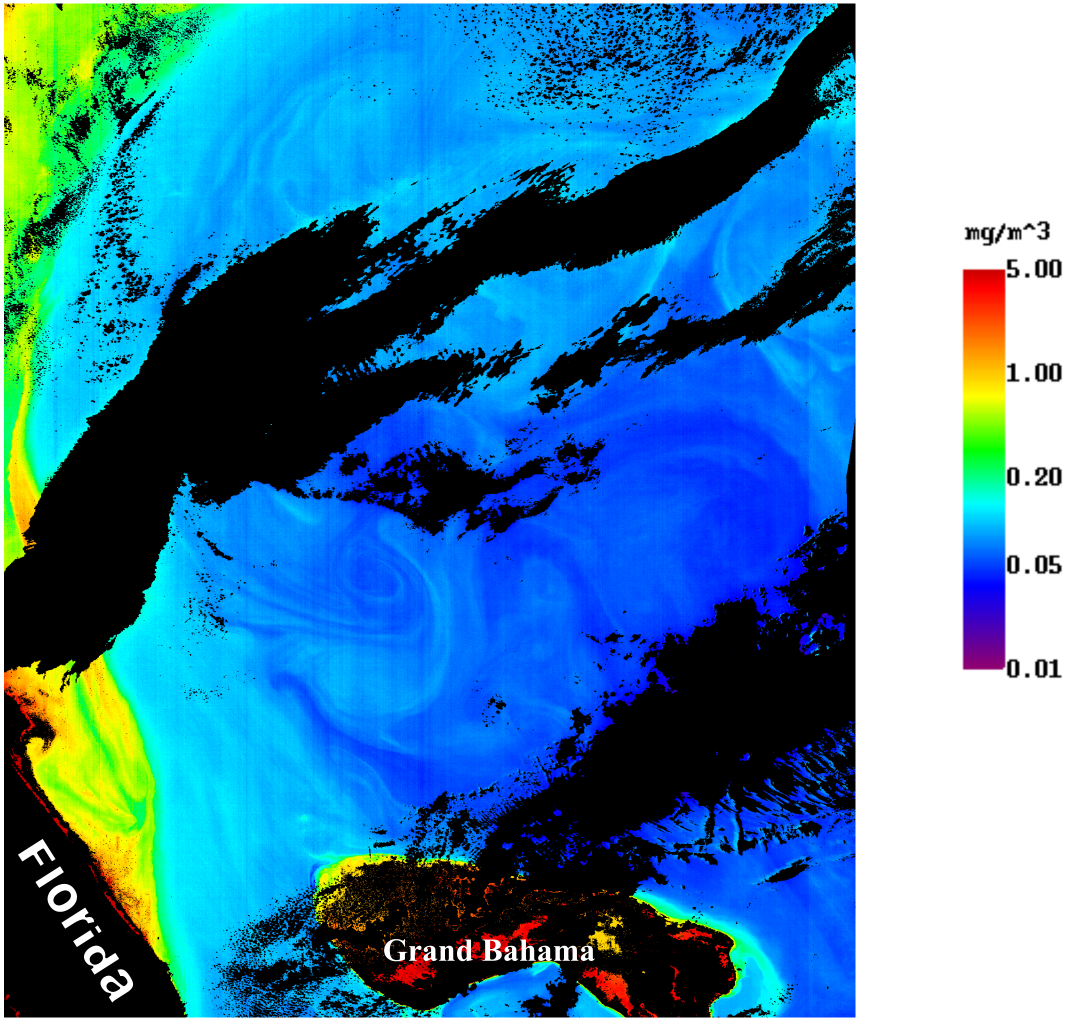
SeaWiFS Evaluation OCI Chlorophyll



MERIS Standard OC4 Chlorophyll



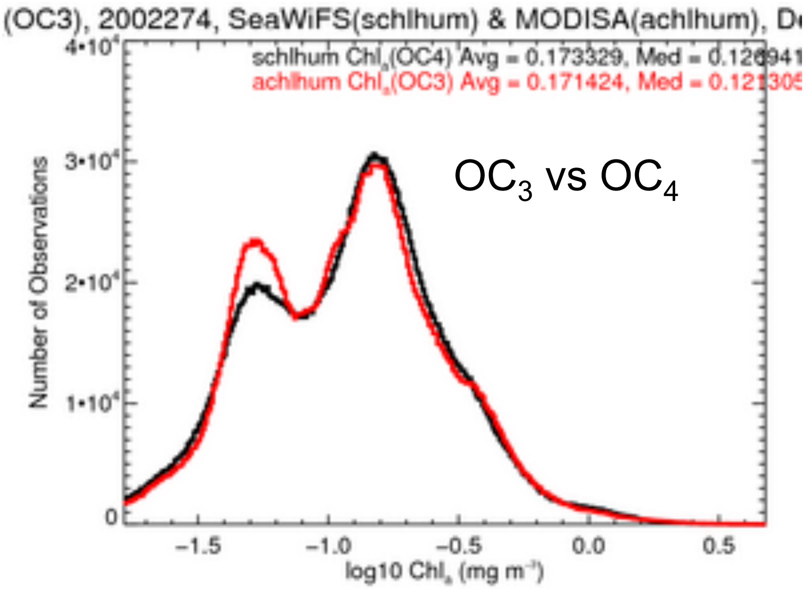
MERIS Evaluation OCI Chlorophyll

