

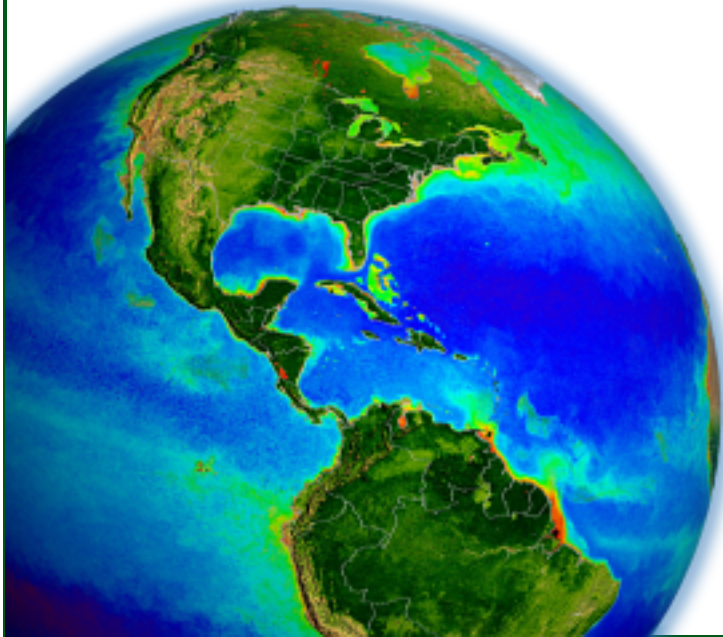
Remote Sensing Reflectance and Derived Products

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	<i>instrument calibration</i>
P. Jeremy Werdell	<i>in-water algorithms, SeaBASS</i>
Sean W. Bailey	<i>vicarious calibration, algorithms</i>
Zia Ahmad	<i>atmospheric correction</i>

and the Ocean Biology Processing Group

Contents

Overview of ocean color products

Status and validation of ocean remote sensing reflectance (R_{rs}) and chlorophyll products

Algorithm refinement

Future plans

What we proposed ...

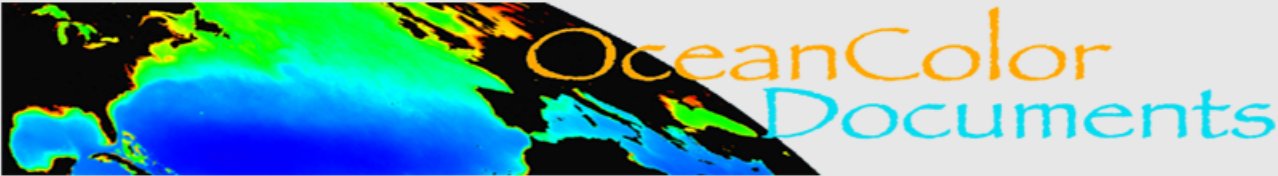
- development & maintenance of Rrs product
 - atmospheric correction algorithm
 - Instrument calibration (w/MCST) & vicarious calibration
- development & maintenance of several key bio-optical algorithms
 - Standard Chlorophyll and diffuse attenuation (K_d) products
- maintenance of ALL standard ocean 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. $R_{rs}(\lambda)$ →	$R_{rs}(412)$
2. Ångstrom	$R_{rs}(443)$ <i>Wang 1994, Ahmad et al 2010, etc.</i>
3. AOT	$R_{rs}(469)$
4. Chlorophyll <i>a</i>	$R_{rs}(488)$ <i>1. 1998 (OC3) updated by Werdell</i>
5. $K_d(490)$	$R_{rs}(531)$ <i>2) algorithm (similar to OC3)</i>
6. POC	$R_{rs}(547)$ <i>et al. 2008</i>
7. PIC	$R_{rs}(555)$ <i>2005, Gordon et al. 2001</i>
8. CDOM_index	$R_{rs}(645)$ <i>entili 2009</i>
9. PAR	$R_{rs}(667)$ <i>2003</i>
10. iPAR	$R_{rs}(678)$
11. nFLH	<i>Behrenfeld et al. 2009</i>

Current MODIS OC Evaluation Products

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



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

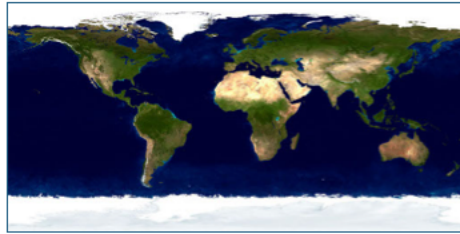
1. [Chlorophyll Concentration from OCI \(chl_oci\)](#)
2. [Inherent Optical Properties from GIOP \(giop\)](#)
3. [Inherent Optical Properties from GSM \(gsm\)](#)
4. [Inherent Optical Properties from QAA \(qaa\)](#)
5. [Euphotic Depth from Lee \(Zeu_lee\)](#)
6. [Euphotic Depth from Morel \(Zeu_morel\)](#)
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>

General Search Parameters:

Between the dates of... 1930-01-01 ...and... 2013-04-10

Within the coordinates...



N: 90
W: -180 E: 180
S: -90

From...

A	PI	E/C	Search String
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="text"/>
			<input type="button" value="+"/>
			<input checked="" type="radio"/> Any <input type="radio"/> All

Ocean Color Product Validation

Search Type:

Bio-optical Pigment Validation

The validation search allows visitors to search for match-ups between water measurements and coincident satellite products. Water leaving values are calculated by SeaBASS staff using select data files that were submitted to SeaBASS. For more information on how match-ups were performed, refer to: S.W. Bailey and P.J. Werdell, "A multi-sensor approach for the validation of satellite ocean color data," *Remote Sens. Environ.* 102, 12-23 (2006).

Compare:

MODIS Aqua vs. In situ
 MODIS Aqua vs. MODIS Terra

Water Depth:

Minimum: 0.0 Maximum: 10000

Exclusion Criteria:

- Minimum Valid satellite pixels (in %):
- Maximum Solar Zenith Angle:
- Maximum Satellite Zenith Angle:
- Maximum Time Difference between satellite and in situ (in min):
- Maximum Coefficient of Variation of satellite pixels:
- Maximum difference between measured and modeled Irradiance:
- Maximum Windspeed:

Satellite Version(s):

aqua: operational
terra: operational

Products:

- a adg aot aph bbp Chl a
- Kd par pic poc Rrs
- Zeu Zsd

Data Sources:

SeaBASS Only All* AERONET-OC Only* MOBY Only*
*MOBY and AERONET results are preliminary.
Data acquired from the Aerosol Robotic Network - Ocean Color (AERONET-OC) details. Additional data usage policies apply.

Search

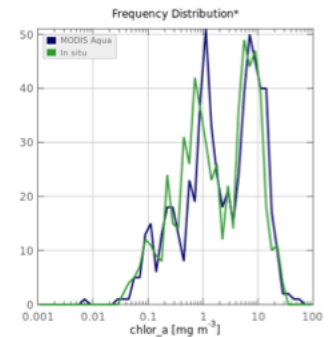
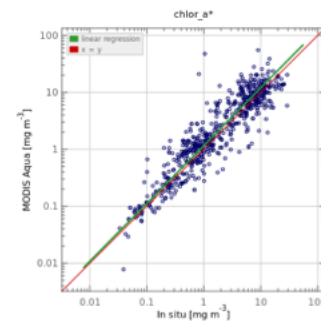
chlor_a Download Stats/Plots Generate CSV Download CSV

Statistics Data

Product Name	MODIS Aqua Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R ² *	Median Ratio	Abs % Difference	RMSE*
chlor_a	0.03340, 29.04500	0.00781, 55.23780	631	1.01529	0.06471	0.86487	0.86773	32.88839	0.27831

* statistical calculations based on log10

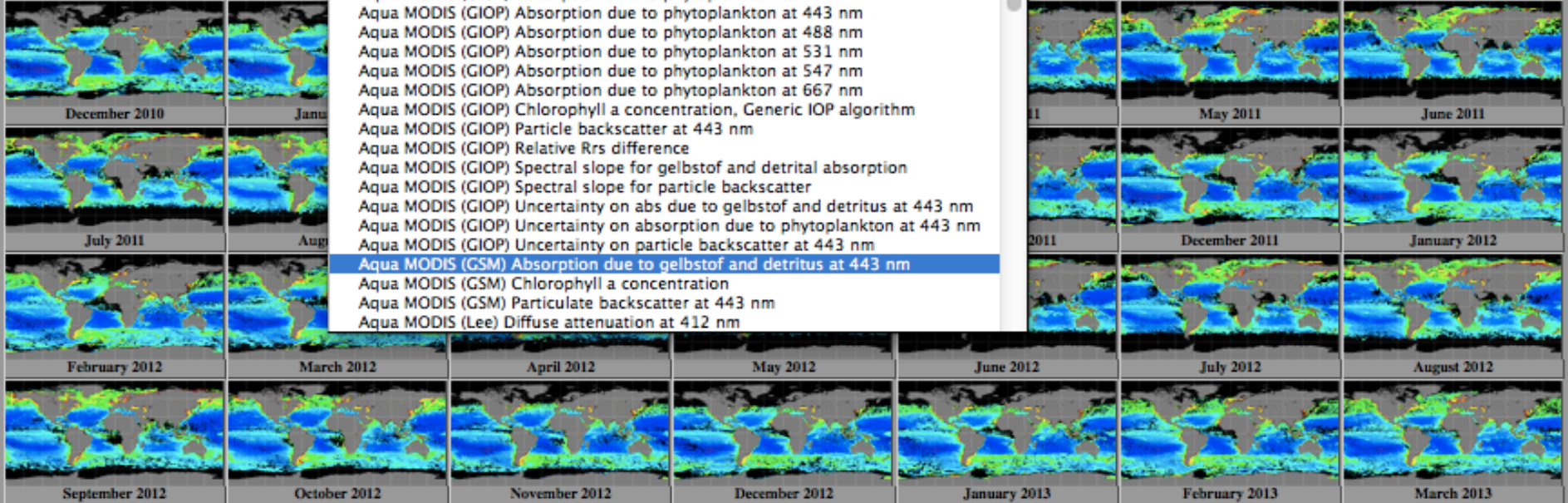
The linear regression algorithm has been changed to reduced major axis.



Evaluation products Aqua MODIS (GSM) Absorption due to gelbstof and detritus at 443 nm Monthly 9 km

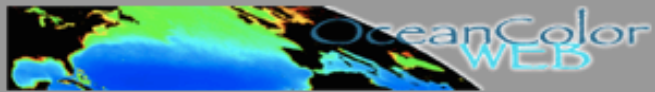
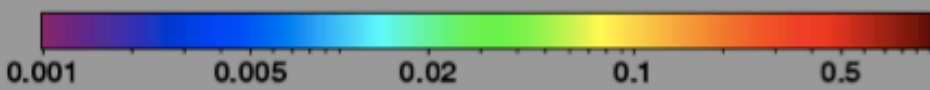
28 thumbnails

- 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



Jul02 Aug02 Sep02 Oct02 Nov02 Dec02 Jan03 Feb03 Mar03 Apr03 May03 Jun03 Jul03 Aug03 Sep03 Oct03 Nov03 Dec03 Jan04 Feb04 Mar04 Apr04 May04 Jun04 Jul04 Aug04 Sep04 Oct04
 Nov04 Dec04 Jan05 Feb05 Mar05 Apr05 May05 Jun05 Jul05 Aug05 Sep05 Oct05 Nov05 Dec05 Jan06 Feb06 Mar06 Apr06 May06 Jun06 Jul06 Aug06 Sep06 Oct06 Nov06 Dec06 Jan07 Feb07
 Mar07 Apr07 May07 Jun07 Jul07 Aug07 Sep07 Oct07 Nov07 Dec07 Jan08 Feb08 Mar08 Apr08 May08 Jun08 Jul08 Aug08 Sep08 Oct08 Nov08 Dec08 Jan09 Feb09 Mar09 Apr09 May09 Jun09
 Jul09 Aug09 Sep09 Oct09 Nov09 Dec09 Jan10 Feb10 Mar10 Apr10 May10 Jun10 Jul10 Aug10 Sep10 Oct10 Nov10 Dec10 Jan11 Feb11 Mar11 Apr11 May11 Jun11 Jul11 Aug11 Sep11 Oct11
 Nov11 Dec11 Jan12 Feb12 Mar12 Apr12 May12 Jun12 Jul12 Aug12 Sep12 Oct12 Nov12 Dec12 Jan13 Feb13 Mar13

Absorption due to gelbstof and detritus at 443 nm (m⁻¹)



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

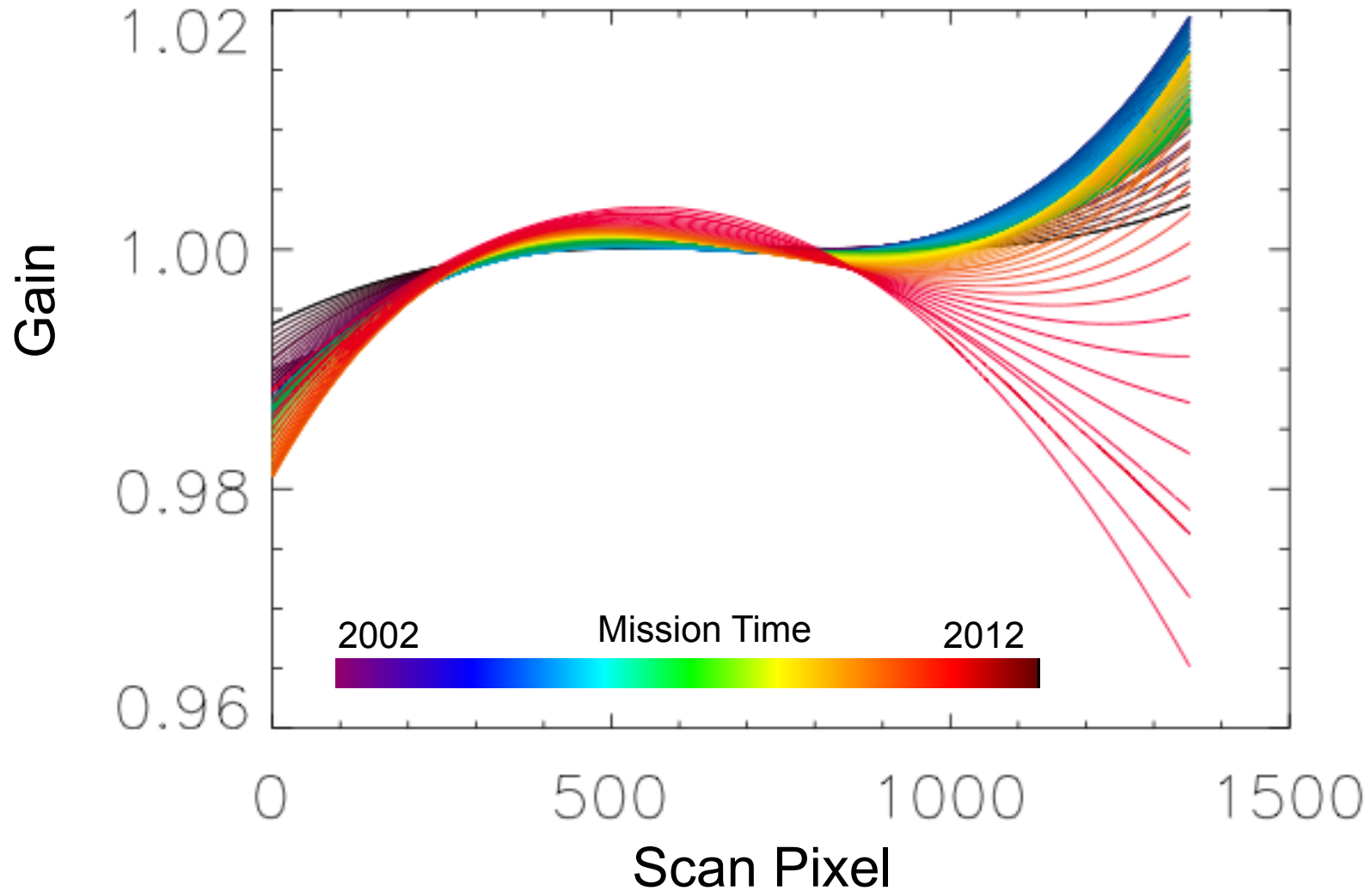
Additional cross-scan correction developed by OBPG