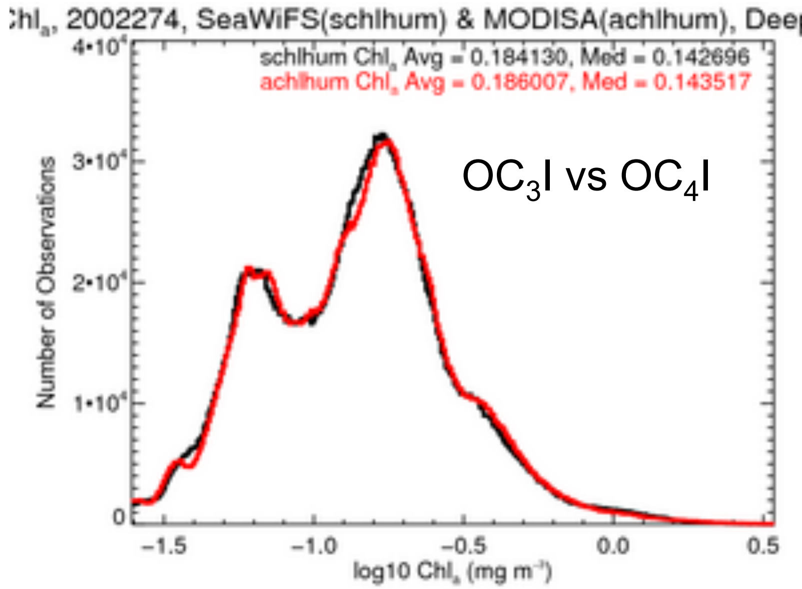


Improved Agreement in Chl Distribution

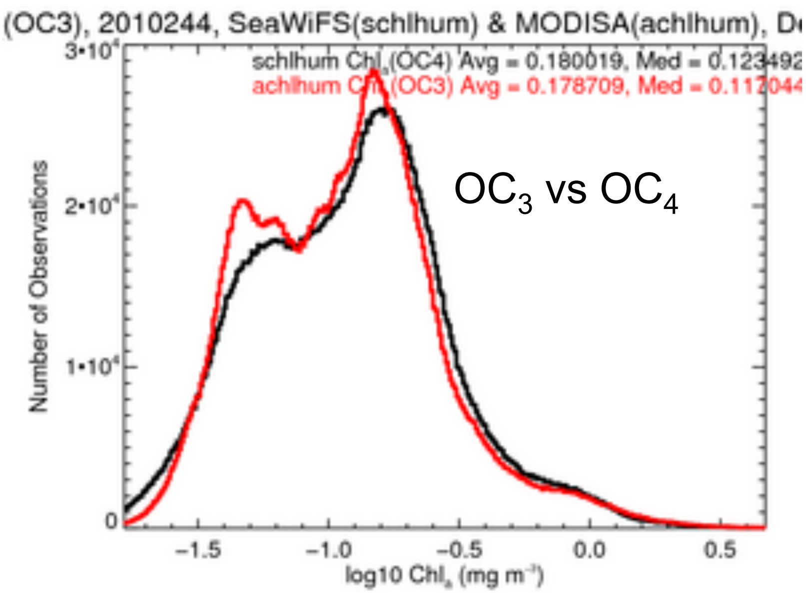
Deep-Water Monthly Mean, MODISA (red) & SeaWiFS (black)