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

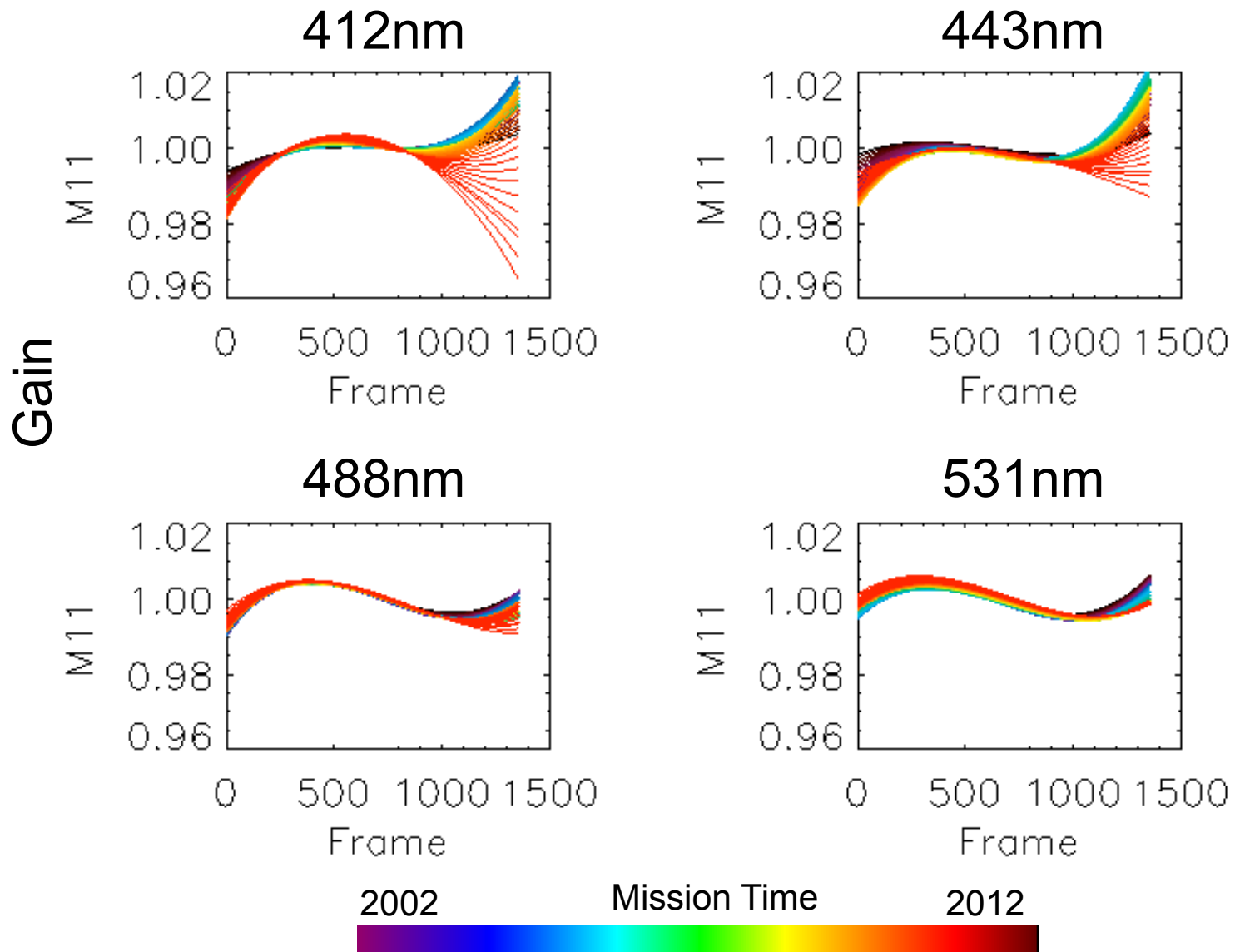
See talk by Gerhard Meister on Wednesday

OBPG MODISA Cross-Scan Corrections at 412nm relative to MCST desert-based C6 calibration

412nm, Detector 5, Mirror-Side 1

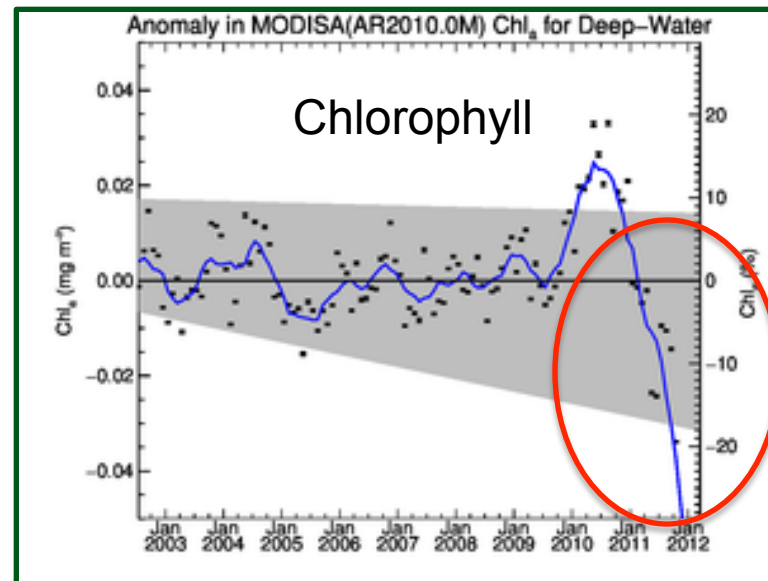
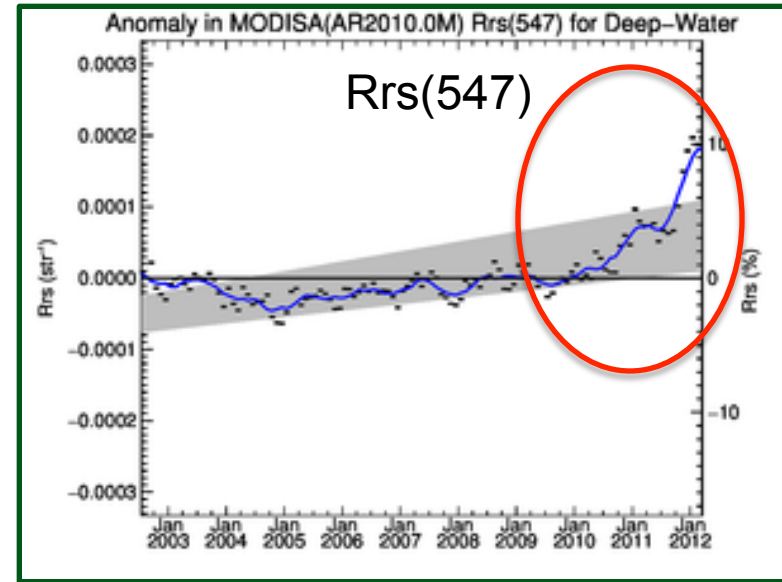
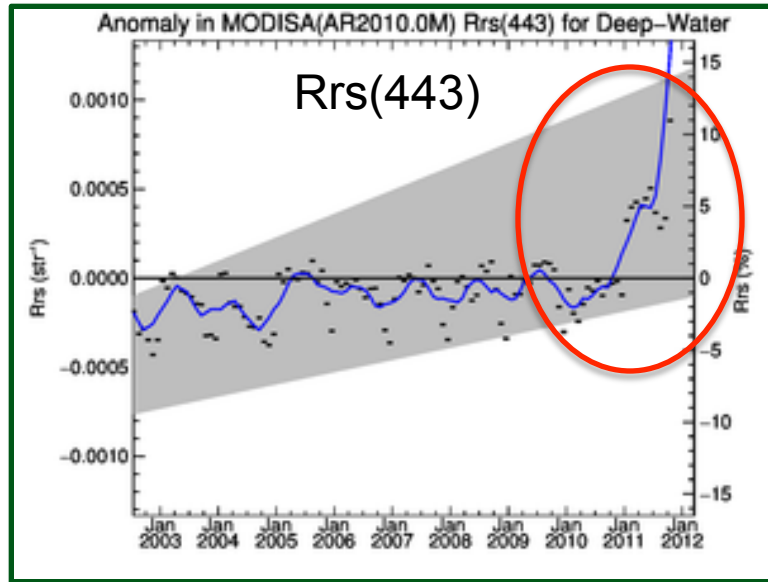


OBPG MODISA Cross-Scan Corrections relative to MCST desert-based C6 calibration



MODISA R2010.0 Temporal Anomalies (2002-2012)

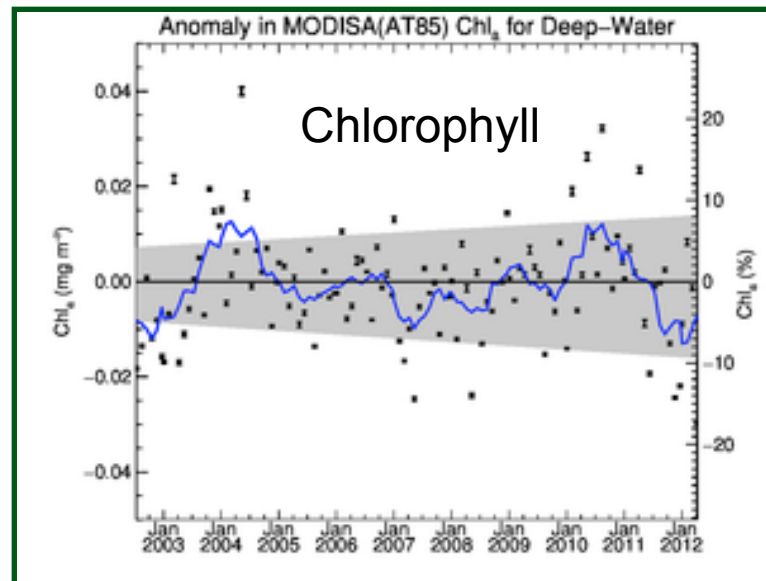
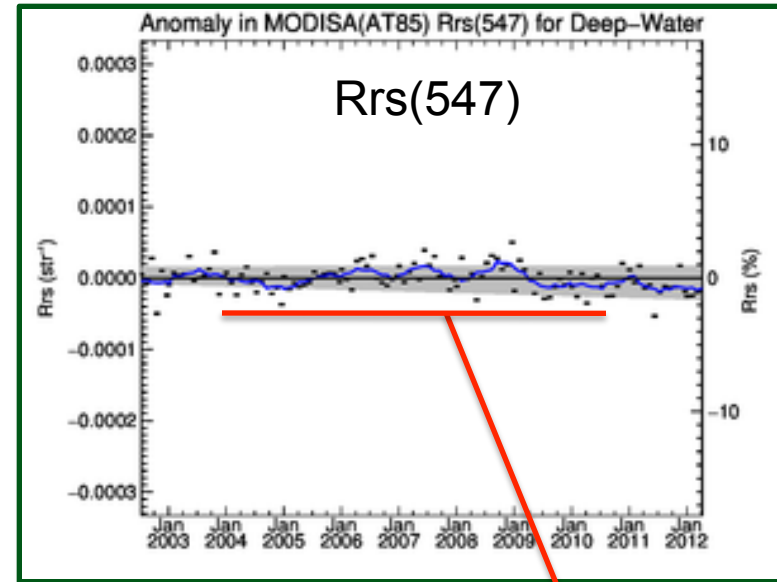
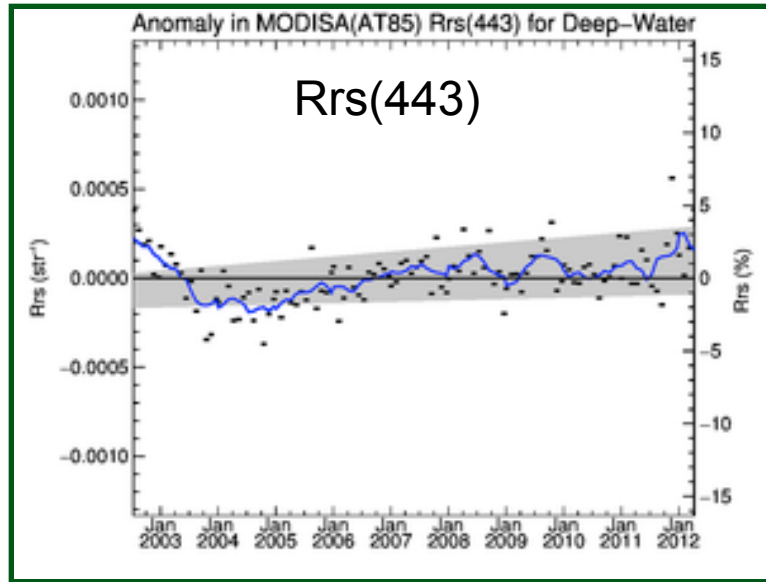
Deep-Water



Big
Trending
Errors

MODISA R2012.0 Temporal Anomalies (2002-2012)

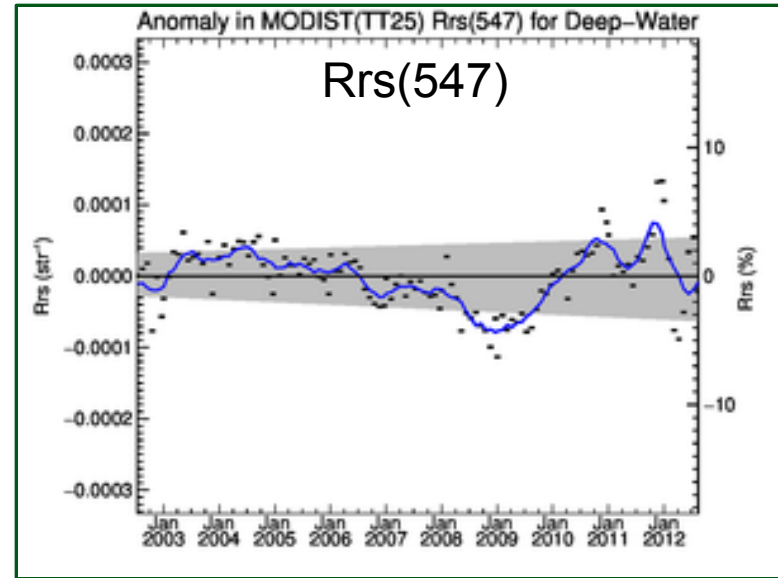
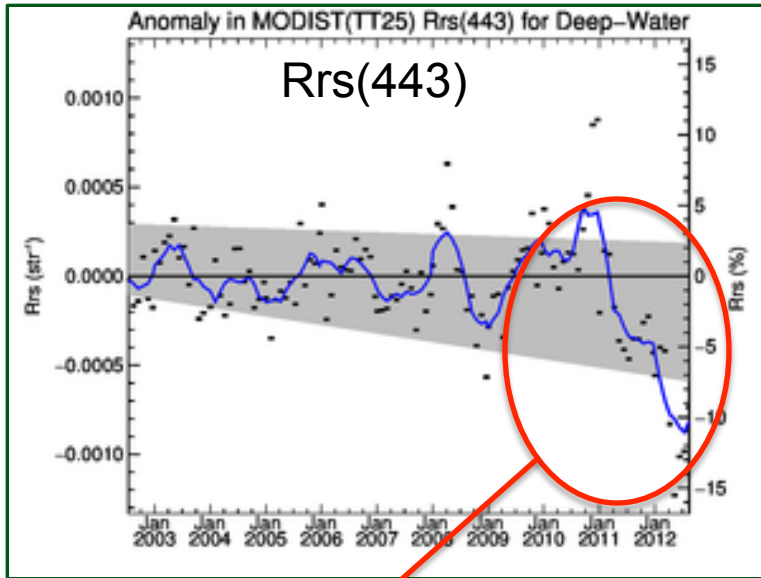
Deep-Water



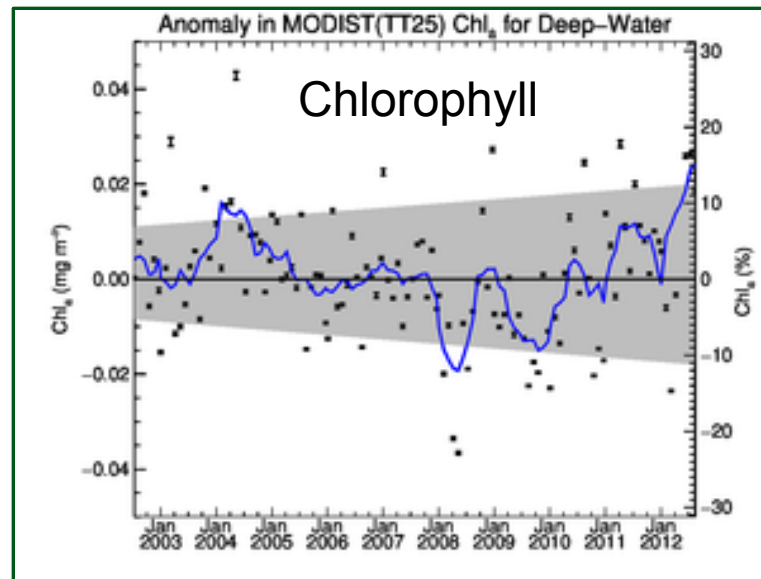
consistent with
expectation

MODIST R2010.0 Temporal Anomalies (2002-2012)

Deep-Water



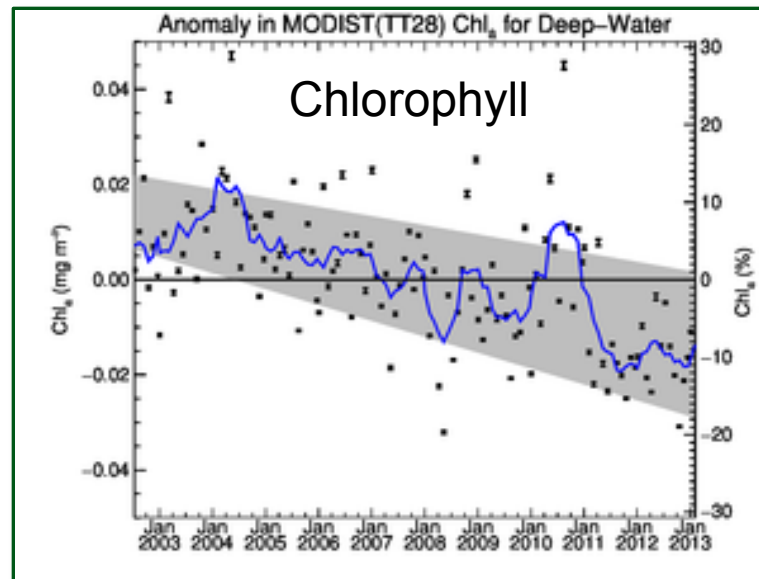
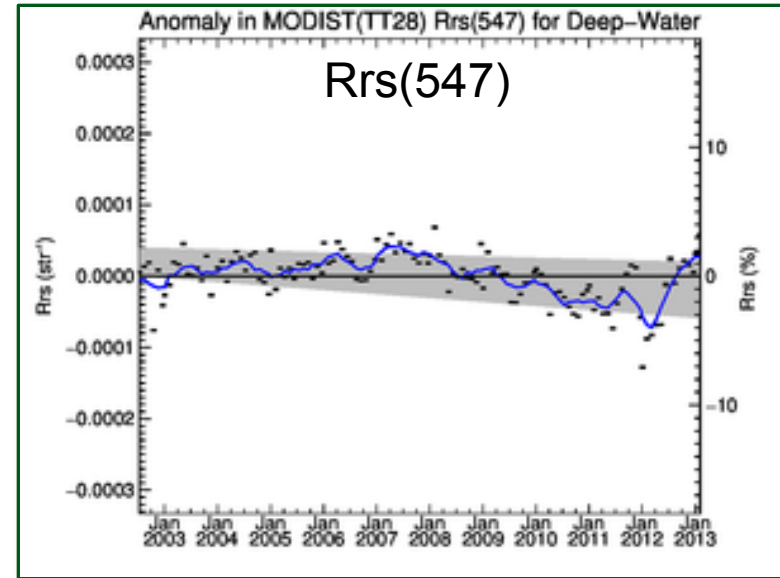
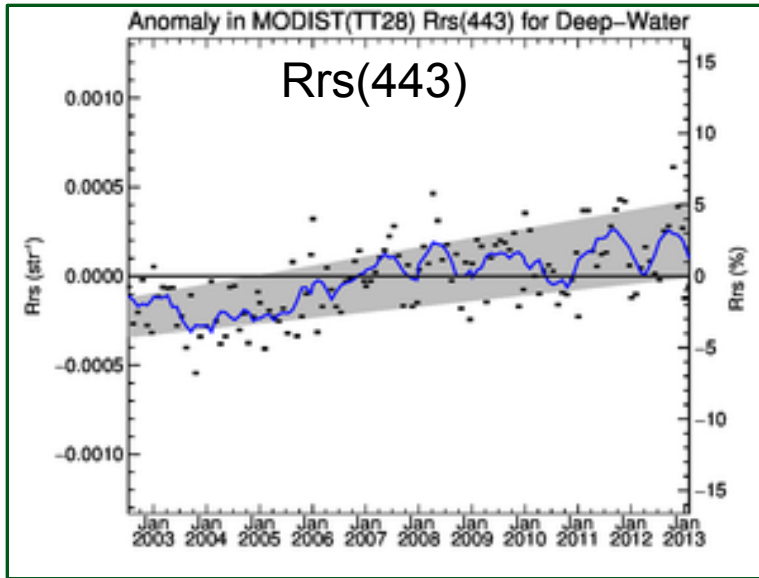
Big
Trending
Errors



MODIST R2013.0 Temporal Anomalies (2002-2012)

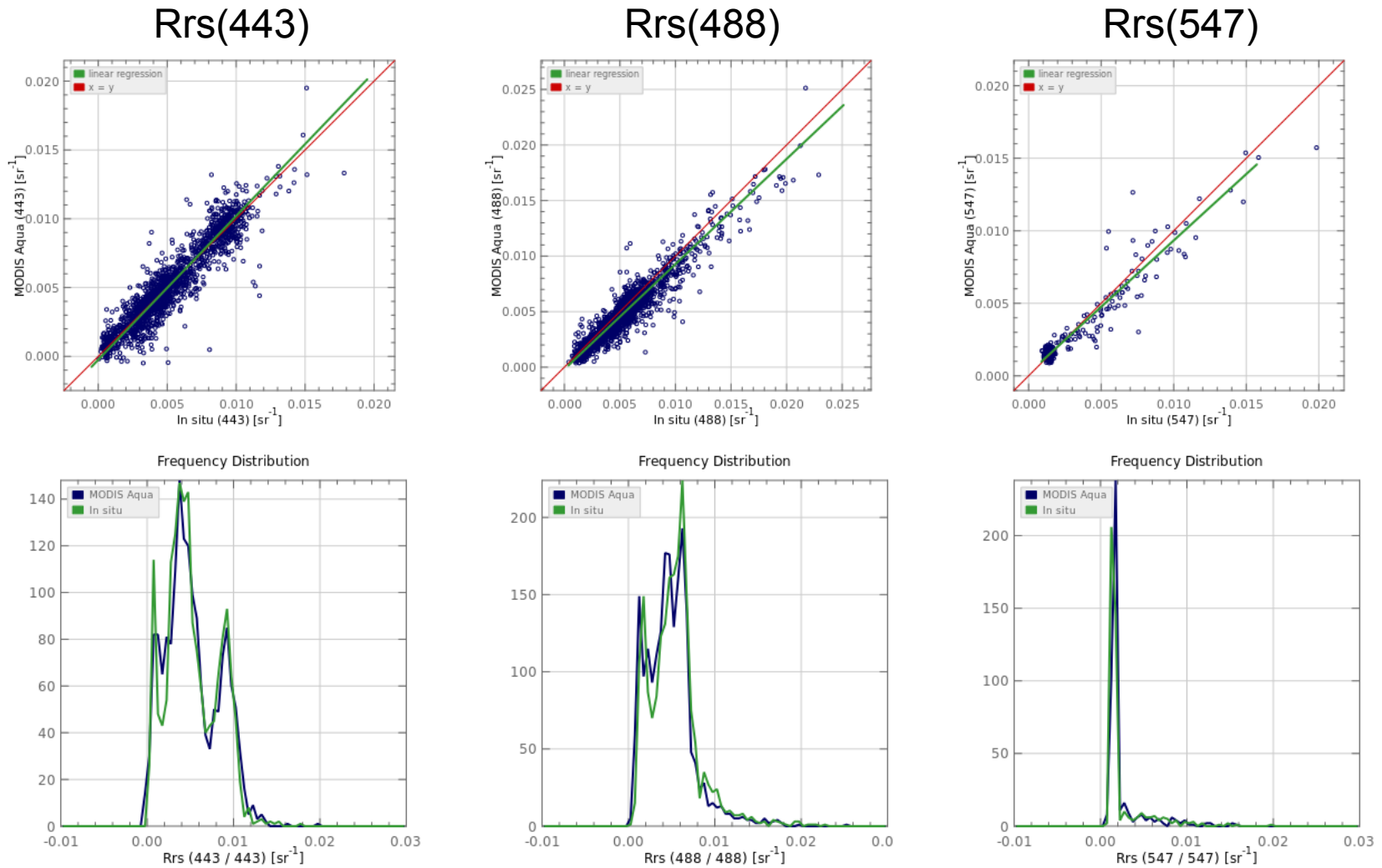
preliminary

Deep-Water



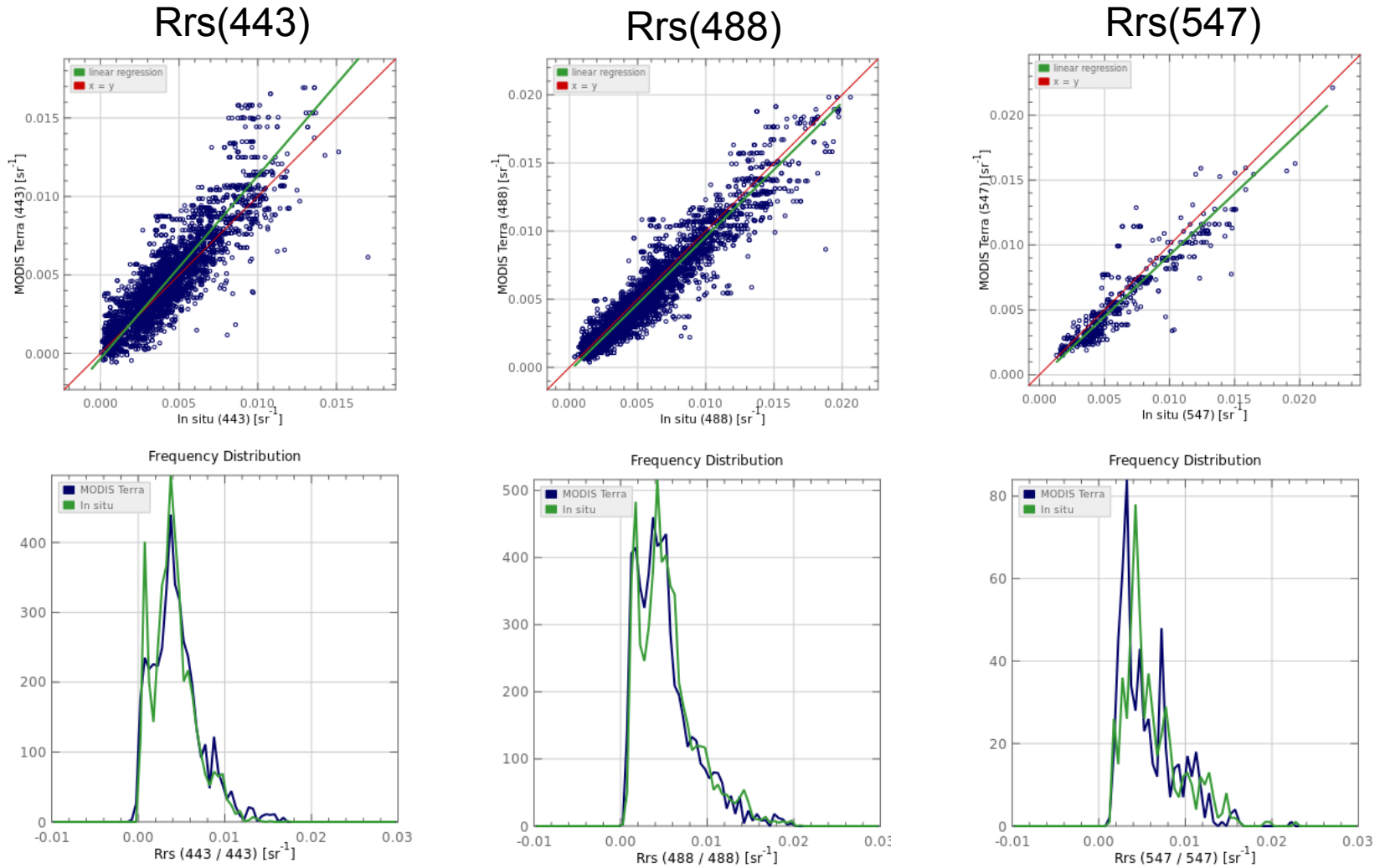
Test Results
after MCST C6 Calibration
and
OBPG cross-cal to MODISA
for RVS and polarization

MODISA (R2013.0) Rrs vs Field Measurements



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

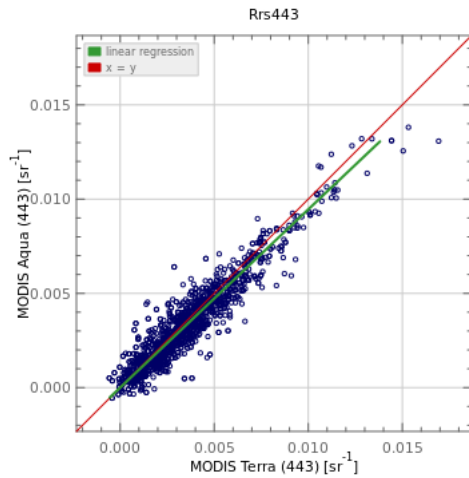
MODIST (R2010.0) Rrs vs Field Measurements



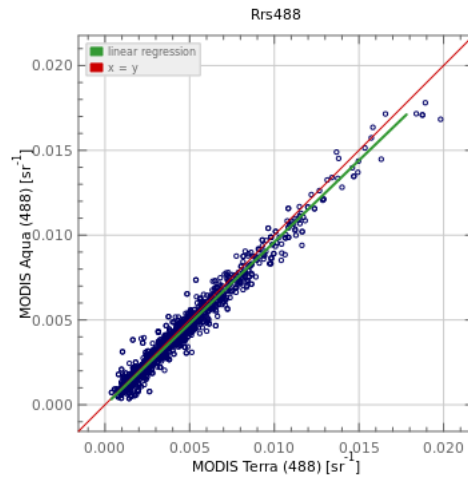
Mean APD 13-20%, Mean Bias < 15%, $R^2 > 0.8$

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

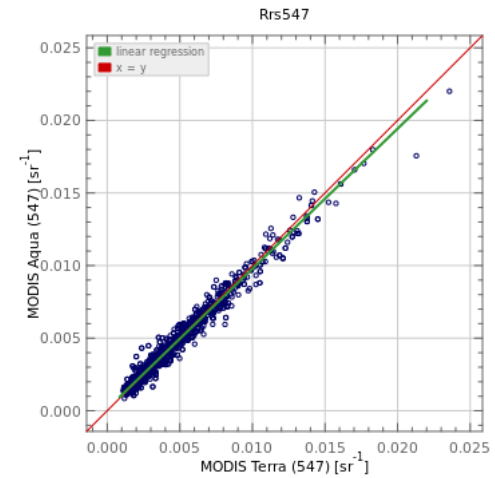
Rrs(443)



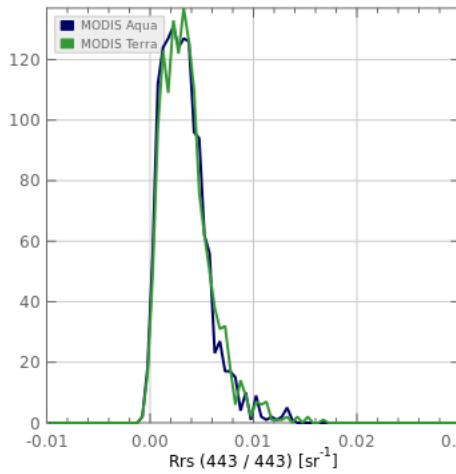
Rrs(488)



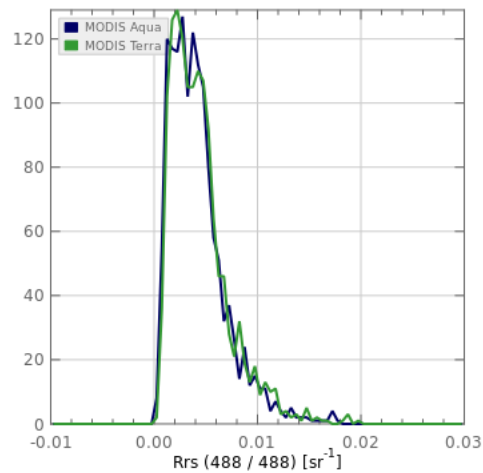
Rrs(547)



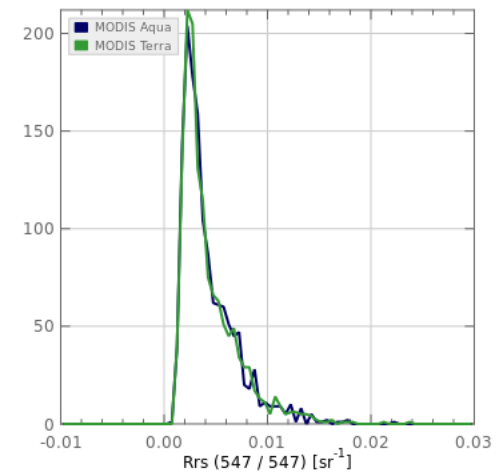
Frequency Distribution



Frequency Distribution

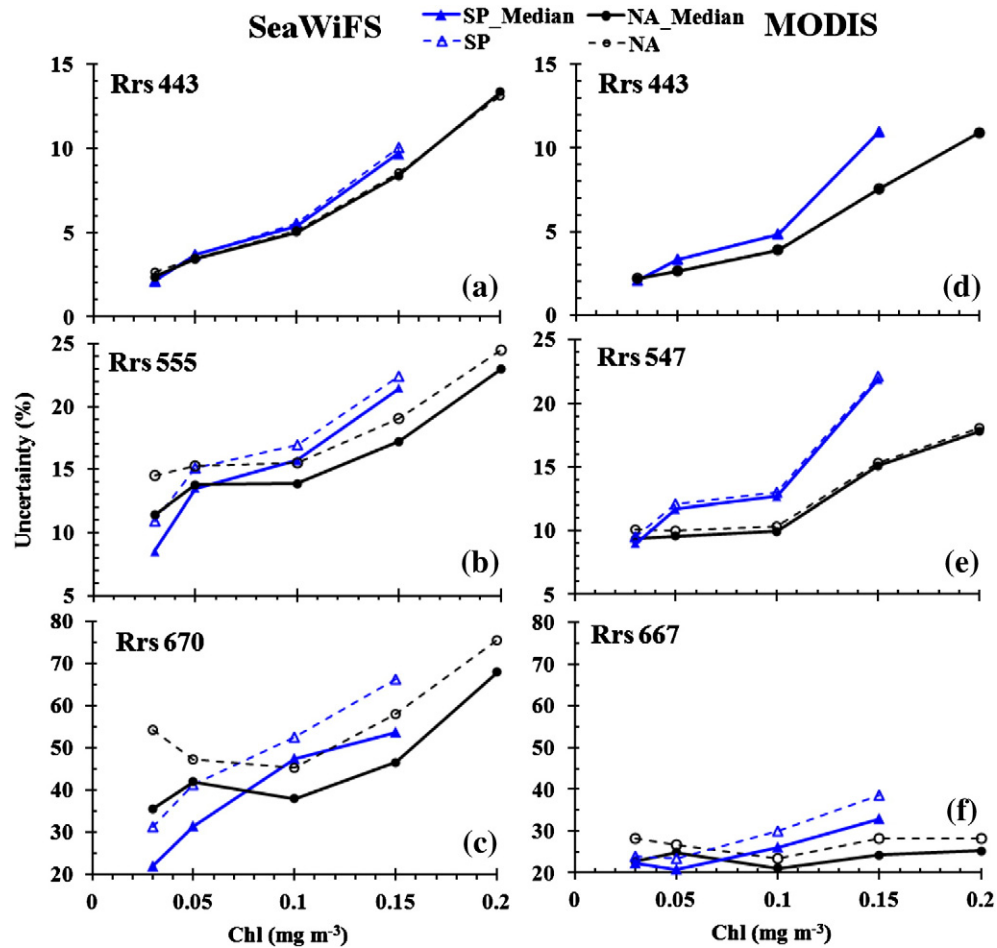


Frequency Distribution



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

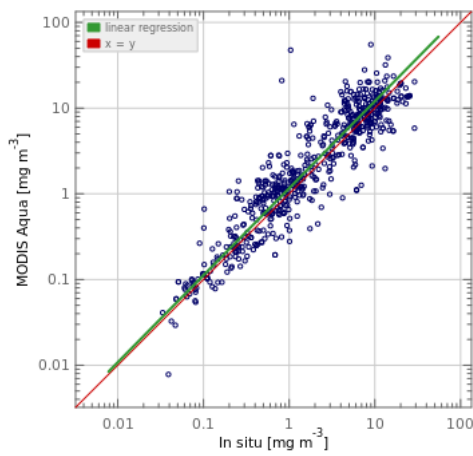
Rrs Uncertainty



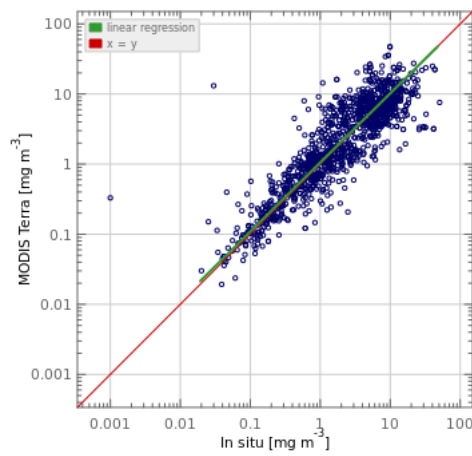
Hu, C., L. Feng, Z. Lee (2013). *Uncertainties of SeaWiFS and MODIS remote sensing reflectance: Implications from clear water measurements*, *Remote Sensing of Environment*, Volume 133, 15.