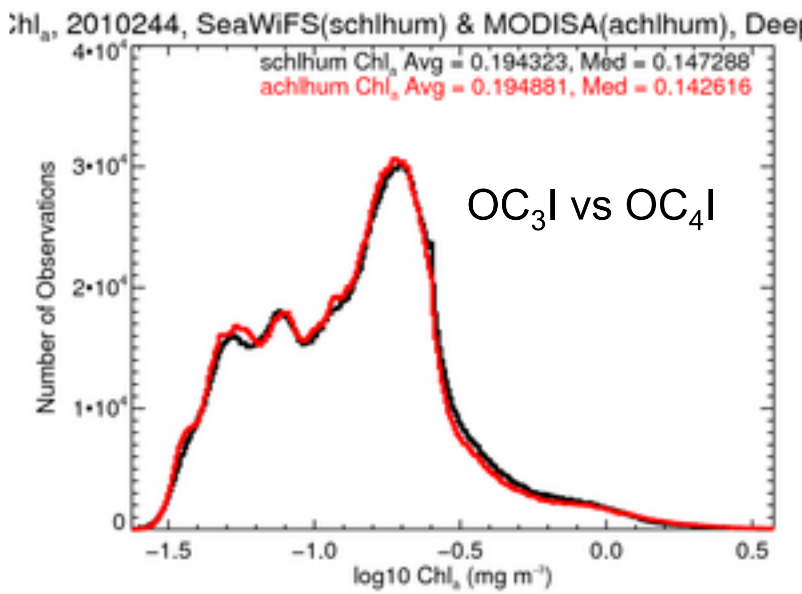
Fall 2002





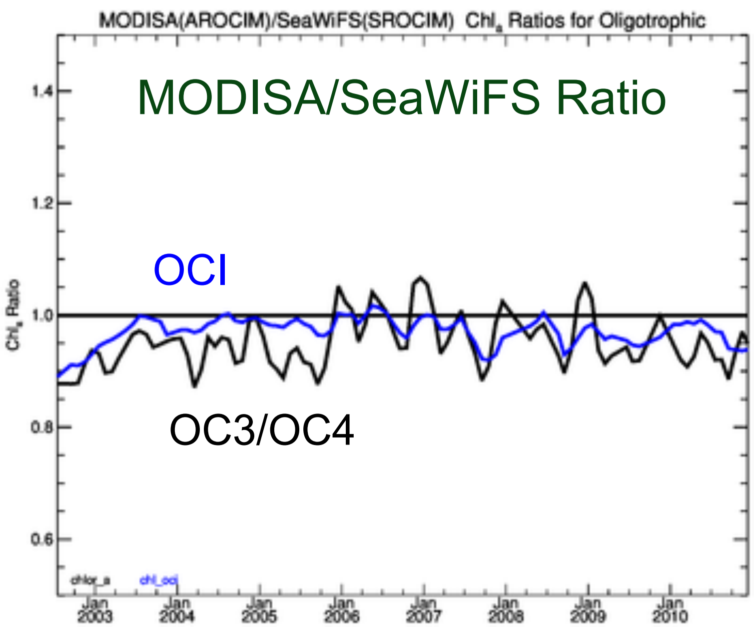
Fall 2010

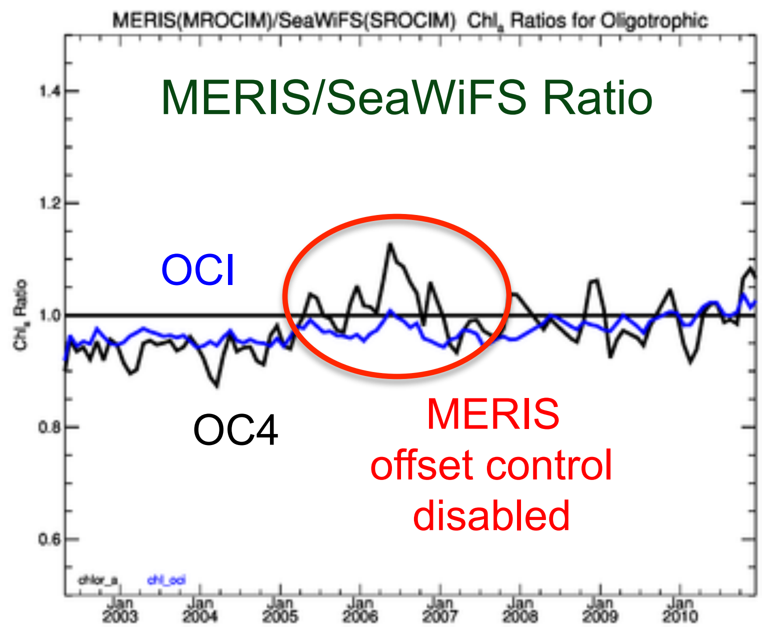