Chl_a in Good Agreement with Field Measurement

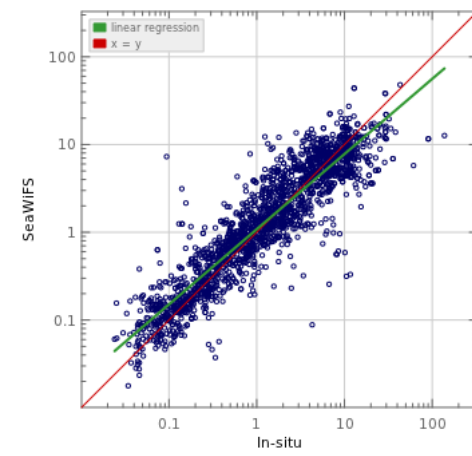
MODISA



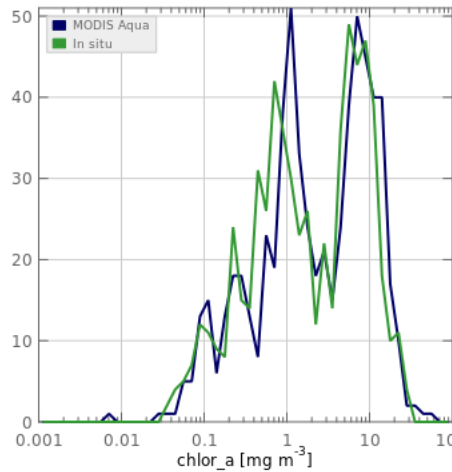
MODIST



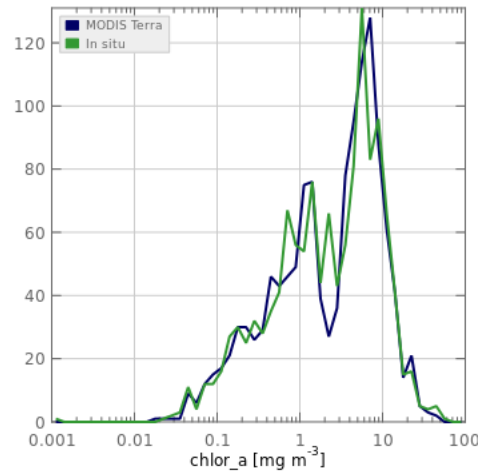
SeaWiFS



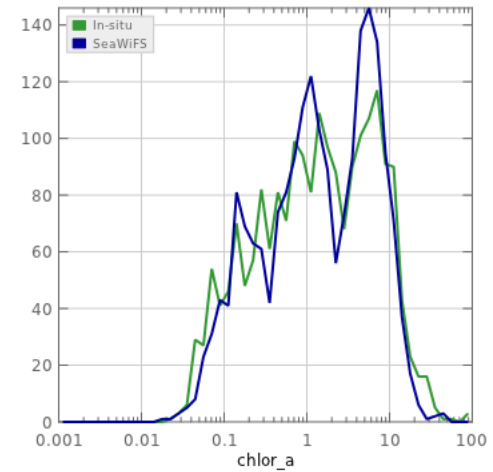
Frequency Distribution*



Frequency Distribution*

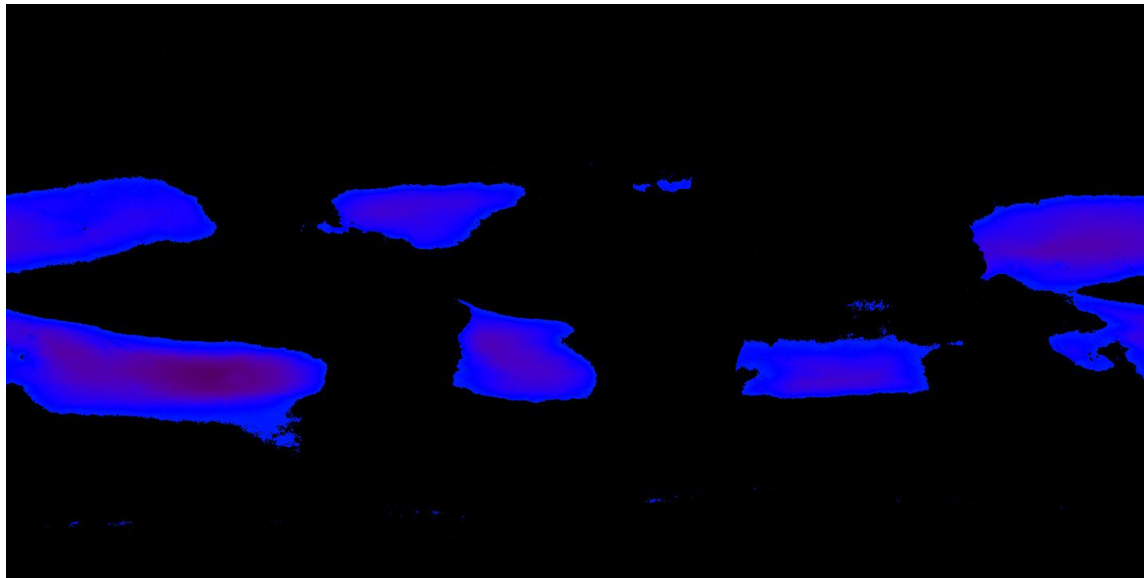
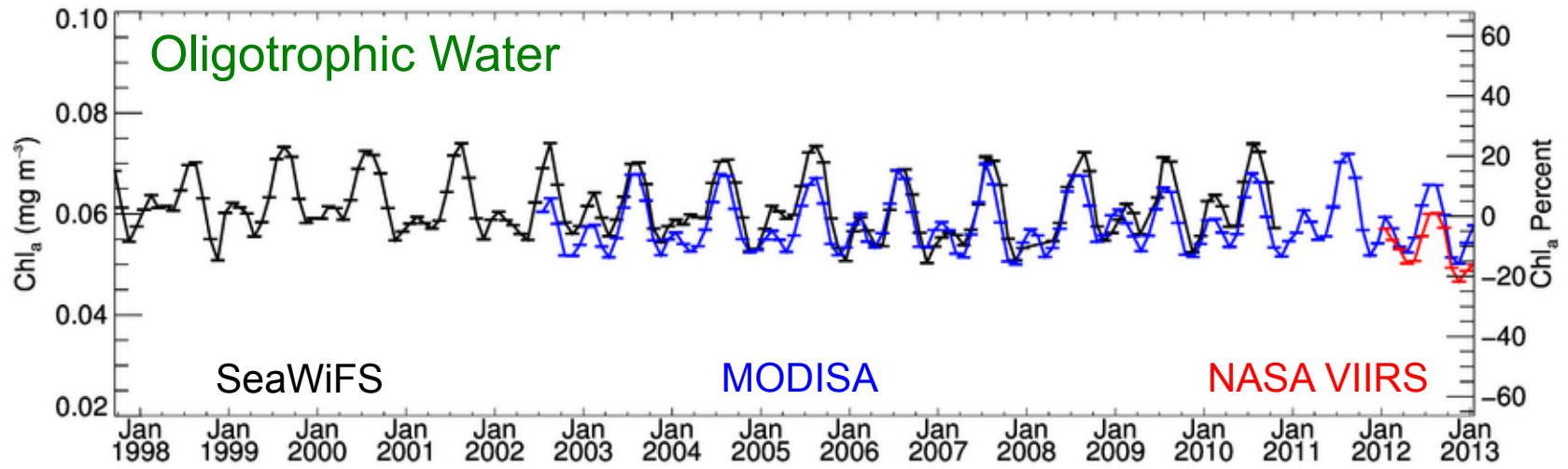


Frequency Distribution*

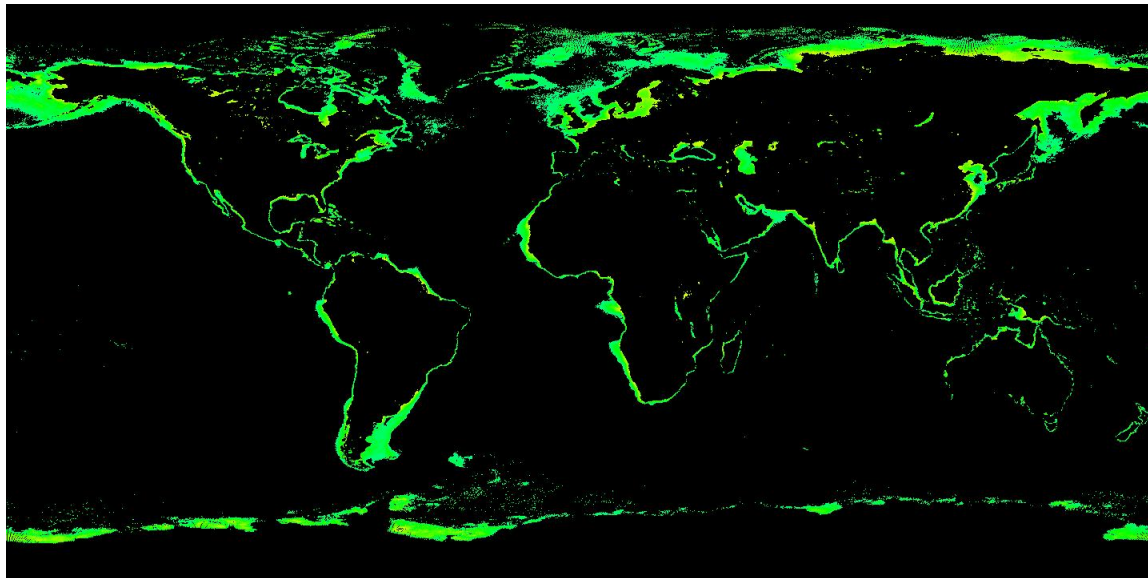
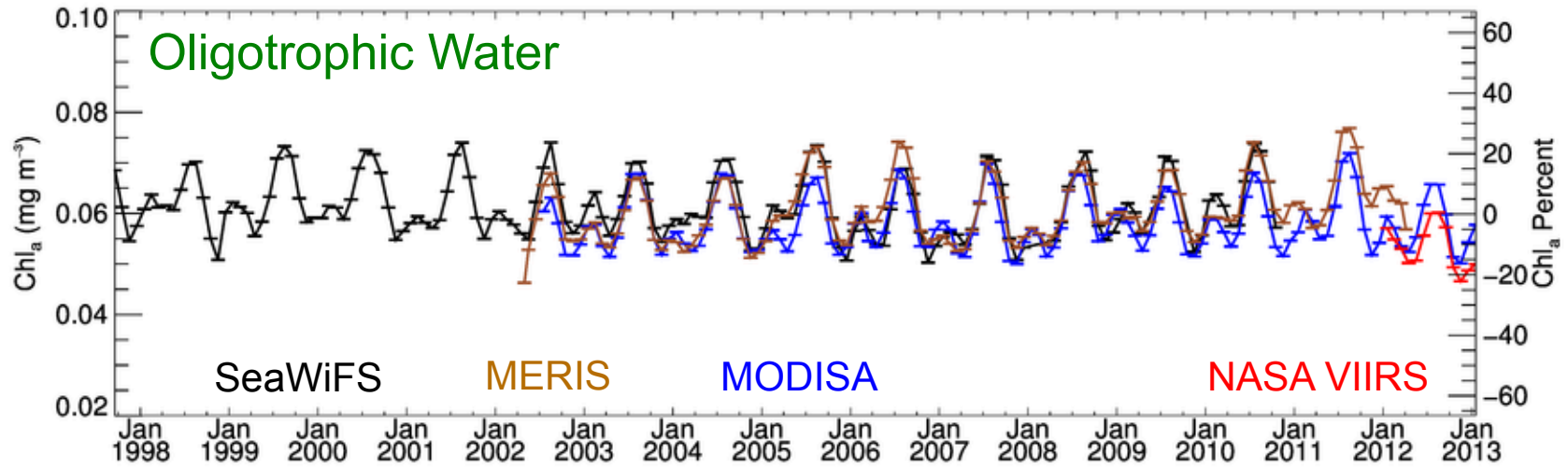


Mean APD 35%, Mean Bias < 15%, R² > 0.8

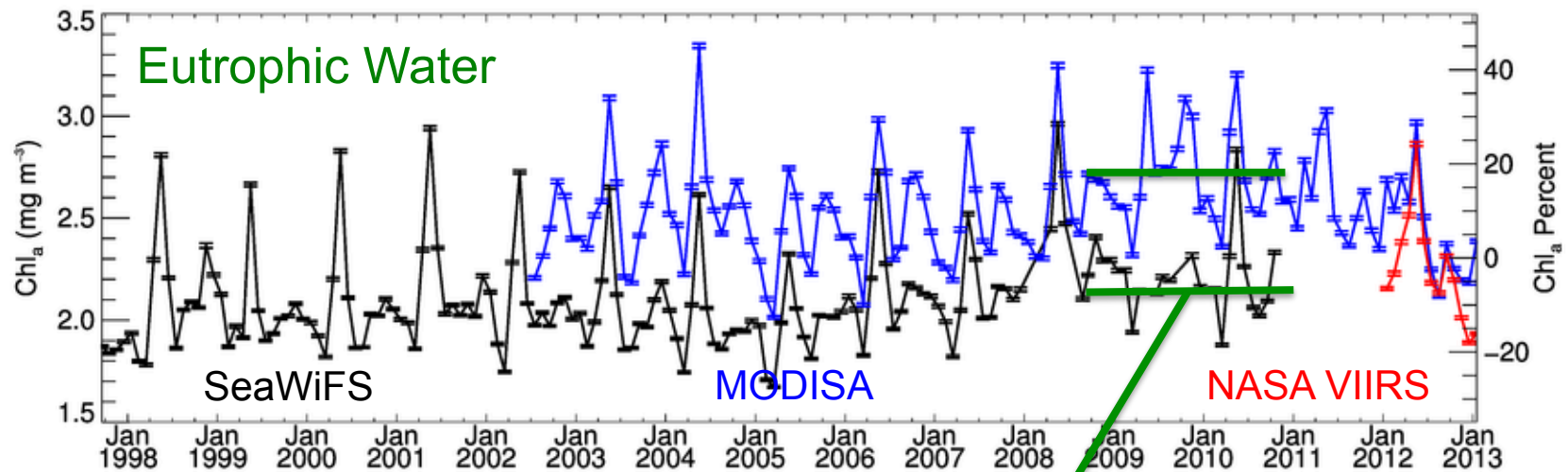
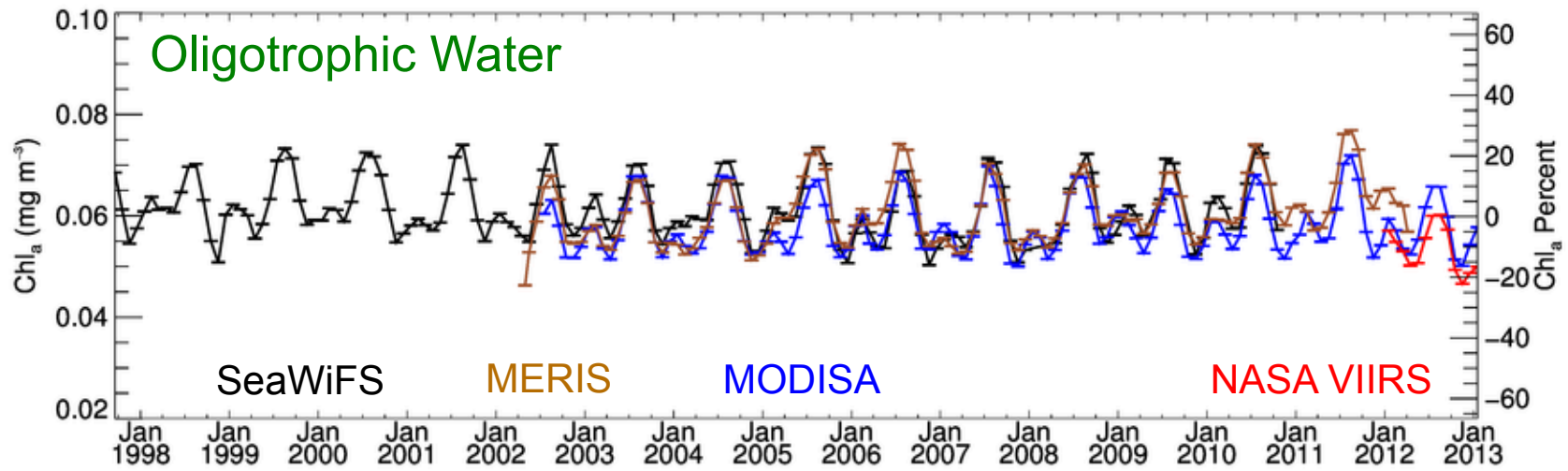
Multi-mission Chlorophyll Record



Multi-mission Chlorophyll Record

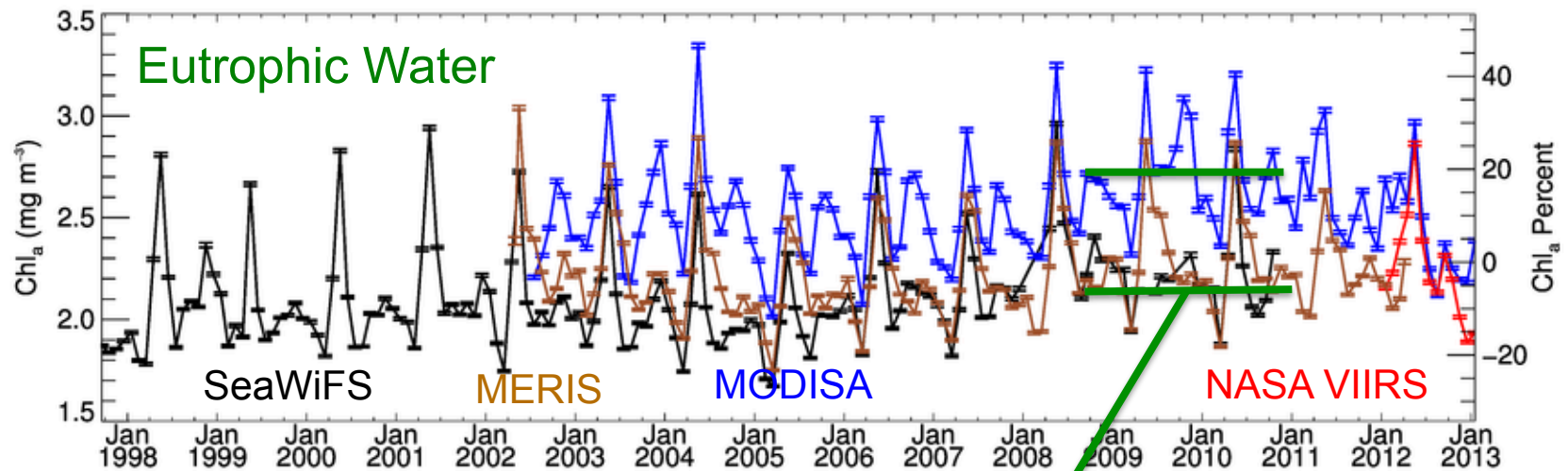
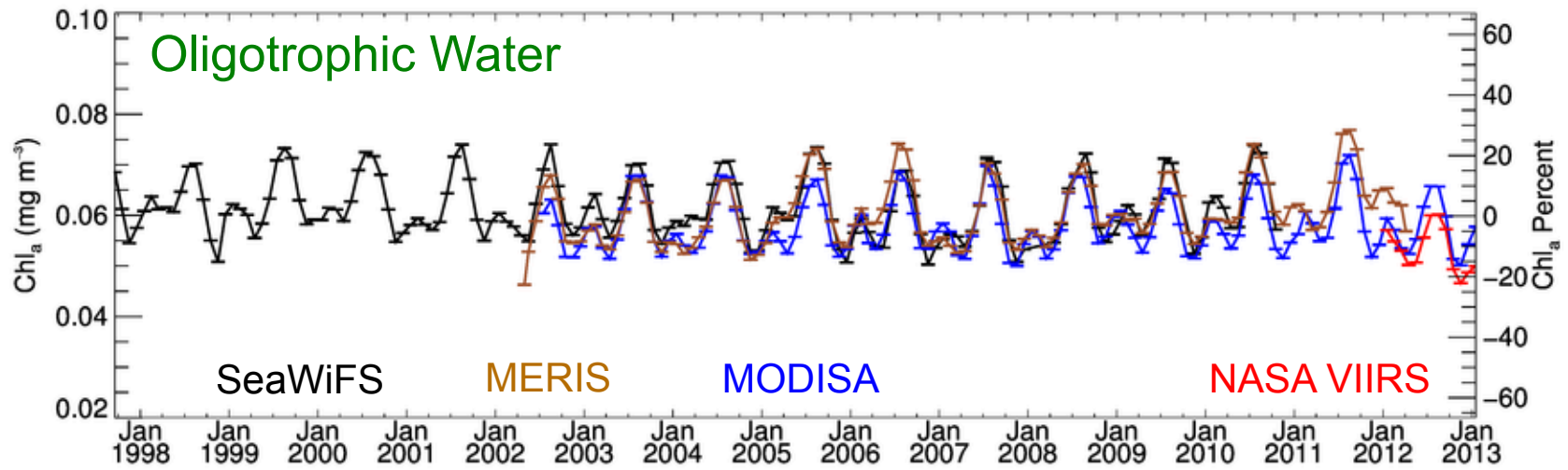


Multi-mission Chlorophyll Record



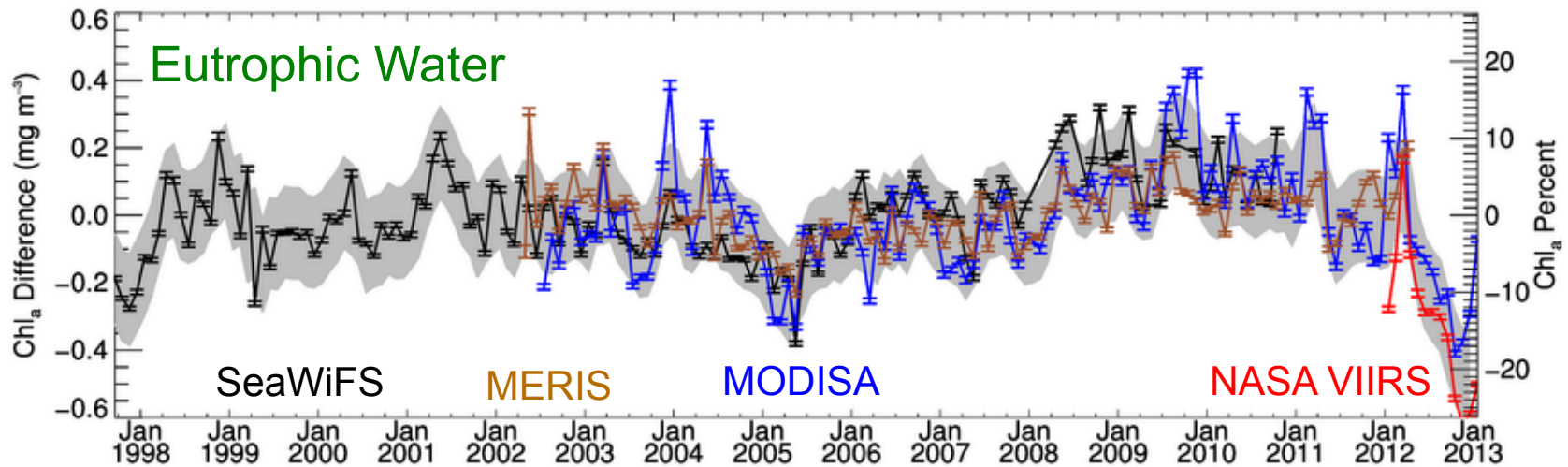
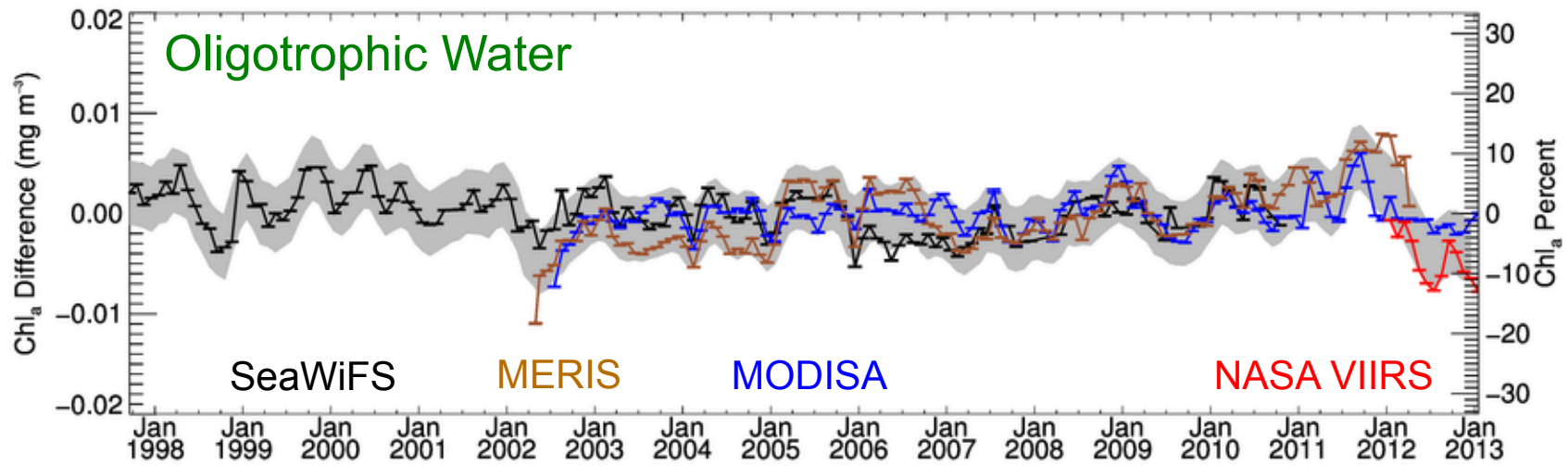
10%-20% difference due to lack of 510 nm

Multi-mission Chlorophyll Record



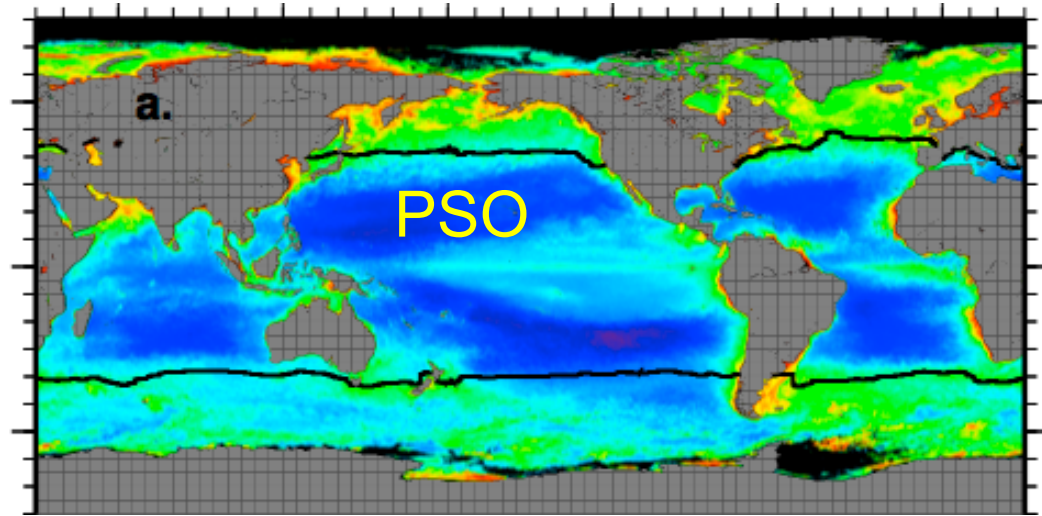
10%-20% difference due to lack of 510 nm