Chlorophyll Algorithm Refinement

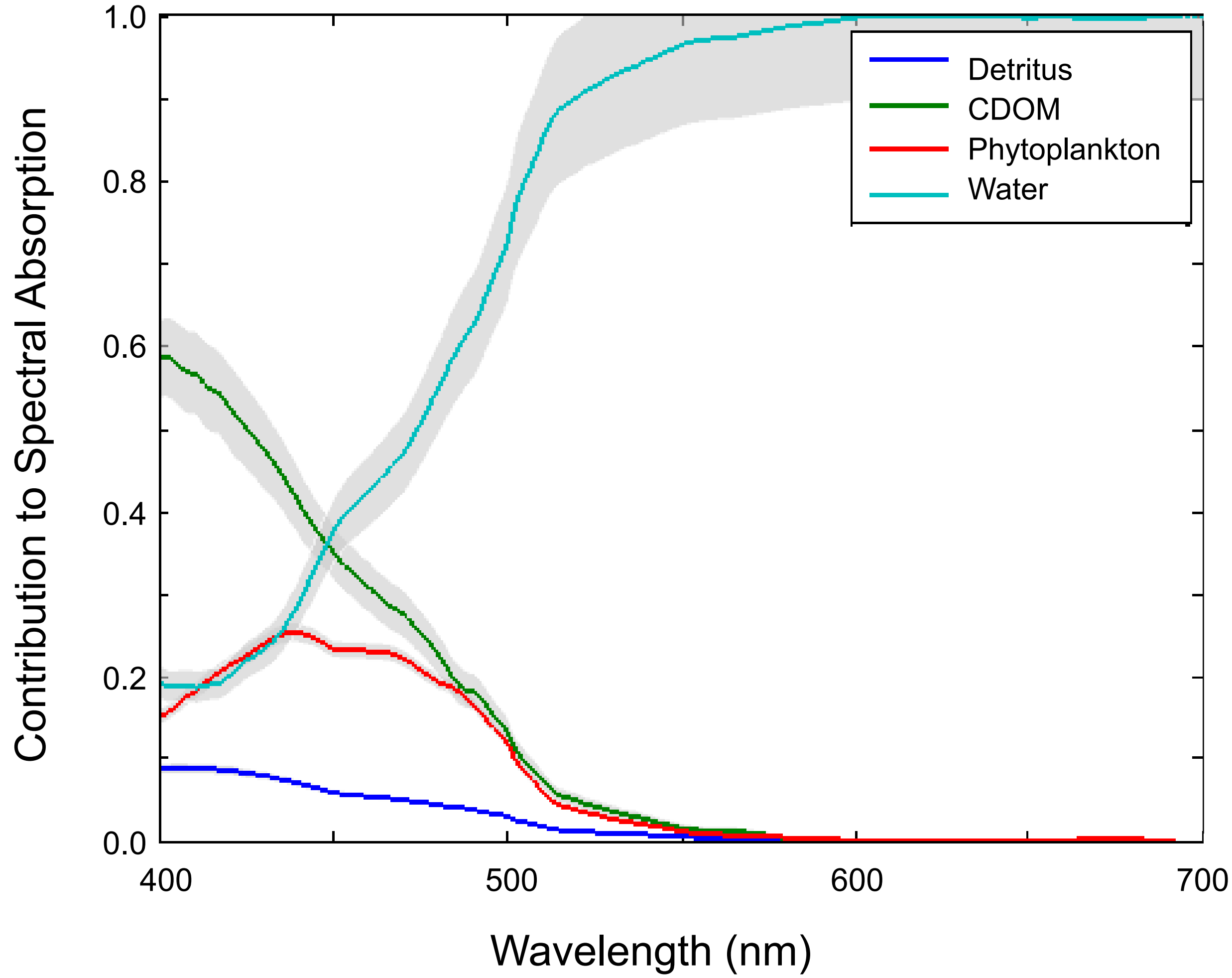
improved agreement between sensors in clear water