Multi-mission Chlorophyll Anomaly Record

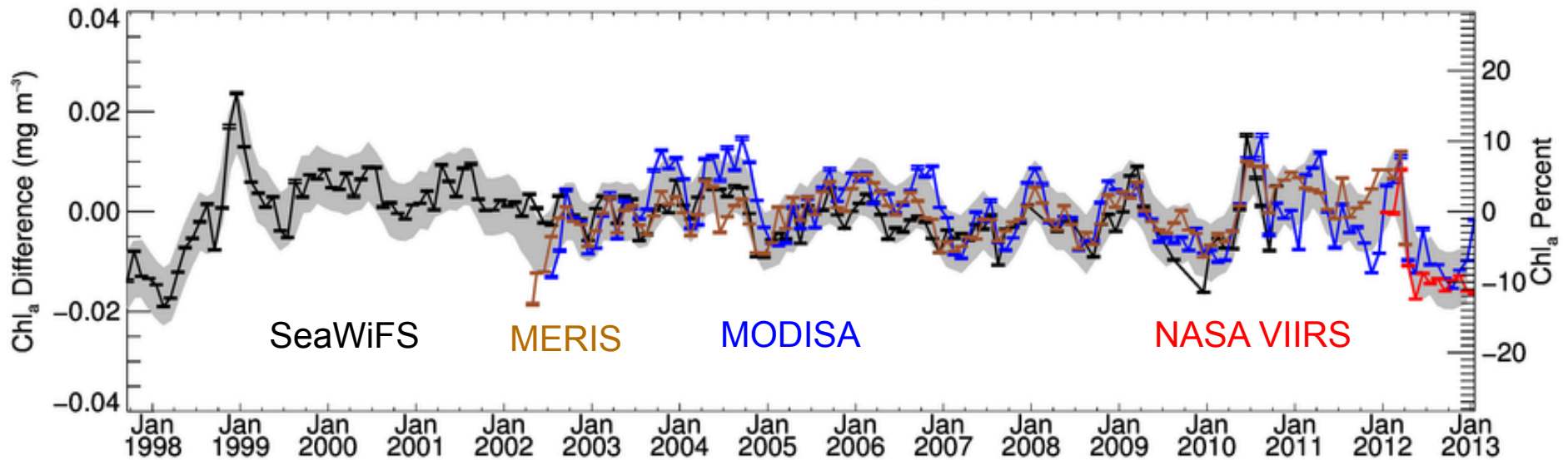


Multi-mission Chlorophyll Anomaly Record

Following
Berenfeld et al. 2006
Mean SST > 15C

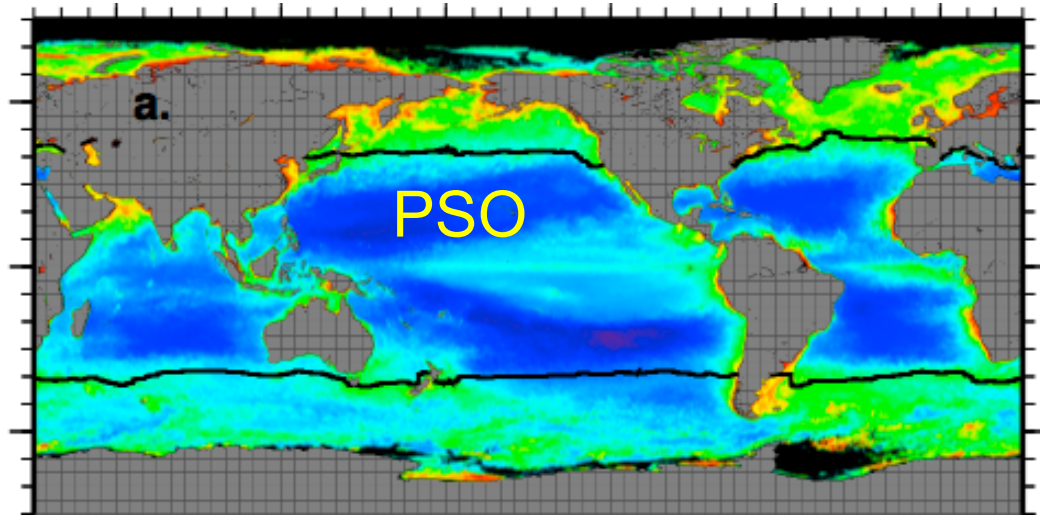


PSO Anomaly

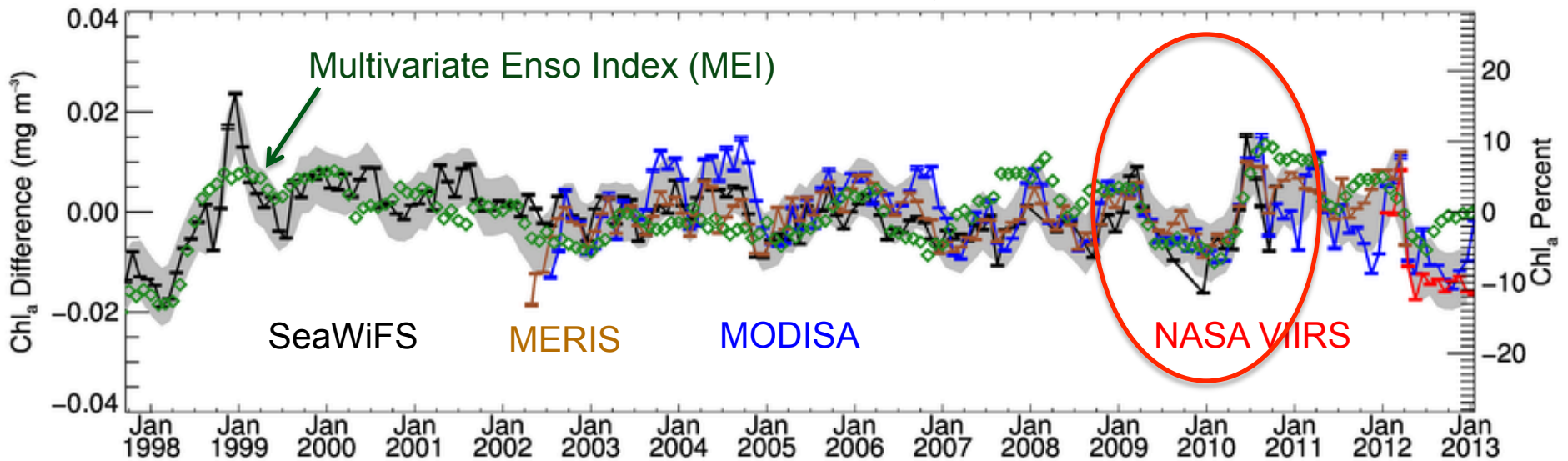


Multi-mission Chlorophyll Anomaly Record

Following
Berenfeld et al. 2006
Mean SST > 15C

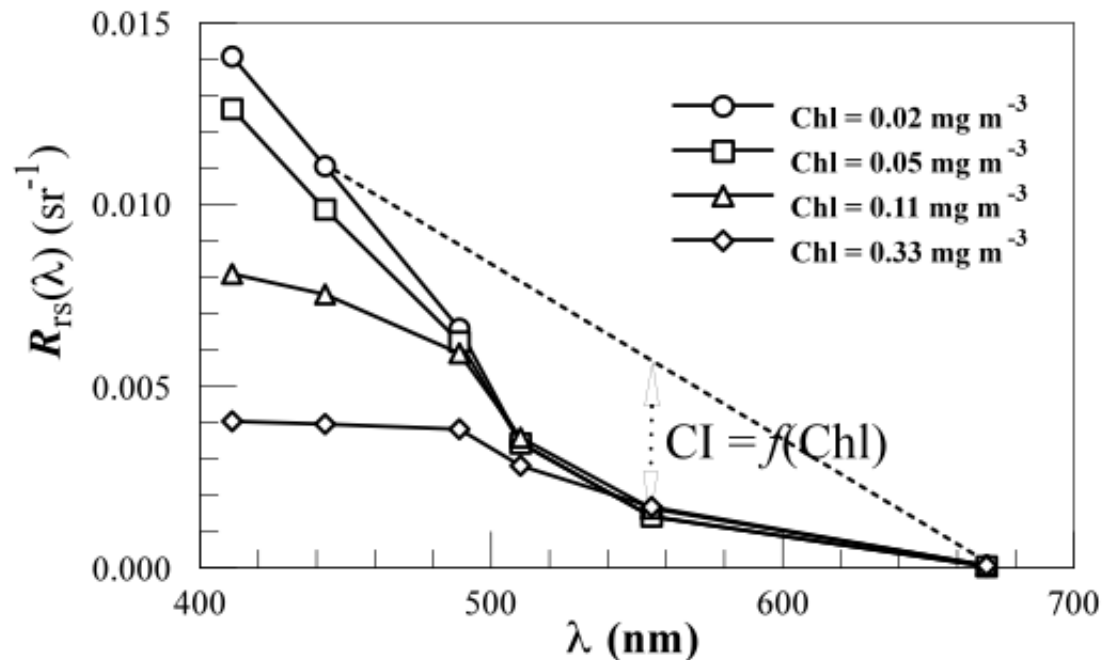


PSO Anomaly



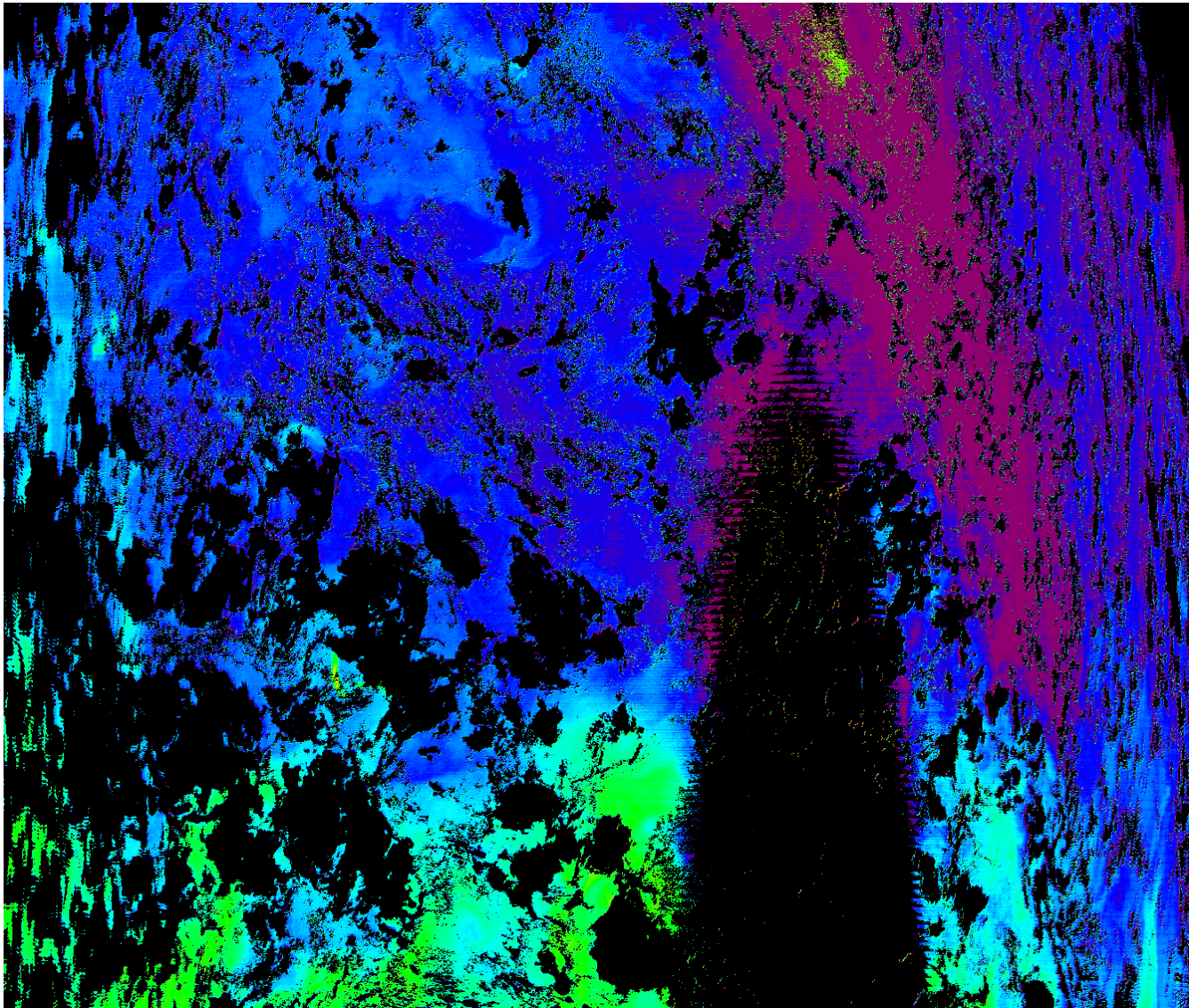
Chlorophyll Algorithm Refinement

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

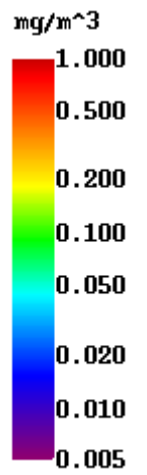


Hu, C., Z. Lee, and B.A. Franz (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference, J. Geophys. Res., 117, C01011, doi:10.1029/2011JC007395.