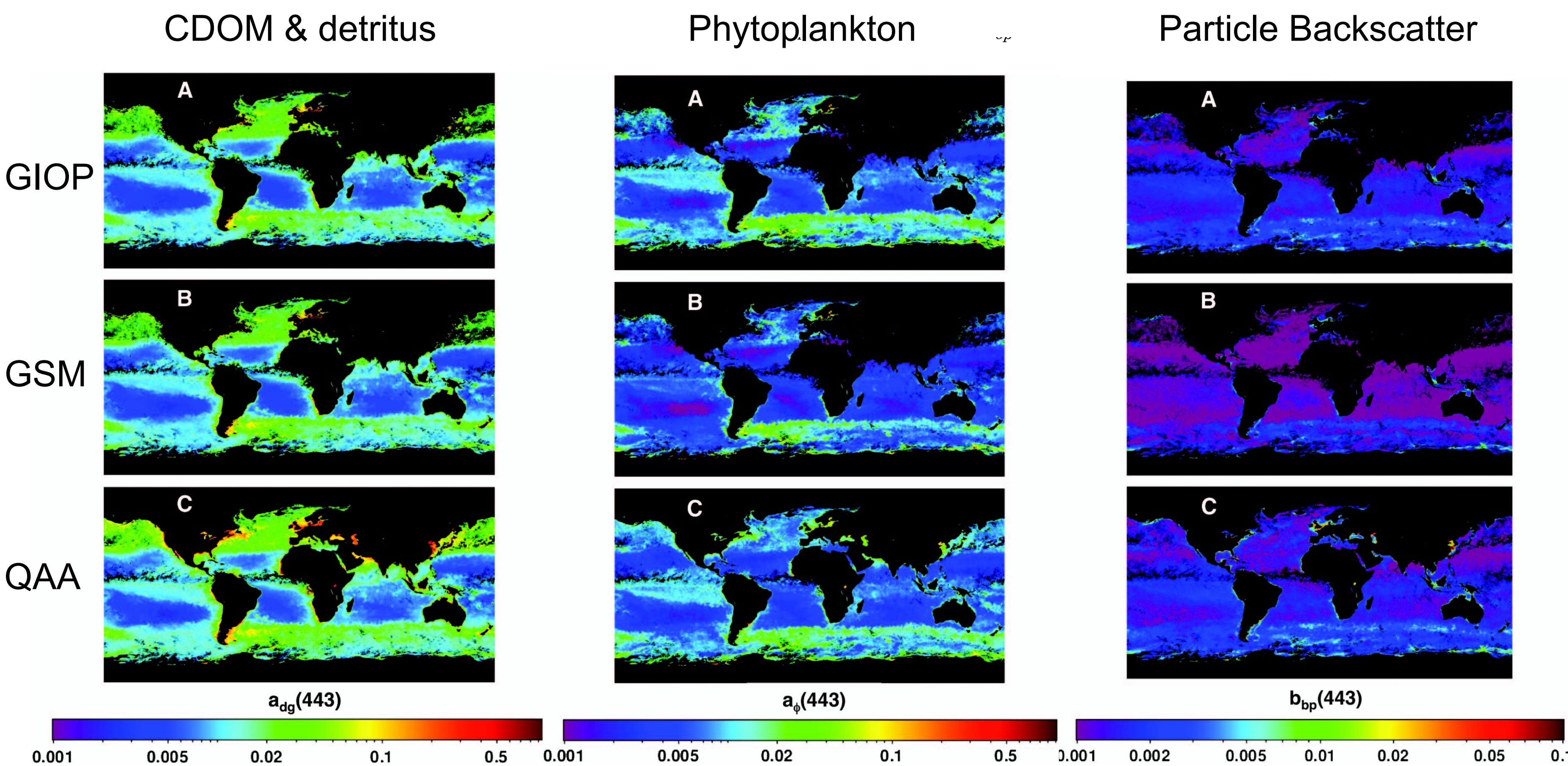
Hu, C., Z. Lee, and B.A. Franz (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference, J. Geophys. Res., 117, C01011, doi:10.1029/2011JC007395.

Beyond Chlorophyll



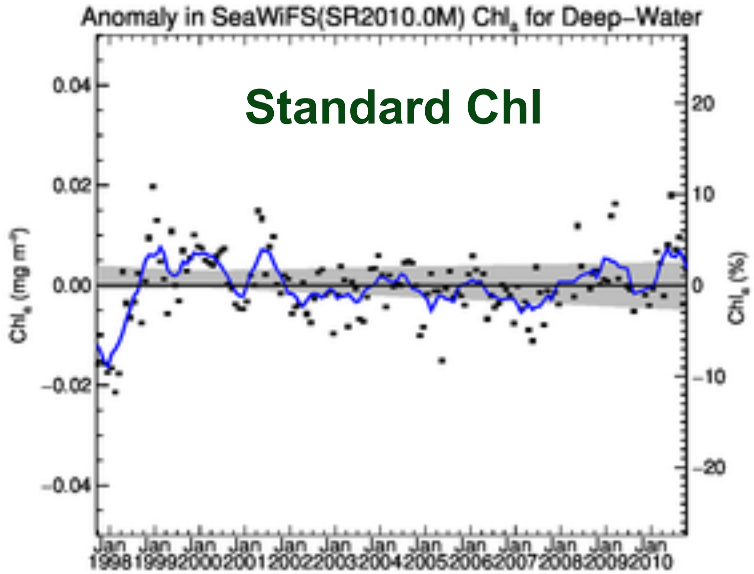
Siegel et al. 2013, RSE

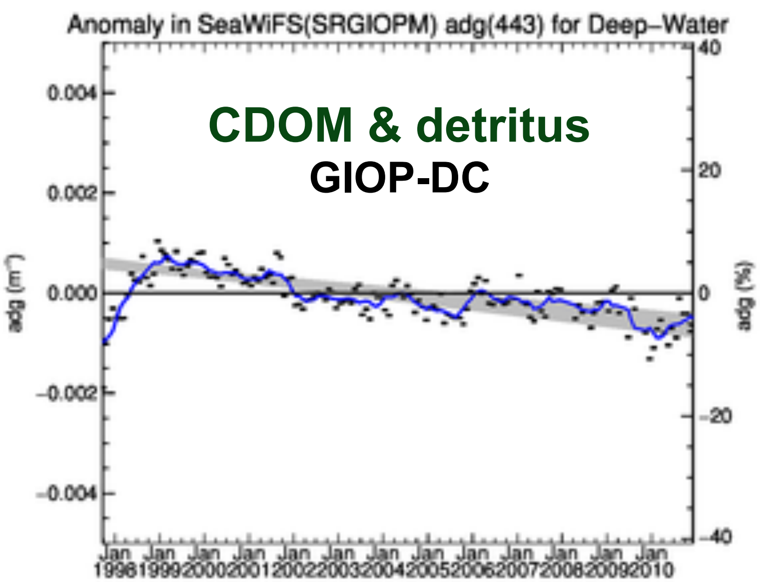
Separation of Constituent Absorption

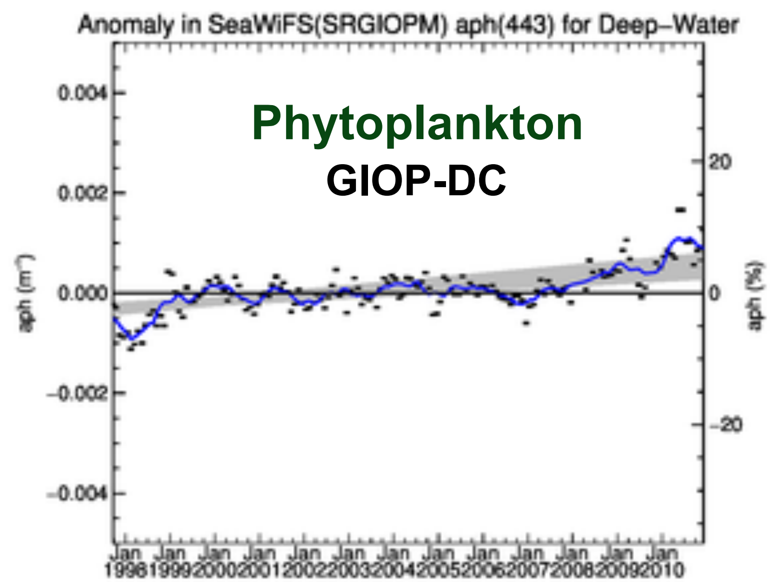


Werdell, P.J., B.A. Franz, S.W. Bailey, G.C. Feldman and 15 co-authors (2013). Generalized ocean color inversion model for retrieving marine inherent optical properties, Applied Optics 52, 2019-2037.

Beyond Chlorophyll







Future Plans

Next multi-mission reprocessing anticipated 2013-2014

Incorporate algorithm refinements

- advancements in atmospheric correction (Ahmad, Franz)
- new chlorophyll algorithm (Hu, Werdell)
- updates to PIC algorithm (Balch)
- updates to PAR algorithm (Frouin)

Expand standard product suite

- IOP products (algorithm TBD)
- Rrs uncertainties (method TBD)
- others ?

Change data formats

- moving to CF-compliant netCDF4

Thank You

Ocean Science Team Members

MODIS

1. Barney Balch
2. Peter Cornillon
3. Heidi Sosik (Hui Feng)
4. Bryan Franz*
5. Watson Gregg
6. Antonio Mannino
7. Stephane Maritorena
8. Galen McKinley (Colleen Mouw)
9. Peter Minnett
10. Norm Nelson
11. Crystal Thomas
12. Toby Westberry

NPP/VIIRS

1. Barney Balch
2. Watson Gregg
3. Peter Minnett
4. Dave Siegel
5. Kevin Turpie*
6. Menghua Wang

* Discipline Leads

Chlorophyll Algorithm Refinement

Standard OCx Band Ratio Algorithm
better at mid to high chlorophyll

$$\mathrm{Chl}_{\mathrm{OC4}} = 10^{y}$$

$$y = \mathrm{a}_0 + \mathrm{a}_1\chi + \mathrm{a}_2\chi^2 + \mathrm{a}_3\chi^3 + \mathrm{a}_4\chi^4$$