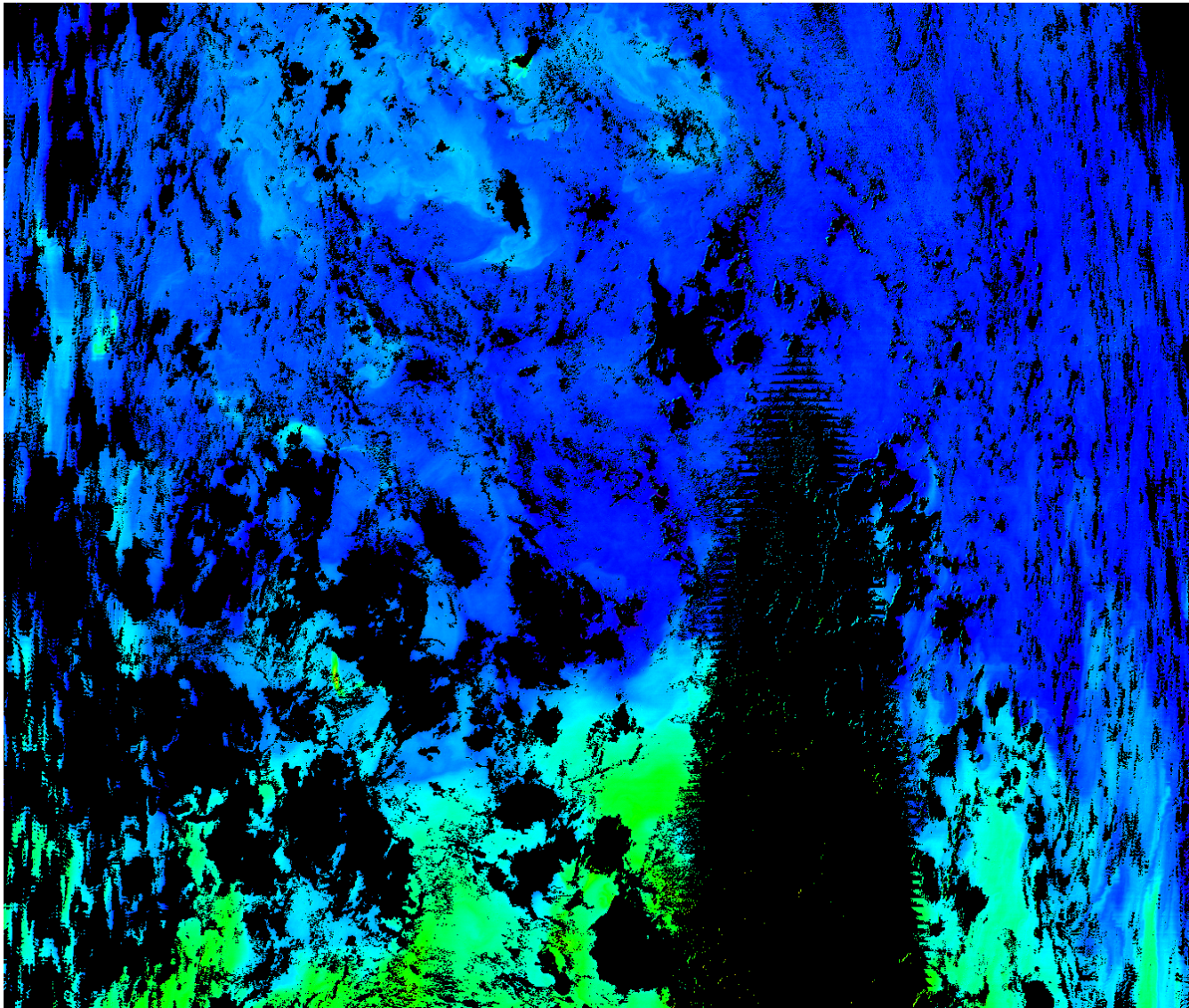
MODISA Standard OC3 Chlorophyll



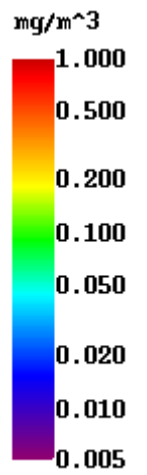
Chl_{OC3}
Flags off



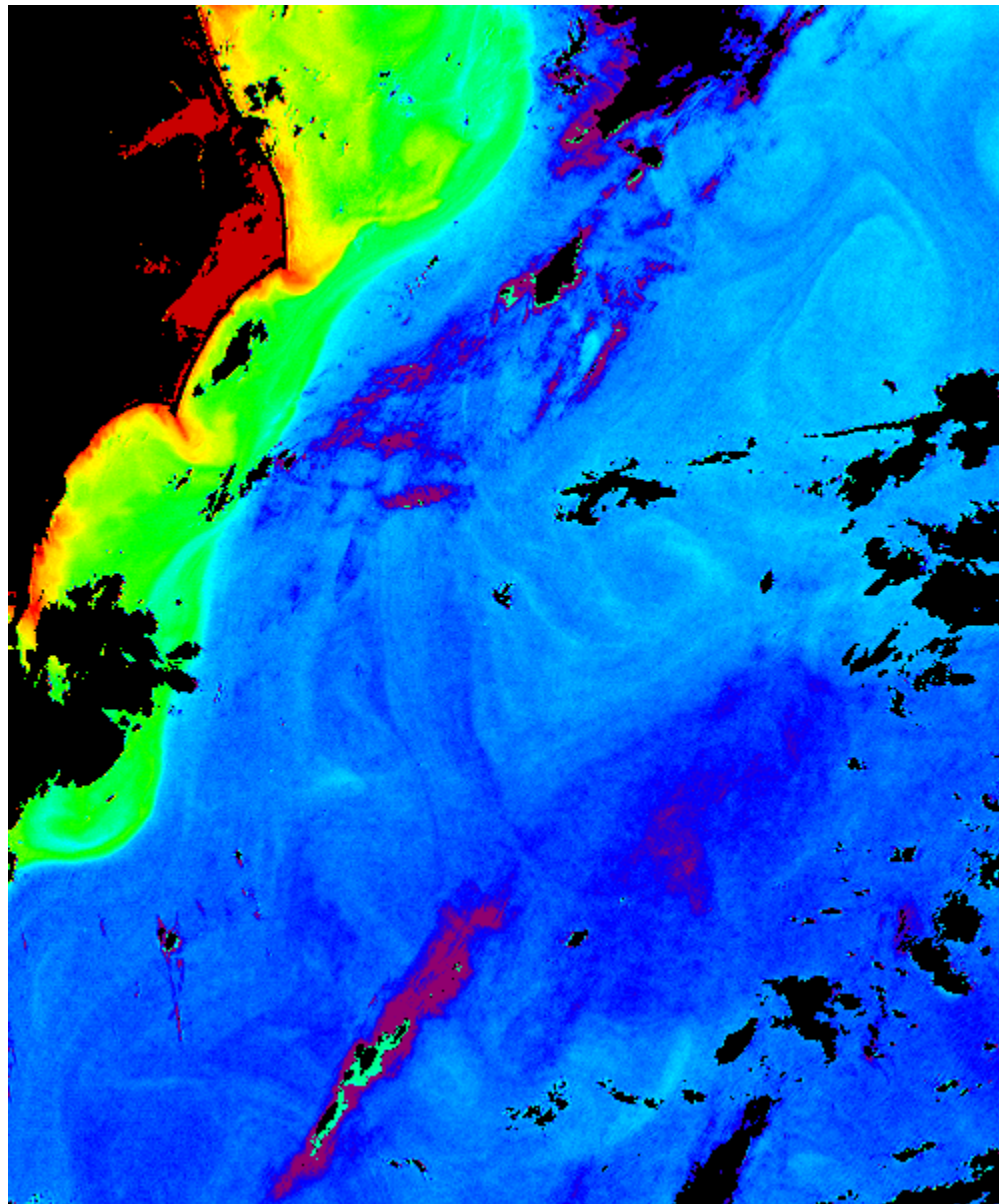
MODISA Evaluation OCI Chlorophyll



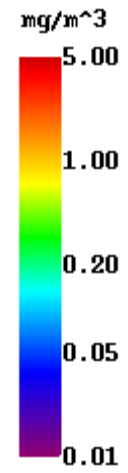
Chl_{CI}
Flags off



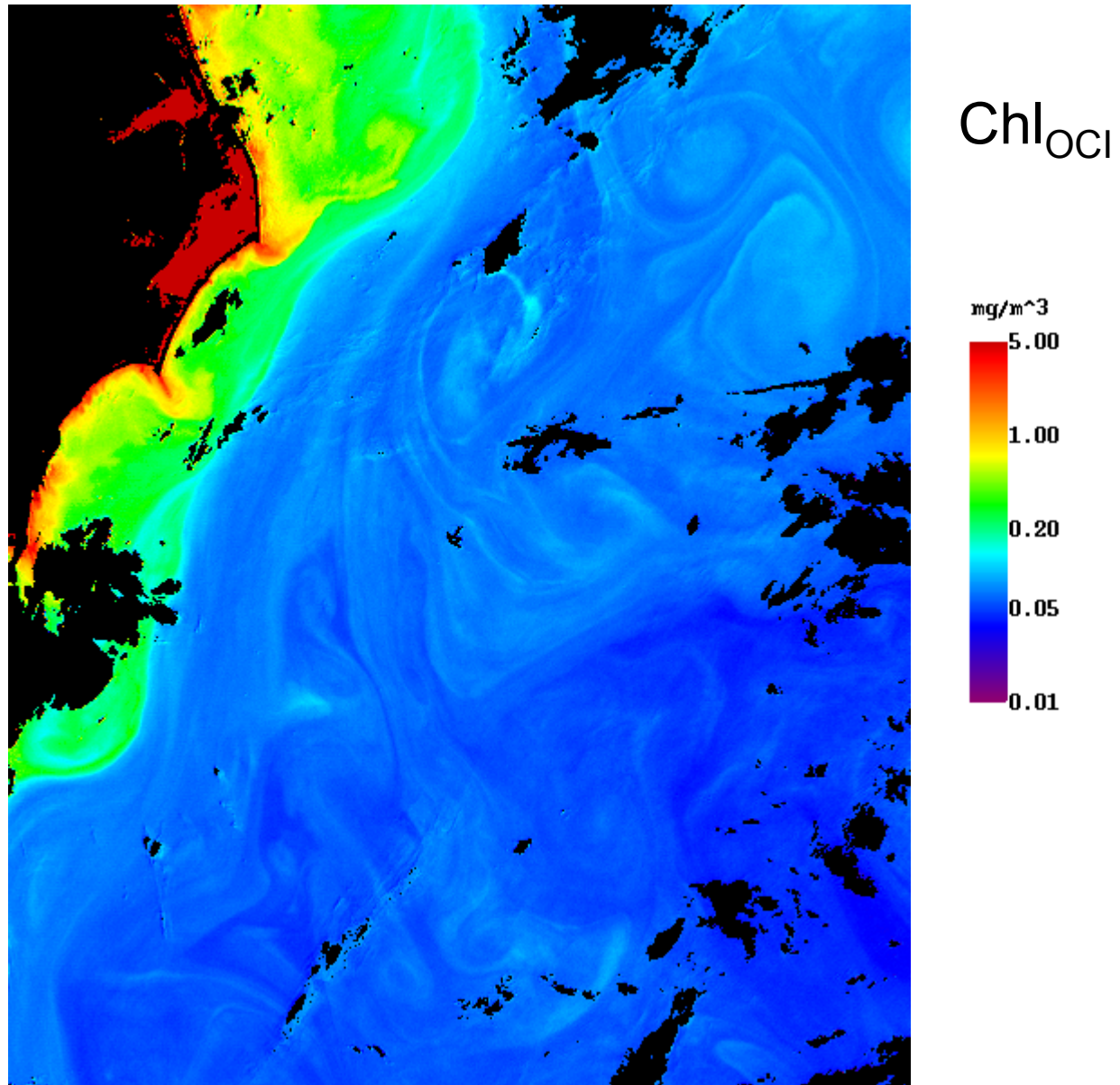
SeaWiFS Standard OC4 Chlorophyll



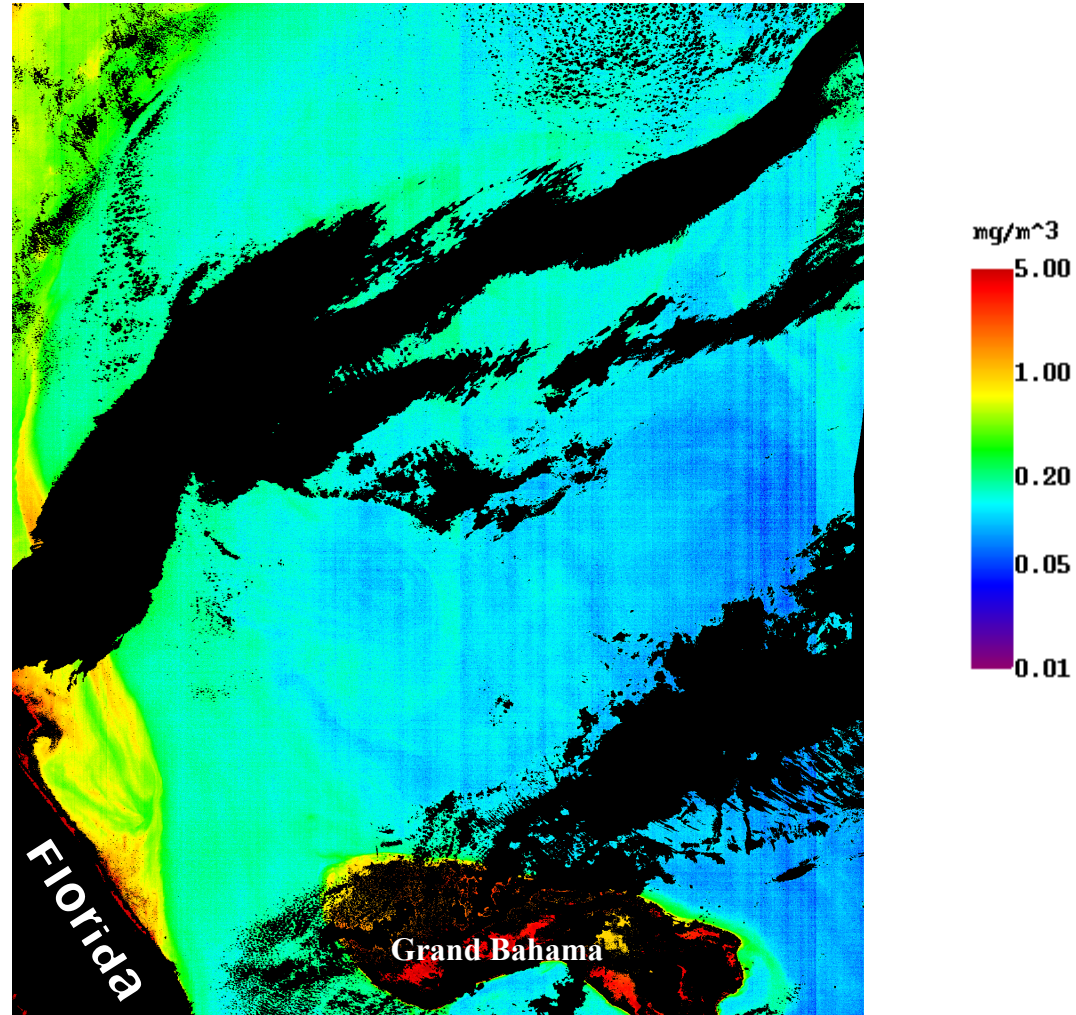
Chl_{OC4}



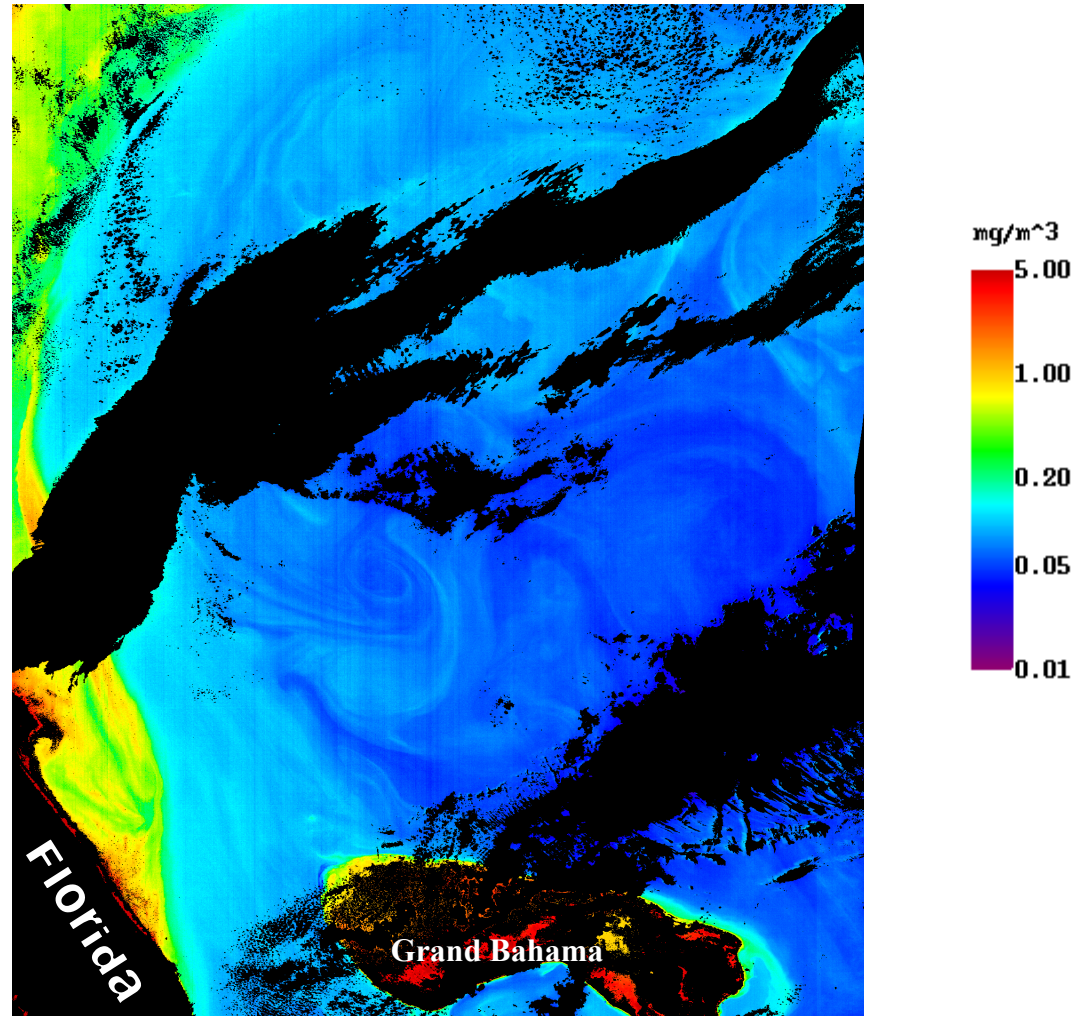
SeaWiFS Evaluation OCI Chlorophyll



MERIS Standard OC4 Chlorophyll



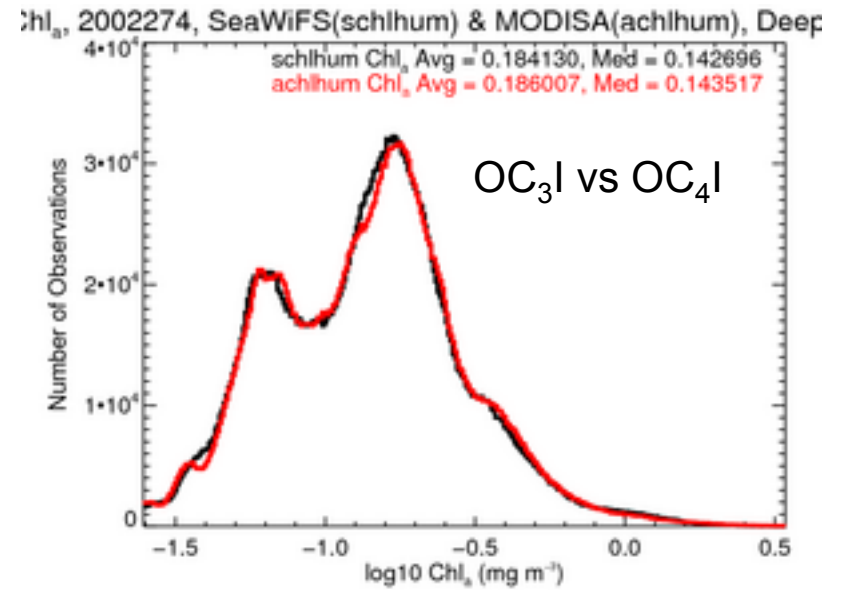
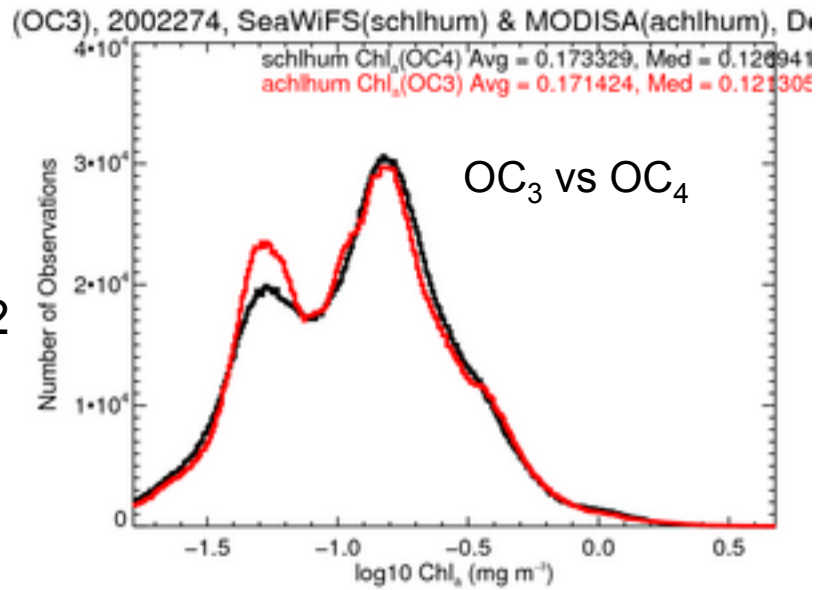
MERIS Evaluation OCI Chlorophyll



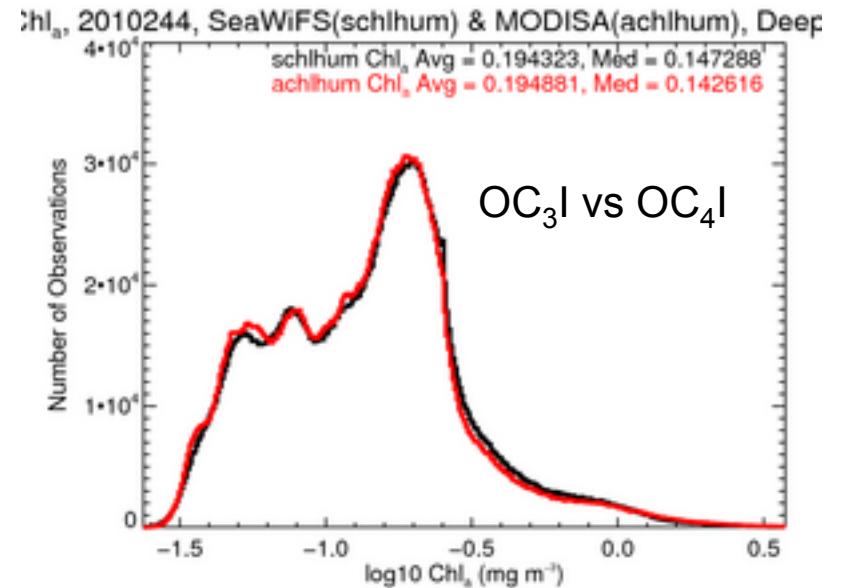
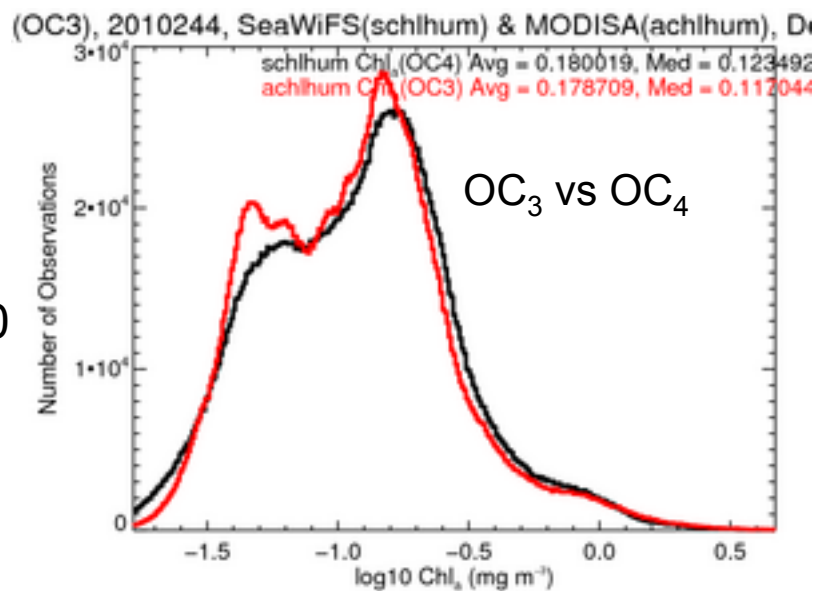
Improved Agreement in Chl Distribution