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

New CI Line Height Algorithm
better at low chlorophyll

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

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

Proposed OCI Algorithm

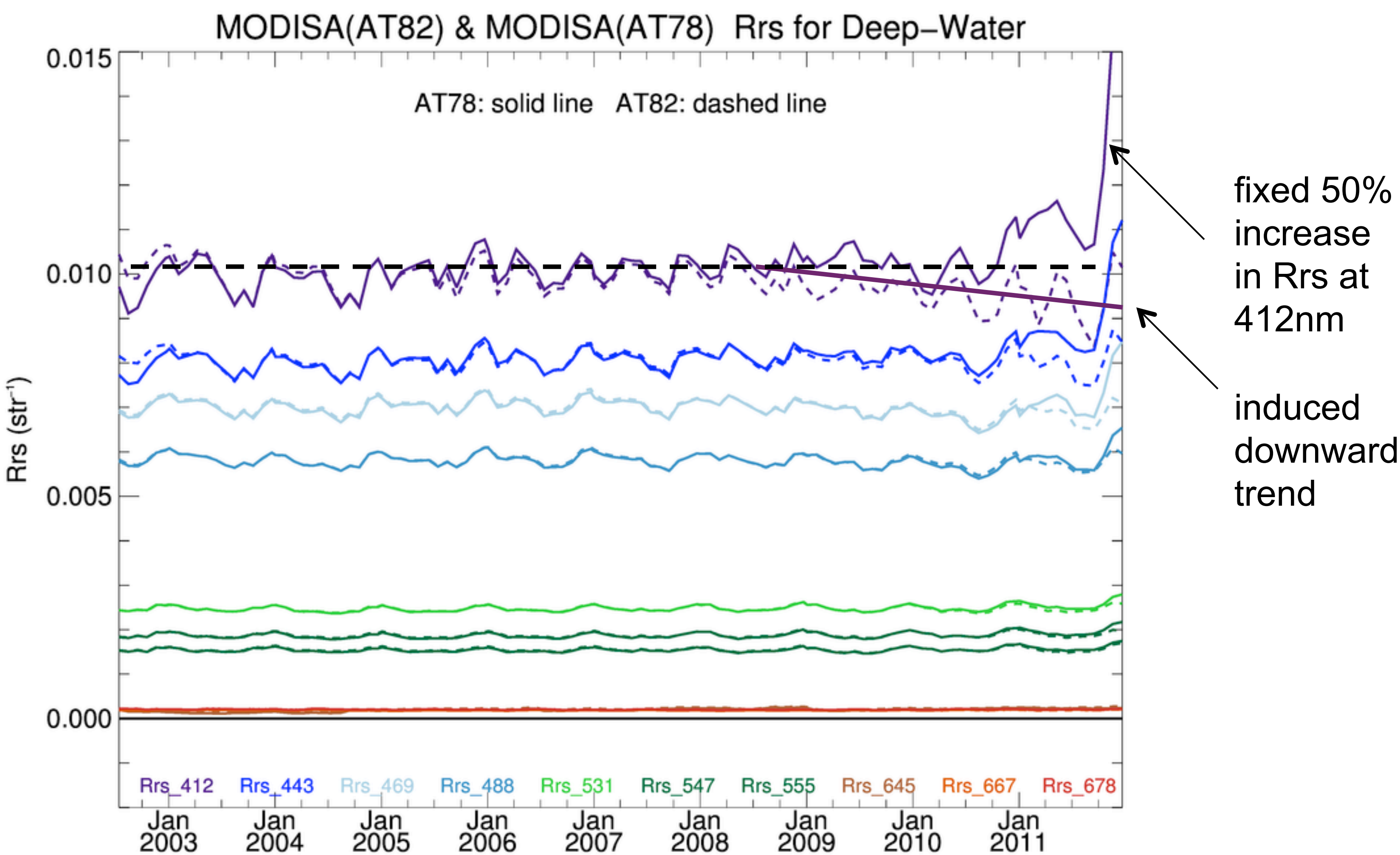
$$\mathrm{Chl}_{\mathrm{OCI}} = \mathrm{Chl}_{\mathrm{CI}}\left[\text{for } \mathrm{Chl}_{\mathrm{CI}} \leq 0.25 \text{ mg m}^{-3}\right]$$

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

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

Hu, C., Z. Lee, and B.A. Franz (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference, J. Geophys. Res., 117, C01011, doi:10.1029/2011JC007395.

C6 Calibration introduced trend in 412



GIOP Framework

Lee et al. 2002

$$r_{rs}(\lambda,0^{-}) = \frac{R_{rs}(\lambda)}{0.52 + 1.7R_{rs}(\lambda)}$$

Morel f/Q - or -
Gordon quadratic

$$r_{rs}(\lambda,0^{-}) = G(\lambda)\left(\frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}\right)$$

Levenberg-Marquardt
Amoeba (downhill simplex)
SVD matrix inversion
LUD matrix inversion

GIOP Framework

fixed $M_{bp}b_{bp}^*$ from:
- QAA
- Loisel & Stramski

tabulated b_{bp}^*
power-law with:
- fixed exponent
- Lee (QAA)
- Ciotti
- Morel
- Hoge & Lyon
- Loisel & Stramski

$$b_b(\lambda) = b_{bw}(\lambda) + \sum M_{bp} b_{bp}^*(\lambda)$$

$$a(\lambda) = a_w(\lambda) + \sum M_{dg} a_{dg}^*(\lambda) + \sum M_{\phi} a_{\phi}^*(\lambda)$$

tabulated a_{dg}^*
exponential with:
- fixed exponent
- Lee (QAA)
- OBPG

tabulated $a_{\phi}^*(\lambda)$
Ciotti $a_{\phi}^*(\lambda)$
Bricaud $a_{\phi}^*(\lambda)$

Beyond Chlorophyll

$$R_{rs}(\lambda) \approx \left(\frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} \right)$$

$$b_b(\lambda) = b_{bw}(\lambda) + \sum M_{bp} b^*_{bp}(\lambda)$$

$$a(\lambda) = a_w(\lambda) + \sum M_{dg} a^*_{dg}(\lambda) + \sum M_{\phi} a^*_{\phi}(\lambda)$$