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

Fall
2002

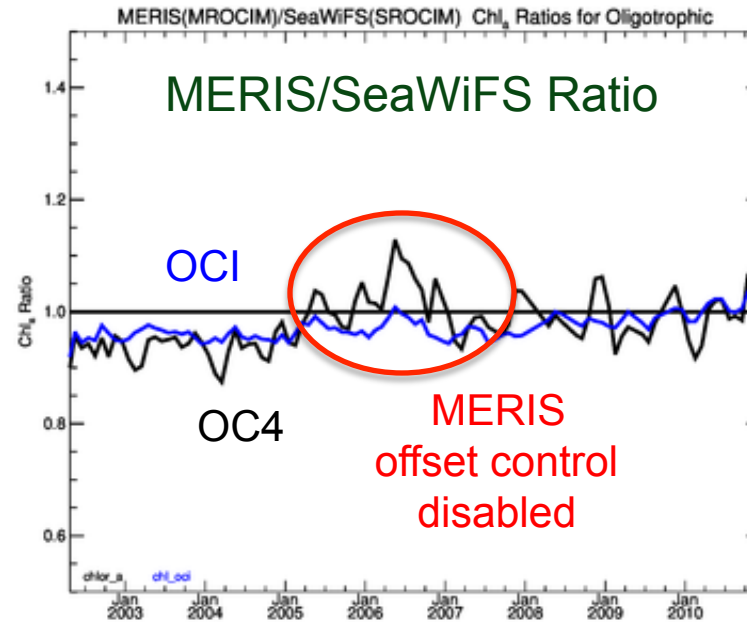
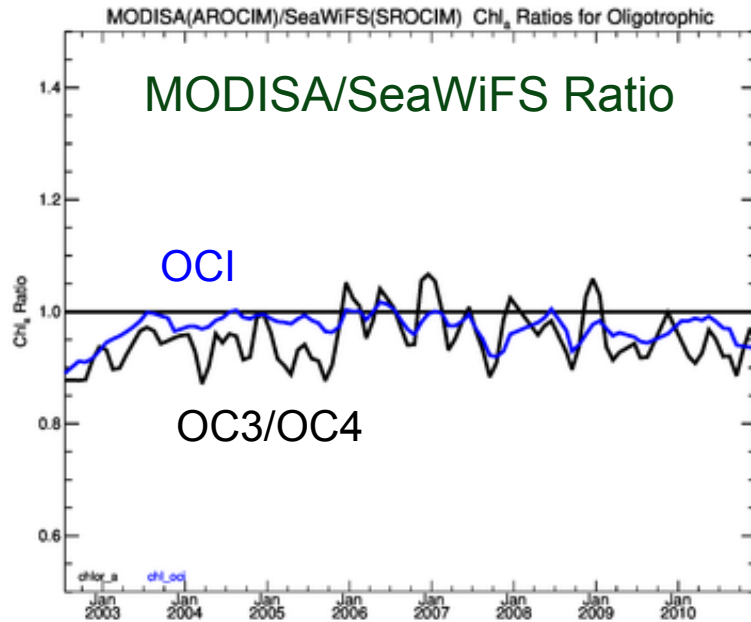


Fall
2010



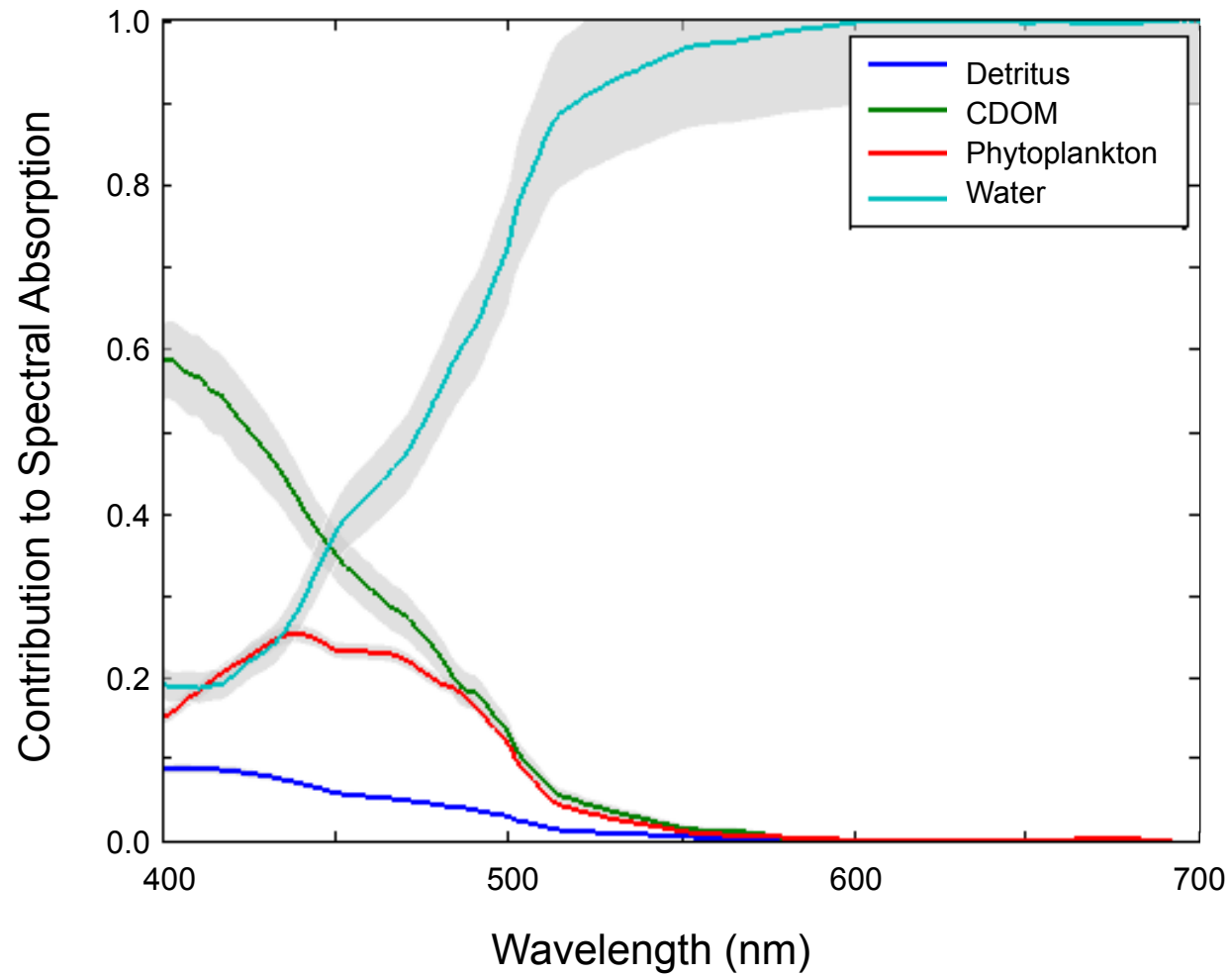
Chlorophyll Algorithm Refinement

improved agreement between sensors in clear water

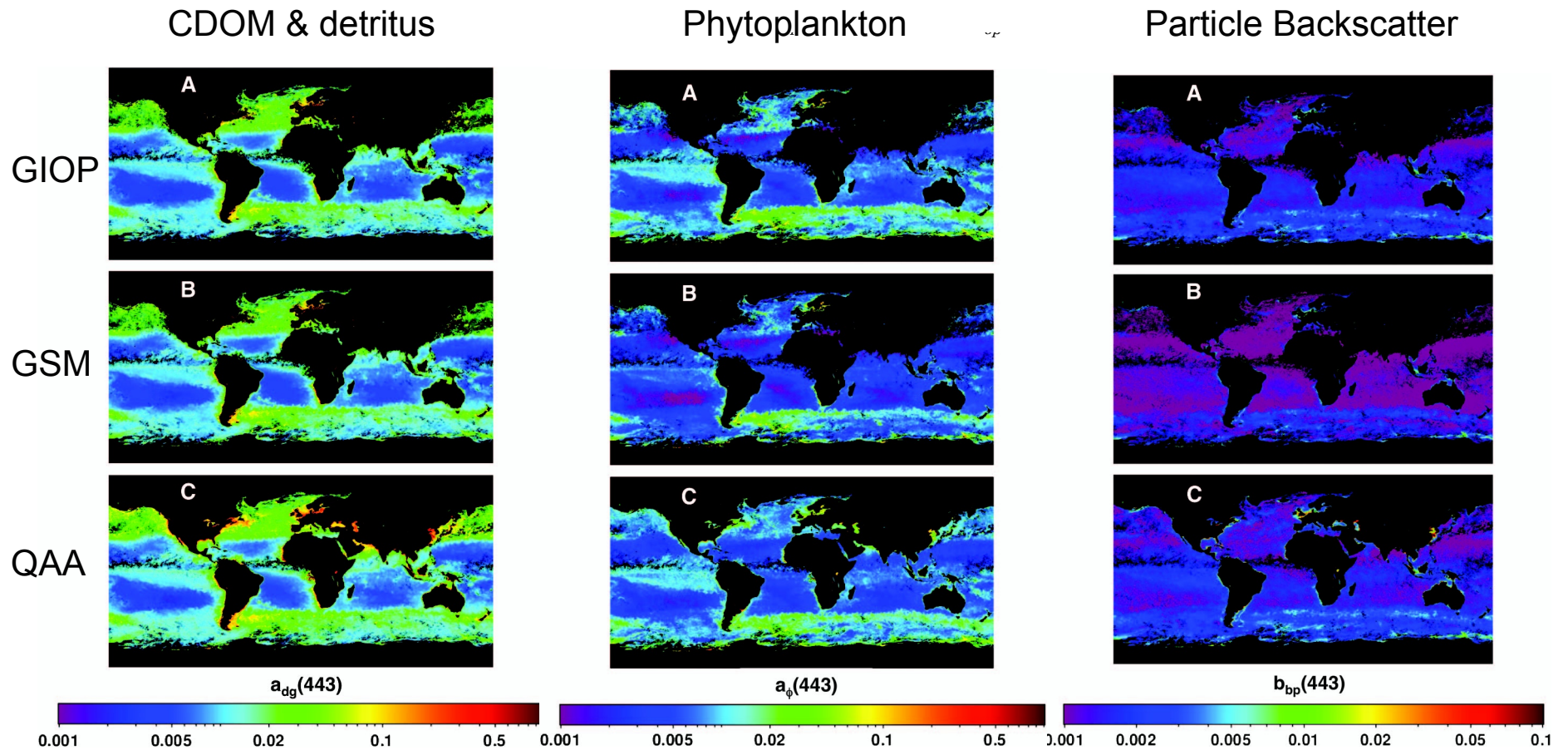


Hu, C., Z. Lee, and B.A. Franz (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference, J. Geophys. Res., 117, C01011, doi:10.1029/2011JC007395.

Beyond Chlorophyll

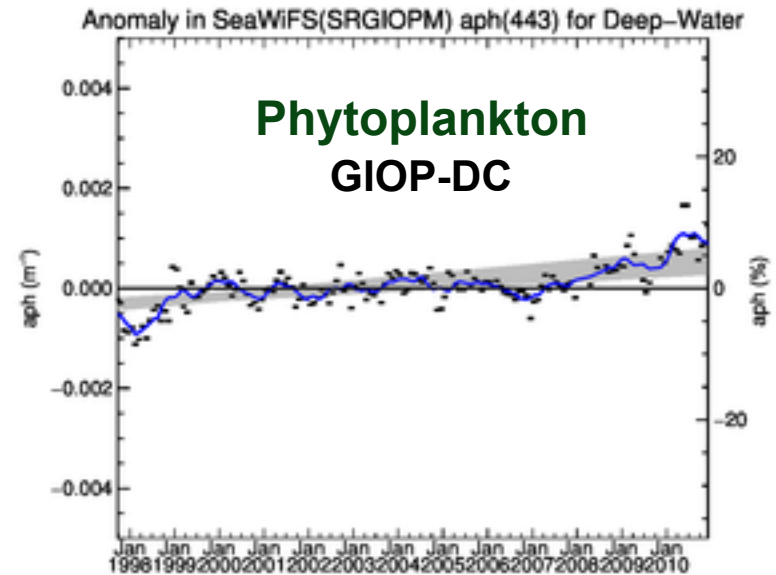
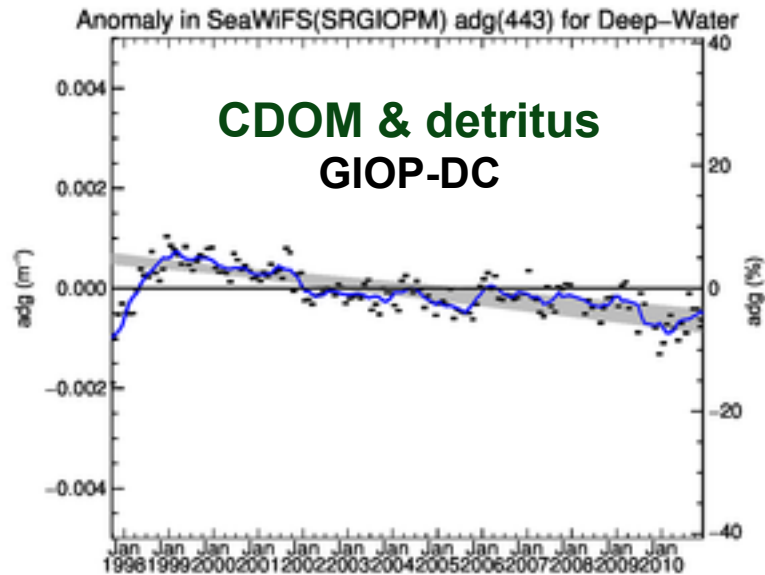
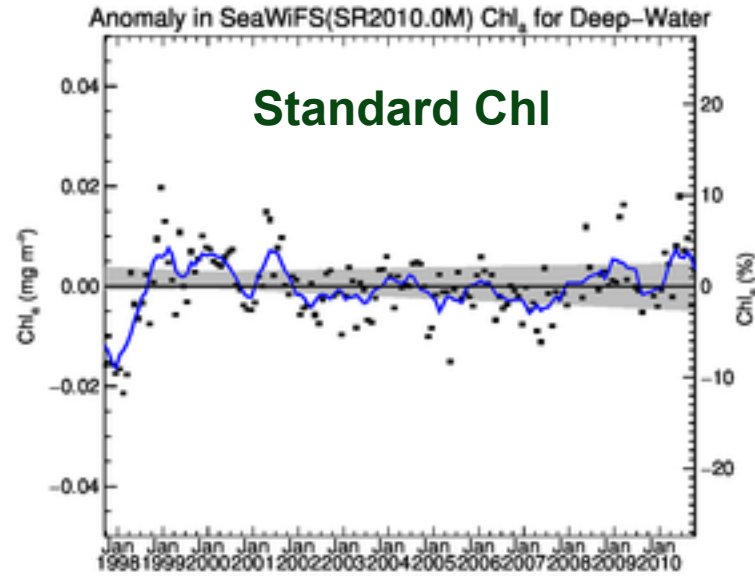


Separation of Constituent Absorption



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

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

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

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

New CI Line Height Algorithm
better at low chlorophyll

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

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

Proposed OCI Algorithm

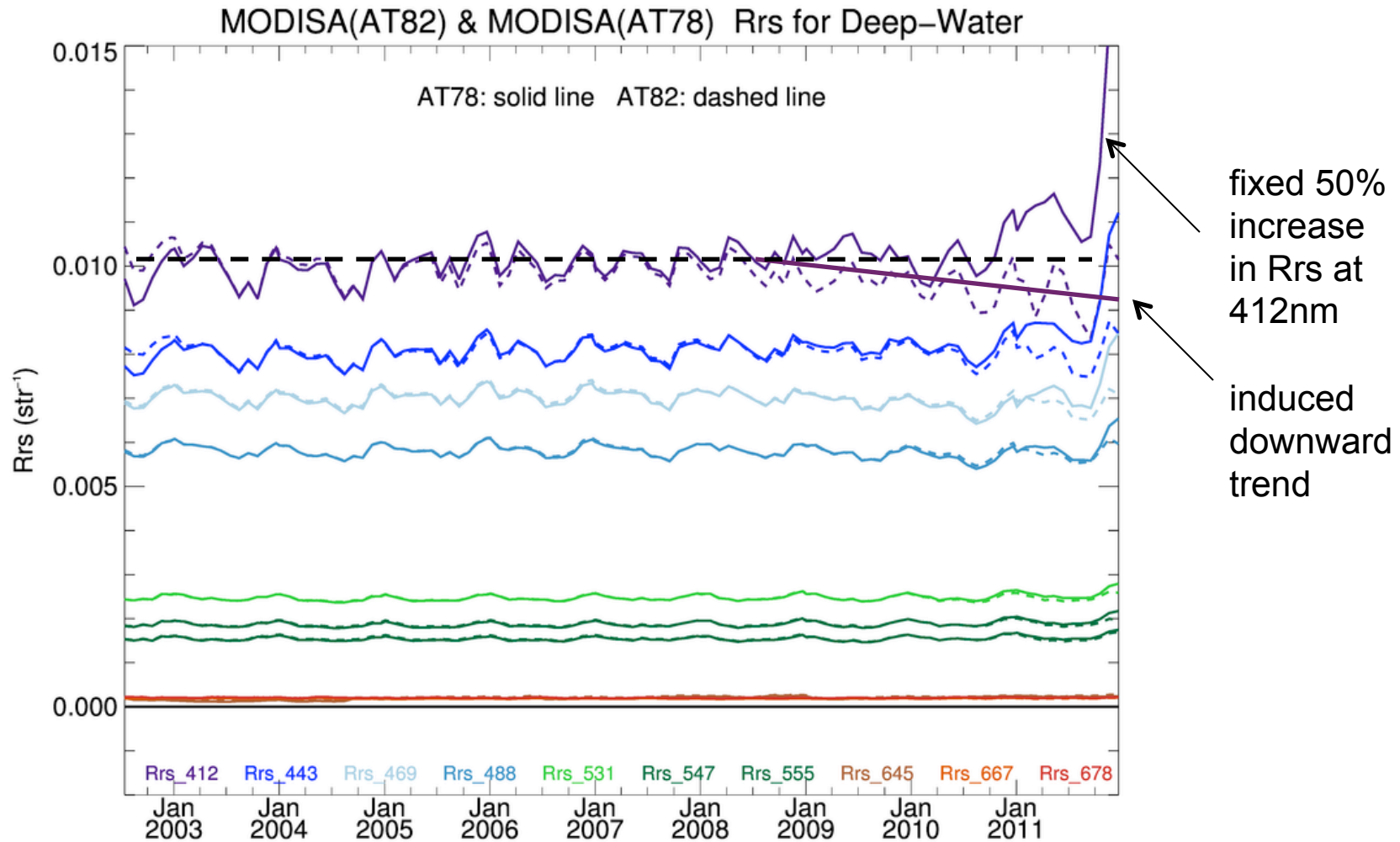
$$\text{Chl}_{\text{OCI}} = \text{Chl}_{\text{CI}} [\text{for } \text{Chl}_{\text{CI}} \leq 0.25 \text{ mg m}^{-3}]$$

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

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

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.

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

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

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

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